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Reconstruction of cross- and tailwind components from flight data

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Context

Work performed as part of the EU Future Sky Safety program

P3 – Solutions for Runway Excursions

- Development of new methods to identify veer-off risk using operational flight data

Research questions

Crosswind is an important factor in veer-off occurrences:

- In 24% of veer-offs crosswind is a factor

Research questions:

? Can we use flight data to estimate surface wind components during the critical phase of the landing?

? What is the accuracy that can be achieved?

If satisfactory: *can we monitor cross wind exposure from flight operational data to monitor critical events and trends?*

Requirements

Determination of surface wind components (cross- and tail-wind components:

- Instantaneous wind, during the last 20 seconds before touchdown
- Corrected to a single height (10 m AGL)
- Accuracy: ~ 2 kts

Why not using existing parameters?

- FMS-wind: typically moving-averaged over 30 seconds and not-corrected for sideslip
- IRS-wind: typically 2 s LP filtered, not corrected for sideslip, minimum accuracy 12 kt, low sample rate (0.25 Hz)
- METAR-wind: 10 minutes averaged, recorded per half hour

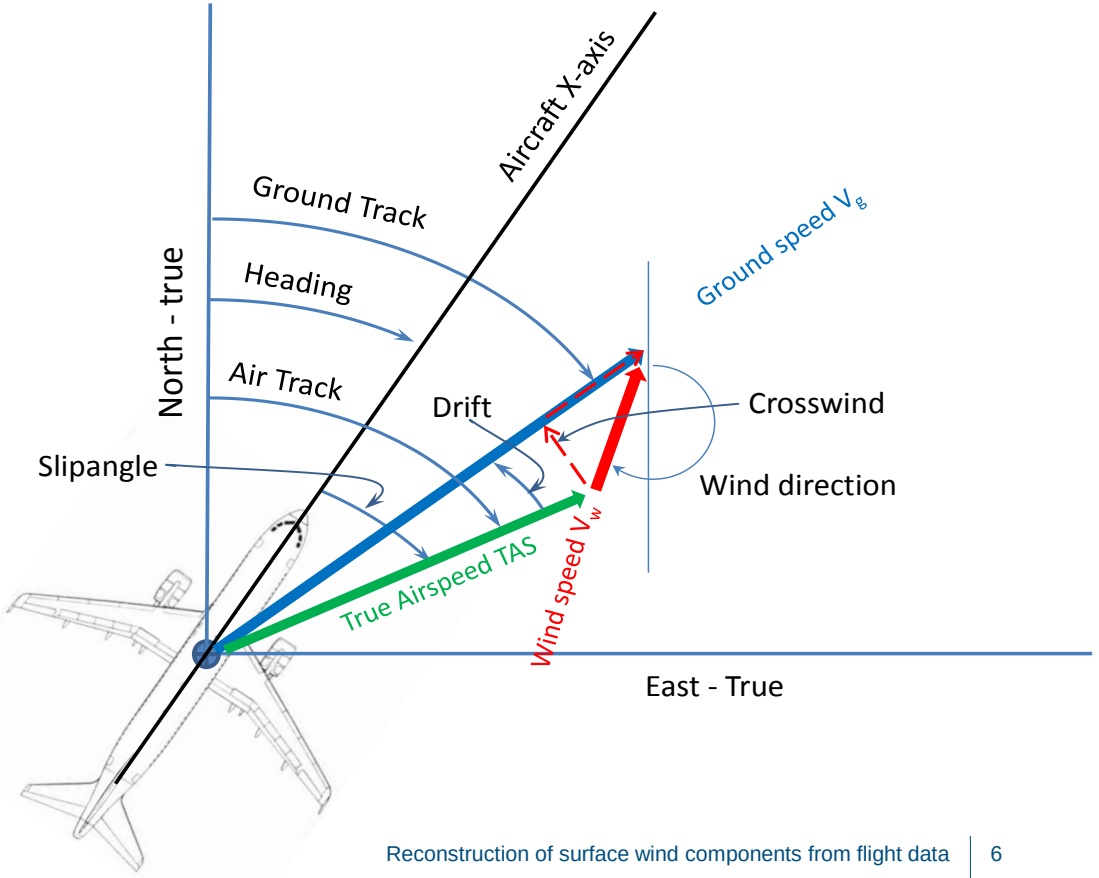
=> None is clearly suited as an accurate representation of the instantaneous wind during the landing phase.

