A Methodology to Assess the Safety of Aircraft Operations when Aerodrome Obstacle Standards cannot be met

Hartmut Fricke, Christoph Thiel

June 2013
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Dr. Hartmut Fricke

Faculty of Transportation and Traffic Sciences, Institute of Logistics and Aviation, Chair of Air Transport Technology and Logistics • Company for Air Traffic Safety Research, GfL

Agenda

1. Obstacle related Safety Assessment: Status Quo
2. Obstacle Clearance Impact Factors
3. Determination of non compliant Obstacles
4. Proposed Safety Assessment Methodology
5. Applied Safety Case: Frankfurt Main Airport
6. Conclusions: a balanced risk picture
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Obstacle Clearance – Setting the Scene

- **Standards:** **ICAO Annex 14, PANS OPS Doc. 8168**
- **In 2014 EASA CS ADR DSN** entering into force
- **Review shows:** Existing regulations on obstacle clearance ~ collision risk allocation are “suspicious”:

<table>
<thead>
<tr>
<th>TLS in Aviation</th>
<th>Source</th>
<th>Flight Phase</th>
<th>TLS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ICAO ANNEX 10</td>
<td>Enroute</td>
<td>5.00E-9</td>
<td></td>
</tr>
<tr>
<td>ICAO A-SMGCS</td>
<td>Ground Roll</td>
<td>1.00E-8</td>
<td></td>
</tr>
<tr>
<td>ICAO CRM</td>
<td>ILS Approach</td>
<td>1.00E-7</td>
<td></td>
</tr>
<tr>
<td>Eurocontrol</td>
<td>All (ATM related)</td>
<td>1.55E-8</td>
<td></td>
</tr>
</tbody>
</table>

**ICAO Doc. 9774** allows violations if an **Aeronautical Study** shows equivalent safety levels – but how?

Fatal Accidents per Flight Phase (2002-2011)

- Total: 79 accidents
- Accident Rate: 0.39 per million departure
- Landing 20%  
- Takeoff 10%  
- Initial climb 6%  
- Initial approach 14%  
- Descent 4%  
- Cruise 11%

Source: Boeing Statistical Summary, July 2012
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Impact Domains

**Runway Design**
- Set of surfaces limiting objects (OAS, OLS, OIS, OFZ,...)

**Procedure Design**
- 3D for any NAV concept with IFR/VFR ambiguity: instrument approach ends at OCA/H - VSS as a visual segment

**Aircraft Certification**
- EASA CS 25 / FAA Part 25 consider aerodynamic and flight control issues with degraded flight performance

Source: ICAO Annex 14, Att B; p 313
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Minimum Requirements Analysis

- Different “safety surfaces” = different minimum performance:

\[
\frac{\text{ROC}}{\text{ROD}}_{\text{min}} = \frac{\text{TAS}}{\sin \gamma_{\text{min}}} \approx \frac{\text{CAS}}{\gamma_{\text{min}}}
\]

<table>
<thead>
<tr>
<th>Reference</th>
<th>Flight Phase</th>
<th>Surface Angle (\gamma) [°]</th>
<th>Minimum ROC/ROD [ft/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLS</td>
<td>DEP/APP</td>
<td>1.145</td>
<td>300</td>
</tr>
<tr>
<td>OAS</td>
<td>APP</td>
<td>-1.62</td>
<td>430</td>
</tr>
<tr>
<td>OAS</td>
<td>Missed APP</td>
<td>1.43</td>
<td>380</td>
</tr>
<tr>
<td>Net TO</td>
<td>Flight Path</td>
<td>1.89</td>
<td>500 (incl. 0.8% safety margin)</td>
</tr>
</tbody>
</table>

- No consistency while assessing flight safety in different conditions / flight phases
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Cross Sections

- Height of ILS glidepath
- ANP corridor lat/vert
- PANS OPS OAS Surface
- Annex 14 OLS Surface

