Analyzing & Implementing Delayed Deceleration Approaches

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Aircraft Operations Environment Assessment

• Initial scoping study to identify & evaluate operational techniques to reduce fuel burn and environmental impacts in the near/mid-term with minimal implementation barriers*

• Objectives:
  – Identification, evaluation and prioritization of 60+ options
  – Detailed analysis of benefits & barriers of promising options
    • Cruise Altitude and Speed Optimization
    • Delayed Deceleration Approaches
  – Promote deployment of best practice operations
    • Socialization with stakeholders
    • Integration strategies for current & future operations

Delayed Deceleration Approach (DDA) Concept

- Keep aircraft “clean” for longer on approach when appropriate without impacting terminal area entry or final approach stabilization criteria
  - Between these speed gates, opportunity for encouraging more efficient approach speed profiles

**“Clean” configuration**

- Terminal area entry speed
- Delayed Decel. => Low Power/ Low Drag

**“Dirty” configuration**

- Typical Conventional
- Final approach speed
- Runway

<table>
<thead>
<tr>
<th>Distance to Touchdown</th>
<th>Airspeed</th>
</tr>
</thead>
<tbody>
<tr>
<td>≈30 NM</td>
<td>230-250 kts IAS</td>
</tr>
<tr>
<td>≈10 NM</td>
<td>160-180 kts IAS</td>
</tr>
</tbody>
</table>

- Sample flap 1
- Sample flap 2
- Delayed Deceleration Approach (DDA) Concept
Outline

• Delayed Deceleration Approach (DDA) Concept

• DDA fuel burn and emissions reduction potential

• Analyzing speed profiles and barriers at US airports

• Noise analysis

• Implementing DDA via RNAV procedures

• Conclusions & Recommendations
DDA Benefits Potential

European A320 Flight Data Recorder Analysis (similar results for B757 & B777)

- Lowest fuel burn flights (green profiles) associated with delayed deceleration

30-50% fuel burn reduction potential from DDAs from 10,000 ft to touchdown
**System-Wide DDA Benefit Potential**

- Estimated system-wide fuel saving benefits potential of increased DDA utilization

**Aircraft Weight Class**

- **RJ**
- **Small NB**
- **Large NB**
- **Two Engine WB**
- **Four Engine WB**

**Example Aircraft Types**

- **RJ** CRJ, ERJ
- **Small NB** A320, B737
- **Large NB** B757
- **Two Engine WB** A330, B777
- **Four Engine WB** A340, B747

**DDA Saving per Approach**

- RJ 120
- Small NB 146
- Large NB 183
- Two Engine WB 276
- Four Engine WB 375

**Approx # Flights per Day**

- RJ 7500
- Small NB 14,400
- Large NB 1,800
- Two Engine WB 3,900
- Four Engine WB 2,400

**Fuel Reduction Benefit Pool (gal/yr)**

- RJ 49m
- Small NB 115m
- Large NB 18m
- Two Engine WB 59m
- Four Engine WB 49m

**$ Annual Savings per 1% Inc. in DDA Use**

- RJ $1.5m
- Small NB $3.5m
- Large NB $0.5m
- Two Engine WB $1.8m
- Four Engine WB $1.5m

**Totals**

- $8.8m

*FAA investment analysis recommended fuel price of $3.02/gal
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Fuel Burn Correlations with Other Observable Metrics

• Need to find correlations between fuel burn and states observable in US radar track data

• Correlation analysis identified Airspeed and Time with Flap1 as main drivers of fuel burn
  – Flap1 speed 180-210 kts for most “large” aircraft

Time flown below 180kts used as proxy for fuel burn for large weight category aircraft
Quantifying Speed Profiles at US Airports

- Analyzed speed profiles at range of US airports
  - Capacity-constrained standalone airports (ATL, LAX, BOS, CLT)
  - New York metroplex airports (EWR, JFK, LGA)
  - Washington DC metroplex airports (DCA, IAD, BWI)
  - Capacity-unconstrained standalone airports (STL, RIC, DFW)

- 9 months of radar archives from 2011 and 2015
- Ground speed converted to airspeed using NARR wind data
ATL Approach Speed Analysis

“Large” aircraft arrivals from ZDC, 4 sample days

Airspeeds

\[ \leq 210 \text{ KIAS} \]

\[ \leq 180 \text{ KIAS} \]
ATL Approach Speed Analysis

Time flown below 180 kts correlated most strongly with fuel burn for “large” aircraft type.

