Design for RVSM Compliance

RSSE & 3σ Error Evaluation

James Egberg
Aerospace Engineer

RSSE & 3σ Error Evaluation

Presentation Overview

- Company
- Experience
- RVSM compliance
- Systematic altitude error & SSEC
- Random altitude error & estimation

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…

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

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

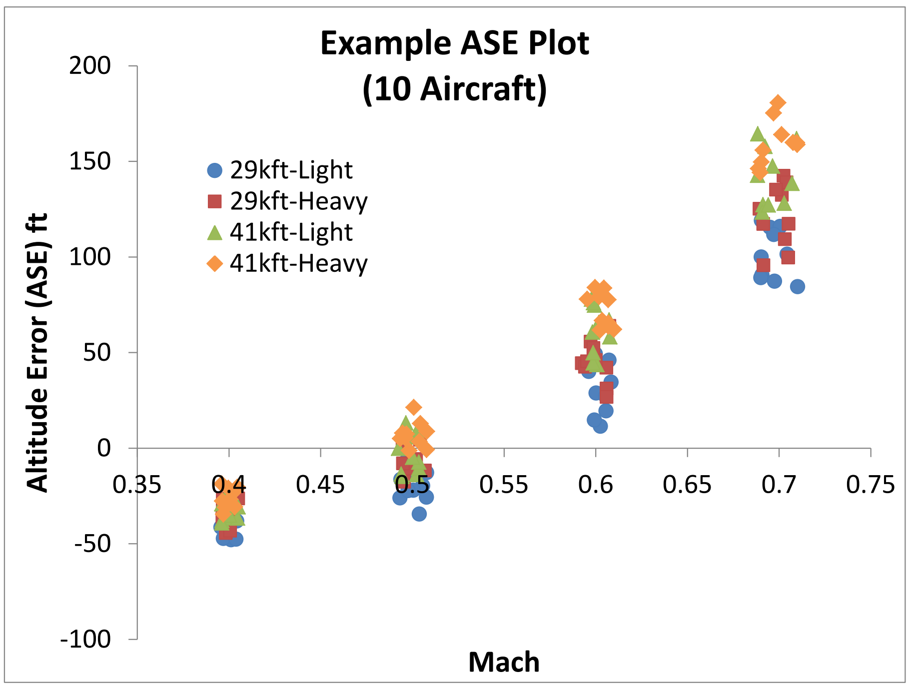
"This AC describes an acceptable means, but not the only means, for authorization of aircraft and operators to conduct flight in airspace or on routes where RVSM is applied"

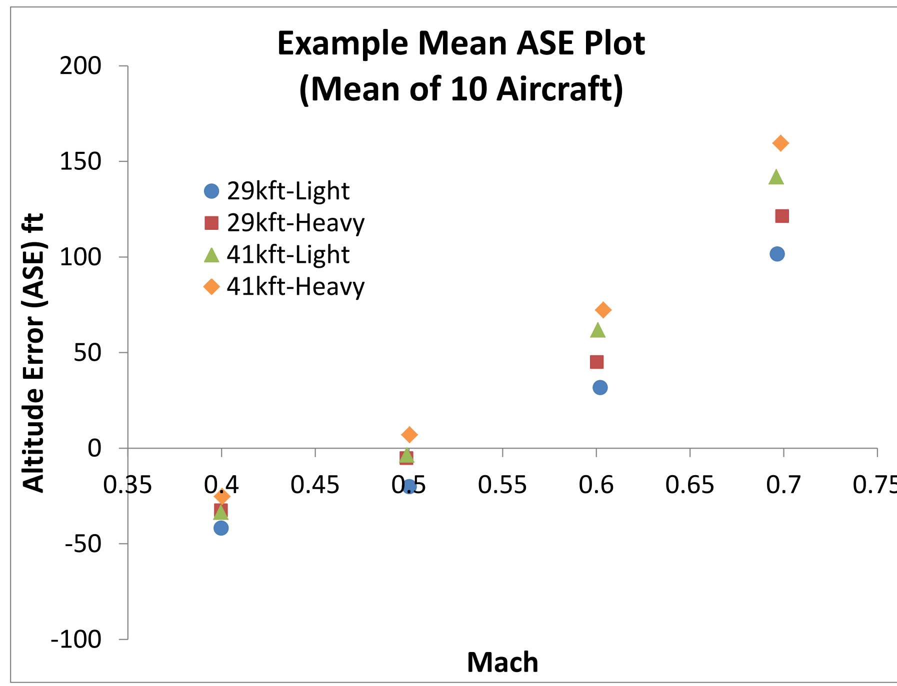
MEAN ASE < 80 FT

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)



