# A Comparison of Honeywell FMS and NASA CTAS (Descent Advisor) Trajectory Characteristics

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# 1 Introduction

CTAS DA (Descent Advisor) has  a need to predict how an FMS equipped aircraft would fly a descent from cruising altitude down to a metering fix. There is a major difference in how FMS-equipped aircraft and non FMS-equipped descend. The latter descend in an airmass mode, with pilots using rules of thumb and real time corrections to achieve their desired trajectory. An FMS-equipped aircraft, however, is required to preplan a descent path, and to stay on it as long as is feasible. The descent path is an array of distance-to destination and altitude pairs. It is thus referenced to the ground. To model the behavior of an FMS-equipped aircraft with airmass mode techniques could be very misleading. The differences range from procedural (e.g. Nav database cycle consistency) through modeling techniques and data, to  semantics ( e.g. meaning of Top of Descent) and have been described by Schwab et al.[1] and Burdon[2].

The concept of the descent path is simple, but its creation and use in the real world is not. The Honeywell approach to descent path construction and control is given by Burdon[3].

Note that the descent path is a guiding element, it is not the actual trajectory. The actual trajectory results from the real time application of various control laws.

This document is a description of factors that could cause a difference between the descent trajectories created by Honeywell FMSs and CTAS DA (Descent Advisor). An attempt has been made to examine the magnitude or relevance of the differences by using the DFW CTAS lateral flight plans in a Honeywell FMS and examining the resulting descent path. However a significant difference in thrust-minus-drag between CTAS and Honeywell FMS aero/engine models of the Boeing 757 dominates the differences. This problem came at the end of the project and no further analysis was funded.

Section 2 describes many of the differences that exist between the FMS trajectory prediction and that of the DA.

Section 3 describes the differences in the notion of Top of Descent, and how to use it.

Section 4 describes the significant problem of replanning in descent.

Section 5 describes some of the experimental results.

It should also be pointed out that most of the complications of the descent path construction and control occur at lower altitudes where altitude and speed constraints have to be met. The FAST region appears to represent the trajectory in a completely different manner from  the FMS. See ref[3] for details of approach path construction

# 2 Variations in Profile

## 2.1 Conceptual Differences

The two descent profiles are based on different prime criteria:

CTAS: Based on an awareness of other traffic.

FMS: Based on lowest cost[1], and the performance and guidance capabilities of the individual aircraft.

The most apparent effect resulting from these different criteria is that the CTAS trajectory is predicated on good speed control and the FMS is not. Of the many design criteria considered in the Honeywell FMS descent design, accurate speed control is a low priority. Optimal speed targets are generated for control purposes, but actual speed can vary ± 10kt or ± 20kt (system dependent) from these target speeds. Of course, by the design of the descent path, speed limits and speed constraints[2] are always obeyed; but see Section 2.2.

The Honeywell FMS is specific to the aircraft in which it is installed. The level of specificity includes

- engine models
- aerodynamic models
- performance models (speed envelope, optimal speeds etc.)
- guidance laws (both lateral and vertical)

Some of these differences are necessary because of different physical characteristics of the aircraft, and others are desires of the aircraft manufacturer, or necessary for certification purposes.

[1] It should be noted that the cost of a descent must also include the latter part of cruise, it is not merely the cost of descent from cruising altitude.

[2] Regulatory speed limits and speed constraints at a fix are taken as “not to exceed” values.

Throughout this document the terms Boeing type and Airbus type will be used. These types represent the two groups of characteristic air transport Honeywell FMS designs.

### Boeing Types:

- B747-400
- B757
- B767
- B777
- MD80
- MD90

### Airbus Types

- A310
- A320
- A330
- A340
- Fokker 100
- MD11

## 2.2 Airmass Descent vs. Path Descent

Inherent in CTAS is the notion that the aircraft will descend from a given geographic location to a metering fix, using a given speed schedule relative to the airmass. **This will not be true for aircraft using Honeywell FMS vertical profile control.** The Honeywell FMS builds a path in space from touchdown point to cruise flight level. This path is relative to the ground. This means that whatever the actual winds (within some reasonable tolerance) the guidance system will emit pitch and throttle commands to keep the aircraft on that given descent path (although the position along the path may not be exactly what was predicted i.e. a speed/time error).