Margin between ILS height and:
- OAS Surface: 144.5 m
- OLS Surface: 179.0 m

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Cross Sections

- Height of ILS glidepath
- ANP corridor lat/vert
- PANS OPS OAS Surface
- Annex 14 OLS Surface

Margin between ILS height and OAS Surface: 96.6 m, OLS Surface: 114.2 m
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Cross Sections

- Height of ILS glidepath
- ANP corridor lat/vert
- PANS OPS OAS Surface
- Annex 14 OLS Surface

Margin between ILS height and OAS Surface: 72.7 m, OLS Surface: 81.7 m
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Cross Sections

Height of ILS glidepath

ANP corridor lat/vert

PANS OPS OAS Surface

Annex 14 OLS Surface

Margin between ILS height and

OAS Surface
OLS Surface

36,9 m 33,1 m

OAS below OLS
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Safety Assessment Methodology - Architecture

- ICAO Doc 9774: “An aeronautical study is ... to identify ... a solution that is acceptable without degrading safety”
- Hazard = collision with a non-compliant obstacle.
Safety Assessment Architecture – Normal Operations Model (NOM)

- Represent more than 99% of all operations at large airports
- Processing historic aircraft track data at the investigated airport (>6 months)
- Real track data combined to the defined track data → offset probability density function (comparable to ICAO PBN Concept)
- Gauss distribution is typical
- Integration of the local PDF to an Obstacle
- Comparison of the calculated Collision Risk to a preset TLS
Degraded Operational Performance Model (DOM)

- Empirical frequency < 1% of all operations
- But increased obstacle collision risk especially if combined with additional adverse environmental conditions (e.g. OEI and strong crosswind)

- Model is applied for **Approach/Missed Approach** and **Takeoff** scenarios
- Flight performance analysis is embedded in a **5-step evaluation scheme**
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DOM 5-step Evaluation Scheme (1)

DOM Step 1: Vertical Performance Analysis
- "Do all aircraft pass the obstacle safely even though a direct trajectory towards the obstacle is assumed?"

DOM Step 2: Procedure Design Analysis
- "Does the obstacle violate any departure or approach procedures clearance requirements?"

DOM Step 3: Lateral Performance Analysis
- "Is the obstacle’s location critical even if we assume OEI and adverse wind conditions?"

Hazard detected: Continue
Else
Analysis completed
DOM 5-step Evaluation Scheme (2)

DOM Step 4

• Critical Trajectory Lat. Performance Check
  • “Is the developed most critical trajectory flyable at all in terms of flight performance and flight mechanics?”

DOM Step 5

• Critical Trajectory Vert. Performance Check
  • “Are those aircraft flying the most critical trajectory able to ensure clearance to cross the obstacle safely?”

• Mitigation Measures (if required)
  • Cancel published/critical route
  • Set stricter prerequisites (e.g. PDG) for that route
  • Provide hot spot infos in AIP / NOTAM

Hazard detected: Continue
Else
Analysis completed
Risk Mitigation
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Applied Safety Case: Frankfurt Main Airport

- 80m tall tower building
- Violating the OLS of the center RWY 25C/07C and the south RWY 25L/07R
- OAS not violated
Safety Case: Frankfurt Main Airport - NOM Application

**Outbound Traffic**
- Analyzing all departure routes from RWY 07C
- Flight tracks turning north are most relevant (Route BIBTI E)
- Collision Risk:
  - $\text{XTT}: 2.10E-115$
  - $\text{VTT}: 1.97E-02$
  - Combined: $4.13E-117$

