Design Considerations of Vertically-Constrained PBN Procedures for Trajectory Management

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Overview

1. Problem Statement

2. KDCA Delay Absorption Potential Simulation

3. Vertically Constrained OPDs to Increase Delay Absorption Potential

4. Comparison with Actual KDCA Operations

5. Conclusion
Performance Based Navigation

- PBN Standard Terminal Arrival Routes (STARs) are sometimes referred to as Optimised Profile Descents (OPDs) as they allow the aircraft’s automation to optimise the descent.

- Australia: Runway-linked STARs

- Europe: Point Merge

- United States: Metroplex redesign

- The Challenge: to manage 4th Dimension Time!
4D-TRAD & Literature Review

- 4D-Trajectory Downlink (4D-TRAD)

- De Smedt et al. (2013, 2015) used an actual arrival scenario at Melbourne, Australia to model the concept of 4D-TRAD. The study concluded that airborne time-of-arrival-control only to absorb delay within 200NM from arrival, is not sufficient.

- Jones et al. (2013) investigated the use of time constraints at 500NM. This increased the delay absorption potential, but complexities occurred when merging these flights with short haul flights. Thus, sufficient delay absorption potential remains required closer to arrival, for final landing time assignment.
Herndon et al. (2013) found when several different FMSs were faced with PBN arrival procedures containing a large number of constraints, the resulting behaviour can vary widely. While not investigated, constraints on a PBN procedure will likely impact the ability of an aircraft to meet a time constraint.
Problem Statement

• Previous research work suggests that the interdependencies between the design of PBN procedures, FMS operating logic, and the concept of 4D-TRAD, are little understood

• With use of an FMS testbed environment, the impact of constraints on a PBN procedure to the range of delay that can be absorbed into the arrival trajectory is investigated

• This range of delay will be compared to a sample of actual delay data from a representative operational scenario
FMW Simulation Set-up

- GE Flight Management Workstation
- B737-500
FMW Simulation Set-up (2)

- KDCA FRDMM Arrival
- ETA min/max @200NM
- 3 scenarios
  - Original (O)
  - Unconstrained (U)
  - Altitude Constraints (A)
- 3 Gross Weights
  - 81.3 klbs
  - 101.6 klbs
  - 122.0 klbs
- 2 Cost Indices
  - 0 – slow
  - 200 – fast
Results: Altitude Profiles (W=81.3klbs)
Results: Flight Time Range

- Scenarios O: limited ability to speed up due speed constraints, limiting the range of achievable delay.
- Scenarios A: range of achievable flight time and delay largest, and least sensitive to mass.
- Scenarios U: descent to ALWYZ flown at idle thrust. Range of achievable delay increased (no spd constr.), but maximum flight time reduced.
Results: Airspeed Profiles

- Scenarios O/A: shallower than the optimal profile; the at-or-below altitude constraints limit the cruise extension in case of a high cost index to speed-up (A)
- Scenarios U: for the same target speeds, a later descent. At same CAS, TAS is reduced later, and therefore shorter max flight time, but also faster min flight time.
Generalised Simulation Set-Up

- Generalised scenario for aircraft at cruise conditions, 200NM from landing, conducting an idle-thrust descent and a geometric descent
- Flight path angle for geometric descent varied between -3.5 and -1.5 degrees with steps of 0.5 degrees
- Cruising altitude varied between 33,000ft and 39,000ft with steps of 2000ft
- Boeing 737-500 to replicate the GE FMW environment
- EUROCONTROL’s Base of Aircraft Data (BADA) 4 for aircraft performance computations
Results

- -3 degrees geometric descent corresponds closest to the idle descent in terms of fuel burn and achievable flight time range.

- A trend of increasing minimum, maximum and range of achievable flight times for the geometric descents, at the cost of increased fuel burn.
Vertically Constrained OPDs to Increase Delay Absorption Potential

• Altitude requirement can be dynamically set by ATC to increase the delay absorption potential, when needed
• Provides closed-loop clearance than can be entered into the FMS
• ‘Vertical Point Merge’ (kind of…)
Results

- In comparison to the geometric descents, range of achievable flight times is larger for the same fuel penalty.
- If airspace is available, this could provide a practical means to increase delay absorption potential.
Comparison with Actual KDCA Ops

- An 18-hr block traffic sample collected on October 14, 2016
- Fine WX
Comparison with Actual KDCA Ops

• Original FRDMM procedure with all altitude and speed constraints (O), delay of ~25% of the delays could have been absorbed along the procedure
• For the unconstrained idle descents (U) this improves to ~40%
• The largest range of delay is achieved by maintaining the vertical constraints (A); only ~55% of the delays could have been absorbed along the procedure
Conclusion

• Speed constraints are detrimental to the delay absorption potential, but the appropriate use of altitude constraints can lead to increased delay absorption potential.
• Forcing the aircraft to descent earlier than optimal top of descent (of an unconstrained idle-thrust descent) increases the flight time window at the expense of additional fuel burn (which needs to be offset against conventional delaying methods).
• Typical delay is generally in excess of what can be absorbed. There will need to be a strong reliance on improved air traffic flow management procedures, to enable full 4D trajectory management, runway to runway.
Thank you

Flying has torn apart the relationship of space and time: it uses our old clock but with new yardsticks.

— Charles A. Lindbergh.