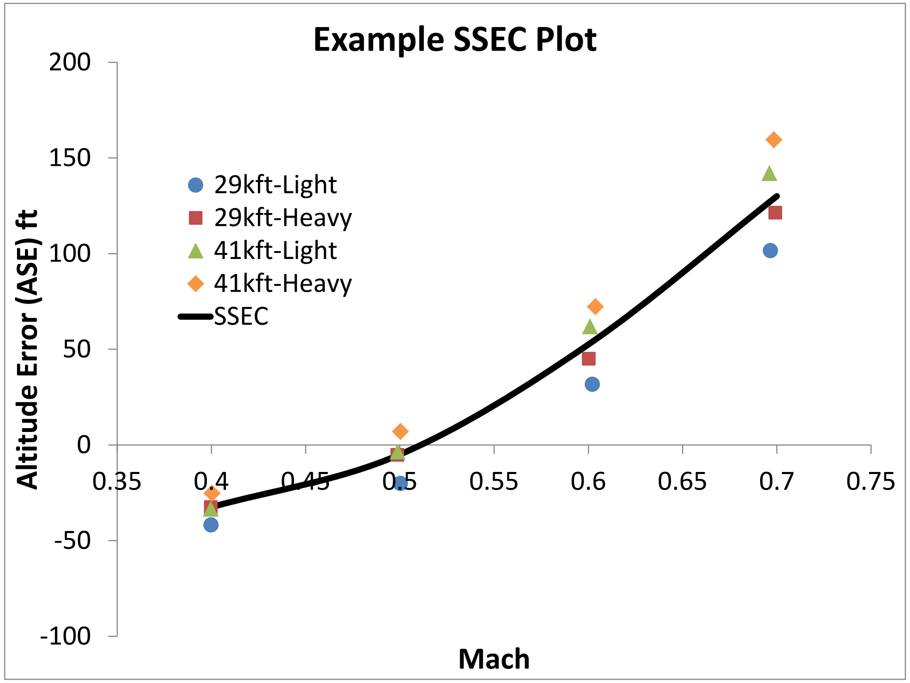


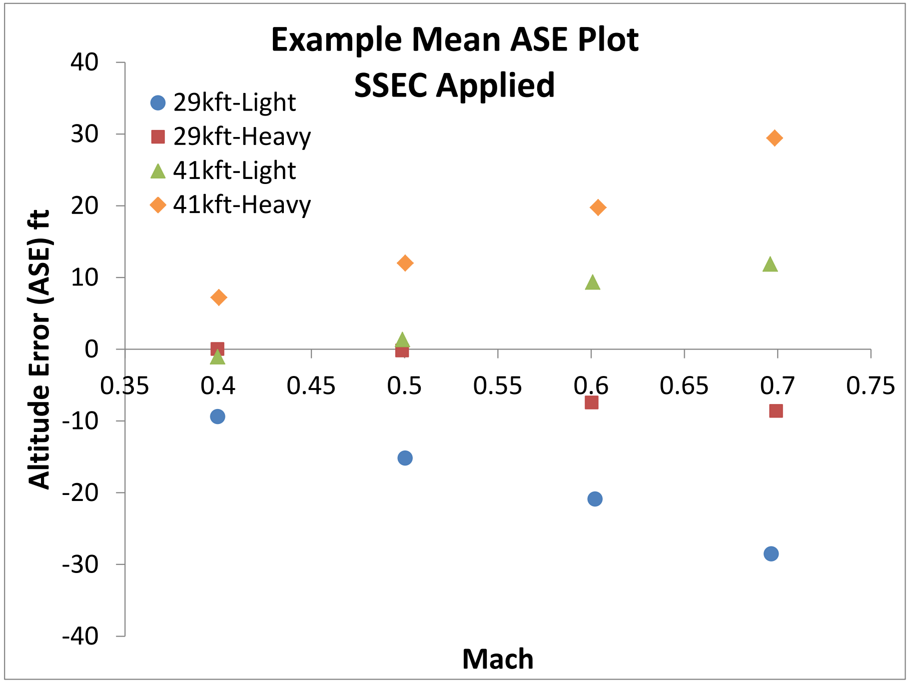
Note: All data presented herein is generated for educational purposes

