Characterizing Uncertainty in Measurements of Vertical Wind

An Evaluation Focused on DEEPWAVE

Al Cooper

NCAR / RAF

DEEPWAVE Workshop Short Presentation
23 Oct 2014

MEASURING WIND FROM AN AIRCRAFT

How wind is measured:

Wind = (Air wrt Earth) = (Air wrt Aircraft) + (Aircraft wrt Earth)

(Air wrt Aircraft): "Relative wind"

magnitude of airspeed, angles of attack and sideslip

(Aircraft wrt Earth):

GPS provides groundspeed and climb rate

A Key Complication

A 3-angle rotation is required to transform relative wind and ground motion to the same axes.

- Measurements required are pitch, roll, and heading.
- For vertical wind, the crucial measurement is **pitch**.
- For horizontal wind, the crucial measurement is heading.
- For relative wind, the crucial measurements are **angle of attack** and sideslip.

THE BASIC EQUATION

$$w \simeq V(\alpha - \theta) + w_p$$

where V is true airspeed, α angle of attack, θ pitch, and w_p the upward motion of the aircraft.

NEEDED MEASUREMENTS:

Required measurements are then:

- true airspeed, from dynamic pressure and (T, p)
- angle of attack, from the radome pressure distribution
- pitch, from the IRU
- vertical motion of the aircraft, from GPS

LARGEST CONTRIBUTORS TO UNCERTAINTY:

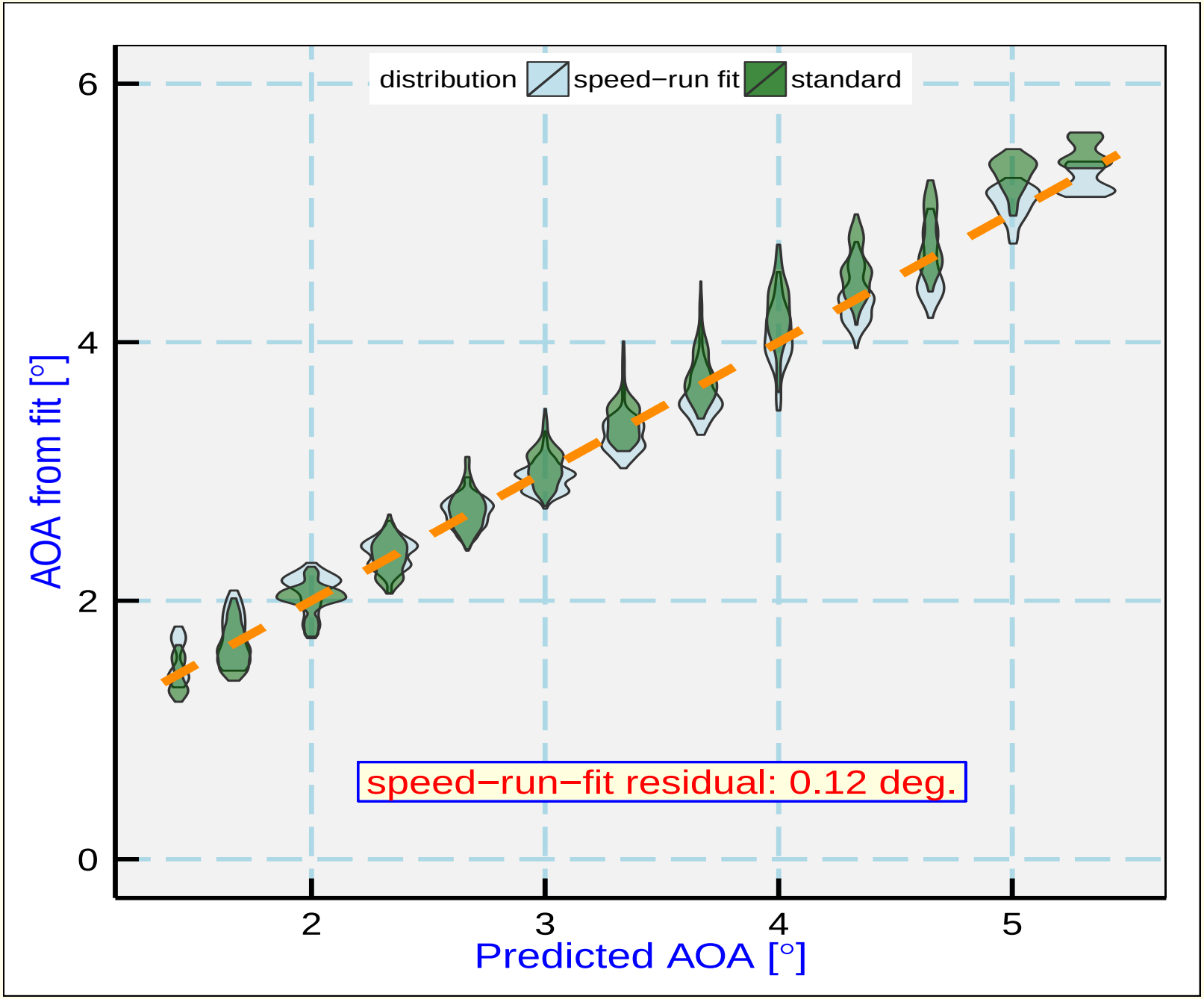
FOR VERTICAL WIND?

- PITCH! Measurement depends on initial alignment of the IRU.
  - IRU specs are $\pm 0.05^\circ \Rightarrow \delta W \simeq V \delta\phi \simeq 0.2\,\text{m/s}$ at 225 m/s
  - Not just a constant bias; changes during the flight
- Angle of attack: Easier to control via calibration

FOR HORIZONTAL WIND:

- HEADING.
- Sideslip, esp. the offset in sideslip
- True airspeed, dependent on dynamic pressure

ANGLE OF ATTACK: GOOD REPRESENTATION



SUMMARY TABLE FOR VERTICAL WIND

#	measure-ment	bias	random error	δw bias $\mathrm{m\,s^{-1}}$	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	–	–
9	temperature ATX	0.3°	0.1°C	–	–

CONCLUSIONS RE VERTICAL WIND

1. Estimated σ_w (standard uncertainty) is about $0.2\,\mathrm{m\,s^{-1}}$.
2. Pitch is the primary cause of uncertainty in w:
   (a) uncorrected, responsible for about $0.2\,\mathrm{m\,s^{-1}}$ uncertainty.
   (b) for specific flight periods, partial compensation is provided by calibration of angle of attack.
3. New angle-of-attack sensitivity coefficients determined:
   (a) contribute only about $0.1\,\mathrm{m\,s^{-1}}$ uncertainty to σ_w.
   (b) partially compensate for an offset in pitch
4. Other measurements make negligible contributions to uncertainty:
   (a) pressure measurements on the radome
   (b) dynamic pressure
   (c) Earth-relative motion of the aircraft including vertical
   (d) ambient pressure and temperature