Aircraft ASE and RVSM Collision Risk Analyses

Presented to: ASE Workshop
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Regional Monitoring Agencies

In all regions where RVSM has been implemented, regional monitoring agencies (RMAs) have been established by the appropriate planning and implementation regional groups (PIRGs) to satisfy the goals of the RVSM monitoring program.

An RMA supports the continued safe use of RVSM within a designated airspace.
Annual Vertical Collision Risk Report

• ICAO Doc 9574, paragraph 6.4.4 and 6.4.5, Responsibilities of an RMA
  – One of the duties and responsibilities includes providing annual reports to the Planning and Implementation Regional Group (PIRG)
    • Reports contain assessments of risk in the system against the overall safety objectives to support the continued safe use of the RVSM
  – These reports are provided to the relevant groups within the ICAO Regions
Tools for Safety Assessment

- **ICAO Collision Risk Methodology**
  - Used to develop ICAO Doc 9574 global system performance specification, height keeping performance specification and aircraft height keeping performance requirements
  - Consists of:
    - Target Level of Safety (TLS) (=safety goal),
    - collision risk model (=risk estimation tool), and
    - agreed means to evaluate risk
Tools for Safety Assessment

• ICAO Collision Risk Methodology
  – Risk model was adapted to account for:
    • aircraft technical risk on same track and on intersecting tracks
    • effect of large height deviations on system risk
  – Same methodology is used by all RMAs worldwide
Safety Goals

- The estimate of vertical collision risk associated with RVSM is compared to the agreed RVSM safety goals.

**Safety Goal 1:** Technical risk, or the risk of collision associated with aircraft height-keeping performance, does not exceed a Target Level of Safety (TLS) of $2.5 \times 10^{-9}$ fatal accidents per flight hour (fapfh).

Reference: ICAO Doc 9937, paragraph 2.3.1, 2.4.2
Safety Goals

• The estimate of vertical collision risk associated with RVSM is compared to the agreed RVSM safety goals.

Safety Goal 1: Technical risk, or the risk of collision associated with aircraft height-keeping performance, does not exceed a Target Level of Safety (TLS) of $2.5 \times 10^{-9}$ fatal accidents per flight hour (fapfh).

Safety Goal 2: Overall risk, or the risk of collision due to all causes, which includes the technical risk and all risk due to operational errors, such as pilot/controller errors - does not exceed a TLS of $5 \times 10^{-9}$ fapfh*.

*For example the 2015 estimate of annual flight hours in continental United States is 9.8 million flight hours. A TLS of $5 \times 10^{-9}$ fapfh equates to an acceptable value of risk of roughly 1 fatal accident every 20 years resulting from a loss of vertical separation.
Data Requirements

• Results from aircraft height-keeping performance monitoring systems
  – Both from regional monitoring systems and data-sharing with other RMAs

• Collect reports of large height deviations (LHD) and traffic sample data (TSD) from Air Navigation Service Providers (ANSPs)
Risk Categories

• “Technical risk” is the term used to describe the risk of collision associated with aircraft height-keeping performance. Some of the factors which contribute to technical risk are:
  a) errors in aircraft altimetry and automatic altitude control systems;
  b) aircraft equipment failures resulting in unmitigated deviation from the cleared flight level, including those where not following the required procedures further increases the risk; and
  c) responses to false collision avoidance resolution advisories.
Risk Categories

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  a) errors in aircraft altimetry and automatic altitude control systems;
  b) aircraft equipment failures resulting in unmitigated deviation from the cleared flight level, including those where not following the required procedures further increases the risk; and
  c) responses to false collision avoidance resolution advisories.

• The term “operational error” is used to describe any vertical deviation of an aircraft from the correct flight level as a result of incorrect action by ATC or the flight crew.
Key Collision Risk Model Parameters

- There are two **vertical overlap probability** parameters that take into account the ASE performance of the aircraft population.

- To estimate Technical Risk, risk associated with aircraft technical height-keeping performance, specifically the performance affected by the avionics of the aircraft, not the flight crew.
  - $P_z(1000)$, is the probability that two aircraft nominally separated by 1000 ft are in vertical overlap.
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- There are two vertical overlap probability parameters that take into account the ASE performance of the aircraft population.
- To estimate Technical Risk, risk associated with aircraft technical height-keeping performance, specifically the performance affected by the avionics of the aircraft, not the flight crew.
  - $P_z(1000)$, is the probability that two aircraft nominally separated by 1,000 ft are in vertical overlap.
- To estimate Operational Risk, risk due to all other causes, including the risk due to operational errors.
  - $P_z(0)$, is the probability that two aircraft flying at the same flight level are in vertical overlap.
Aircraft Total Vertical Error (TVE)

Actual Altitude

Total Vertical Error (TVE)

Altimetry System Error (ASE)

Flight Technical Error (FTE)

Displayed Altitude

Correspondence Error

Transponded Altitude

Assigned Altitude

Assigned Altitude Deviation (AAD)
Vertical Overlap Probability Parameter

• The process to assess aircraft total vertical error (TVE) and estimate $P_z(1000)$ and $P_z(0)$ is the same

• Data required:
  – Assigned altitude deviation (AAD)
    • Radar data
  – Large Height Deviations (LHDs), including events due to turbulence and aircraft equipment failures
  – Aircraft type population
  – ASE performance for the aircraft observed in airspace
### Top 10 Aircraft Types by Airspace (in terms of Flying Hours)

