Accuracy Requirements for Airborne Wind Measurement in Aerial Application

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Introduction

- Weather is a significant factor affecting drift
- Wind of particular importance
- Wind information to gauge drift behavior
  - Representative of area (right here)
  - Timely (right now)
- Wind measurement on spray aircraft
  - Guaranteed to be right here, right now

Accuracy?

- Airborne data uniquely valuable

  …but, only if sufficiently accurate

Accuracy Target

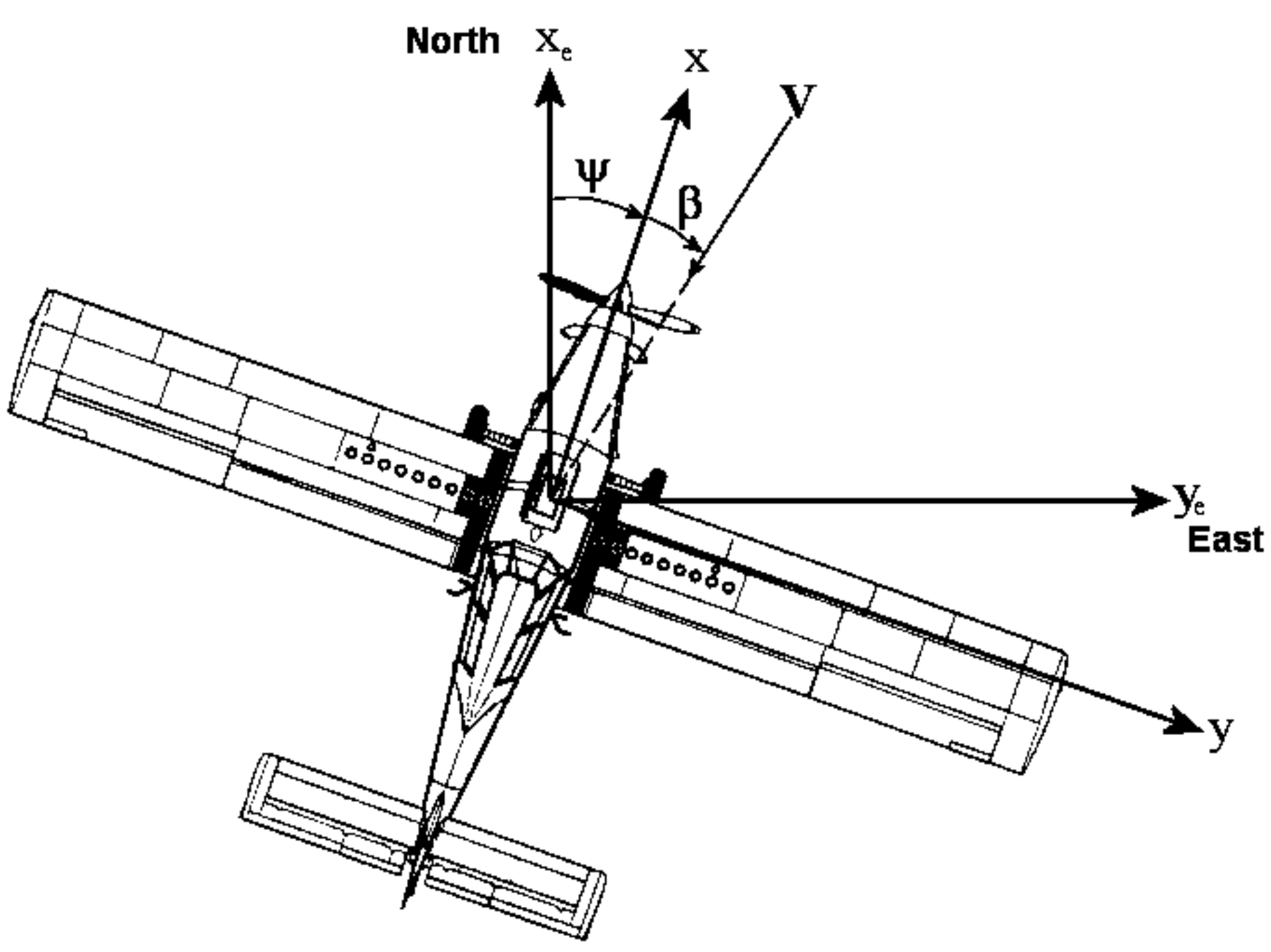
- Drift guideline: 10 mph maximum wind speed
- Error should be reasonably small fraction of typical working range of wind speeds
- Target accuracy: 1 mph ballpark proposed (10% error at typical maximum speed)

