Analysis of OPD Benefits and Impact on Daytime Operations

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Introduction

• Purpose for the Study
  – Rising fuel costs (Jet fuel ~ $4.00 per gallon)
  – Growing environmental awareness (Carbon trading)

• Analysis Focus
  – Optimized Profile Descent (OPD) operations are expected to reduce fuel usage and pollutant emissions
  – Questions to ask:
    • How will the proximity of arrival and departure flows change if OPDs are implemented?
    • Will OPD implementation require a compromise?
    • What will the overall benefit be assuming these compromises?
Outline

• Description of a typical flight
  – Description of a baseline arrival
  – Description of an equivalent OPD trajectory

• Baseline arrival vs. equivalent OPD arrival
  – Track comparison
  – Flow stream comparison
  – Fuel burn and emissions comparison

• Four OPD operational scenarios
  – Unrestricted OPD
  – OPD with step down flexibility
  – OPD with low altitude vectoring
  – OPD with both step down flexibility and low altitude vectoring
Description of a Typical Baseline Arrival
B737-300

- **Trajectory and Fuel burn**
  - **Left-hand side scale:**
    - Blue = Speed
    - Red = Flight level
  - **Right-hand side scale:**
    - Green = Fuel burn rate
    - Yellow = Speed brake

- **Baseline flight**
  - Trajectory derived from radar track data
  - Fuel burn and speed brake computed with iTRAEC trajectory model
  - Aircraft parameters from BADA
Description of an Equivalent OPD
B737-300

• Trajectory and Fuel burn
  – Left-hand side scale:
    • Blue = Speed
    • Red = Flight level
  – Right-hand side scale:
    • Green = Fuel burn rate
    • Yellow = Speed brake

• Transform this flight to an equivalent OPD
  – Ground track is unchanged
  – Speed profile is unchanged
  – Descent profile is computed assuming idle thrust

30 NM range ring

Top of descent
Baseline to OPD Comparison
B737-300

• **Summary**
  - Comparison plot
    • Bold lines = OPD
    • Thin lines = Baseline
  - Total fuel savings is computable from comparison of fuel burn (6 lbs/gallon):

  **Net Fuel Savings = 220 lbs**

* compare to Boeing & LVNL estimate of 240 lbs for B737-800

What happens if this is applied to all arrivals?
DEN Example Flows
Baseline Arrival Tracks
DEN Example Flows
Equivalent OPD Tracks with Modeled Vertical Profiles
Discussion of Equivalent OPD

• Existing baseline arrivals are transformed into OPDs
  – Cruise is extended
  – Thrust on descent is set to idle
  – Ground tracks are left unchanged
  – Speed profiles are left unchanged

• Additional OPD operational considerations
  – Implementing OPD operations will require decision and automation support
  – Transformed tracks lose all vertical separation

• Answers the question: If we design and implement OPDs during all operating hours, where would we need to address operational conflicts and what level of benefit would be derived?
Evaluation Scenarios

• **Scenario 1: Unrestricted OPD**
  – Begins at the maximum cruise altitude
  – Ends as the aircraft transitions to a landing configuration

• **Scenario 2: Delayed initiation**
  – Begins at an altitude lower than the maximum cruise altitude
    • Normal setting of the top of descent above the OPD initiation altitude
    • Allows step-downs before descent
  – Ends after transition to landing configuration

• **Scenario 3: Early termination**
  – Begins at the maximum cruise altitude
  – Ends at a specified lower altitude
    • Normal operations below the OPD termination altitude
    • Allows arrival shelf level-offs

• **Scenario 4: Combination of Scenarios 2 and 3**
Scenario 0: Baseline Arrival Operations

South runway configuration, Jets only
Departures from 17L and less used flows omitted for clarity
Flow tubes encompass ~90% of tracks for each flow stream

cyans = departures
purples = arrivals
Scenario 0: Baseline Arrival Operations

Potential conflict zones:

- Short-side arrivals fly under departures
- Long-side arrivals fly under/over departures
Scenario 0: Baseline Arrival Operations
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Baseline Arrival Operations
Baseline Arrival Flows
Plan and Profile View

- Baseline tracks flow tubes are shown for two sample flows
  - Red lines are the average track
  - Yellow lines bound the flow tubes
- Waypoints and altitude restrictions are indicated
  - Yellow dots indicate where the level-offs occur
  - LANDR to RWY16L level-offs
    - 17,000 ft MSL (TRACON entry)
    - 13,000 ft MSL (under departures)
  - DANND to RWY16L level-offs
    - 19,000 ft MSL (TRACON entry)
    - 13,000 ft MSL (over departures)
    - 11,000 ft MSL (turn onto final)
Scenario 1
Unrestricted OPD

- **Extent of the OPD portion**
  - Begins at the maximum cruise altitude
  - Ends as the aircraft transitions to the landing configuration

OPD Initiation Altitude = 40,000 ft MSL

OPD Termination Altitude = runway elevation
Conflict Zones
Baseline Arrivals

- Tubes shown enclose ~90% of the tracks in each flow
- Northern arrivals
  - All flows fly under the departures heading north
- Southern arrivals
  - Arrivals from POWDR and DANDD fly over departures
  - Arrivals from LARKS and QUAIL fly under departures
Conflict Zones
Unrestricted OPD

- Equivalent OPD flow tubes have higher altitudes
- Northern arrivals
  - *Slight conflict* with departures to the north
- Southern arrivals
  - Arrivals from POWDR and DANDD fly higher over departures – *decreased conflict*
  - Arrivals from LARKS and QUAIL fly through departures – *direct conflict*
Baseline Arrival Flows
Plan and Profile View

• Baseline tracks flow tubes are shown for two sample flows
  – Red lines are the average track
  – Yellow lines bound the flow tubes

• Waypoints and altitude restrictions are indicated
  – Yellow dots indicate where the level-offs occur
  – LANDR to RWY16L level-offs
    • 17,000 ft MSL (TRACON entry)
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    • 13,000 ft MSL (over departures)
    • 11,000 ft MSL (turn onto final)
Equivalent OPD Arrival Flows
Plan and Profile View

• Equivalent OPD flow tubes are shown
  – Altitudes are higher
  – Widths are larger
  – Vertical constraints of baseline operations are not met

• Previous altitude restrictions are removed
  – Yellow dots indicate where the level-offs previously occurred
  – LANDR to RWY16L level-offs
    • 17,000 ft MSL (TRACON entry)
    • 13,000 ft MSL (under departures)
  – DANDD to RWY16L level-offs
    • 19,000 ft MSL (TRACON entry)
    • 13,000 ft MSL (over departures)
    • 11,000 ft MSL (turn onto final)
Scenario 1
Maximum Fuel and Emissions Savings Estimate

- Total maximum fuel savings and emissions benefit can be estimated by assuming unrestricted OPD implementation with no conflict mitigation compromises
  - Savings of approximately 20,000 gallons per day
  - Daily reduction of approximately 200 tons CO₂ and 100 lbs of SO₂
  - Actual implementation will require compromises to avoid conflicts between aircraft, which will reduce the overall actual savings realized

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<th>Arrival Fix</th>
<th>Fuel Savings (lbs)</th>
<th>Emissions Savings</th>
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<td>CO₂ (lbs)</td>
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Scenario 2
Delayed Initiation

- **Extent of the OPD portion**
  - Begins by the specified OPD initiation altitude
    - Above that altitude the aircraft may be in normal operations
    - Allows step down transitions from cruise
  - Ends as the aircraft transitions to the landing configuration

[Diagram showing OPD Initiation Altitude and OPD Termination Altitude equal to runway elevation]
Scenario 2
Benefit vs. Initiation Altitude

- Values for initiation altitude of Flight Level (FL) 400 equal the unrestricted OPD benefits.