Reconstruction from flight data

Basic parameters

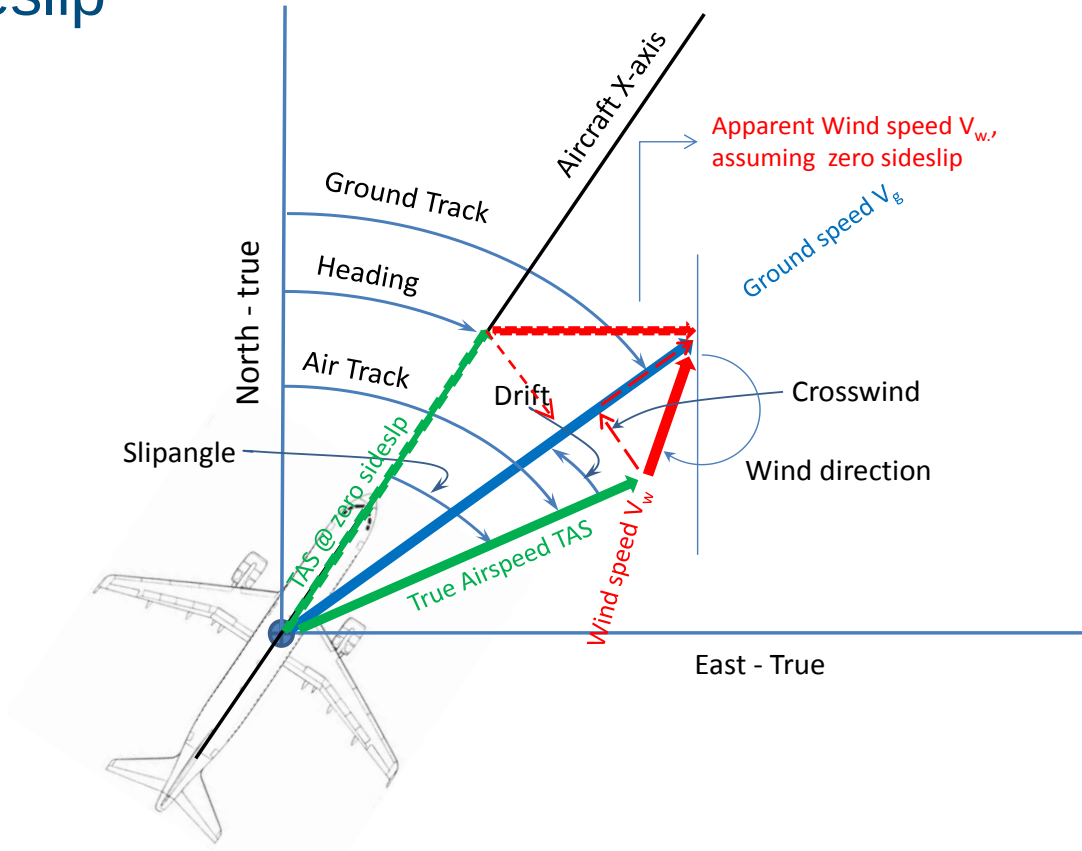
- Ground Track (χ)
- Heading (ψ)
- True Airspeed (V)
- Ground speed (V_g)
- Sideslip angle (β)

$$V_{Wcross} = V \sin(\chi - \psi - \beta)$$
$$V_{Wtail} = V_g - V \cos(\chi - \psi - \beta)$$



Impact of neglecting sideslip

- Significant effect on crosswind
- Limited effect on headwind



Min. Performance Requirements (ADIRU, Arinc738)

Parameter	Max Filter Bandwith (Hz)	Max Transport delay (Msec)	Resolution	Accuracy (95%)	Units
True Airspeed	2	110	.0625	±4	knot
Groundspeed	2	110	.125	±12	knot
True Heading	2	110	.0055	±4	deg
True Track	2	110	.0055	±5	deg
Flight Path Angle	2	110	.05	±4	deg
Wind speed	2	110	1	±12	knot
Wind Direction	2	110	.7	±10	deg

Accuracy of windcomponents based on minimum performance specification

Accuracy (2σ):

