Verification of ADS-B Performance to Provide 5 Nautical Mile Separation Services in the Gulf of Mexico

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ADS-B/WAM Separation Standards Working Group

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Overview

• Background
• General Approach
• Analysis of Flight Tests
• Analysis of Targets of Opportunity
• Conclusions
Background

• Motivation
  • Prior to Automatic Dependent Surveillance – Broadcast (ADS-B), non-radar separation was necessary in the Gulf of Mexico due to limited surveillance and air-ground communication
  • 5 NM separation using ADS-B improves capacity and streamlines IFR operations for helicopter operators, higher-altitude en route traffic, and other airspace users

• Objective
  • Verify ADS-B supports 5 NM en route separation services in the Gulf of Mexico using Virtual Radars

• Automation system considerations
  • ADS-B data was transformed to emulate MSSR data by establishing two virtual radars (VRs)
  • Host automation platform does not ingest ASTERIX data format
SBS Key Site: Gulf of Mexico
Approach

• Conduct a comparative analysis assessing existing separation standards of VRs to existing radar surveillance systems:
  • Simulation of sensor performance
  • Automation analysis
  • Flight Tests
  • Targets of Opportunity (TOO)
• Data collection required flight in airspace with coverage from MSSRs and VRs
Summary of Simulation and Automation Results

- Simulation results indicate that VR separation error is less than MSSR separation error in all scenarios (except In-Trail Radial, similar to other analyses).
- Automation results demonstrate the fidelity of the Host virtual radar reports to the reports received from the ERIT virtual radar and aircraft truth data.
Flight Test Analysis
Flight Tests: Background

• **Overview:** Flight tests intended to validate the modeling and simulation results by assessing surveillance sensor accuracy

• Flown November 4-6, 2009 using two aircraft:

<table>
<thead>
<tr>
<th>Registration</th>
<th>Model</th>
<th>General Description</th>
<th>Operator</th>
<th>1090ES Transponder</th>
<th>UAT Transponder</th>
</tr>
</thead>
<tbody>
<tr>
<td>N56</td>
<td>Learjet 60</td>
<td>Twinjet</td>
<td>FAA/AVN</td>
<td>ACSS XS950</td>
<td>Garmin GDL 90</td>
</tr>
<tr>
<td>N200U</td>
<td>King Air C90A</td>
<td>Twin turboprop</td>
<td>Ohio University</td>
<td>ACSS XS950</td>
<td>Garmin GDL 90</td>
</tr>
</tbody>
</table>

• Aircraft were also equipped with Ashtech DGPS units to collect truth data, as well as TCAS to maintain at least 5 NM separation
Flight Tests: Data Collection

- **Data Collection:**
  - DGPS truth data provided by flight crews (1 report / second)
  - ERIT data for MSSRs and VRs provided by the FAA Technical Center via secure FTP site:
    - MSSRs: Slidell (NEW) and Lake Charles (LCH) in CD-2 format (1 report / 12 seconds)
    - Virtual radars: VRW and VRE in CD-2 format (1 report / 12 seconds)
Flight Test Profiles

Equivalent to profiles flown other ADS-B key sites

In-Trail [Sabine Pass VOR/DME (SBI) to BLVNS]

Parallel [Sabine Pass VOR/DME (SBI) to BLVNS]

Lake Charles VORTAC (LCH) In-Trail Arc

Lake Charles VORTAC (LCH) Parallel Arc

Leeville VORTAC (LEV) In-Trail Arc

Leeville VORTAC (LEV) Parallel Arc
Separation Error Calculation

- **Quantities of Interest:**
  - Separation error of MSSRs = MSSR separation – truth separation
  - Separation error of VRs = VR separation – truth separation
Example Results – Parallel Arc about Lake Charles VOR (LCH), both Aircraft Operating 1090ES

### LCH MSSR

- Mean Sep. Error [NM]: -0.01
- Median Sep. Error [NM]: -0.02
- Standard Dev. [NM]: 0.07
- Chi Squared Value: 1.03
- Critical Value: 204.69
- 5% CDF [NM]: -0.12
- 95% CDF [NM]: 0.10

### VRW

- Mean Sep. Error [NM]: -0.01
- Median Sep. Error [NM]: -0.01
- Standard Dev. [NM]: 0.08
- Chi Squared Value: 1.01
- Critical Value: 204.69
- 5% CDF [NM]: -0.14
- 95% CDF [NM]: 0.13
Flight Test Summary Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean Sep. Error [NM]</th>
<th>Median Sep. Error [NM]</th>
<th>Standard Dev. [NM]</th>
<th>Chi Squared Value</th>
<th>Critical Value</th>
<th>5% CDF [NM]</th>
<th>95% CDF [NM]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radar – Truth</strong></td>
<td>0.04</td>
<td>0.03</td>
<td>0.17</td>
<td>1.05</td>
<td>1,922.42</td>
<td>-0.15</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>Virtual Radar – Truth</strong></td>
<td>0.04</td>
<td>0.04</td>
<td>0.09</td>
<td>1.18</td>
<td>1,922.42</td>
<td>-0.12</td>
<td>0.19</td>
</tr>
</tbody>
</table>
Summary: Flight Test Analysis

- The mean and median of the separation errors for the virtual radars closely matched those for the MSSRs (within 0.01NM)
- The standard deviation of the separation errors for the virtual radars was 47% lower than the standard deviation of the separation errors for the MSSRs (0.09NM versus 0.17NM)
- No anomalous data was observed and no significant errors were reported by the automation systems for the remainder of the profiles
Target of Opportunity (TOO) Analysis
Targets of Opportunity: Background

