Reducing Uncertainty in Measurement of Vertical Wind

Adjustment Based on the Schuler Relationships

Al Cooper

Research Aviation Facility, Earth Observing Laboratory
National Center for Atmospheric Research

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Outline

CHARACTERIZING UNCERTAINTY IN MEASUREMENTS

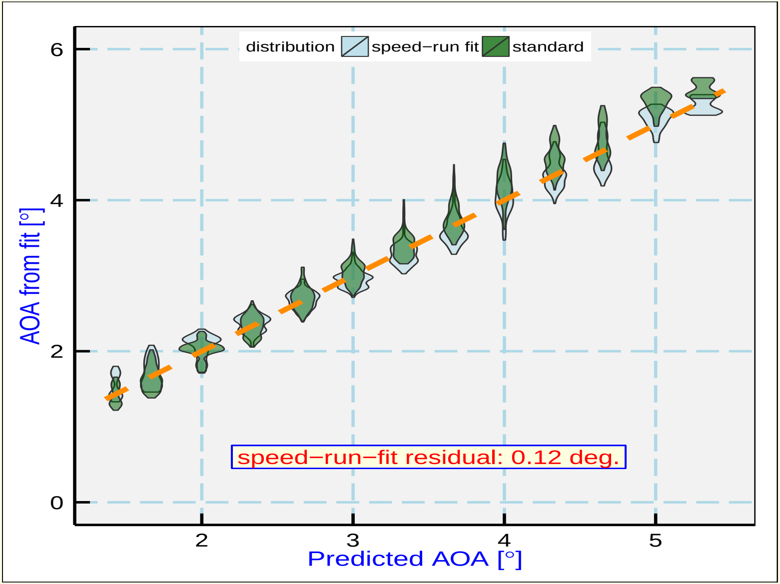
Conventional Approach:

1. Review measurement method
2. Characterize measurements involved:
   (a) Sensors: uncertainty characteristics
   (b) Calibrations, intercomparisons, etc.
   (c) Other studies of measurement uncertainty
3. Tabulate elemental uncertainties and net uncertainty
4. Discuss individual elements, esp. significant ones
5. Consider limiting factors and ways to improve the measurement.

RESULTS TO DATE:

#	measurement	bias	random error	δw bias m s^{-1}	δw, random
1	radome ADIFR	0.07 hPa	0.002 hPa	–	–
2	AOA: fit	0.03°	0.001°	0.12	0.04
3	sideslip	0.07 hPa	0.002 hPa	–	–
4	dynamic pressure QCF	0.34 hPa	0.01 hPa	<0.02	0.001
5	**pitch**	**0.05°**	**0.02°**	**0.19**	**0.08**
6	GV vertical velocity	0.03 m/s	<0.03 m/s	0.03	<0.03
7	GV u, v motion	0.03 m/s	<0.03 m/s	–	–
8	pressure PSF	0.10 hPa	0.001 hPa	–	–

ANGLE OF ATTACK: GOOD REPRESENTATION



DOMINANT CONTRIBUTOR TO UNCERTAINTY

PITCH

- Uncertainty estimate (0.05°) comes from Honeywell specs.
- Comparison of redundant measurements:
  - differences of at least 0.02° for roll within range $\pm 5^\circ$
  - RMS difference 0.12° without that restriction.
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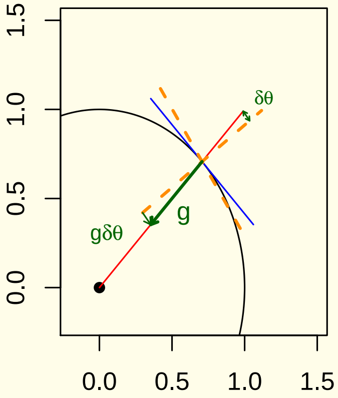
3. Use the coupling between acceleration errors and pitch errors to deduce a correction for pitch.

SCHULER COUPLING OF ERRORS

Effect of a pitch error:

1. False platform orientation produces a false horizontal component of sensed gravity

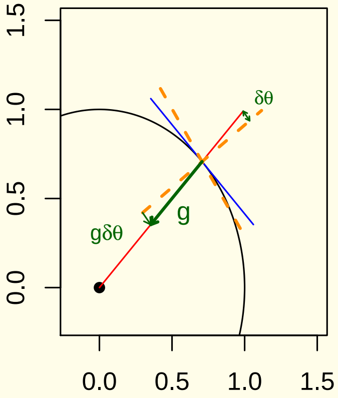


SCHULER COUPLING OF ERRORS

Effect of a pitch error:

1. False platform orientation produces a false horizontal component of sensed gravity
2. Result is a false acceleration, leading to growth of an error in the ground speed:

$$\frac{d(\delta v_n)}{dt} = -g\delta\theta$$



OSCILLATION OF ERRORS

Position error offsets pitch error:

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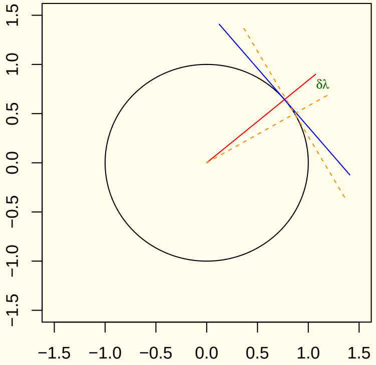

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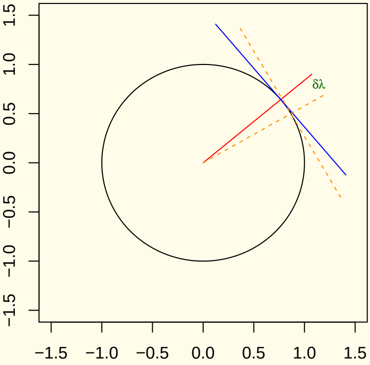

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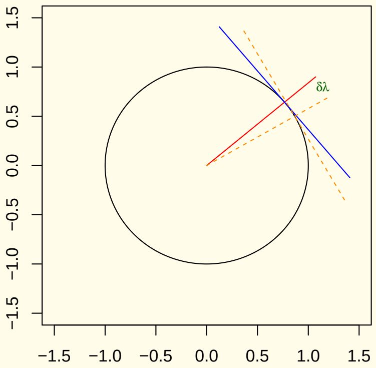

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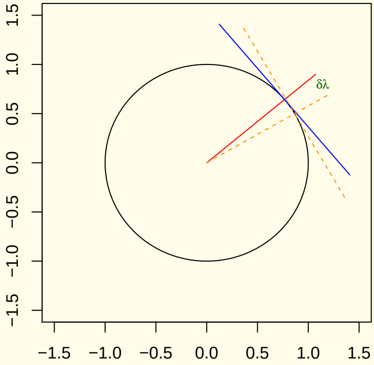


Result: oscillation of bounded errors.
Roll: analogous to pitch.

MUST CONSIDER REFERENCE FRAMES

Four reference frames involved:

1. body frame: oriented wrt aircraft axes [b-frame]
2. local-level frame: ENU (east-north-up) [l-frame]
3. earth-fixed frame: z from CG to N pole, x -> prime meridian
4. inertial frame: like earth-fixed frame but x -> the vernal equinox and does not rotate

Key transformation:

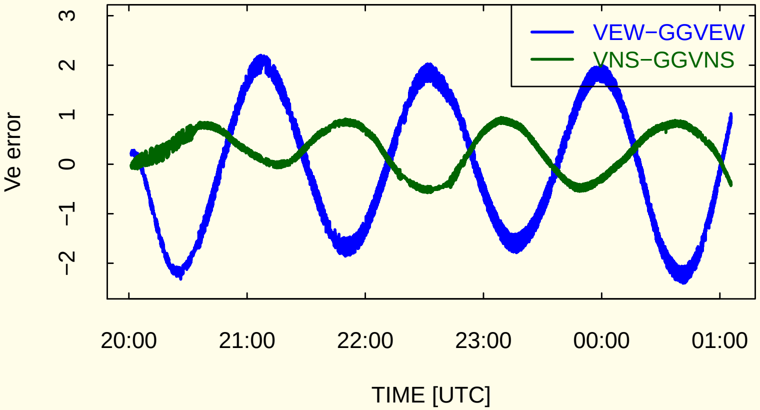
- Pitch, roll, heading defined in body frame
- INS and GPS provide ground-speed components in the l-frame
- The attitude angle changes are best seen in the l-frame
- Key transformation is from errors in l-frame to errors in b-frame

MIXING OF ROLL AND PITCH ANGLES

Imagine a unit vector in the l-frame representing angle errors

- Use to represent what the INU thinks is the upward direction in the l-frame.
- Will have components $\delta\theta$ and $\delta\phi$ representing the respective errors in pitch and roll.
- The general aircraft orientation is in some other frame than along the l-frame axes:
  - a positive pitch error for northbound flight will be a negative pitch error for southbound flight.
  - other flight directions mix the components of the angle error, with e.g. the roll error for northbound flight becoming the pitch error for eastbound flight.
- The relevant transformation, l-frame to b-frame, is the inverse of the one we normally use for wind processing.

AN EXAMPLE OF GROUND-SPEED ERRORS



DEEPWAVE ferry flight ff02, Hawaii to Pago Pago, 1 June 2014, flying mostly near-southbound.