Wind speed: ~12 kt

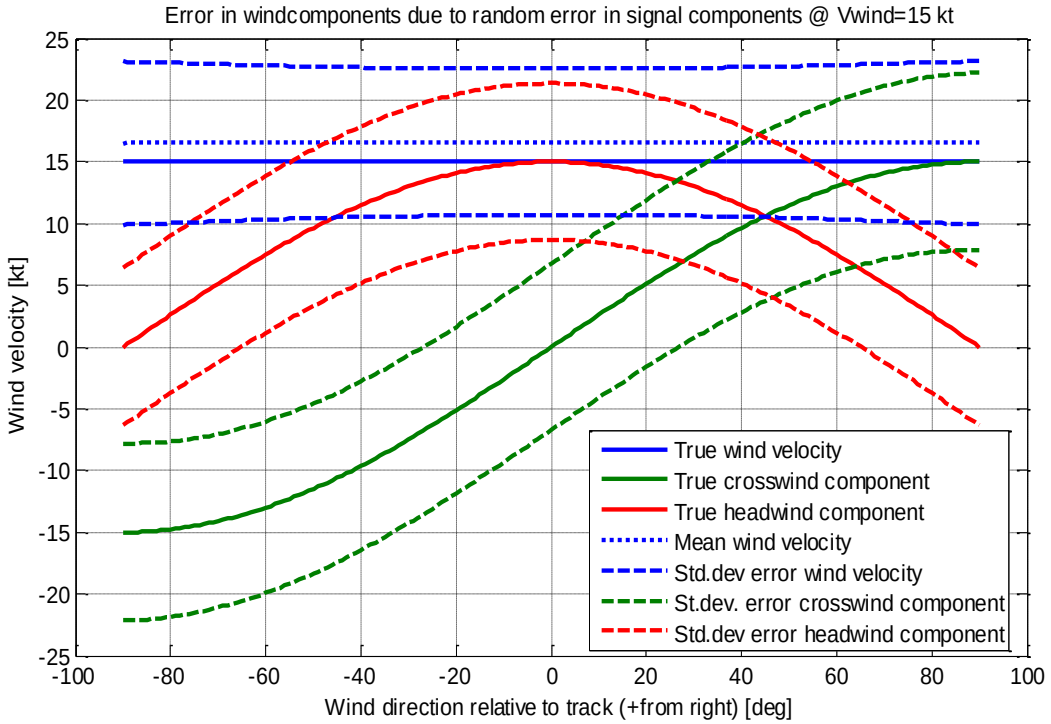
Crosswind: ~14 kt

Headwind: ~12 kt

Dominant error sources:

Crosswind: HDG and TRK

Headwind: Vg and TAS



Actual accuracy?

Accuracy spec is minimum requirement!

What can be expected in operational practice?

- Analysis based on available flight data:
  - Modern regional jet
  - Approaches to runway 27 at Schiphol
  - 396 cases (in 2009)
  - Quick Access Recorder Data (41 parameters)
  - Sample rate recorded ADIRS-wind .25 Hz, basic parameters 1 Hz

Flight data analysis

Objective: analyse flight data to estimate actual accuracy of the basic parameters (Heading, Track, True Airspeed & Ground speed)

How?

By comparison with independent other parameters.

True Airspeed (ADC)

True Airspeed is directly related to:

- Impact pressure (q_c), relates to CAS (from ADC)
- Static Pressure (P_s), relates to Pressure Altitude PA (from ADC)
- Static Air Temperature, SAT (from ADC)

TAS can be directly reconstructed from recorded CAS, PA and SAT.

Example TAS reconstruction

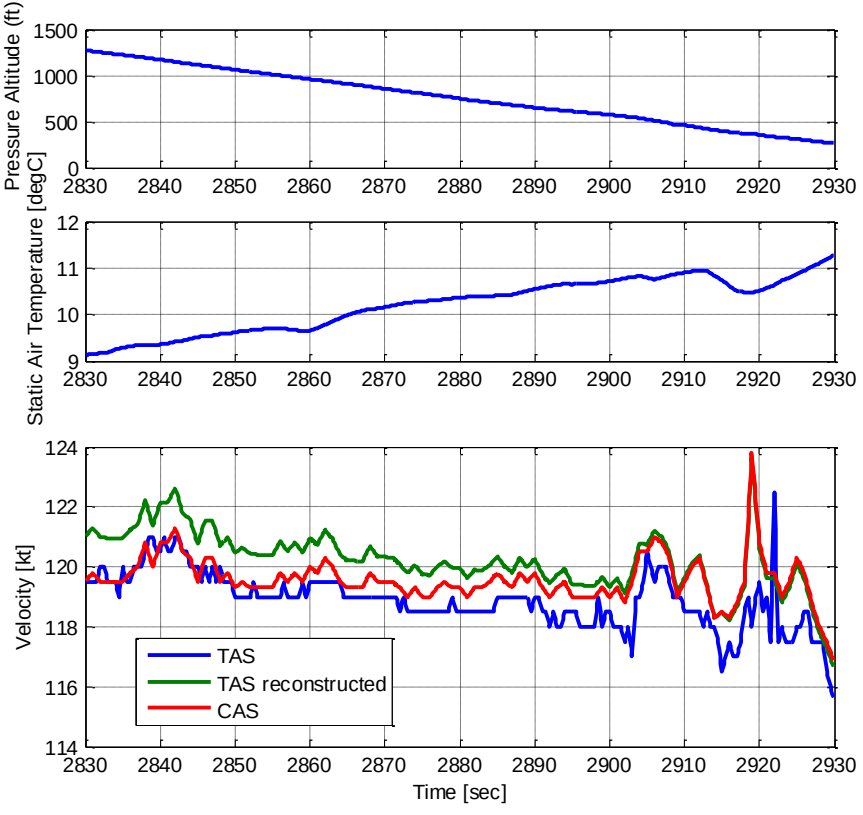
Error estimate (all runs)