Cumulative curves of time flown below 180 kts used as key airport speed metric.

Arrivals from ZDC JAN – SEP 2011
NYC Metroplex Approach Speed Analysis

• Earlier decelerations generally observed under IMC compared to VMC
• LGA under IMC has earliest decelerations

Arrivals from ZDC, 8 sample days

<table>
<thead>
<tr>
<th>Airport</th>
<th>VMC</th>
<th>IMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWR</td>
<td>&lt;= 210 KIAS</td>
<td>&lt;= 180 KIAS</td>
</tr>
<tr>
<td>LGA</td>
<td>&lt;= 210 KIAS</td>
<td>&lt;= 180 KIAS</td>
</tr>
<tr>
<td>JFK</td>
<td>&lt;= 210 KIAS</td>
<td>&lt;= 180 KIAS</td>
</tr>
</tbody>
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Percentage of All Landings

Arrivals from ZDC JAN – SEP 2011

- LGA VMC n = 10,530
- LGA IMC n = 1,600
- JFK VMC n = 9,070
- JFK IMC n = 1,048
- EWR VMC n = 4,435
- EWR IMC n = 775
Airport Approach Speed Profile Comparison

Arrivals from ZDC
JAN - SEP 2011

Time Flown Below 180 kts for 50% of Flights (mins)

- VMC
- IMC
- Weighted

Arrivals from ZDC
JAN – SEP 2011
Analyzing Drivers of Speed Profiles

• Need to understand causes of differing speed profiles to identify opportunities for increased DDA operations
  – If primary drivers to encourage greater DDA usage are easily modifiable (e.g., ATC training or procedures) => good target airports
  – More difficult to increase DDA-type procedures at airports where primary drivers are elements such as airspace or airport constraints

• Created decision trees to find combinations of independent variables correlated with time flown below 180kts

• Independent Variables
  – Weather (VMC or IMC)
  – Hourly Airport Acceptance Rate (AAR)
  – Total arrival demand (15 min bins)
  – Airport configuration
  – Airline
Classification Tree Approach

- Technique identified key drivers of approach speed profiles
  1. Weather conditions (VMC vs. IMC)
  2. Dominant operator
  3. Airport configuration
  4. Higher capacities (AAR)

- Relative importance varies by airport

- Dominant carrier influence suggests airline procedural effect

ATL Example

Wx=VMC
Config=West flow
ArrDem >= 18.5
AAR >= 113
AAR >= 114.5
Airline=Delta

ArrDem >= 18.5
AAR >= 107.5

Time Flown
Below 180kts (s)

1: t < 122
2: 122 <= t < 169
3: 169 <= t < 267
4: t >= 267

AAR = Airport Acceptance Rate (per hr)
ArrDem = Arrival Demand (per 15 mins)
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DDA Noise Impacts

- Airframe and engine noise both important during approach & landing

Empirical & modeling studies conducted to understand DDA noise impacts
BOS Noise Measurement Campaign
Measurement Period: 11/13/15 – 1/25/16

Research Outputs:
- Noise modeling validations
- Noise as a function of speed, configuration, approach procedures, aircraft type

Runway 22L/22R Arrivals
Jan-Mar and Jun-Aug 2014

Airline Standard Operating Procedures, Flap Schedules, etc.

No. of Radar Surveillance Hits

No. of Radar Surveillance Hits

VMC  IMC  Weighted

Time Flown Below 180 kts for 50% of Flights (min)

DCA  LGA  EWR  BOS  AD  JFK  BWI  LAX  ATL  RIC  STL
Slight negative trends indicate marginal decrease in noise with increasing airspeed on average

Similar results for Lmax

10-15 dBA variability in data

- Not removed when correction for energy change rate applied
- Attributed to atmospheric differences
TASOPT, BADA4 & ANOPP Model Integration

Performance Model Inputs:
- Operating/mission parameters
- Aircraft sizing/performance parameters
- Engine sizing/performance parameters

