SFO Tailored Arrivals Environmental Analysis

by

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JPDO Environmental Working Group 
Operations Standing Committee 
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Background

- Oceanic Tailored Arrivals (OTA) field test with UAL B777 since 2005 - prediction accuracy (both EDA and FMS)

Current Status

- This is an operational implementation, not a trial
- Both B777 and B747 aircraft are now participating
- Not all flights requesting will get a full TA. Some will, but without the full automation (NASA’s EDA), not all will get a full TA and the FAA is not promising they will. Rather, they get about 1/3 of the benefit by flying a partial TA (TA until broken off by ATC)
- FAA has moved very quickly, leveraging a new system (Ocean21)
- Recognize NASA’s EDA role, and pioneering role
- List of approved airlines (Number of flights per day) – UAL(12), ANZ(1), JAL(2), QAF(1), ANA(1)
- Airlines looking to start very soon – NCA(2), SIA(2), NWA(1 A330), KAL(1), …
- Other candidate airlines – AAR(1), EVA(2), CCA(1), …
This is an example Tailored Arrival Clearance via SUPER (8 Sept 2008)

- From ALCOA, PAINT, DACEM, etc.
- Clearance includes published procedure, transition, and runway
- Clearance includes vertical, lateral, and speed constraints
- Clearance is from en route airspace through to destination

PACIFIC ONE TA
At ALCOA cleared to
- SUPER -----/21000A
- RAINS -----/21000B
- PIRAT 250/15000B
- BRINY 250/12000B
- N3722 W12223 -----/6000A
- OSI
- MENLO 210/4000A
- ILS28R Approach
- Runway 28R
- Maintain FL370

A smooth descent for multiple airframes, across multiple ATS facilities
In the US, Data-link distinguishes Tailored Arrival only for programmatic separation with 3DPAM, whereas Voice Only has been used for the demonstrations in the Dutch and Australia Tailored Arrival Projects.
End-to-end system context

The key hurdles

1. E.g., EDA, TAATS
   Ground automation generates TA trajectory clearance

2. TA clearance coordinated across ATC domains / systems

3. CPDLC
   TA clearance delivered to aircraft over data link

4. TA trajectory received and loaded into FMS on pilot concurrence

5. TA trajectory flown with FMS

6. Aircraft downlinks ETA information (at waypoints) along with other useful parameters for ATC trajectory confirmation and tuning

7. TA procedure broken off if trajectory cannot be continued for any reason
1. Data analysis included Tailored Arrivals flight candidates
   - ANZ8, JAL2, UAL (34, 74, 76, 78, 830, 838, 852, 856, 858, 862, 870, 872, 886, 888, 892)
   - Most Flights from 12/4/07–5/27/08, UAL (78, 856, and 892) included after 3/23/08
   - Flights that arrived via Woodside (OSI)
2. Primary data source: radar data from the SFO ANOMS8 system
   - 5 days (1/3/08, 1/24/08-1/26/08, and 2/23/08) were missing due to ANOMS8 outages
3. Flights sorted by
   - Tailored Arrivals sort criteria using ATS clearances and ADS-C reports
   - Analysis of ANOMS8 radar data to verify and refine the initial sorting
4. Fuel consumption calculations based on prediction:
   - For low speed performance below 10,000 ft altitude, using the Boeing Climb-out Program (BCOP)
   - Above 10,000 ft altitude, using the Boeing INFLT tool for cruise & descent.
   - Vertical profile generated from BCOP and INFLT was matched to the mean descent paths of the collective ANOMS8 radar data
   - Common start point at cruise
5. Tailored Arrivals (TA) sort criteria, using ATS clearances and ADS-C data
   • Non participating - Opted out of procedure or were ineligible
     *Note: As ineligible flights are included in the above statistics, numbers should not be interpreted as pilot participation in Tailored Arrivals*
   • Partial Tailored Arrival – Met SOME of the TA criteria
   • Full Tailored Arrival – Met ALL of the TA criteria

6. **Environmental Criterion:** Radar data shows no more than ONE Level Flight Segment and that is no more than \(\frac{1}{2}\) Nmi.

7. Evaluated all the ANOMS8 data to check if met Environmental Criterion including Non-Tailored Arrivals.

8. Noise Measurement Screening Criteria
   • Lateral offset angle < 60 degrees
   • Noise event less than 2 minute cutoff
Results - Baseline and TA Flights

ANOMS 8 Tracking Data

777-200 & 747-400 Flights
ANZ8, JAL2, UAL (34, 74, 76, 78, 830, 838, 852, 856, 858, 862, 870, 872, 886, 888, 892)

12/4/07 - 5/15/08

173 Full TA's
177 (36 Env) Partial TA's
1247 (88 Env) Non-TA's

76 Holding, Go-Around, or Other Runway

Distance to Touchdown, ft

Altitude, ft
ANOMS 8 Tracking Data – Lateral Path

777-200 & 747-400 Flights

ANZ8, JAL2, UAL (34, 74, 76, 78, 83, 838, 852, 856, 858, 862, 870, 872, 886, 888, 892)