Bias: μ=1.5 kt

Random Noise: σ=.6 kt

$\Rightarrow$ Accuracy (95% of observations)

2.7 kt (< 4kt)



Groundspeed (IRS)

Groundspeed can be derived as time derivative from GPS position, but..

- GPS position is recorded at .25 Hz
- Derived Groundspeed can become noisy due to differentiation
- Noise can be reduced by appropriate filtering method

Example Ground Speed reconstruction

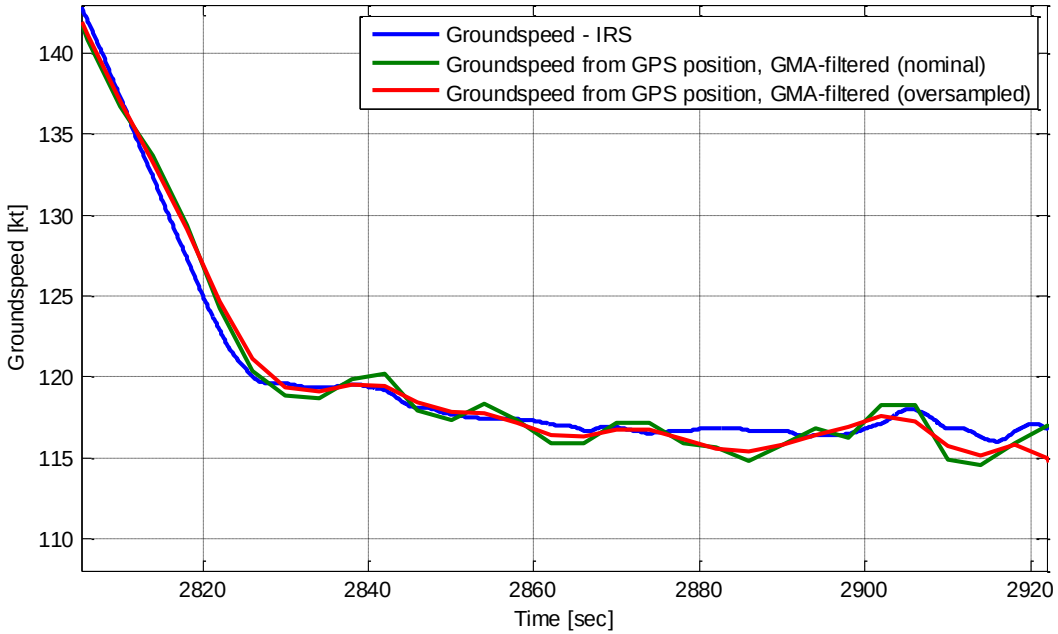
Error estimate (all runs)

Bias: μ=0 kt

Random Noise: σ=1 kt

$\Rightarrow$ Accuracy

~2 kt (<< 12 kt)