TASOPT

BADA4 Existing Aircraft Data

Performance Model Outputs:
- Aircraft/engine performance & geometry

Aircraft Type

Procedure Definition:
- Lateral Path
- Speeds
- Configuration

Flight Procedure Generator

Flight Procedure:
- Thrust, velocity, position, gear/flap settings per time

Noise Model Control Inputs:
- Propagation Settings
- Observer Locations

ANOPP

Single-Event Noise Grids
Modeling of Enhanced DDA Operations

- Modeled range of approaches with different aircraft types & profiles

Overall, negligible effect of DDA speed profiles on noise impacts on ground
Outline

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• Analyzing speed profiles and barriers at US airports

• Noise analysis

• Implementing DDA via RNAV procedures
  – Feasibility of RNAV procedures for DDA implementation
  – Design considerations for RNAV DDAs
  – Assessing RNAV Procedure Targets

• Conclusions & Recommendations
Assessing Feasibility of RNAV DDAs

• Biggest uncertainty in effective implementation of DDA: track distance to touchdown
  – PBN (RNAV/RNP) approach procedures reduce uncertainty

• Simulated approaches with:
  – Same programmed lateral/vertical route as published RNAV arrivals
  – Different speed constraints
  – Different aircraft weights

• Utilized Lincoln FMS analysis capability
  – Pegasus FMS flight code
  – Integrated to B757-200 simulation
Simulated B757 ATL RNAV DDA Arrivals

- Early deceleration shown to use 54% more fuel in TRACON compared to late

- Late deceleration fuel burn shows the least sensitivity to aircraft weight

<table>
<thead>
<tr>
<th>Deceleration Profile</th>
<th>Late</th>
<th>Medium</th>
<th>Early</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRACON Duration</td>
<td>12 mins</td>
<td>14 mins</td>
<td>15 mins</td>
</tr>
<tr>
<td>TRACON Fuel Use</td>
<td>1030 lbs</td>
<td>1347 lbs</td>
<td>1588 lbs</td>
</tr>
<tr>
<td>TRACON Fuel Use Relative to Lowest</td>
<td>-</td>
<td>+31%</td>
<td>+54%</td>
</tr>
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</table>
Design Considerations for RNAV DDAs

- For RNAV DDA procedures to be practically useful, need to minimally modify existing procedures and be flyable by different types
- Evaluated speed envelope for range of representative profiles and aircraft types
- Significant differences in deceleration profiles observed between types

Based on BADA 4 analysis

Approach Profiles at Median Weight and Flap Extension Speeds

Need to account for aircraft deceleration capabilities in RNAV DDA design
Comparison of Fuel Saving with Different Speed Profiles for Different Types

- Modeled fuel burn on BOS ROBUC2 RNAV arrival with four different speed profiles

- Significant difference between “B757 latest” and “a/c type latest”
  - Trade-off between procedure simplicity and fuel saving
Assessment of Current RNAV Arrival Speed Targets

- Compared speed profiles of range of current RNAV arrivals compliant with
  - “As published” speed targets
  - Latest speed profile flyable by B757 reference aircraft
Assessment of Current RNAV Arrival Speed Targets

- Area between lines indicates how close published procedure speed targets are to B757-optimized speed profile
  - Area comparison methodology proposed as a procedure efficiency screening tool
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Conclusions

• DDA is a promising concept for reducing approach fuel & emissions

• Radar analysis and classification tree approach provides insight into airports with highest benefit potential and lowest barriers

• Noise analysis showed negligible effects of DDA on noise impacts on ground

• RNAV arrival procedures offer a promising implementation path

• Tools presented for identifying RNAV arrival procedure candidates for modified speed targets to gain DDA benefits
Recommended Next Steps

• Further promote DDA concept to relevant stakeholders
  – ATC facilities, Airlines/flight crews, Procedure designers

• Use proposed methodologies and tools to undertake:
  – Wider screening of existing procedures
  – Identify candidates for re-design process
  – Redesign, analyze and deploy appropriate modified procedures to realize DDA benefits in operational system

• Assess human factors implications of DDA on ATC and flight crews

• Explore how new automation (e.g., TSS) could be leveraged to promote DDA

TSS = Terminal Sequencing and Spacing
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