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





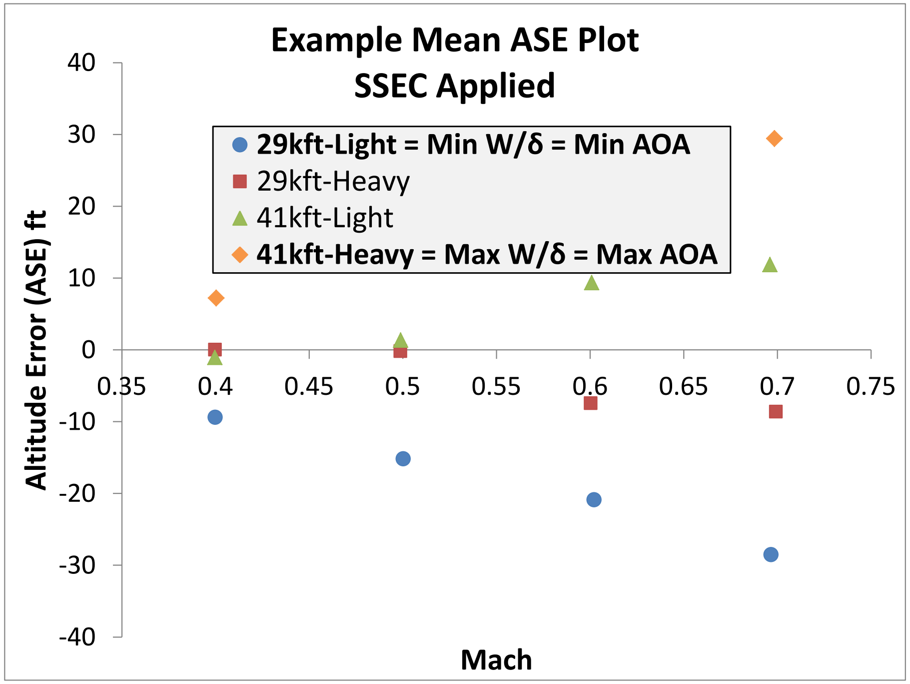
SSEC is typically a Mach based correction (at minimum)

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
AOA = ƒ(Speed, Altitude, Weight, …)



