Flight Trials of CDA with Time-Based Metering

at

Atlanta International Airport

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Federal Aviation Administration

Presented by: Jim Brooks

JPDO Operations Panel – NASA Ames
Agenda

- Background
- Operational Concept
- Time-Based Separation Analysis
- Time-Based Metering
- KATL KIRMT RNAV CDA Design
- KATL CDA Spacing Matrix
- KATL CDA Initial Benefit Results
- KATL CDA Merging and Spacing
Benefits of CDA

- **Environment**
  - Higher trajectory and reduced thrust over much of the arrival and approach results in reduced noise impact
  - Less time spent below “mixing height” and reduced thrust results in reduced emissions

- **Fuel burn**
  - Fuel savings due to less vectoring and less time flying low and slow with flaps extended

- **Flight time**
  - Time to complete arrival and approach reduced due to less vectoring and less time flying low and slow

- **Lower controller and pilot workload**
Operational Concept

- Intermediate metering point connects descent from cruise, to final
- Target spacing (or time interval) recommended at metering point
  - Uninterrupted operation at a desired probability, but not absolute
- Key is to determine the recommended value of target spacing or time interval and establish these values in real world operations
  - Modeling and managing trajectory variation and uncertainty
Minimum Feasible Time Interval

- Protect against separation minima
- Minimum feasible spacing will be a probability distribution
Conditional Probability for Given Target Time Interval

- Integral of minimum feasible interval pdf from zero to the target interval

\[ P_{R_i} = \int_0^{T_i} p_i d\tau \]
Sequence Specific Metering for Better Throughput

- Target Interval $T_{i1}$
  - Minimum Feasible Interval, $p_1$
  - AC Type A – Type B

- Target Interval $T_i$

- Target Interval $T_{i2}$
  - Minimum Feasible Interval, $p_2$
  - AC Type B – Type A

Probability Density

Time Interval at Metering Point
Time-Based Metering

- Achieving target time interval through minor speed adjustments
  - Speed adjustment given during en route

- Rely on accurate estimation of time of arrival at the metering point
  - Routing, vertical profile, speed profile, winds

- Speed adjustment optimized for system wide efficiency
  - Total fuel burn, total flight time
  - Subject to flight schedule and other operational constraints

- More complex objective function with multiple operators
  - Next steps
Time-Based Metering

- Use minor speed adjustments
  - Act early, adapt to uncertainty
  - Within ATC permitted speed deviation range (±0.02 Mach) if possible
  - Minimum deviation from optimum speed

![Example Narrow Body Jet](image1.png)
![Example Wide Body Jet](image2.png)


Time-Based Metering

- Change in RTA vs. Speed Adjustment
  - Cruise at FL360 or above, ground speed at TOD = 500 kt

![Graph showing change in RTA at metering point vs. action time prior to TOD with different lines representing different change values.](image-url)
KATL KERMT RNAV CDA Design

- Unrestricted CDA from cruise altitude
  - Idle descent from cruise altitude to base leg
- Designed for overnight arrivals from the west of US
- Overlaid on current traffic pattern
- Designed for multiple aircraft types
  - B737-800, B757-200, B767-300, B767-400
- RMG selected as the metering point
  - 55 nm to runway 09R; 66 nm to runway 26R; 16,000 ~ 20,000 ft
- Merging occurs at RMG
  - KSDF 2004 flight test merging occurred at cruise altitude
- Most challenging task:
  - Efficiently managing spacing/timing at metering point
KIRMT RNAV ARRIVAL (KIRMT.KIRMT 1)

Vertical Descent Planning
Arrival must be flown with FMS LNAV and VNAV guidance

ATC COMMUNICATION

Filed clearance is via the ERLIN 2 arrival. 
Upon the initial check in with Atlanta Center request KIRMT 1 Arrival.
If able, Atlanta Center will issue clearance via the KIRMT 1 Arrival.
Expect a descend via plots discretion to 11,000'.
Upon initial check in with Atlanta Approach advise the KIRMT 1 Arrival.
If clearance to descend via the KIRMT 1 Arrival is not received prior to DALAS
and alternate instructions have not been issued, proceed direct ATL VOR and
maintain last assigned altitude.

Pilot Notes
- Load KIRMT 1 Arrival and corresponding ILS. Close Discontinuity only after clearance from approach.
- Set current wind information.
- Set speed/altitude constraints to match STAR plate.
- Set FMS descent speed.
- MCP altitude should be lowest ATC clearance.
- Enter any ATC speed or route changes in FMS and use thrust or speed brakes to reacquire VNAV Path.
- For best VNAV path performance maintain speed close to commanded speed.
- Arm APPCH in accordance with your fleet procedures.
- After glide slope capture, set SPD window to match CDA profile.

