Circle Maneuvers

Some Things You Can Learn by Flying in Circles

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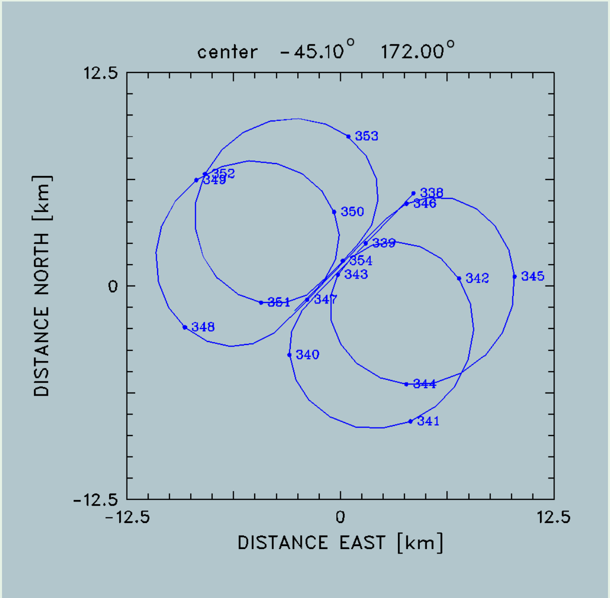
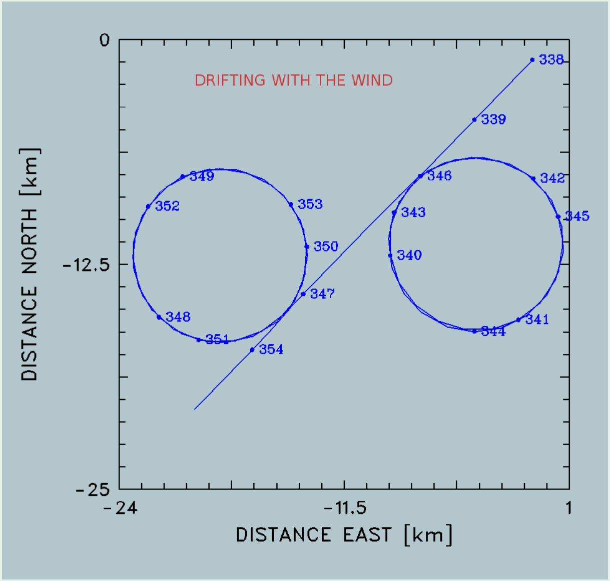
EXAMPLE OF CIRCLE MANEUVER

DEEPWAVE flight 15, 3:38:30 – 3:54:30 UTC.



SAME MANEUVER, DRIFTING WITH WIND

DEEPWAVE flight 15, 3:38:30 – 3:54:30 UTC.



EXPECT CONSTANT WIND AROUND TURNS

Constraints Imposed:

1. Wind can be determined from GPS track only!
2. TAS bias: Wind will change from upwind to downwind direction.
3. Heading or sideslip bias: Wind will change from crosswind-right to crosswind-left positions.
4. These can be separated by using circle maneuvers with different roll angles and measured sideslip vs roll.
5. Departures from constant wind can be used to determine possible time shifts.

Each will be explored in this presentation.

WIND FROM GPS TRACK

Fit to GPS ground-speed components:

- Fit Parameters: wind(u_x, u_y), TAS, $\delta\psi$
- Minimize error function defined as

$$\chi^2 = \sum(\delta v_x^2 + \delta v_y^2)$$

where

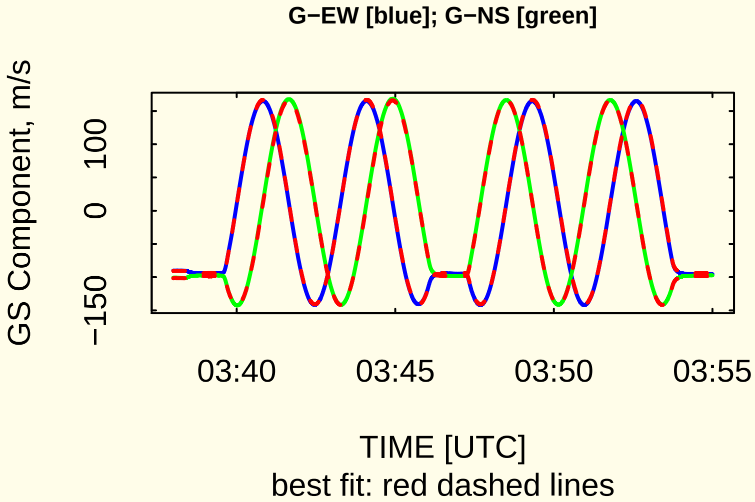
$$\delta v_x = g_x - u_x - TAS \sin(\psi + \delta\psi)$$