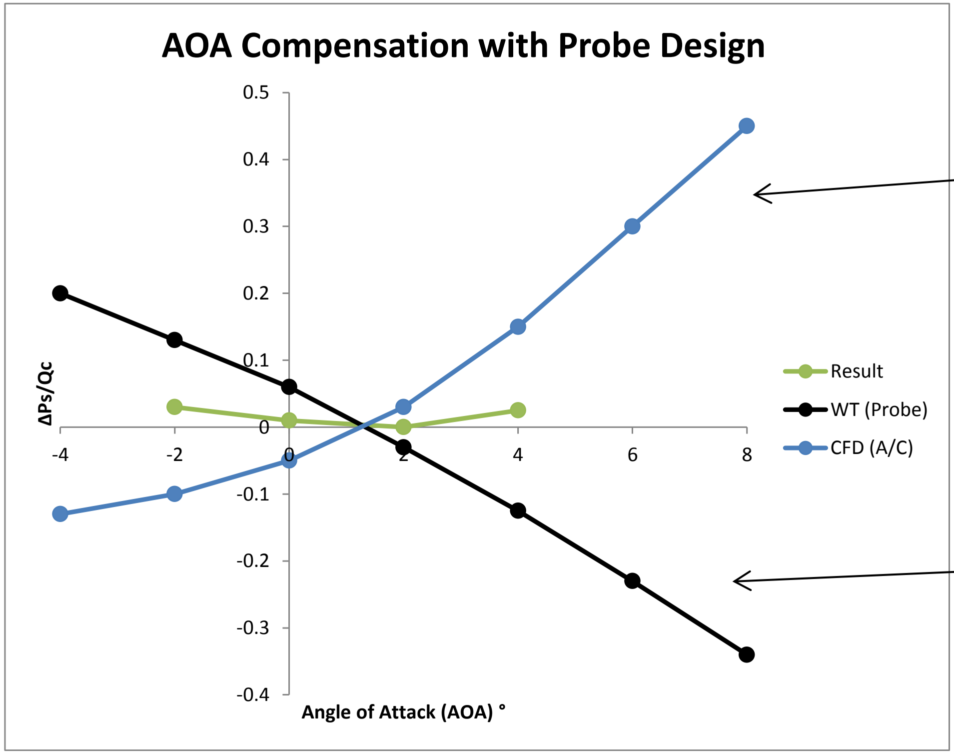
Reducing Mean ASE

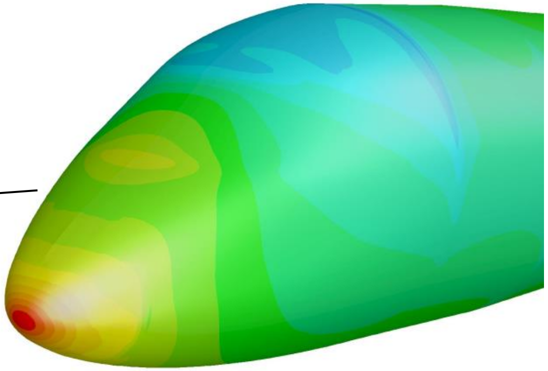
- Probe Placement
- Probe Design
- AOA/Altitude/Weight Compensation.

MEAN ASE < 80 FT

AOA Effect Mitigation – Probe Design

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



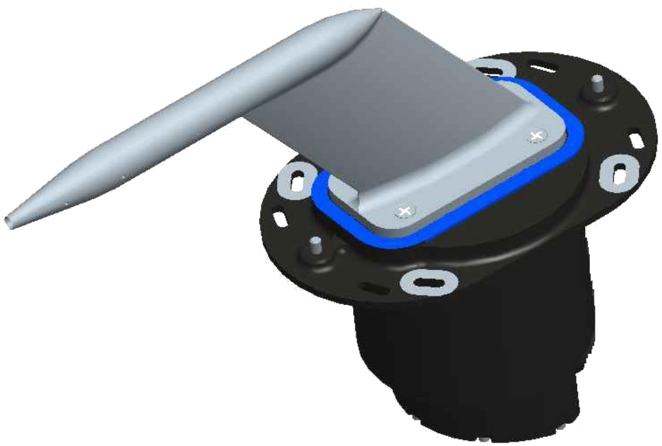


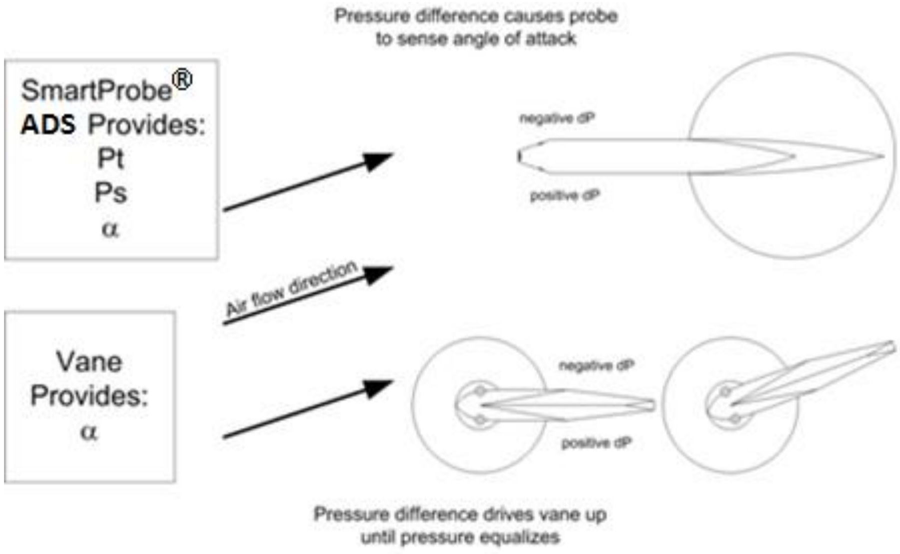
The probe can also be designed to reduce the magnitude of the Mach-based SSEC correction.