Accuracy Target

- Speed error is also issue for resolving wind direction
- Example
  - Wind error 4 mph
  - True wind 2 mph
  - Wind direction could be reversed – 180 degree error!
- Error should be less than typical wind speeds to prevent gross direction errors
- 1 mph wind speed error: serious direction errors only for wind speeds less than 1 mph ✓

Airborne Wind Measurement

- Air-flow speed and direction are measured
- Key difference: flow relative to aircraft frame of reference
  - Flow speed / aircraft-relative wind (true airspeed)
  - Flow direction (sideslip)
- Wind: transform flow to ground reference
  - Aircraft orientation (primarily heading)
  - Aircraft velocity
- What limits does ~1mph accuracy impose on true airspeed, heading and sideslip data?


North
x_e
x
y
ψ
β
y_e
East
y

Airborne Wind Speed Error

$$|\Delta V_w| \leq |\Delta V \cos(\Psi - \Psi_w)| + |V \Delta\Psi \sin(\Psi - \Psi_w)|$$

$$\Psi \equiv (\psi + \beta)$$

- Error bounded by sum of
  - On-track error due to true-airspeed error
  - Cross-track error due to heading + sideslip error
  - Terms weighted by direction flown relative to wind direction

Wind Speed Error

- Desirable to have error not change radically with direction flown
- Design requirement: magnitude of two terms equivalent, defined as δ
- Maximum error
  - heading 45 degrees to the wind
  - Wind speed error = 1.4 δ

Wind Speed Error

- Reference case
  - Cessna 188, 100 knots TAS, standard sea-level
- Maximum wind speed error of 1 knot
  - Max speed error = 1.4 δ
  - δ = 1 / 1.4 = 0.7 knots
  - TAS error maximum = 0.7 knots
  - Heading + sideslip error = 0.007 rad (0.4 deg)

How Difficult Is 0.7 kts TAS Accuracy?

- At 100 kts TAS, represents 0.7% accuracy
- Corresponding pitot-static pressure accuracy = 23 Pa (0.0033 psi)
- Studied pressure variation under wing with wing loading change
  - Aerodynamic pressure = pitot-static error
  - Pressure several times 23 Pa limit
  - Change in pressure also several times limit