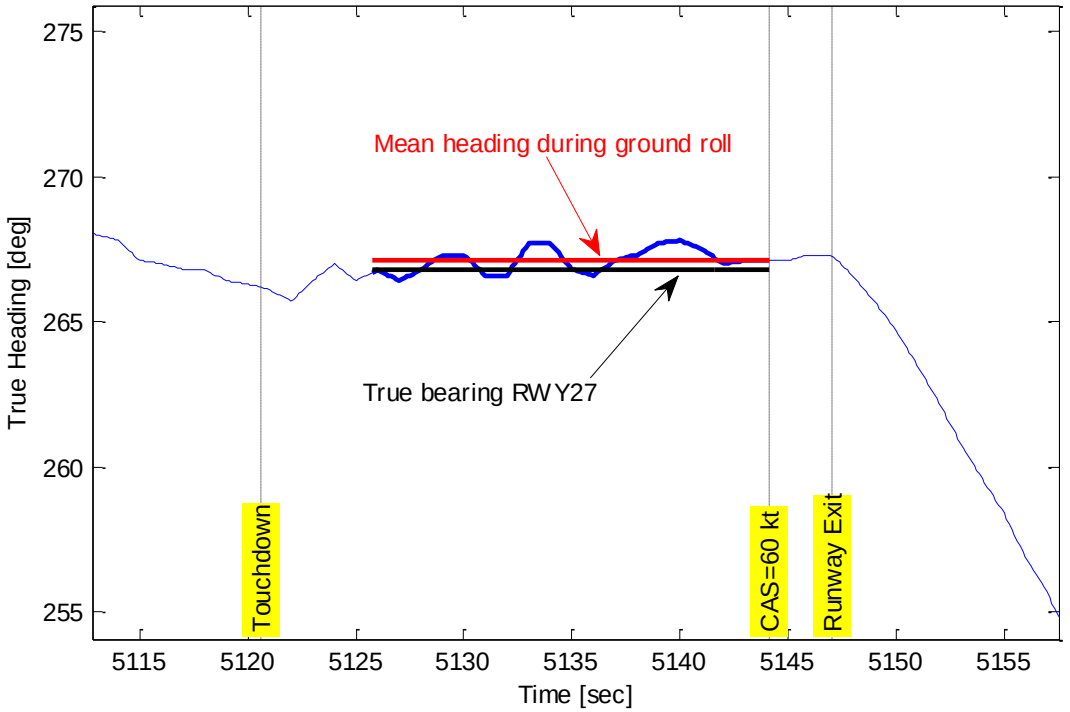
Heading (IRS)

No direct other reference for Heading is available.

Alternative method devised, based on knowledge of Landing runway heading.

Hypothesis:

Mean A/C heading = RWY heading During ground roll

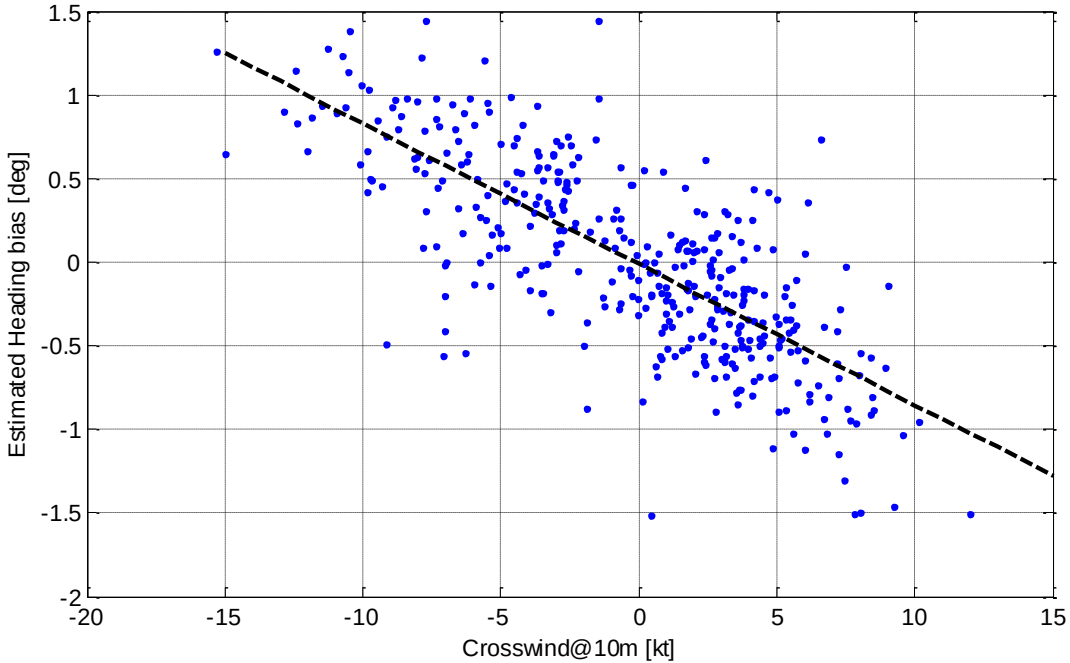


Impact of crosswind

Hypothesis incorrect!
Due to crosswind effect:

On average
0.8 degree tyre slip per
10 kt crosswind

Estimated heading
accuracy: ~1 deg (< 4 deg)



Track Angle (FMS)

Track Angle can be derived from:

1. Subsequent GPS coordinates
2. ILS Localizer deviation

Ad 1) Low sample rate (.25 Hz) and low resolution (~2 deg), noisy

Ad 2) Possibly affected by ILS characteristics (e.g. beam bends)