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

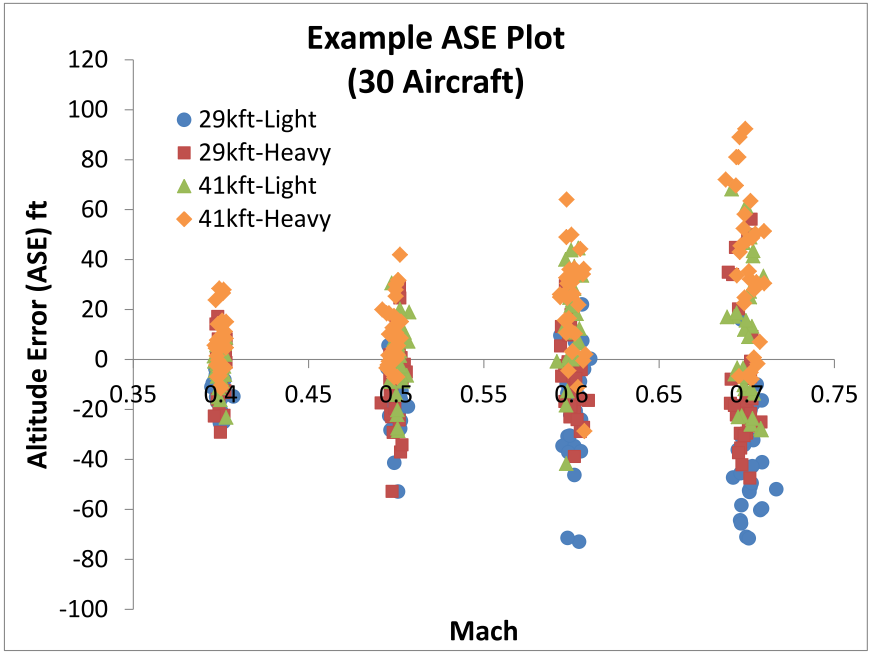
3-SIGMA RANDOM ERROR

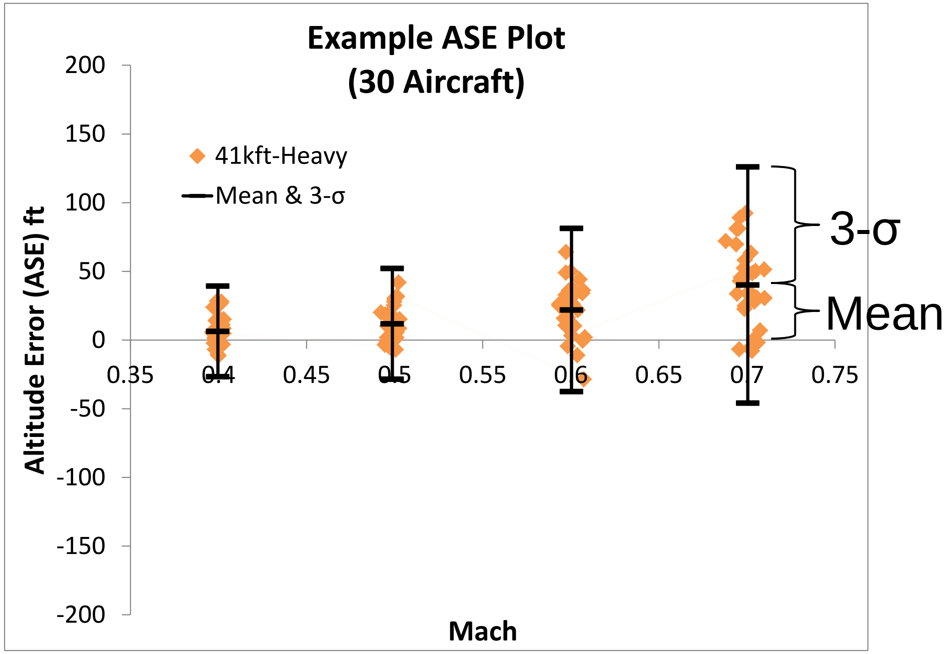
Mean ASE + 3σ < 200ft

<u>Random error sources</u>

Aircraft Manufacturing | Probe Mounting

Probe/Port Manufacturing | Pressure Transducer

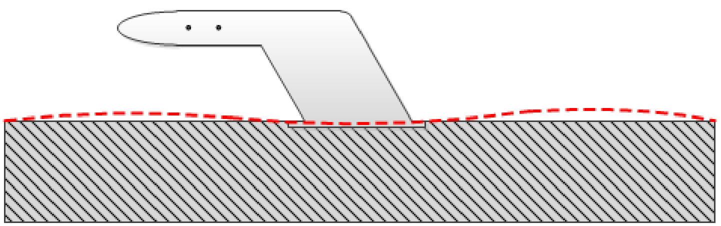