Keeping on the path guarantees that all altitude constraints will be met and this is the prime responsibility of descent guidance. The next level of responsibility for guidance is to obey all speed constraints and limits. This is not guaranteed since the FMS has no means of controlling speed brakes, but if the winds have been properly accommodated, then the path will ensure correct deceleration to all speed constraints, limits and restrictions.

Should the aircraft be taken off path for some reason, different Honeywell FMS design philosophies govern subsequent action:

- Boeing type systems the guidance system flies SOE(Speed On Elevator), i.e. it takes its target speed from the path but does not attempt to recapture the path.
- Airbus type systems the guidance system will emit commands to return the aircraft to path at the earliest opportunity, usually by increasing speed target and flying SOE.

## 2.3 Engine/Airframe

Each aircraft type has its own specific engine, aerodynamic, and performance models. Additionally each airframe and engine variant are specifically modeled. This allows accurate calculation of thrust and drag in descent path building and predicting.

### 2.3.1 Factors Affecting the FMS Models

#### 2.3.1.1 Tuning Factors

Tuning factors can be applied to FMS performance calculations. The values of the factors are set either by an airline policy file (in the NDB – Navigation Database or AMI – Airline Modifiable Interface) or by the pilot on the CDU. Their purpose is to adjust the standard model characteristics to the individual aircraft characteristics. **Unless the engine/airframe models used by CTAS and FMS are exactly the same, knowing the tuning factors will not help.** If CTAS gets FMS aero/engine models then it will be of some use, but if any other model is used the factors' values are irrelevant.

#### 2.3.1.2 Anti Ice

A pilot can opt to divert some engine energy to cause warming of the engine cowls or leading edges of the wings when he believes that there is a probability of ice building up on these surfaces. Diverting this energy reduces the thrust available from the engines, which in turn affects the descent path profile.

- Boeing type systems, a pilot can select an altitude below which the decent path generation assumes anti ice thrust reduction will be in effect.
- A340 anti ice is always assumed to be "off".
- MD11 anti ice "on" or "off" can be set on the MCDU descent forecast page.
- A320 anti ice is always assumed to be "off", except when a descent path is rebuilt with the aircraft in approach, then anti ice "on" is assumed.

### 2.3.2 Non-Idle Descents

In Boeing type systems the descent paths are built assuming true idle whenever possible. In Airbus systems the contained path segments are built using idle thrust plus a small additional thrust. This extra thrust has been found to enable better autothrottle control for gusty wind conditions. The amount of added thrust is usually a function of altitude.

## 2.4 Shallow Flight Path Angles

In all Honeywell FMS there is a small range of angles where the autothrottle control system cannot maintain speed at or near idle conditions. Currently, constrained path segments arise because of altitude constraints that are coded in the arrival procedures. These in turn stem from ATC requirements. So, usually, they are shallow and require that they are flown with non-idle thrust. However, the segment geometry and atmospheric conditions can combine to cause the throttles to fluctuate between full idle and non-idle. There is not a continuous change in throttle settings between these two states, and since the control mode is speed on throttle, there can be an unfortunate and unwelcome oscillation of both throttle and actual speed.

**Whilst such segments are rare today, it may be that CTAS, in trying to achieve idle descents in the FAST region, may inadvertently cause this to become a frequent occurrence. This phenomenon should be analyzed further.**

## 2.5 Gross Weight

TOD (Top of descent) and the whole vertical profile is considerably affected by variations in gross weight. The active flight plan predictions accurately predict the fuel burn and from a prediction point approaching TOD, and the FMS estimates the landing weight and uses this for the backwards descent path construction.

## 2.6 Lateral Differences

When CTAS is deployed in the field, there may or may not be special CTAS arrival procedures where all defining elements are represented as fly-by or fly-over waypoints. This section explains how today's FMSs cope with the existing wide variety of flight plan descriptors defined in the standard document ARINC 424. See ref [2] for details on this.

## 2.7 Effects of Wind Models

Different FMSs have different representations of wind. In descent some have a four or five element array, each element holding an altitude, wind bearing, and speed. Others (A310) have a fixed profile such as constant wind from ground to 10000 ft then a linear change from 10000 ft to a pilot entered wind velocity at TOD. No scheme has any lateral information. It is possible that even if the same wind data is available to CTAS and the FMS, the different interpretation may lead to different trajectories.

