Design for RVSM Compliance
RSSE & 3σ Error Evaluation

James Egberg
Aerospace Engineer
DESIGN FOR RVSM COMPLIANCE

RSSE & $3\sigma$ Error Evaluation

Presentation Overview

Company

Experience

RVSM compliance

Systematic altitude error & SSEC

Random altitude error & estimation

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UNITED TECHNOLOGIES AEROSPACE SYSTEMS

Burnsville, Minnesota

UTC/UTAS
Formerly, Goodrich
Formerly, Rosemount Aerospace (current legal identity)

Air Data Products (RVSM Related)
Pitot-Static Probes
Flush-Static Plates
SmartProbe® Air Data System
Air Data Computers

Air Data Products (Other)
Pitot Probes
AOA/AOS Vanes
TAT Probes
Ice Detectors
And More…

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JAMES EGBERG
Aerospace Engineer

B.S. from U of MN in Mechanical Engineering

11 years experience at UTAS (Goodrich) with Pitot-static probes and altimetry systems.

Extensive work on altimetry system of 19 different aircraft designs from a number of aircraft manufacturers. 11 Of these currently have, or plan to obtain RVSM certification.

Expertise:

   Flight test data processing and evaluation (10 Aircraft)
   SSEC calibration (15 Aircraft)
   Pitot/static system performance evaluation (9 Aircraft)
   Wind tunnel testing and evaluation
RVSM COMPLIANCE

Our Role in RVSM Compliance

System Design
  Probe design
  Probe placement
  Estimation of altimetry systems accuracy

Flight Test Evaluation
  Calibration of altimetry system
  Evaluation of residual altitude errors

RVSM Certification
  Produce material for RVSM certification package

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RVSM REQUIREMENTS

Overview

Requirement: 91.180, Appendix G of Part 91

Appendix G, Section 2, (e)(1): “At the point in the full RVSM envelope where mean ASE reaches its largest absolute value, the absolute value may not exceed 80 feet.”

Appendix G, Section 2, (e)(2): “At the point in the full RVSM flight envelope where mean ASE plus three standard deviations reaches its largest value, the absolute value may not exceed 200 ft.”

Informational Document: A-C 91-85

“This AC describes an acceptable means, but not the only means, for authorization of aircraft and operators to conduct flight in airspace or on routes where RVSM is applied”
MEAN ASE < 80 FT

Definitions

ASE: The difference between the pressure altitude calculated by the air data system and the free stream (true) pressure altitude.

Mean ASE: The average ASE across the fleet at a given flight condition. (UTAS interpretation)

Note: All data presented herein is generated for educational purposes.
MEAN ASE < 80 FT

Static Source Error Correction

SSEC (Static Source Error Correction): Correction of the pressure sensed by the static system to the undisturbed ambient pressure

SSEC is typically a Mach based correction (at minimum)
**MEAN ASE < 80 FT**

**Example: AOA Effect**

Relationship between measured static pressure and freestream static pressure can change as a function of aircraft AOA.

This may also be considered an altitude, weight or W/delta effect

\[
\text{AOA} = f(\text{Speed, Altitude, Weight, } \ldots )
\]

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**Reducing Mean ASE**

- Probe Placement
- Probe Design
- AOA/Altitude/Weight Compensation.

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AOA Effect Mitigation – Probe Design

Probes can be custom designed to minimize AOA effects caused by A/C aerodynamics.

The probe can also be designed to reduce the magnitude of the Mach-based SSEC correction.
MEAN ASE < 80 FT

AOA Effect Mitigation – SmartProbe® Air Data System

Pneumatic AOA used for SSEC correction

Multiple RVSM compliant systems with SmartProbe® ADS
MEAN ASE < 80 FT

Sources of Mean ASE

Un-calibrated Aerodynamic Effects:
  - Mach effect
  - AOA effect
  - Altitude effects (related to Reynolds number)
  - Optional A/C components which affect pressure field

Imperfections in SSEC:
  - Unmitigated random errors of flight test aircraft
  - Errors in reference system of flight test aircraft

Transducer aging

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3-SIGMA RANDOM ERROR
Mean ASE + 3σ < 200ft

Random error sources

Aircraft Manufacturing
Probe/Port Manufacturing

Probe Mounting
Pressure Transducer

Example ASE Plot
(30 Aircraft)

Example ASE Plot
(30 Aircraft)

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Quantifying the effect: Theoretical computation, wind tunnel, flight testing, and/or CFD
3-SIGMA RANDOM ERROR

Probe Manufacturing

Probe Contour

Static Port Placement

Static Port Finish

Probe Alignment

Quantifying the effect: Wind tunnel testing

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3-SIGMA RANDOM ERROR

Probe Mounting

Quantifying the effect: Theoretical computation, wind tunnel, flight testing, and/or CFD
3-SIGMA RANDOM ERROR

Pressure Transducer Accuracy

Typically a small error contributor

200 ft error at 41kft correlates to 1.71 mbar

Commonly accepted measurement accuracy of static pressure is near 0.25 mbar (EUROCAE ED-140, ARINC 738)
3-SIGMA RANDOM ERROR

Quantify effects of Random Error

Statistical analysis to compute 3-σ random altitude error

Flight test data verifies this estimation – but a statistically representative sample will not be available until after RVSM certification is complete.

Due to RSS’ing, the impact of large error sources are disproportionately large.

\[ \sqrt{100^2 + 25^2 + 25^2 + 25^2 + 25^2} = 112 \]
The systematic error (Mean ASE) and random error (3-σ) can be estimated by analysis in the design of the altimetry system.

Aerodynamic effects are the primary sources of ASE (especially at high Mach), while transducer accuracy is a minor source of error.

There are many sources of error that must be accounted for in the evaluation of RVSM compliance. This requires extensive analytical effort and flight testing in order to show compliance to RVSM requirements.
3-SIGMA RANDOM ERROR

Quantify Effects of Random Error

Example: Mach 0.7, 35kft, Light Weight

<table>
<thead>
<tr>
<th>Error Type</th>
<th>3-σ Error Level (ft)</th>
<th>Effect on RSS (ft)</th>
<th>Typical level of error (1-σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin Waviness</td>
<td>120</td>
<td>49</td>
<td>40</td>
</tr>
<tr>
<td>Steps&amp;Gaps</td>
<td>90</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>Probe Repeatability</td>
<td>60</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>Probe Mounting</td>
<td>45</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>Pressure Transducer</td>
<td>30</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td><strong>RSS</strong></td>
<td><strong>170</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although large sources of error tend to dominate the 3-sigma analysis, smaller sources of error can impact the accuracy of an individual unit.
FLIGHT TESTING

RVSM Airspace

Typically done in with Mach sweeps

Either done at a range of W/delta, or a range of weights and altitudes

- or -

Each Point at Heavy and Light Weight

Typically a trailing cone used as reference static system