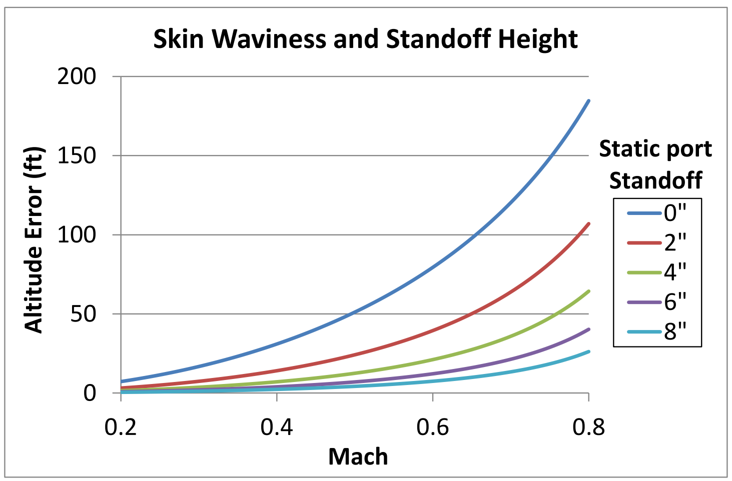


3-SIGMA RANDOM ERROR

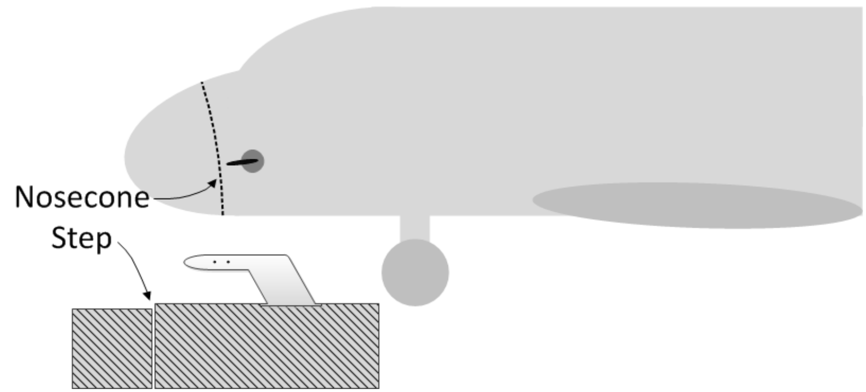
A/C Manufacturing Tolerance

<u>Skin Waviness</u>





<u>Steps & Gaps</u>

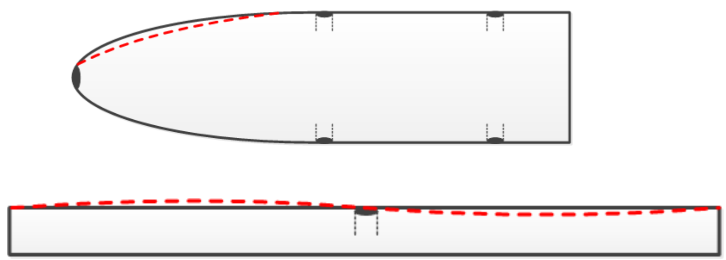


Quantifying the effect: Theoretical computation, wind tunnel, flight testing, and/or CFD