## 2.8 Effects of Level/Non-Level Deceleration Segments

The FMS guidance does not recognize a "Speed At" constraint in the same way as it recognizes "Altitude At". All speed restrictions are taken as upper limits, hence any predicted speed at a waypoint which is less than the speed value (constraint) at that waypoint is acceptable. With this philosophy, building a descent path by backwards integration can accommodate a forward deceleration by assuming a given vertical speed, say -500 ft/min, which will definitely cause the aircraft to decelerate. Integration backwards with this vertical speed will eventually reach the target speed, but at some arbitrary point, not a waypoint. As the backward integration passes over a speed constrained waypoint, provided predicted speed is less than the speed at the waypoint, integration continues. (Should the backward integration hit the speed value before passing over the waypoint, then the speed is held constant until the waypoint is sequenced).

Thus it seems that there are probably some differences in the resulting speed profiles, and these should be examined. Further, in Boeing type systems speed constraints cannot be applied at waypoints without a corresponding altitude constraint. Even applying an apparently null-effect altitude constraint, say an at-or-above at ground level causes changes to the profile. See Figure 2-1 Speed-Only constraint problem.

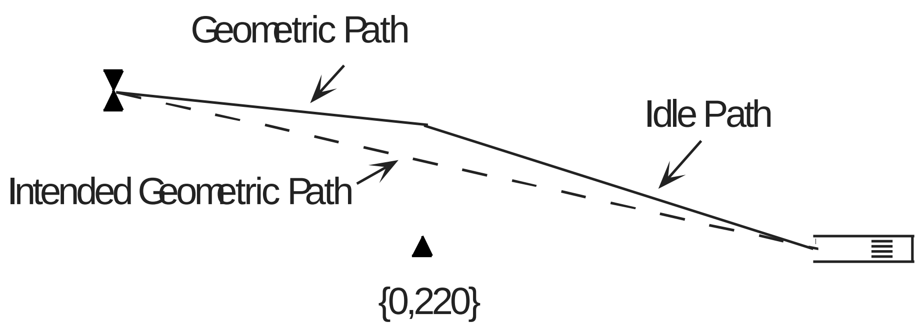


***Figure 2-1 Speed-Only constraint problem***

## 2.9 Effects of Acceleration Segments

The FMS never builds a path segment to represent a forward acceleration. In the case where a descent speed is different from the end of cruise speed, the path is built up to cruise flight level assuming descent speeds. Then a level deceleration segment is added at the end of cruise to make the speeds match. Accelerations are ignored in the construction, and it is left to guidance to match the speeds after TOD.

If, while in descent, a path is rebuilt with speeds different from current, then still no deceleration or acceleration segment are created. In Airbus types it is left to the guidance function to bring the aircraft back to the path at the correct path speed. In Boeing types the guidance continues with SOE and no attempt is made to recover to the path.

There may be some effect from this different implementation, and it should be examined.

## 2.10 Speed Selection

### 2.10.1 Cost Index

The CI (Cost Index) is a factor entered into the system by the pilot via the MCDU. It is a weighting factor used by the optimization algorithms to adjust for the relative importance of time based costs. If time based costs are of no importance then a zero CI is entered, and speeds are based on minimum fuel. If time is of the essence, then a CI of 999 may be entered, and speeds are speed envelope limits. Usually a value of CI is determined by the airline corresponding to its operations and remains unchanged from flight to flight. However pilots can and do use this factor in a tactical way to achieve some peculiar effects (such as steeper/shallower descent paths).

Consequently, the speeds which a Honeywell FMS will use to calculate a TOD and descent profile can vary across the whole of its aircraft's speed envelope, resulting in very different results. CTAS intends to produce *fuel* efficient descent profiles, but this is not the same as the FMS which produces *cost* efficient profiles. Note that Honeywell BCAS (Business and Commuter Aircraft Systems) FMS has a fixed default speed schedule for descent (can be modified by pilot entry).

### 2.10.2 Envelope limits

The speed envelope used by the Honeywell FMS to generate descent profiles will not usually match the maximum and minimum speeds provided by the pilots' manuals. There are several reasons for his:

#### 2.10.2.1 Comfort Margins

The high speed end is reduced by a few knots (typically 5 or 10 kts) to allow for some slop in the speed control during certain maneuvers.

The low end is usually "green dot" limited or stall limited, which is a function of current weight.

If the CTAS performance database will contain speed envelope modeling, then such details should be included.