Example Track Angle reconstruction

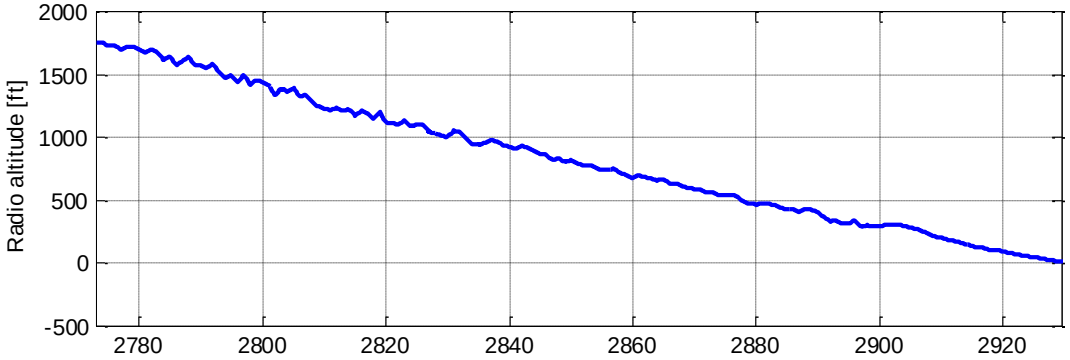
Error estimate (all runs)

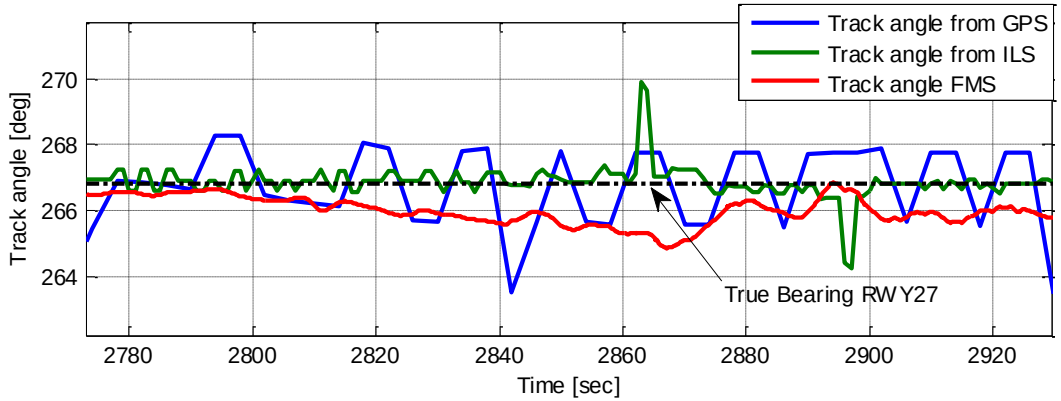
Bias: μ=0 deg

Random Noise: σ=0.55 deg

$\Rightarrow$ Accuracy

~1.1 deg (< 5 deg)





Reconstruction of Sideslip Angle

Sideslip Angle is not recorded, but can be reconstructed from measured signals:

$$\beta = \frac{C_y - (C_{y_{\delta r}}\delta_r + C_{y_p} p\frac{b}{2V} + + C_r r\frac{b}{2V})}{C_{y_\beta}}, \text{ where } C_y = \frac{W}{.5\rho V^2 S} n_y$$

Thus requires:

- Rudder deflection δ_r
- Yaw rate *r* and roll rate *p*
- Lateral load factor n_y