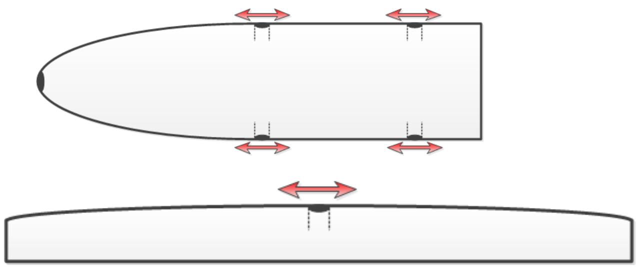
3-SIGMA RANDOM ERROR

Probe Manufacturing

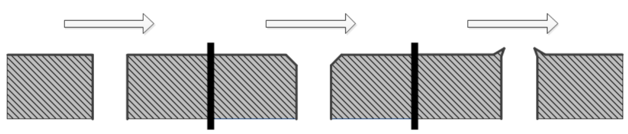
Probe Contour



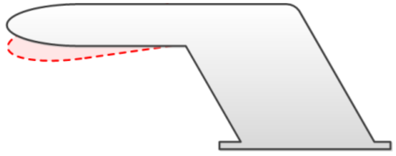
Static Port Placement



Static Port Finish



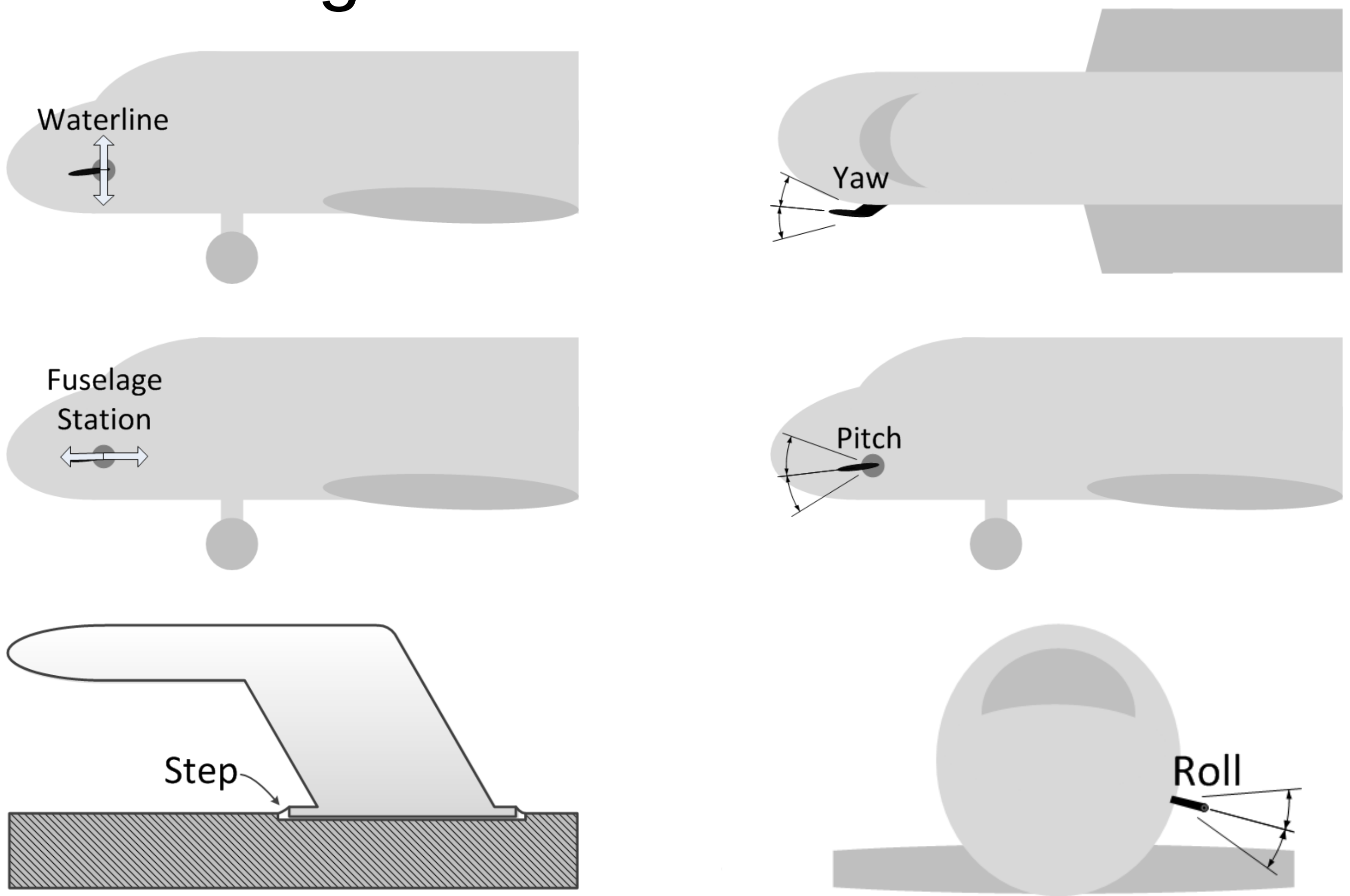
Probe Alignment



Quantifying the effect: Wind tunnel testing

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

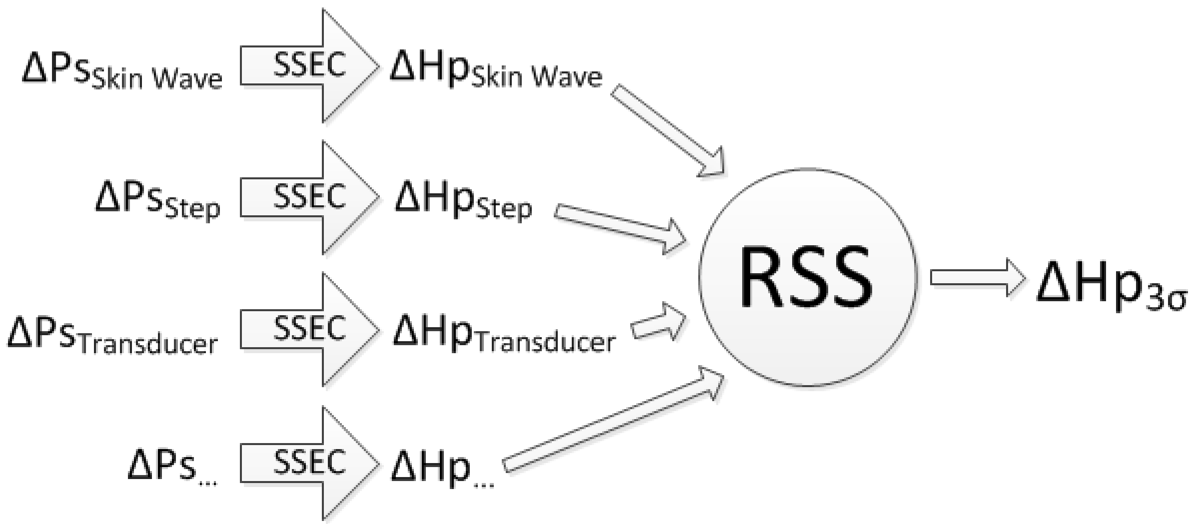
Typically a small error contributor

- 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.

$$\sqrt{100^2 + 25^2 + 25^2 + 25^2 + 25^2} = 112$$

SUMMARY

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.

QUESTIONS

3-SIGMA RANDOM ERROR

Quantify Effects of Random Error