#### 2.10.2.2 Special Considerations

Sometimes other design effects modify the envelope. For example, MD11 aircraft have wing tip tanks which prevent wing flutter when they contain fuel. Mmo and Vmo are .87/365 when these tanks are full. When the tip tanks are empty, Mmo and Vmo are limited to .83/320. The MD11 FMS attempts to anticipate when the tip tank fuel will be used, based on predicted fuel remaining. This information is then used in constructing the descent path. When flying the descent path, the FMS uses real time input from the Fuel Quantity Gauging System to determine the Mmo/Vmo limits, possibly resulting in a mismatch between speed targets used for constructing the path, and the speed targets used for flying the path.

# 3 Pilot FMS Interface

## 3.1 CTAS Descent Parameter Entry

### 3.1.1 Descent Mach/CAS entry

Entry of the desired descent Mach /CAS profile has different effects in different systems. These effects are outlined here: for more detail see ref[3].

#### 3.1.1.1 A320

##### 3.1.1.1.1 Construction

Descent Mach/CAS can be entered in cruise mode and are considered to be replacements for the automatic Mach/CAS pair that the system would produce in its economy mode. This means that all speed constraints in the flight plan will be obeyed (as not-to-exceed values), and decelerations through approach are built.

If the cruise speed is economy, and it is higher than the descent speed then an end of cruise deceleration segment will be created. TOD is located at the start of this deceleration.

If the cruise speed is economy , and it is lower than the descent speed then no modification to cruise is made.

##### 3.1.1.1.2 Guidance

If the cruise speed is economy , and it is lower than the descent speed then the acceleration will occur after TOD as a result of the descent Mach becoming the speed target. However the speed controllers are not aggressive in zeroing out this mismatch of speeds, and a significant part of the descent path may be flown before the descent target speed is attained.

If the cruise speed is manually entered, then this same speed remains the target in descent until the pilot takes action to invoke the previously entered descent Mach/CAS targets.

#### 3.1.1.2 MD11

##### 3.1.1.2.1 Construction

Descent Mach/CAS can be entered in cruise mode and are treated differently by descent path construction and guidance. For path construction the manually entered pair are considered as replacements for the automatic Mach/CAS pair that the system would produce in its economy mode. This means that all speed constraints in the flight plan will be obeyed (as not-to-exceed values), and decelerations through approach are built.

If the cruise speed is economy, and it is higher than the descent speed then an end of cruise deceleration segment will be created. TOD is indicated at the start of this deceleration.

If the cruise speed is economy , and it is lower than the descent speed then no modification to cruise is made and the speed up will occur as a result of the descent Mach becoming the speed target at TOD. However the speed controllers are not aggressive in zeroing out this mismatch of speeds, and a significant part of the descent path may be flown before the descent speed is attained.

If the cruise speed is manually entered, then this same speed remains the target in descent until the pilot takes action to invoke the previously entered descent Mach/CAS targets.

#### 3.1.2 TOD Entry

CTAS will provide the aircraft with its estimated TOD and supply this information to the pilot along with the required Mach/CAS schedule. There is no means by which a TOD can be imposed on the system. However the pilot can enter a waypoint corresponding to the required TOD, string it into his flight plan, and on sequencing this waypoint he can initiate descent.

## 3.2 Display of TOD

Top of descent is calculated by the FMS and displayed usually on both the MCDU and EFIS navigation display. The meaning of the positioning of TOD varies with system. This is explained in ref[2]. Replanning in Descent.

This section outlines the behavior resulting from a change to the flight plan after the aircraft has sequenced TOD. In Boeing and Airbus type systems, any change to the lateral definition of the path (added / changed waypoint, direct to a waypoint, change to temperature, wind, speed etc.[3]) A new path is created from the runway backwards. Reaction to this event varies as described below.

## 3.3 Boeing FMS

Details of Vertical Guidance behavior are provided in [3] Volume I. In broad terms, though, the characteristic of a Boeing system is as follows.

If the aircraft is above the first altitude constraint in descent, a new path is built according to the new profile parameters assuming idle thrust. The profile will end at aircraft current altitude. The aircraft will usually be above or below this new path. The guidance mode changes to SOE using whatever the current target speed is. The position of the aircraft relative to the new path depends on several factors, including the steepness of the new path, the deceleration required at a constraint. Vertical deviation display will indicate to the pilot where he is relative to the descent path.