Plus corresponding stability derivatives

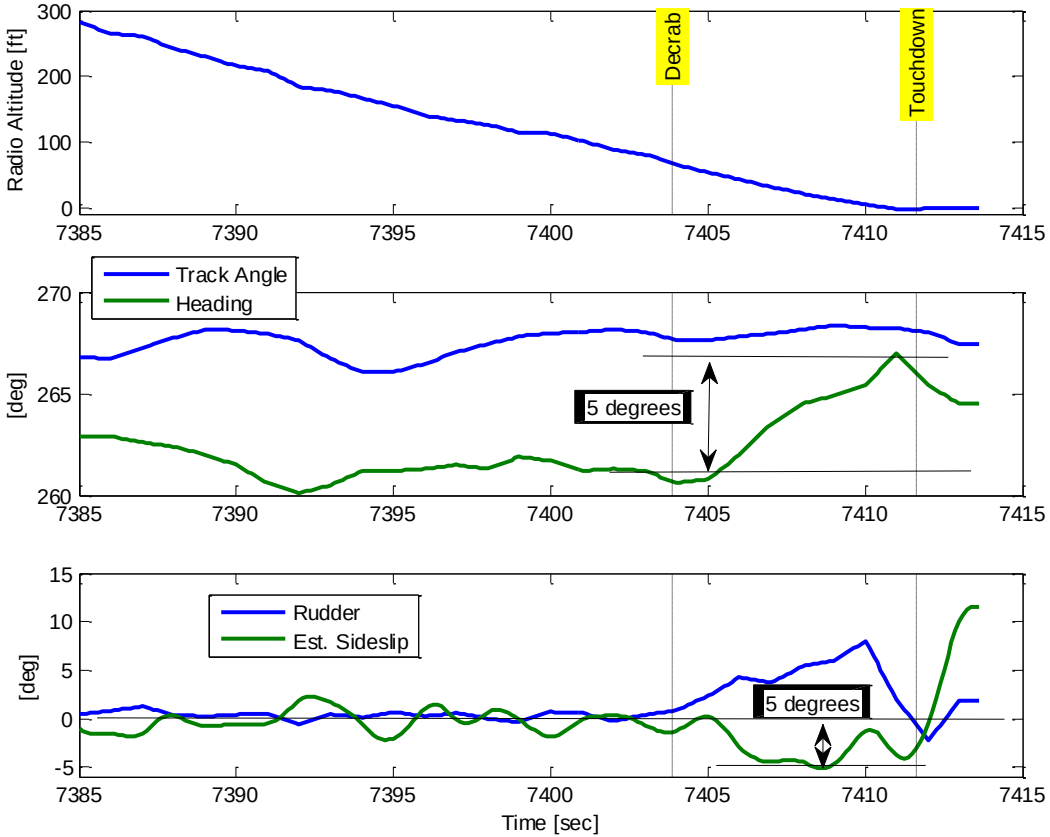
Example sideslip reconstruction

With fair estimate of

Stability derivatives

a good approximation of sideslip angle during decrab

can be made!!