Example: Mach 0.7, 35kft, Light Weight

Error Type	**3-σ Error Level (ft)**	**Effect on RSS (ft)**	**Typical level of error (1-σ)**
Skin Waviness	120	49	40
Steps&Gaps	90	26	30
Probe Repeatability	60	11	20
Probe Mounting	45	6	15
Pressure Transducer	30	3	10
RSS	170		

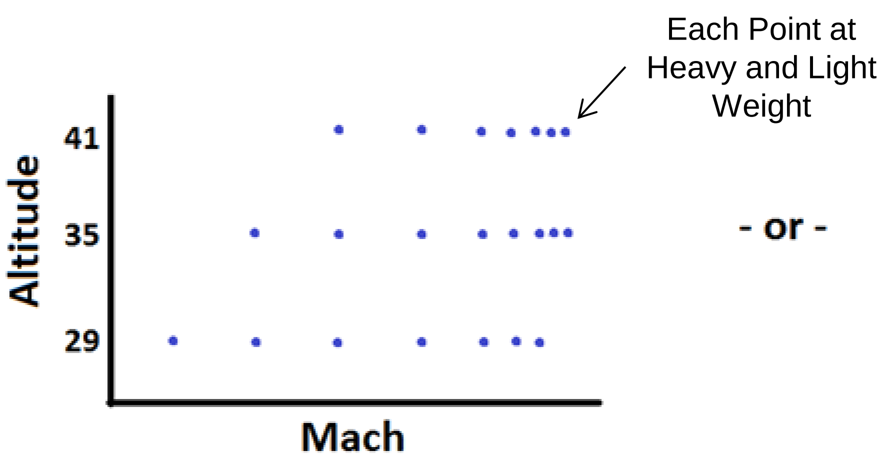
Although large sources of error tend to dominate the 3-sigma analysis, smaller sources of error can impact the accuracy of an individual unit.

FLIGHT TESTING

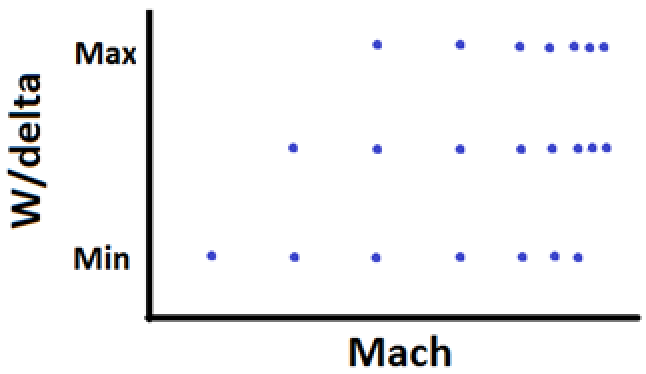
RVSM Airspace

Typically done in with Mach sweeps

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



- or -



Typically a trailing cone used as reference static system