- Fuel savings benefits decrease as the initiation altitude is lowered.

- Approximately 85% of the maximum fuel savings benefit can still be obtained with an initiation altitude of FL250.
Scenario 3
Early Termination

• Extent of the OPD portion
  – Begins at the maximum observed cruise altitude
  – Ends at a specified OPD termination altitude
    • Below that altitude aircraft are in normal operations
    • Allows arrival shelf level-offs for merging and spacing

OPD Initiation Altitude = 40,000 ft MSL

OPD Termination Altitude
Scenario 3
Benefit vs. Termination Altitude

- Termination altitude at the field elevation is equivalent to unrestricted OPD

- Fuel savings benefits fall as the termination altitude rises

- Approximately 30% of the maximum fuel savings benefit can still be obtained with a termination altitude of FL150
Scenario 4
Delayed Initiation plus Early Termination

- Extent of the OPD portion
  - Begins above FL250
  - Ends at FL150
  - This scenario removes the level-off at TRACON entry, but keeps other level-offs within the TRACON

OPD Initiation Altitude = 25,000 ft MSL

OPD Termination Altitude = 15,000 ft MSL
Scenario 4
Fuel and Emissions Savings Estimate

- If the scenario 4 version of OPD can be implemented in which
  - Initiation altitude = 25,000 ft MSL
  - Termination altitude = 15,000 ft MSL
- The maximum per day fuel usage savings is estimated to be
  - Savings of approximately 3,000 gallons per day
  - Daily reduction of approximately 30 tons of CO₂ and 15 lbs of SO₂

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Summary of Scenarios

• **Unrestricted OPD implementation**
  – Continuous descent from cruise altitude down to the landing flaps configuration
    • In this case all level-offs are removed and descents are purely at idle thrust
  – For DEN, the maximum total fuel savings is estimated to be 20,000 gallons per day with a daily reduction of approximately 200 tons CO₂ and 100 lbs of SO₂
    • This scenario is highly idealized since realistic OPD implementation will require conflict mitigation compromises, which will decrease the potential benefit

• **Delayed initiation and early termination**
  – The OPD segment of the descent begins above FL250 and ends at FL150
    • This allows step downs from cruise at high altitude and arrival shelf vectoring at low altitude
  – For DEN, the total fuel savings is estimated to be 3,000 gallons per day with a daily reduction of approximately 30 tons of CO₂ and 15 lbs of SO₂
    • This implementation scenario removes the level-off prior to TRACON entry, but retains other level-offs within the TRACON
    • This scenario will still require automation and decision support for merging and spacing
Conclusions

• **Conflicts**
  - Arrivals under departures will conflict more with OPD implementation
  - Arrivals over departures will conflict less with OPD implementation

• **Benefits**
  - Benefits depend on aircraft type and arrival direction
    • Long-side arrivals have more benefit potential than short-side arrivals
    • Maximum fuel savings potential falls in the range 150-350 lbs per flight
    • Maximum emissions reduction potential falls in the range of 400 -1,000 lbs total for CO₂ and SO₂ per flight
  - **Fuel and emissions savings depend on the initiation and termination altitudes**
    • Most of the benefits come from below 25,000 ft MSL
    • Step downs from cruise may be allowed with 15% loss of benefit
Recommendations

- **Specific to DEN in south runway configuration**
  - OPD implementation on the POWDR and DANND STARs would cause the fewest conflicts with departure flows
  - **Conflict mitigation strategies and associated benefits**
    - High altitude step downs from cruise above FL250 can be permitted while still allowing approximately 85% of the maximum potential fuel savings benefit
    - Implementing OPDs which end at FL150, such that arrival flows can be directed under departure flows, can still yield 30% of the maximum potential fuel savings benefit
    - OPDs which permit both high altitude step downs and low altitude level-offs can still yield 15% of the maximum potential fuel savings benefit
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