<table>
<thead>
<tr>
<th>US NAS</th>
<th>Oakland Oceanic</th>
<th>Anchorage Oceanic</th>
<th>New York Oceanic</th>
</tr>
</thead>
<tbody>
<tr>
<td>B738</td>
<td>B77W 16.21%</td>
<td>B744 22.00%</td>
<td>A332 14.87%</td>
</tr>
<tr>
<td>B737</td>
<td>B772 12.79%</td>
<td>B77W 19.69%</td>
<td>A333 14.26%</td>
</tr>
<tr>
<td>A320</td>
<td>A332 9.62%</td>
<td>B772 12.85%</td>
<td>B763 13.54%</td>
</tr>
<tr>
<td>A319</td>
<td>B763 8.54%</td>
<td>B748 10.07%</td>
<td>B772 11.23%</td>
</tr>
<tr>
<td>B752</td>
<td>B744 8.29%</td>
<td>B788 8.28%</td>
<td>B744 8.59%</td>
</tr>
<tr>
<td>CRJ7</td>
<td>B738 8.25%</td>
<td>B77L 6.84%</td>
<td>B77W 7.31%</td>
</tr>
<tr>
<td>B739</td>
<td>B752 6.05%</td>
<td>B763 5.59%</td>
<td>B788 7.24%</td>
</tr>
<tr>
<td>A321</td>
<td>B788 4.80%</td>
<td>MD11 3.12%</td>
<td>A346 5.25%</td>
</tr>
<tr>
<td>E170</td>
<td>A388 3.55%</td>
<td>A388 3.05%</td>
<td>A343 3.83%</td>
</tr>
<tr>
<td>E145</td>
<td>B77L 3.22%</td>
<td>A332 2.69%</td>
<td>B77L 2.16%</td>
</tr>
</tbody>
</table>

**Row Totals:**
- US NAS: 60.14%
- Oakland Oceanic: 81.32%
- Anchorage Oceanic: 94.20%
- New York Oceanic: 88.29%

* B747-400 is number 22 on the list in US NAS Airspace (0.85% of flying hours in US NAS)
### ZAN Oceanic Airspace

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Relative Proportion in ZAN</th>
<th>ASE Mean</th>
<th>ASE Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B744</td>
<td>22.00%</td>
<td>-85.46</td>
<td>48.13</td>
</tr>
<tr>
<td>B77W</td>
<td>19.69%</td>
<td>29.43</td>
<td>37.84</td>
</tr>
<tr>
<td>B772</td>
<td>12.85%</td>
<td>14.51</td>
<td>34.62</td>
</tr>
<tr>
<td>B748</td>
<td>10.07%</td>
<td>18.66</td>
<td>25.51</td>
</tr>
<tr>
<td>B788</td>
<td>8.28%</td>
<td>27.89</td>
<td>34.43</td>
</tr>
<tr>
<td>B77L</td>
<td>6.84%</td>
<td>14.51</td>
<td>34.62</td>
</tr>
<tr>
<td>B763</td>
<td>5.59%</td>
<td>-74.01</td>
<td>51.17</td>
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<tr>
<td>MD11</td>
<td>3.12%</td>
<td>-68.80</td>
<td>49.06</td>
</tr>
<tr>
<td>A388</td>
<td>3.05%</td>
<td>-29.33</td>
<td>36.08</td>
</tr>
<tr>
<td>A332</td>
<td>2.69%</td>
<td>29.23</td>
<td>43.47</td>
</tr>
</tbody>
</table>
Ongoing Safety Monitoring

Collision risk model (CRM) key parameters

- Rate of LHD occurrences
- Growth in traffic and congestion (reflected in passing frequency and occupancy)
- Lateral navigation performance

Yes

No

Identify Remedial Action Implement Change
Example: Pacific Airspace Performance Specification: Pre-Implementation and Today

- **Target Level of Safety** $N_{az} = 2.5 \times 10^{-9}$ fapfh

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-Implementation Value</th>
<th>Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Overlap Probability Pz(1000)</td>
<td>$2.46 \times 10^{-8}$</td>
<td>$4.7 \times 10^{-9}$</td>
</tr>
<tr>
<td>Vertical Overlap Probability Pz(0)</td>
<td>0.42</td>
<td>0.538</td>
</tr>
<tr>
<td>Lateral Overlap Probability Py(0)</td>
<td>0.0263</td>
<td>0.150</td>
</tr>
<tr>
<td>Passing Frequency $N_x$(equivalent)</td>
<td>0.251</td>
<td>0.170</td>
</tr>
</tbody>
</table>
**PARMO Vertical Report to RASMAG/21**

Pacific Airspace – estimated annual flying hours = 1,670,790 hours  
(note: estimated hours based on Dec 2015 traffic sample data)

<table>
<thead>
<tr>
<th>Source of Risk</th>
<th>Risk Estimation</th>
<th>TLS</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RASMAG/20 Total Risk</td>
<td>3.86 $10^{-9}$</td>
<td>5.0 $10^{-9}$</td>
<td>Below TLS</td>
</tr>
<tr>
<td>Technical Risk</td>
<td>0.03 $10^{-9}$</td>
<td>2.5 $10^{-9}$</td>
<td>Below Technical TLS</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>4.26 $10^{-9}$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Risk</strong></td>
<td><strong>4.30 $10^{-9}$</strong></td>
<td><strong>5.0 $10^{-9}$</strong></td>
<td>Below TLS</td>
</tr>
</tbody>
</table>

![Graph showing vertical collision risk by type weighted by flight hours in traffic flows]