Optimized Vertical Profiles
Improving Efficiency in Daily Operations

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Environmental Working Group
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Today to NextGen

• Today, new RNAV SIDS/STARS principally consist of procedures that closely mirror current vector patterns or their conventional counterpart
  – The reasons for this range from airspace complexity to criteria limitations to environmental constraints on large procedural changes

• The current National Airspace Procedures Team (NAPT) list has 307 RNAV SIDS/STARS planned between now and the end of CY 2011
  – 173 of these procedures are “new” designs/implementations

• How can we make these and future procedures measurably more efficient and/or environmentally beneficial?
Optimized Vertical Profiles

Arrivals and Departures

- Leverages RNAV SID/STAR implementations
- Reduce the amount of time spent in level flight on published procedures (i.e., SIDS/STARs) for less fuel/emissions
  - Published procedures will principally consist of PBN procedures though not exclusively (i.e., LAX arrivals)
NAS RNAV/RNP Implementation

Purple – RNAV SIDs/STAR – 339
Yellow – RNAV En route – 124
Green – Airports with RNAV or RNP approaches – 2000+

% of Operations With RNAV/RNP

RNAV/RNP Implementation in the NAS
Optimized Vertical Profiles

Where are we today?

• There are over 1,600 conventional and RNAV SIDS and STARS in the NAS today
• OPDs have been published for every day operations at PHX, SAN, and LAX (RNAV and conventional procedures respectively)
  – 7 procedures total at these airports
• Other OPD implementations or planning include
  – Atlanta (ATL)
  – Louisville (SDF)
  – Charleston (CHS)
  – Hawaii (HCF)
  – Memphis (MEM)
  – Reno (RNO)
  – Anchorage (ANC)
  – Las Vegas (LAS)
  – Denver (DEN)
• Can we do more, can we improve results, at a faster pace?
Near Term Transition

• FAA Goal:
  – Integrated Airspace and Procedure design
  – Site-specific modeling and analysis and a commitment from stakeholders is pivotal to success
    • Optimized vertical profiles for departures and arrivals
• How do we move then from today’s designs and implementations to more optimized/beneficial designs?
  – Integrated SID/STAR design/implementation
  – Focus development resources toward the near term
  – Target efficiency/environmental goals on each design/implementation
• Are near term benefits achievable?
  – Absolutely but it takes additional resources and coordination
• What are the potential benefits?
Phoenix OPD

EAGUL RNAV STAR Procedure with Descend Via (DV) Ops

Oct 20, 2008
ZAB issues DV
As early as DOJOE

Sep 22 – Oct 20, 2008
ZAB issues DV
shortly after SLIDR

FL360
DOJOE
No altitude constraint

FL310
SLIDR
No altitude constraint

FL260
FL240
PAYSO
FL240
280 kts

PICHR
16000'
280 kts

HOMRR
12000'
250 kts

BADNE
9000'

QUENY
8000'

FL240

Oct 2006 – Sep 2008
PHX TRACON
issues DV on EAGUL

ZAB
Handoff to Final

PHX TRACON

Saving 23 gallons
(total) per arrival since implementation

Saved 5 gallons per arrival since implementation

Conventional step-down arrival operations
Fuel & Emission Benefits at PHX

This table shows the reductions in emissions and fuel as a result of descend via implementation from SLIDR and DOJOE.