**Inbound Traffic**
- Analyzing RWY 25C and 25R
- Nearly 99% are ILS approaches
- Collision Risk: $< 1E-117$

<table>
<thead>
<tr>
<th>Distance from DER [m]</th>
<th>VERTICAL Sigma [m]</th>
<th>VERTICAL VTT [NM]</th>
<th>LATERAL Sigma [m]</th>
<th>LATERAL XTT [NM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>85.0</td>
<td>0.092</td>
<td>43.5</td>
<td>0.047</td>
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<tr>
<td>500</td>
<td>85.9</td>
<td>0.093</td>
<td>44.8</td>
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<td>600</td>
<td>86.6</td>
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<td>45.7</td>
<td>0.049</td>
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<tr>
<td>700</td>
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<tr>
<td>800</td>
<td>87.9</td>
<td>0.095</td>
<td>47.7</td>
<td>0.051</td>
</tr>
</tbody>
</table>

Statistical Parameter along the flight track (Outbound)
Safety Case: Frankfurt Main Airport - DOM Application (1)

- Identified hazard scenarios
  1. APP RWY 25R
  2. MA RWY 07L
  3. MA RWY 07L 07C
  4. TO RWY 07C
- Aircraft: traffic mix analysis

**DOM Step 1**

**Vertical Performance Analysis:**
- Minimal Climb Requirements: EASA CS 25
- Results:
  - scenarios 1, 2 & 3 passed
  - scenario 4 does not pass

<table>
<thead>
<tr>
<th>Scenario 4: Obstacle Clearances [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Engines</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>-46.10</td>
</tr>
</tbody>
</table>
DOM Step 2 (Procedure Design Analysis):

- Phase 1: Analyzing most critical DEP route (EU-OPS 1.495)
- Phase 2: Examination of OIS and PDG (ICAO PANS-OPS Vol. II)
- Phase 3: Examination of turn protection areas (ICAO PANS-OPS Vol. II)

→ Results: No violations concerning Phase 1 & Phase 2

Obstacle is located inside protection area (Phase 3)

DOM Step 3 (Lateral Performance Analysis):

Lateral compliance for all scenarios  Vertical violation for scenario 4
Safety Case: Frankfurt Main Airport - DOM Application (3)

DOM Step 4 (Lateral Flyability of Critical Trajectory):
- Determination of aircraft types being able to fly critical trajectory
  \[ v = \sqrt{r \cdot g \cdot \tan(\Phi)} \geq v_2 \]
- Results:
  - Only small aircraft (e.g. Cessna C525/Beechcraft B200GT) can comply with assumed trajectory

DOM Step 5 (Vertical Performance Analysis of Critical Trajectory):
- Determination of climb gradients and lift-off points for these aircraft with OEI
- Results:
  - Critical aircraft category can safely overfly the obstacle with required clearance

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Climb Gradient [%]</th>
<th>Lift-off Point [m]</th>
<th>Crossing Altitude [m]</th>
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</thead>
<tbody>
<tr>
<td>B200GT</td>
<td>5.5</td>
<td>840</td>
<td>160.80</td>
</tr>
<tr>
<td>C525A</td>
<td>3.6</td>
<td>1550</td>
<td>52.24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th>Unit</th>
<th>Numerical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Speed (v)</td>
<td>[m/s]</td>
<td>(\approx 54) (105 kt)</td>
</tr>
<tr>
<td>Turn Radius (r)</td>
<td>[m]</td>
<td>1.100</td>
</tr>
<tr>
<td>Maximum Bank Angle (\Phi)</td>
<td>[°]</td>
<td>15</td>
</tr>
<tr>
<td>Takeoff Safety Speed (v_2)</td>
<td>[m/s]</td>
<td>(\leq 54) (105 kt)</td>
</tr>
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Conclusions: Achieving a consistent Risk Assessment

• ICAO does not provide guidance on how to perform aeronautical studies yet
• The presented model provides a systematic clearance check procedure through estimating risk for the hazard “obstacle collision”
• Methodology was accepted for Frankfurt Airport – candidate for smaller Airports in ongoing projects
• Model to detail ICAO DOC 9774, Appendix 3 as supplement
• Alleviate discrepancies of existing OAs based on a cause – hazard – consequence analysis
• Update of ICAO PANS-OPS (OAS, CRM) with regard to today’s standards and aircraft performance capabilities