12/4/07 - 5/15/08

173 Full TA’s
177 (38 Env) Partial TA’s
1247 (88 Env) Non-TA’s
26 Holding, Go-Around, or Other Runway
<table>
<thead>
<tr>
<th>Data Collected</th>
<th>Total Flights*</th>
<th>% of Total Flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-TA**</td>
<td>942</td>
<td>76%</td>
</tr>
<tr>
<td>Partial TA</td>
<td>177</td>
<td>14%</td>
</tr>
<tr>
<td>Tailored Arrival</td>
<td>89</td>
<td>7%</td>
</tr>
<tr>
<td>Bad-Holding or Wrong Runway</td>
<td>39</td>
<td>3%</td>
</tr>
</tbody>
</table>

* ANOMS8 Data collected for **1247** Total Flights from December 4, 2007 to May 27, 2008  
** Non-TA included non-participating flights and data collected prior to TA start date
Low Altitude Level Flight (Mean & Std Dev)

- Full TA's: 0.30
- Partial TA's: 8.88
- Non TA's: 15.00
- Holding or Go Around: 49.56
- Env/Non TA's: 0.08
Fuel Consumption from Top of Descent Cruise to Landing

Fuel consumption was calculated using the Boeing Climb-out Program (BCOP) for low speed performance below 10,000 ft altitude.

Fuel consumption above 10,000 ft altitude was calculated using the Boeing INFLT tool for cruise and descent.

The vertical profile generated from BCOP and INFLT was matched to the mean descent paths of the collective ANOMS8 radar data.

* Estimates derived from GE90-85B and PW4056 engine data

<table>
<thead>
<tr>
<th></th>
<th>777-200</th>
<th>747-400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-TA</td>
<td>3,410 lbs</td>
<td>6,470 lbs</td>
</tr>
<tr>
<td>Partial TA</td>
<td>2,900 lbs</td>
<td>5,650 lbs</td>
</tr>
<tr>
<td>Full TA</td>
<td>1,980 lbs</td>
<td>3,670 lbs</td>
</tr>
</tbody>
</table>

Fuel Saving from Tailored Arrival per Flight

<table>
<thead>
<tr>
<th></th>
<th>777-200</th>
<th>747-400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full TA</td>
<td>1,430 lbs</td>
<td>2,800 lbs</td>
</tr>
<tr>
<td>Partial TA</td>
<td>510 lbs</td>
<td>820 lbs</td>
</tr>
</tbody>
</table>
## Estimated Actual Fuel & CO2 Savings from SFO Tailored Arrivals*

<table>
<thead>
<tr>
<th>Airline</th>
<th>Airplane</th>
<th>Potential Fuel &amp; CO₂ Savings**</th>
<th>Actual Fuel &amp; CO₂ Savings</th>
<th>% Realized Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Airlines</td>
<td>777-200ER</td>
<td>Fuel: 739,310 lbs CO₂: 2,333,270 lbs</td>
<td>Fuel: 99,930 lbs CO₂: 314,870 lbs</td>
<td>14%</td>
</tr>
<tr>
<td>United Airlines</td>
<td>747-400</td>
<td>Fuel: 1,556,800 lbs CO₂: 4,913,290 lbs</td>
<td>Fuel: 152,200 lbs CO₂: 480,340 lbs</td>
<td>10%</td>
</tr>
<tr>
<td>Japan Airlines</td>
<td>747-400</td>
<td>Fuel: 64,400 lbs CO₂: 203,240 lbs</td>
<td>Fuel: 7240 lbs CO₂: 22,840 lbs</td>
<td>11%</td>
</tr>
</tbody>
</table>

* From December 4, 2007 to May 27, 2008
** Potential Fuel Savings based on Total number of flights recorded by ANOMS8 per Airline
$dBA_{\text{max}}$ Noise Contours for Representative Daily Oceanic Arrivals into SFO - 20 747/777 flights

Boeing Technology | Phantom Works

Non Tailored Arrival

Partial Tailored Arrival

Tailored Arrival
No statistically significant change in noise at four measurement locations.
Conclusions

- Tailored Arrival eliminated the level off segments observed in standard SFO arrivals.
- 21% of the flights collected from the ANOMS8 data participated in a Tailored Arrival.
- 33% of the participating Tailored Arrival flights saved significant amount of fuel along with reducing environmental impacts from noise and emissions.
- The remainder saved some reduced amount of fuel and reduced environmental impact.
- Tailored Arrivals participation resulted in better chances of reduced environmental impact. After 15 March
  - For non-participating flights, only 13% of flights would be considered green.
  - For Tailored Arrival participants, 63% would be considered green.
- No Significant Change in Noise at four measurement locations.
- Significant reduction in noise contours.
## Final Environmental Update

**Due out in Dec 08**

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### Percentages as of Sep 27th, 2008

<table>
<thead>
<tr>
<th>Candidate Flights</th>
<th>27-May</th>
<th>27-Sep</th>
<th>F/P</th>
<th>F/(F+P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>89</td>
<td>286</td>
<td>24%</td>
<td>35%</td>
</tr>
<tr>
<td>Partial</td>
<td>177</td>
<td>532</td>
<td>44%</td>
<td>65%</td>
</tr>
<tr>
<td>Not requested/Denied</td>
<td>384</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not Granted</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Candidate Flights</strong></td>
<td>1202</td>
<td></td>
<td><strong>Total % flights requesting TAs</strong></td>
<td><strong>68%</strong></td>
</tr>
</tbody>
</table>