If the aircraft is below the first altitude constraint in descent, a constant FPA segment is created to the nose of the aircraft and flight continues along the new path.

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[3] Except for altitude pressure reference.

## 3.4 Airbus FMS

Details of Vertical Guidance behavior are provided in [3] Volume II. In broad terms, though, the characteristic of an Airbus system is as follows.

A new path is built according to the new profile parameters assuming idle thrust. The profile will end at aircraft current altitude. The aircraft will usually be above or below this new path. The system now tries to return to path immediately. If returning from above, guidance will change to SOE, with a target speed higher than the descent path speed, thus achieving a closing onto the path. If returning from below the path, guidance invokes a level segment at path speeds.

# 4 Comparison of Test Results (B757 - CTAS)

A sample CTAS descent into DFW was provided for comparison. The lateral plan is shown in Figure 4.1.

The test set is shown in the following table.

| TE | IC | Altitude | Speeds | Weight | Drag | OAT | Wind | Altimeter | Metering |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ABI270/10 | FL370 | .8/.8/280 | 184000 | +0% | ISA | none | 29.92 | no |
| 2 | “ | “ | “ | “ | “ | “ | “ | “ | *HULE |
| 3 | “ | “ | .75/.82/320 | “ | “ | “ | “ | “ | “ |
| 4 | “ | “ | .82/.82/250 | “ | “ | “ | “ | “ | “ |
| 5 | “ | “ | .8/.8/280 | 228,000 | “ | “ | “ | “ | “ |
| 6 | “ | “ | “ | 109,000 | “ | “ | “ | “ | “ |
| 7 | “ | “ | “ | 184,000 | +5% | “ | “ | “ | “ |
| 8 | “ | “ | “ | “ | -5% | “ | “ | “ | “ |
| 9 | “ | “ | “ | “ | +0% | +20C | “ | “ | “ |
| 10 | “ | “ | “ | “ | “ | -20C | “ | “ | “ |
| 11 | “ | “ | “ | “ | “ | ISA | *linear | “ | “ |
| 12 | “ | FL290 | .8/.8/250 | “ | “ | “ | none | “ | “ |
| 13 | “ | FL370 | .8/.8/280 | “ | “ | “ | “ | 30.42 | “ |
| 14 | “ | “ | “ | “ | “ | “ | “ | 29.42 | “ |
| 15 | “ | “ | “ | “ | “ | “ | “ | “ | *AQN, |
| 16 | “ | “ | “ | “ | “ | “ | “ | “ | *AQN, |
| 17 | 5nm left, direct AQN | “ | “ | “ | “ | “ | “ | “ | *HULE N |
| 19 | 20nmpast TOD, on path | “ | @280 to 310 | “ | “ | “ | “ | “ | “ |
| 20 | “ | “ | @280 to 250 | “ | “ | “ | “ | “ | “ |
| 21 | 20nm past TOD above path | “ | @280 to 310 | “ | “ | “ | “ | “ | “ |
| 22 | ABI270/10 | “ | MANUAL /ECON test | “ | “ | “ | “ | “ | “ |
| 23 | “ | “ | “ | “ | “ | “ | “ | “ | “ |
| 24 | “ | “ | “ | “ | “ | “ | “ | “ | “ |
| 25 | “ | “ | “ | “ | “ | “ | “ | “ | “ |
| 26 | “ | “ | .8/.8/280 | “ | “ | “ | “ | “ | *TRAC |

Note: all trajectories end at the runway (160kts/640ft)

*linear wind model: 2 kts per 1000 feet altitude, constant direction out of 085 °.
*HULEN: 250kts/11000ft crossing.
*AQN: 250kts/11000ft crossing.
*TRACON: crossing at HULEN (250/11000), CREEK (210kts/above 640’), HALEY (190kts), HASTY(170kts).

Tests 22 -25 demonstrate the behavior of the Honeywell FMS when using manual and economy speed modes. Specifically for B757:

Test 22 - Cruise ECON 0.77 - Descent MANUAL 0.82/320

Test 23 - Cruise ECON 0.82 - Descent MANUAL 0.82/250

Test 24 - Cruise MANUAL 0.75 - Descent ECON 0.8/320

Test 25 - Cruise MANUAL 0.82 - Descent ECON 0.77/250

This framework of tests was used to create data corresponding to FMS descent paths for the Boeing 757, McDonnell Douglas MD11, Airbus A320, and BCAS (GA). The data produced for these tests are held electronically in Microsoft Excel workbooks and have been provided to NASA. Some data are extracted here to illustrate significant differences. CTAS data was available for Boeing 757 only.