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (t)</th>
<th>SO₂ (t)</th>
<th>Fuel (gallons per arrival)</th>
<th>Cost savings (annualized)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DV from SLIDR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Tracks</td>
<td>1831</td>
<td>0.46</td>
<td>4</td>
<td>$0.4M-$0.8M</td>
</tr>
<tr>
<td>RNAV</td>
<td>644</td>
<td>0.17</td>
<td>2</td>
<td>$0.1M-$0.3M</td>
</tr>
<tr>
<td><strong>DV from DOJOE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Tracks</td>
<td>8735</td>
<td>2.18</td>
<td>23</td>
<td>$1.8M-$3.6M</td>
</tr>
<tr>
<td>RNAV</td>
<td>7028</td>
<td>1.80</td>
<td>23</td>
<td>$1.5M-$2.9M</td>
</tr>
</tbody>
</table>

*Based on estimated fuel cost of $2-$4 per gallon
Los Angeles OPDs

- Enables 50% of LAX traffic an OPD
- 96% compliance with the vertical profile
- Fuel savings of over 2 million gal annually ($4-6 Million dollars)
- Reductions in CO$_2$ emissions estimated at over 41 million metric tons annually
RNAV OPD Site Selection

• Conducted a high-level NAS-wide analysis of airports to prioritize OPD implementation sites

• Analyzed 4,500+ arrival flows at 158 airports across the NAS

• Analysis places statistical weight on the metric categories
  – Weights can be adjusted to address implementation priorities
  – Example: Using a 45/45/10 percent weighting

<table>
<thead>
<tr>
<th>Composite 45/45/10 List</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>6</td>
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<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

### PHL

Analysis of one arrival flow at PHL

<table>
<thead>
<tr>
<th>Average daily arrival count at airport</th>
<th>Number of centers</th>
<th>Number of level-offs</th>
<th>Percent vectoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>660 arrivals</td>
<td>2.6</td>
<td>5</td>
<td>26%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average daily arrival count along flow</th>
<th>Percent Part121 Ops</th>
<th>Percent Jet Ops</th>
<th>Average time in level flight per aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>142 arrivals</td>
<td>76%</td>
<td>84%</td>
<td>585 s</td>
</tr>
</tbody>
</table>

Vertical profile of Rwy 27R arrivals

Arrival flow to PHL Rwy 27R
Benefits Analysis

• Operational data from these 10 airports combined with benefits estimates yield significant monetary and carbon savings

<table>
<thead>
<tr>
<th>Composite 45/45/10 List</th>
<th>5 gal per flight</th>
<th>15 gal per flight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rank</strong></td>
<td><strong>Airport</strong></td>
<td><strong>Savings (Gal/day)</strong></td>
</tr>
<tr>
<td>1</td>
<td>STL – St. Louis, MO</td>
<td>7324</td>
</tr>
<tr>
<td>2</td>
<td>MHT – Manchester, NH</td>
<td>21973</td>
</tr>
<tr>
<td>3</td>
<td>PIT – Pittsburgh, PA</td>
<td>80201</td>
</tr>
<tr>
<td>4</td>
<td>CVG – Covington, KY</td>
<td>4456</td>
</tr>
<tr>
<td>5</td>
<td>RDU – Raleigh-Durham, NC</td>
<td>26734</td>
</tr>
<tr>
<td>6</td>
<td>FLL – Fort Lauderdale, FL</td>
<td>30739</td>
</tr>
<tr>
<td>7</td>
<td>PHX – Phoenix, AZ</td>
<td>16503</td>
</tr>
<tr>
<td>8</td>
<td>MCO – Orlando, FL</td>
<td>13209</td>
</tr>
<tr>
<td>9</td>
<td>SAN – San Diego, CA</td>
<td>8817</td>
</tr>
<tr>
<td>10</td>
<td>SLC – Salt Lake City, UT</td>
<td>6425</td>
</tr>
</tbody>
</table>

• How do we leverage modeling and analysis to optimize integrated airspace and procedures?

• It requires ATC facility(s) and operator consensus and it begins with the kickoff meeting...
Kickoff Meeting
Start with Operational Homework

- Assess the operating environment to discover opportunities for efficiency gains
Kickoff Meeting
Where are Efficiency Opportunities?