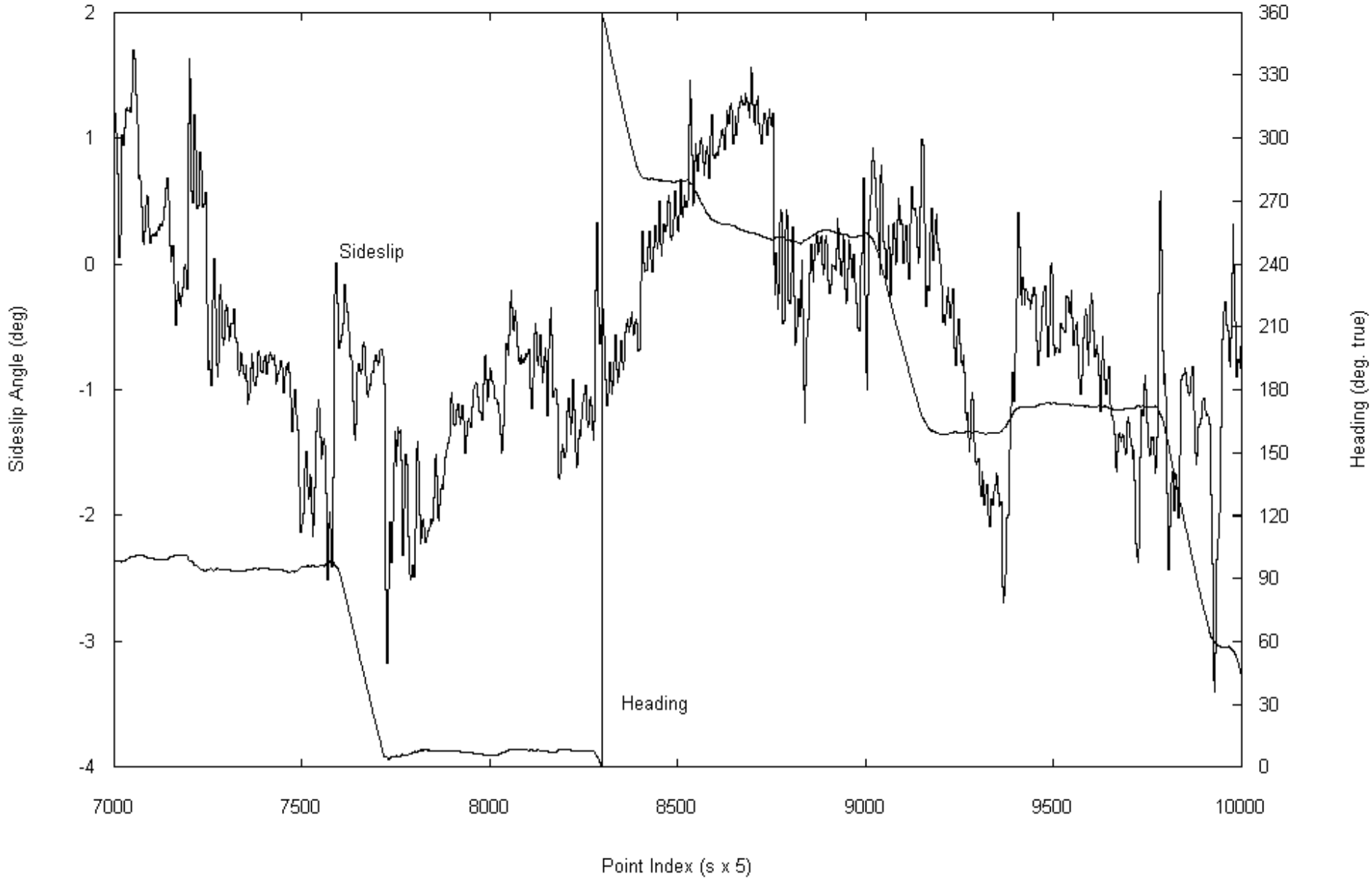
How Difficult Is 0.4 Degree Accuracy?

- Magnetic heading most common reference
- Measure direction of field line in aircraft-frame and relate to true north (declination)
- Declination error:
  - World Magnetic model (spatial error), 0.5 deg
  - Unsteady geomagnetic field (temporal error), 0.25 deg at mid-latitude
  - Local field error (steel on airframe, electric currents) several degrees to be calibrated out

Heading Error

- Best compass hard pressed to do any better than 1 degree true heading accuracy
- Probabilities of larger unknown anomalies (geology, solar activity): reliability problem
- Compass cannot be used as a result

Sample Sideslip Data: Cessna 188



Conclusion

- 1 mph wind speed accuracy proposed for data to be of practical value to in-flight drift management
- Implications for airborne measurement, C188
  - 0.7 kts TAS accuracy
  - 0.4 degree combined heading + sideslip accuracy
- TAS accuracy: aerodynamic state correction req'd
- Heading < 0.4 deg: alternative to compass a must
- Sideslip data necessary (< 0.4 deg)

AIMMS-20: Precise TAS

- Aerodynamic state measured by under-wing mounted air-data probe: measures flow angles explicitly
- Complete corrections performed to account for variations in wing loading on TAS data
- Efficient flight calibration

AIMMS-20: Heading + Sideslip

- Heading determined by
  - Two wing-tip mounted GPS antennas
  - Inertial measurement unit
  - True heading accuracy of 0.1° - 0.2°
- Air-data probe measures sideslip angle
  - Precision 0.05 degrees at 100 knots

AIMMS-20 Air-Data Probe on C188