Observations:

The construction of the descent path in terms of altitude profile and speed profile is significantly different below the metering fix, so timings and distances in this region should be ignored.

Leg transition differences are negligible (at least in this scenario).

The figure on page 15 “Time differences at waypoints” shows that in general the timing differences are only a few seconds, the largest metering fix timing difference being 29 seconds. The trend is for CTAS to be earlier than the FMS (Test 1 comparisons are invalid, since CTAS conditions retain the constraints at HULEN whereas FMS conditions were unconstrained).

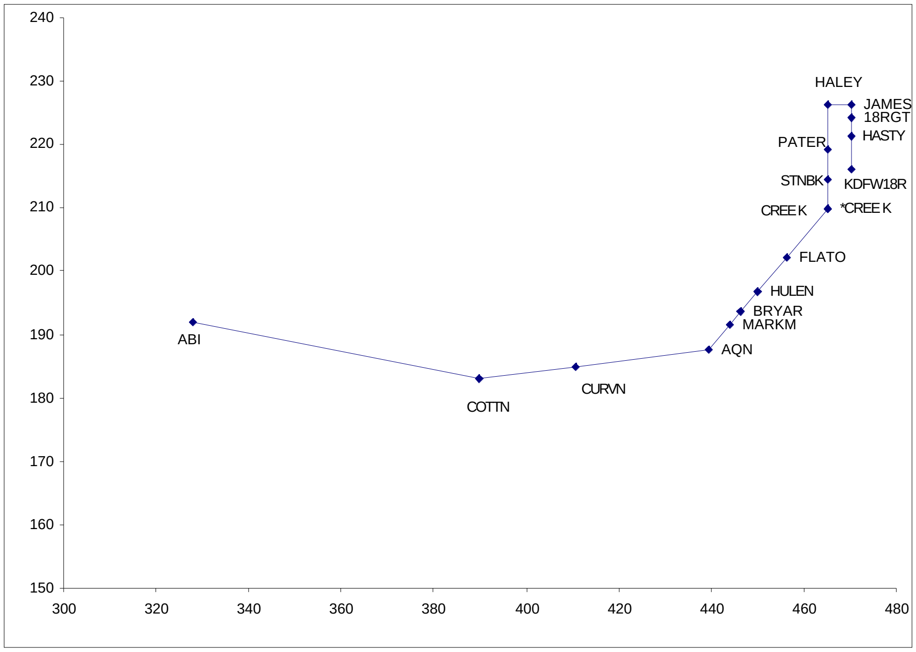
The likely cause of this faster descent can be seen in almost all cases to be the steeper descent profile calculated by CTAS. A steeper descent path (constrained at the metering fix) leads to a TOD downpath of the FMS TOD. Consequently the CTAS prediction is at cruise Mach for longer.

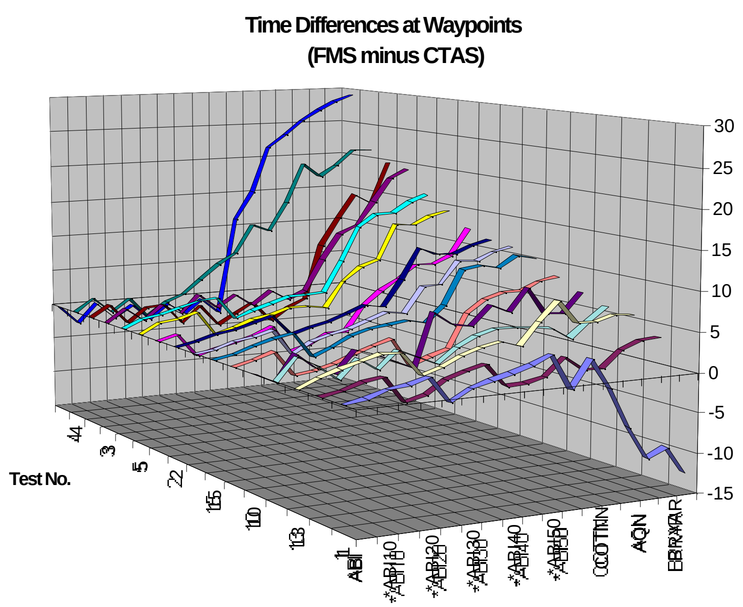
CTAS altitude is greater than the FMS altitude at corresponding lateral points, and so for the same CAS the CTAS groundspeed will be greater.