$$\delta v_y = g_y - u_y - TAS \cos(\psi + \delta\psi)$$

- Best fit: Wind 223.1 / 17.8, TAS=153.8, $\delta\psi = -0.1$.
- Compare to: 223.1 / 18.0, 154.3 from mean of measurements.

Uncertainties: Postpone estimates: Want to improve χ^2 first

BEST-FIT MATCH BETWEEN GROUNDSPEEDS

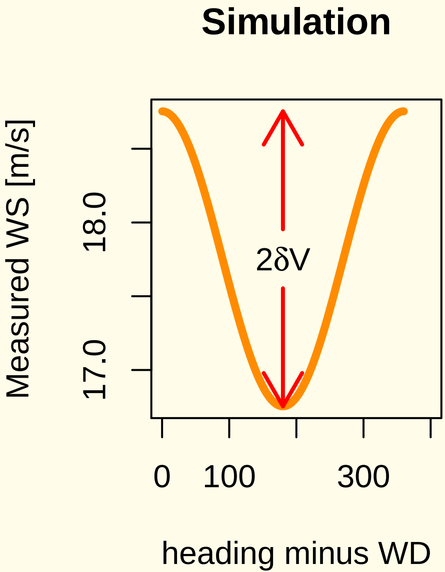


RMS error between ground-speeds: 1.1 m/s.

EFFECT OF AN ERROR IN TAS

Assume an error of δV:

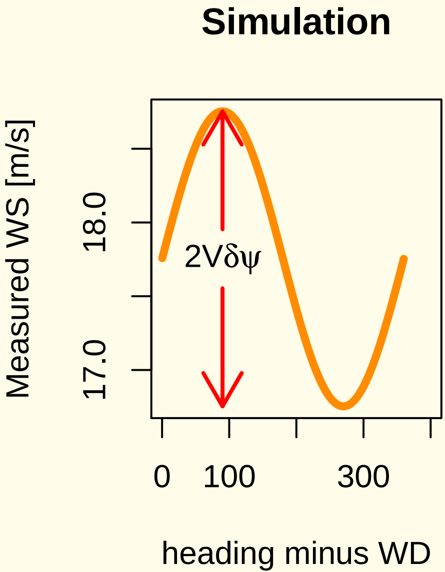
- Expect change of $2\delta V$ from upwind to downwind flight direction
- No change for cross-wind flight
- Expect a cosine-wave fluctuation with peak amplitude δV.



EFFECT OF AN ERROR IN HEADING

Assume an error of $\delta\psi$:

- Expect change of $2V\delta\psi$ from crosswind-left to crosswind-right flight direction
- No change for along-wind flight
- Expect a sine-wave fluctuation with peak amplitude $V\delta\psi$.



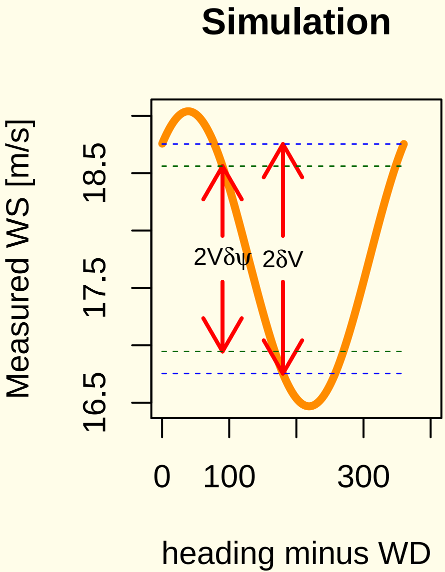
EFFECT OF ERRORS IN TAS AND HEADING

Assume errors of $\delta V = 1$ m/s and $\delta\psi$=0.3°:

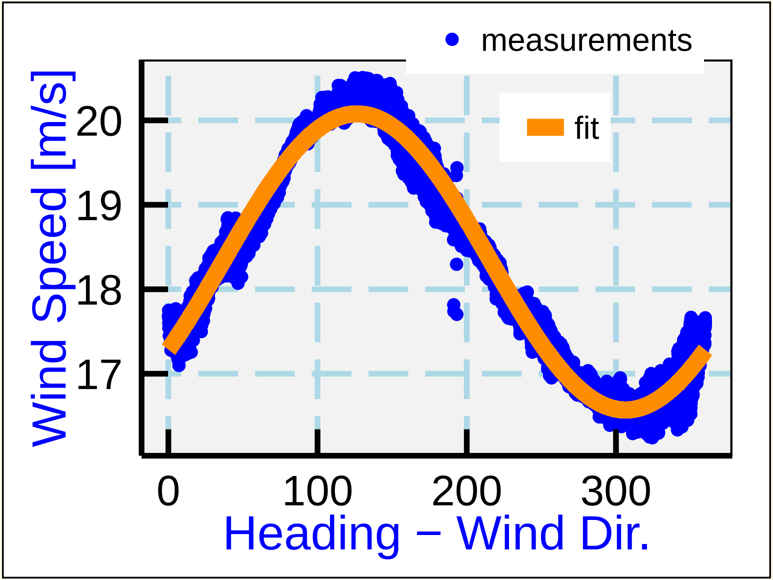
- Expect a sum of sine and cosine curves:

  $\delta G = A_1 \cos\theta + A_2 \sin\theta$

- Can fit to the error curve and determine both $A_1 = \delta V$ and $A_2 = V(\delta\psi)\pi/180$:

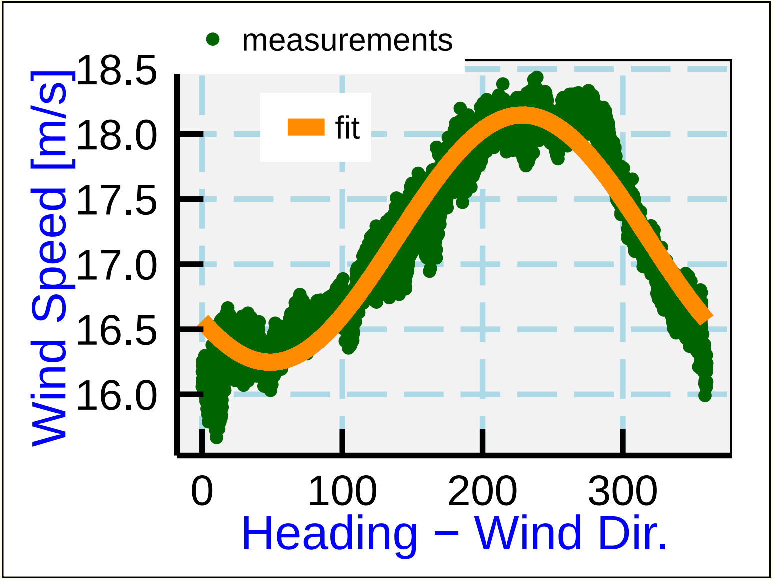


MEASUREMENTS FROM LEFT-TURN CIRCLES



Fit: δV =-1.0 m/s, $\delta\psi'$ =0.52°, sd=0.19 m/s

MEASUREMENTS FROM RIGHT-TURN CIRCLES



Fit: δV =-0.6 m/s, $\delta\psi'$ =-0.26°, sd=0.19 m/s

RESOLVING AN AMBIGUITY PROBLEM

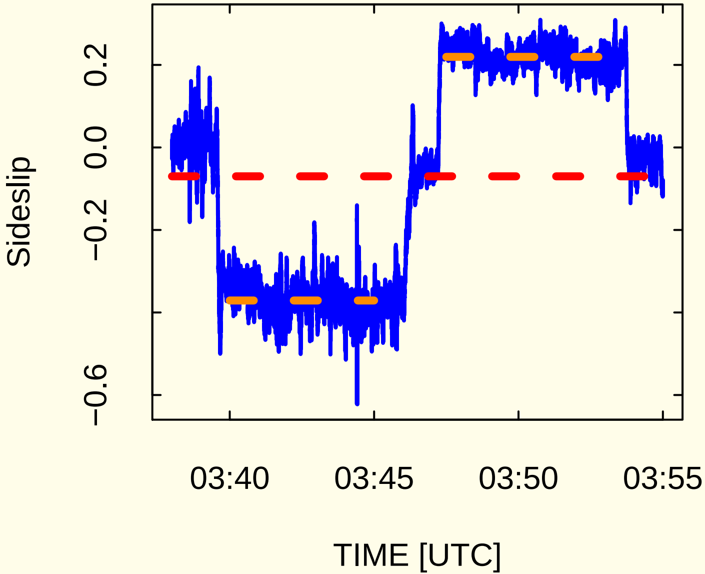
$\delta\psi'$ combines errors from heading and sideslip:

- Sensitive to combined offsets in heading ψ and sideslip β:

  $$\delta\psi' = \delta\psi + \cos\phi\,\delta\beta$$

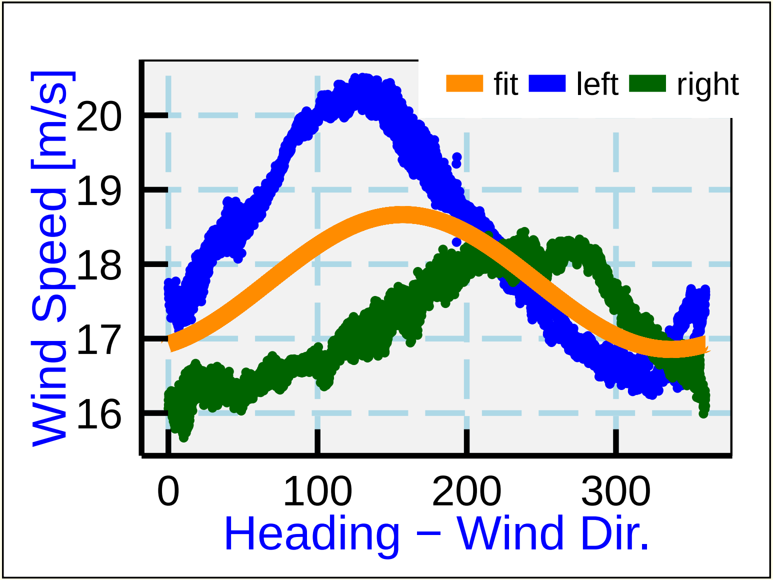
  where $\phi =$roll.
- Right and left turns: same values of $\cos\phi$.
- Circles with different roll angles could separate these effects:
  ->This occurs naturally for circles at different altitudes
- Another approach: Compare sideslip in left vs right turns:
  ->As the aircraft rolls, angle-of-attack and sideslip combine to produce a net lift.
  ->This must result in the same lift in right vs left turns.
  ->Therefore, sideslip reverses sign in right vs left turns.

MEASUREMENTS OF SIDESLIP



For symmetry, add 0.07° to SSLIP

COMBINED RESULTS



Fit: δV =-0.8 m/s, $\delta\psi$ =0.06°, sd=0.97 m/s

SUMMARY OF RESULTS

To minimize wind variations in circles:

Left circles:

1. Offset in TAS: Add -1.0 m/s
2. Offset in sideslip: Add 0.07°.
3. Offset in heading: Add 0.45°

Right circles:

1. Offset in TAS: Add -0.6 m/s
2. Offset in sideslip: Add 0.07°.
3. Offset in heading: Add -0.33°.

Combined::

1. Offset in TAS: Add -0.8 m/s
2. Offset in sideslip: Add 0.07°.
3. Offset in heading: Add 0.06°.

WHY ARE LEFT AND RIGHT CIRCLES DIFFERENT?

Is the TAS correction reasonable?