- **TOO definition:** two aircraft which are concurrently under the surveillance of the same MSSR and VR
- **Objective:** to assess differences in the separation reported under each of six sensor permutations
  - HOU and VRW, HOU and VRE
  - LCH and VRW, LCH and VRE
  - NEW and VRW, NEW and VRE
- Data collected from September 12-21, 2009
- No truth data was collected

*Note:* TOO statistics report separation difference, not separation error (as reported for flight tests)
Separation Difference Calculation

- **Quantity of Interest:**
  - Separation difference = MSSR separation – VR separation
- **Analysis was performed with / without:**
  - Interpolation of MSSR reports to VR time
  - Filter for max. 5,000’ vertical separation between aircraft in the pair

**Separation Difference Calculation**

<table>
<thead>
<tr>
<th>VR Sep.</th>
<th>MSSR Sep.</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-second sampling rate</td>
<td>VR (ADS-B)</td>
</tr>
</tbody>
</table>
Targets of Opportunity: Data Collection

- Data delivery same as Flight Test
- Dataset contains:
  - **General TOOs**: Includes all operations within the airspace under consideration except for controlled TOOs
  - **Controlled TOOs**: Includes flights operated by Embry Riddle Aeronautical University with four aircraft between September 12-21

<table>
<thead>
<tr>
<th></th>
<th>General TOOs</th>
<th>Controlled TOOs</th>
<th>Percent Controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total TOOs</strong></td>
<td>174</td>
<td>124</td>
<td>71%</td>
</tr>
<tr>
<td><strong>Total Data Points</strong></td>
<td>32,341</td>
<td>29,439</td>
<td>91%</td>
</tr>
</tbody>
</table>
Example Results: LCH-VRW Sensor Permutation, Codes 4541, 4530 on September 18

<table>
<thead>
<tr>
<th>Data Points</th>
<th>Mean Separation Difference [NM]</th>
<th>Standard Dev. [NM]</th>
<th>Chi Squared Value</th>
<th>Critical Value</th>
<th>5% CDF [NM]</th>
<th>95% CDF [NM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>44</td>
<td>0.01</td>
<td>0.11</td>
<td>1.00</td>
<td>60.48</td>
<td>-0.16</td>
<td>0.19</td>
</tr>
</tbody>
</table>
## TOO Summary Statistics

### General TOOs, No Altitude Filter, No Interpolation

<table>
<thead>
<tr>
<th>TOOs</th>
<th>Data Points</th>
<th>Mean Separation Difference [NM]</th>
<th>Standard Dev. [NM]</th>
<th>Chi Squared Value</th>
<th>Critical Value</th>
<th>5% CDF [NM]</th>
<th>95% CDF [NM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>General, No Alt. Filter, No Interpolation</td>
<td>278</td>
<td>0.03</td>
<td>0.16</td>
<td>1.03</td>
<td>42,925.38</td>
<td>-0.20</td>
<td>0.29</td>
</tr>
<tr>
<td>General, 5000’ Alt. Filter, Bezier Interpolation</td>
<td>174</td>
<td>0.01</td>
<td>0.14</td>
<td>1.01</td>
<td>32,760.46</td>
<td>-0.20</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Summary: TOO Analysis

• The cumulative statistics demonstrate that separation differences were insignificantly different from zero with 95% confidence regardless of MSSR/virtual radar sensor permutation

• The results for “controlled” TOO pairs confirm the results for general TOO pairs

• Consistent with the flight test results, the TOO analysis reveals no discernable difference between using MSSR and virtual radar data to provide 5 NM en route separation in the Gulf of Mexico using the Host Computer System
Concluding Summary

• The flight tests and TOO analysis indicate that the virtual radar system reported separation with comparable relative accuracy and equivalent absolute accuracy with respect to the radar system. The results support the conclusion that MSSR and virtual radar data may be used interchangeably to provide 5 NM en route separation using the Host Computer System.

• Initial Operating Capability (IOC) for 5 NM en route separation using ADS-B/virtual radars was declared at the Houston Air Route Traffic Control Center on December 17, 2009.

• Virtual radar surveillance is currently used in the provision of en route separation services in the Gulf of Mexico.
Questions
Appendix
Sensor Locations
SBS Key Site: Gulf of Mexico

Long-range radars: HOU, LCH, NEW

Virtual radars: VRW, VRE
TOO Data Processing

- Aircraft are matched to create a TOO pair by:
  - Time
  - Beacon code
  - Altitude (optional)
  - Distance (optional due to multiple helicopters concurrently operating on same beacon code)
- TOOs must be at least 4 points in length
- There must be no more than 7.5 seconds between MSSR and virtual radar reports for comparison to occur
- The analysis can be performed with or without the interpolation of the MSSR reports to the virtual radar reports (using a Bezier polynomial)
- **Quantity of interest:**
  
  Separation Difference = MSSR Separation – VR Separation
Controlled TOO Flight Profiles

- Lafayette, LA (KLFT) to Port Isabel, TX (KPIL)
- Lafayette, LA (KLFT) to Lafayette, LA (KLFT)
- Lafayette, LA (KLFT) to Mobile, AL (KMOB)
- Lafayette, LA (KLFT) to Corpus Christi, TX (KCRP)