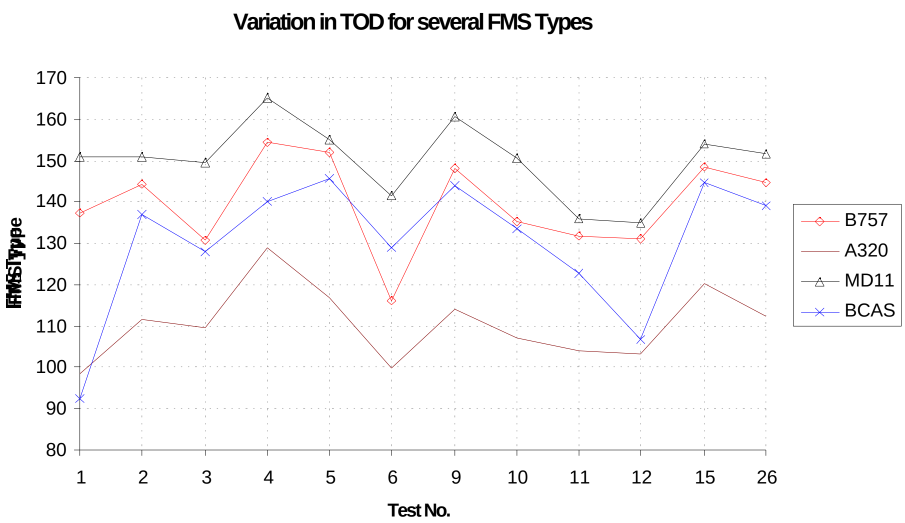
The figure on page 16 shows the TOD for several Honeywell FMS systems, each using operational descent profile speeds.

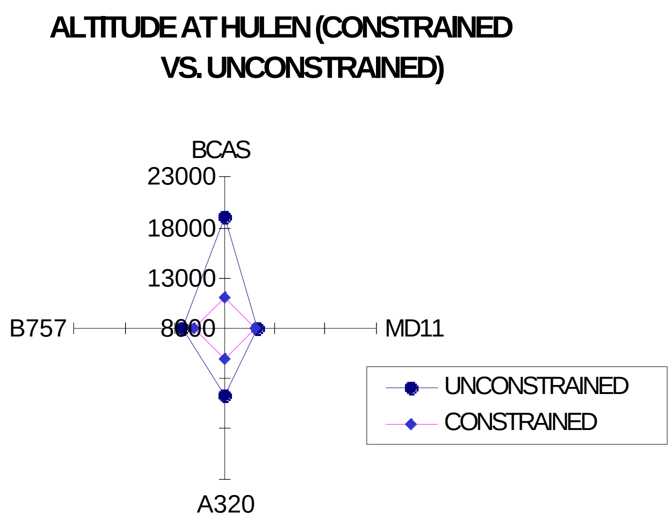
The figure on page 16 shows the path and speed at HULEN for each aircraft’s unconstrained optimal path. Clearly a single metering fix selected to minimally perturb a particular aircraft’s optimal path, will have a significant effect on other aircrafts’ optimal paths.

Figure 4.1 This illustrates the lateral flight plan on which the tests were performed.




Variation in TOD for several FMS Types
170
160
150
140
130
120
110
100
90
80
FMS Type
1
2
3
4
5
6
9
10
11
12
15
26
Test No.
B757
A320
MD11
BCAS


ALTITUDE AT HULEN (CONSTRAINED VS. UNCONSTRAINED)
BCAS
23000
18000
13000
8000
B757
MD11
A320
UNCONSTRAINED
CONSTRAINED

## *References*

[1] Schwab,R, and VanTulder,Paul, Williams, D,"Potential CTAS/FMS Inter-operability Issues", *Draft Document for FANG Industry Group, February 21, 1994.*

[2] Burdon, D, "CTAS-FMS Interoperability Issues Revision B" *NAS1-20219, Task 6 CTAS-Compatible FMS, July 22, 1997.*

[3] Burdon, D, "FMS Descent Path Core Algorithms - Volume I and Volume II", *NAS 1-20219, Dec 1995.*