1. Two left turns consistent, two right turns consistent
2. mean TASX 154.4 (left) vs 154.2 (right); corrected, 153.4 vs 153.6 – mean roll is about 0.45° larger in right turns, requiring a slightly higher airspeed for level flight.
3. Difference expected: lift * cos(roll) = g and lift $\sim V^2$ so for same vertical component $V^2 \cos\phi =$ constant.

$$\frac{2}{V}\delta V = -\frac{\sin\phi}{\cos\phi}\delta\phi$$

$$\delta V = \frac{V\tan\phi}{2}\delta\phi = 0.3$$

   consistent with the +0.2 m/s change in corrected wind.
4. Varying correction seems needed to get the right answer
5. Puzzle then is why the correction varies with turn direction.

HEADING CORRECTION IS MORE PROBLEMATIC

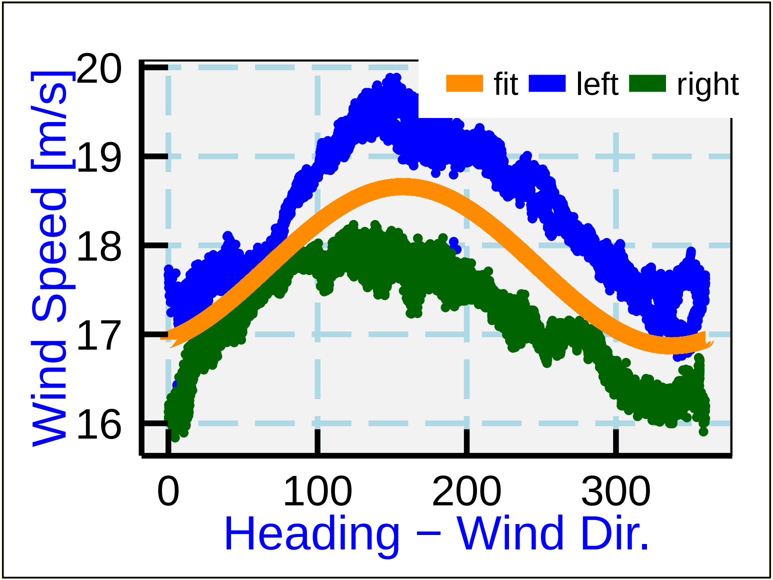
Effect is significant:

Change in correction is 0.8°, amounting to crosswind component change of $V \tan\delta\psi \simeq 2$ m/s.

Possible explanations?

1. Real heading error may accumulate as a result of prolonged acceleration in turns? (No evidence of this in plots)
2. Timing difference may cause reference groundspeed and relative-wind components to differ in phase, producing a different offset turning right vs left.
   (a) Explored shifting GGVEWB in time: best RMS for moving GPS speeds forward 6 25-Hz samples (240 ms)
   (b) RMS of shifted data: 0.6

PLOT OF SHIFTED DATA



Fit: $\delta V =$-0.8 m/s, $\delta\psi =$0.06°, sd=0.64 m/s

RESULTS – SUMMARY

Offsets:

Combined::

1. Offset in TAS: Add -0.8 m/s
2. Offset in sideslip: Add 0.07°.
3. Offset in heading: Add 0.06°
4. Delay in GGVSPB, etc: Move forward 6 25-Hz samples.

Remaining Problems:

- Why is there a difference in deduced wind speed in right vs left turns? (1.2 m/s)
- (related) Why is the best residual error still 0.6 m/s? (0.26 if WS offset removed)
- Plots of residuals show an apparent $\sin(2\psi)$ pattern; what can cause this?
- Estimate uncertainties in correction terms.

A NOTE RE SOURCES AND ARCHIVAL

This presentation was generated using RStudio via the program CirclePresentation140915.Rnw, available on tikal.eol.ucar.edu. Running this on tikal via the web interface to RStudio generates the pdf-format presentation file while running R to generate the fits and plots discussed in that presentation, so the program can be adapted to additional circle maneuvers by changing the data and time references. The data used are those from in-the-field processing and are also stored on EOL workspace in the file /h/eol/cooperw/RStudio/DEEPWAVE/CircleData.Rdata.gz.

The presentation is available at this link:
https://drive.google.com/file/d/0B1kIUH45ca5AM0JZUXFLcmRrVWs/edit?usp=sharing