• Analyze departure/arrival flows to target opportunities for modified procedures

<table>
<thead>
<tr>
<th>Average daily arrival count along flow</th>
<th>Percent Part121 Ops at the airport</th>
<th>Percent Jet Ops at the airport</th>
<th>Time in level flight per aircraft along flow</th>
<th>Number of Level Offs</th>
<th>Number of Facilities Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>48 arrivals</td>
<td>87%</td>
<td>81%</td>
<td>244 s</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Selected Altitudes</th>
<th>Time in Level Flight (sec)</th>
<th>Gal/min burn rate</th>
<th>Gal/day burned</th>
<th>Cost/day ($)</th>
<th>CO2 emitted (tons/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9000</td>
<td>26</td>
<td>9.9</td>
<td>205</td>
<td>600</td>
<td>2</td>
</tr>
<tr>
<td>11000</td>
<td>42</td>
<td>9.9</td>
<td>335</td>
<td>1000</td>
<td>3</td>
</tr>
<tr>
<td>13000</td>
<td>94</td>
<td>9.9</td>
<td>741</td>
<td>2200</td>
<td>7</td>
</tr>
<tr>
<td>14000</td>
<td>12</td>
<td>9.9</td>
<td>99</td>
<td>300</td>
<td>1</td>
</tr>
<tr>
<td>19000</td>
<td>45</td>
<td>10.0</td>
<td>356</td>
<td>1100</td>
<td>3</td>
</tr>
</tbody>
</table>
Kickoff Meeting

Where are Efficiency Opportunities?

Analysis of Chicago and Midway departure/arrival interactions. Analysis provides the means to optimize new or revised procedures in any TRACON.
Kickoff Meeting
Modeling, Analysis and Design Options

- FAA tasked MITRE to develop a trajectory model for procedure design support
- Enables fast time fuel burn, emissions, and track metrics analysis
- Models FMS VNAV path construction
- Addresses operational variability
  - Fleet Mix
  - Wind
  - Cost Index
  - Speed restrictions
- On the spot simulation to test design options and variability
• Trajectory modeling provides an understanding of how an aircraft will fly post-implementation
• This allows for an analysis of the magnitude of benefit a procedure may provide
• This also allows for modeling the benefit delta between multiple procedure designs

<table>
<thead>
<tr>
<th>Fuel Burn (kg/flight)</th>
<th>STAR_R0</th>
<th>STAR_R1</th>
<th>STAR_R2</th>
<th>STAR_C1</th>
<th>STAR_C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SID_D0</td>
<td>1227.4</td>
<td>1224.1</td>
<td>1226.0</td>
<td>1223.9</td>
<td>1223.3</td>
</tr>
<tr>
<td>SID_D1</td>
<td>1213.4</td>
<td>1210.1</td>
<td>1211.9</td>
<td>1209.9</td>
<td>1209.3</td>
</tr>
<tr>
<td>SID_D2</td>
<td>1181.5</td>
<td>1178.2</td>
<td>1180.1</td>
<td>1178.0</td>
<td><strong>1177.4</strong></td>
</tr>
<tr>
<td>SID_C1</td>
<td>1202.9</td>
<td>1199.7</td>
<td>1201.5</td>
<td>1199.5</td>
<td>1198.8</td>
</tr>
<tr>
<td>SID_C2</td>
<td>1224.2</td>
<td>1220.9</td>
<td>1222.8</td>
<td>1220.7</td>
<td>1220.1</td>
</tr>
</tbody>
</table>
Summary

• Optimized Vertical Profiles can produce significant cost and environmental savings
  – One part of the FAA strategy for Integration of Airspace and Procedures that will maximize benefits to the widest net of stakeholders
  – FAA is working locations today: ATL, MIA, CHS, BHM, SDF, LAX, STL, PHL, ABQ
• Begin the process and set goals at kickoff and measure progress against those goals
• Implementation challenges
  – Environmental requirements
  – Airspace complexity
  – Mixed equipage
  – Facility readiness and site specific airspace design/re-design
  – Automation

BUT

• Near-term benefits will result from taking design/implementation to the next step and addressing those challenges