FINDING PITCH AND ROLL ERRORS IN THE *I*-FRAME

pitch, roll, ground-speed errors: $\delta\theta$, $\delta\phi$, $\delta v_{n,e}$:

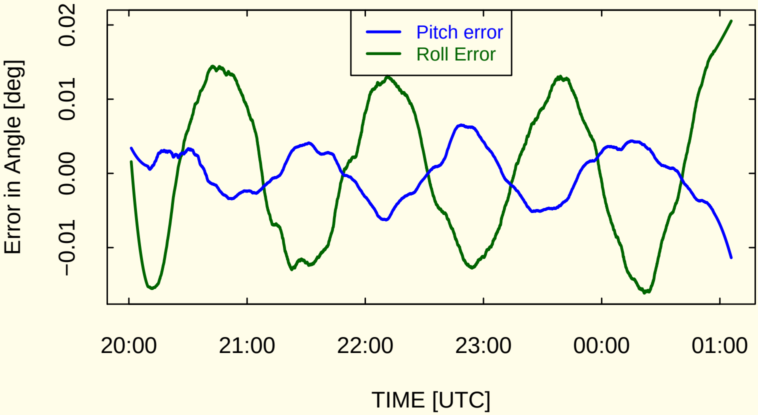
$$\delta\theta = -\frac{1}{g}\frac{d(\delta v_n)}{dt}$$

$$\delta\phi = -\frac{1}{g}\frac{d(\delta v_e)}{dt}$$

Find the right-side derivatives in the I-frame:

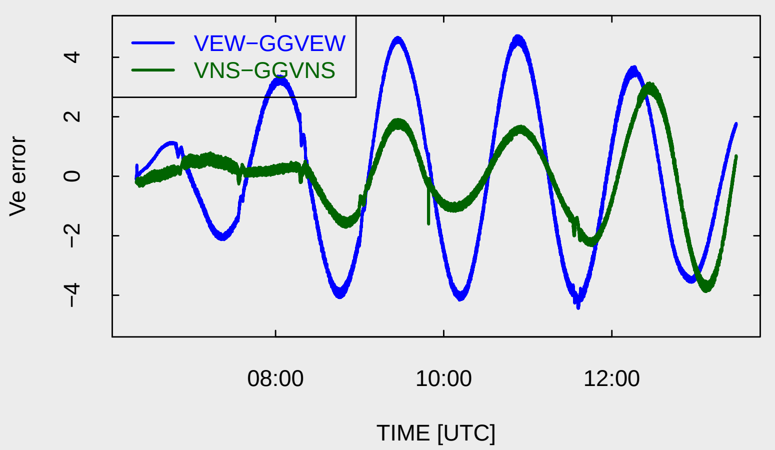
1. Second-by-second, $\Delta\delta v_{n,e}/\Delta t$ are too noisy
2. $A\cos(\Omega_{Sch}t+\zeta)$? Need to allow A and ζ to vary
3. Instead, chose 4th-order polynomial fit centered over 1/5 Schuler period or 1013 s.
4. Technique: Savitzky-Golay polynomials

DEDUCED PITCH AND ROLL ERRORS

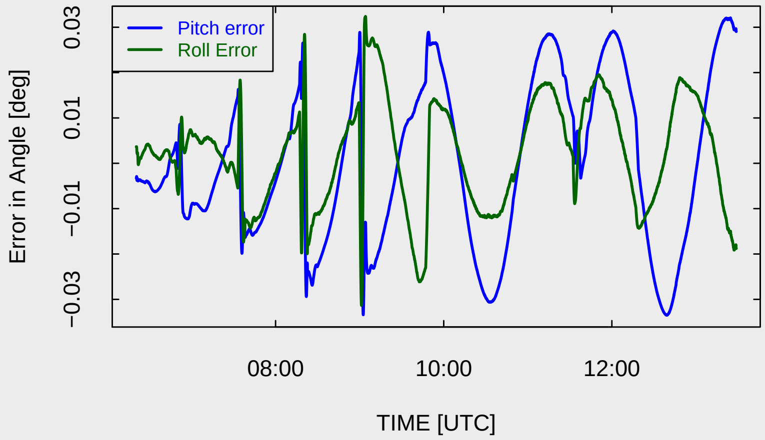


For DEEPWAVE ff01, pitch errors are max. 0.005°, or 0.1×specifications, exc. in final descent.

GROUND-SPEED ERRORS IN DEEPWAVE rf01, *l*-frame:



PITCH ERRORS IN DEEPWAVE rf01, b-frame:



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7. Growing errors in lateral velocity may constrain the heading error. (Future investigation?)

SUMMARY

A correction can be applied to pitch and hence to vertical wind

1. Deduce the error in pitch from the time derivative of the error in ground speed.
2. Transform to the b-frame using the inverse of the conventional 'gusto' transformation.
3. Consider a new pitch variable (PITCHC?) and new vertical-wind variable (WI_SCH or WIS or ?)
   (a) To first order, just add TASX*$\delta\theta_b$ to the vertical wind.
   (b) More complicated in turns; maybe for DEEPWAVE just provide the simpler variable with the qualification that this correction is not valid in turns.
4. Second-pass processing after nimbus is preferable because it allows the calculation of the time derivative of the ground-speed error using centered intervals.

Reproducibility Information:

Project:	SchulerPresentation
Archive package:	SchulerPresentation.zip
Contains:	attachment list below
Program:	SchulerPresentation.Rnw
Original Data:	/scr/raf_data/DEEPWAVE
Git:	git@github.com:WilliamCooper/SchulerStudy.git

Attachments: SchulerPresentation.Rnw
SchulerPresentation.pdf
chunks (code imported into SchulerPresentation.Rnw)
SessionInfo