Routing

<table>
<thead>
<tr>
<th>Landing</th>
<th>DALAS Int via RNAV routing to STUTZ Wpt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landing</td>
<td>DALAS Int via RNAV routing to VINII Wpt</td>
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</table>

Lost Communications:
11000' until ERLIN, then descend via KIRMT 1 Arrival
Typical Vertical Profiles

Wind: 270/70 kt
### Typical Target Time Intervals

CDA to Runway 26R, Wind: 270/70 kt at 37,000 ft

<table>
<thead>
<tr>
<th>Leading Aircraft</th>
<th>Target Time Interval at RMG, seconds</th>
<th>Trailing Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>B738</td>
<td>72.8</td>
<td>B738</td>
</tr>
<tr>
<td>B752</td>
<td>134.8</td>
<td>B764</td>
</tr>
<tr>
<td>B764</td>
<td>137.6</td>
<td></td>
</tr>
</tbody>
</table>

**Leading Aircraft**: B738, B752, B764

**Trailing Aircraft**: B738, B764
## Initial Benefit Results

### CDA B757-200 Simulation data 24-Apr-07

<table>
<thead>
<tr>
<th>Aircraft Weight</th>
<th>Fuel, TOD to runway</th>
<th>Time, RMG to runway</th>
</tr>
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<tbody>
<tr>
<td>179,700 (Delta average)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CDA09R</strong></td>
<td>783.80 lb</td>
<td>116.99 gal</td>
</tr>
<tr>
<td><strong>CDA26R</strong></td>
<td>830.38 lb</td>
<td>123.94 gal</td>
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### CDA B767-300 Simulation data 24-Apr-07

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<th>Aircraft Weight</th>
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<tr>
<td>265,800 (Delta average)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CDA09R</strong></td>
<td>1122.07 lb</td>
<td>167.47 gal</td>
</tr>
<tr>
<td><strong>CDA26R</strong></td>
<td>1172.74 lb</td>
<td>175.04 gal</td>
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### Conventional B757-200 Aircraft estimated data 24-Apr-07

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<th>Aircraft Weight</th>
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<tr>
<td>180,550 (Average of two flights)</td>
<td></td>
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<tr>
<td><strong>STD09R</strong></td>
<td>1850.00 lb</td>
<td>276.12 gal</td>
</tr>
<tr>
<td><strong>STD26R</strong></td>
<td>2500.00 lb</td>
<td>373.13 gal</td>
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<td>264,150 (Average of two flights)</td>
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<tr>
<td><strong>STD09R</strong></td>
<td>2500.00 lb</td>
<td>373.13 gal</td>
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### Est. Reduction B757-200 24-Apr-07

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<tr>
<td><strong>CDA09R</strong></td>
<td>1019.62 lb</td>
</tr>
<tr>
<td><strong>CDA26R</strong></td>
<td>1327.26 lb</td>
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### Est. Reduction B767-300 24-Apr-07

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Note:
1. All data based on 24-Apr-2007 weather environment and equipment assignment
2. Simulation data obtained using Georgia Tech fast time simulation tool, aircraft weight based on Delta average over a month
3. Aircraft estimated fuel data obtained from flight plan.
4. Aircraft estimated time data obtained from crew reports. These numbers were reported before CDA was loaded, thus considered conventional (STD)
5. Runway 09R estimated data not available
Clayton Tino and Heinrich Souza (Georgia Tech) processing CDA profiles and wind data, Marcus Lowther participated on other days.

20-24 May 2007, Denver, CO
Merging and Spacing Task (GFF)
Forecast Winds (Flight Plan Tool)
Estimated Time of Arrival (Attila™)
Example Speed Adjustments

- Speed adjustment up-linked via ACARS by way of dispatcher
- For DAL1002, DAL0752, DAL0780
  - 8:14:51, DAL1002, M0.789, CHANGE TO M0.800
  - 8:46:50, DAL0752, M0.802, CHANGE TO M0.820
  - 9:03:24, DAL1002, M0.805, CHANGE TO M0.820
    - Resume normal speed of M0.780 prior to TOD
  - Speed increase selected because all three flights are behind schedule. Slowdown of trailing aircraft are used otherwise to save more fuel
Properly Spaced Arrival Flow
Properly Spaced Arrival Flow
Challenges

- **Modeling of CDA trajectory variations**
  - Assure accurate spacing matrix
  - TASAT verified by ATL and previous flight tests

- **Optimization algorithm**
  - Systems approach, multiple objectives
  - Schedule and other operational constraints
  - Dynamic, may change over time

- **En route trajectory prediction**
  - Winds, winds, winds: forecast, wind mix, use of ACARS report
  - Aircraft routing uncertainty: convective weather a major factor
  - Aircraft operational uncertainty: speed change by crew
  - Ground based or air based?
    - Attila™ ETA more consistent and stable than aircraft report