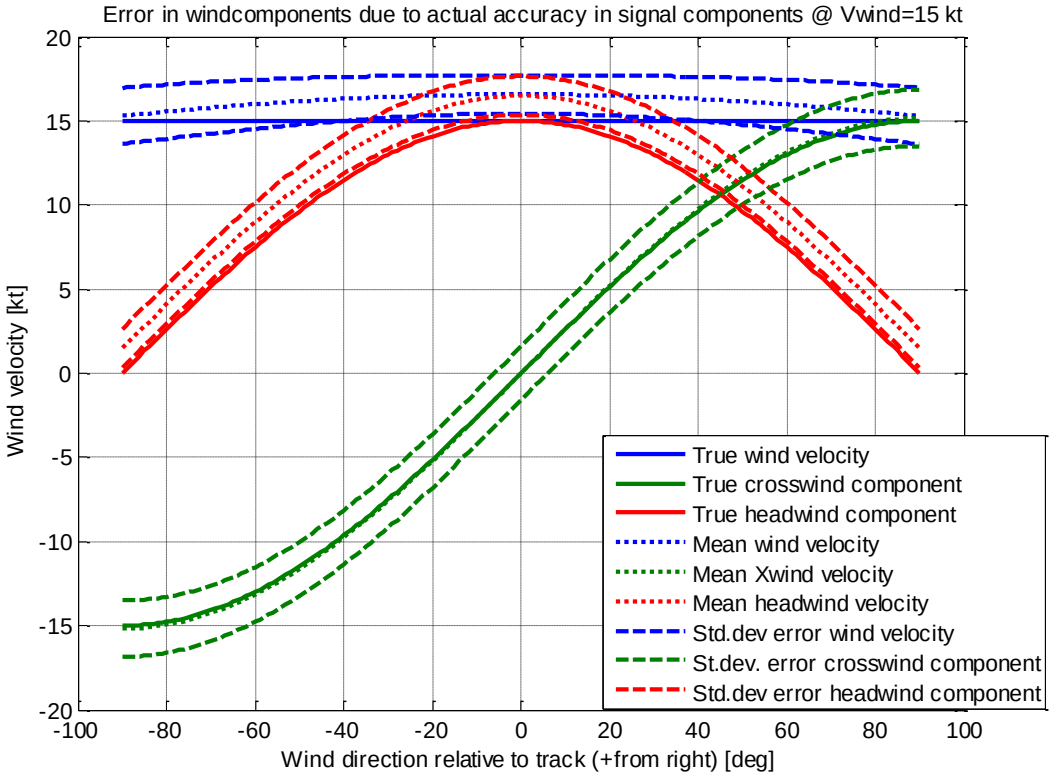


Estimated error due to actual signal inaccuracies

Bias μ
- Crosswind: ~0 kt
- Headwind: ~1.5 kt

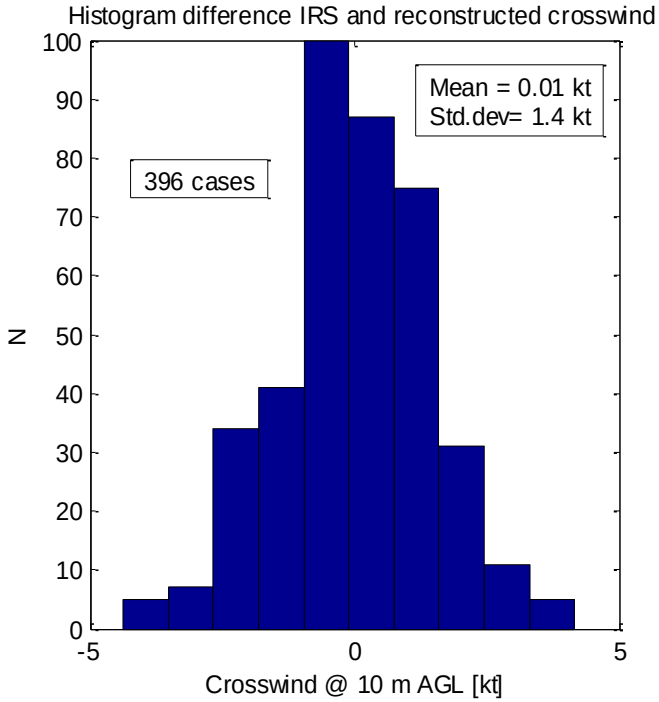
Std. Dev. σ
- Crosswind: ~1.5 kt
- Headwind: ~1.2 kt

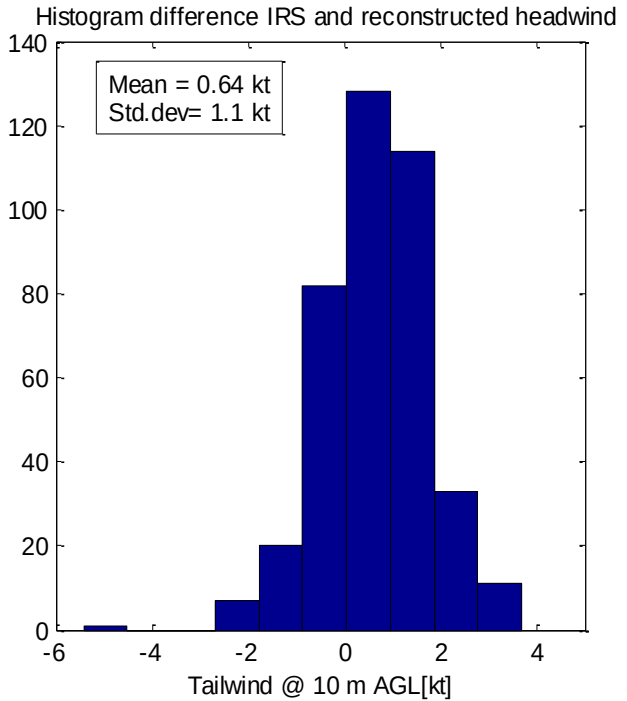
Accuracy (95%)
- Crosswind: ~3 kt
- Headwind: ~4 kt



Actual difference between ADIRS and reconstructed wind

Matches fairly well with theoretical results.

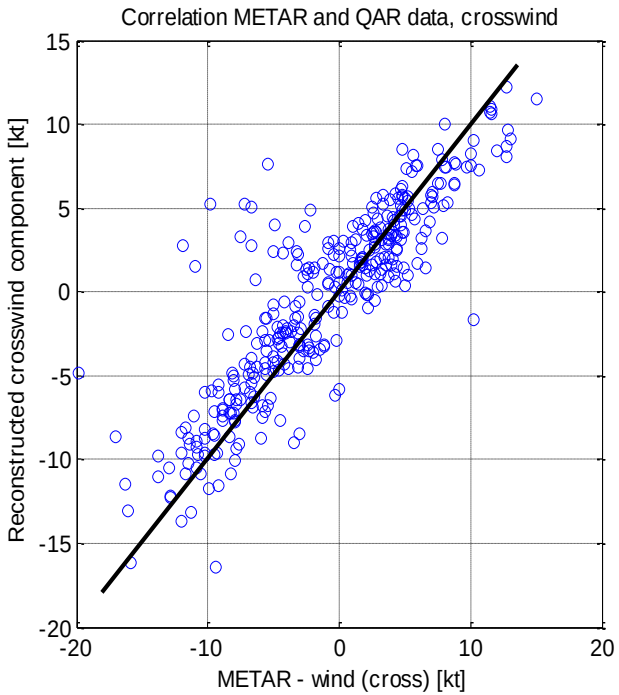




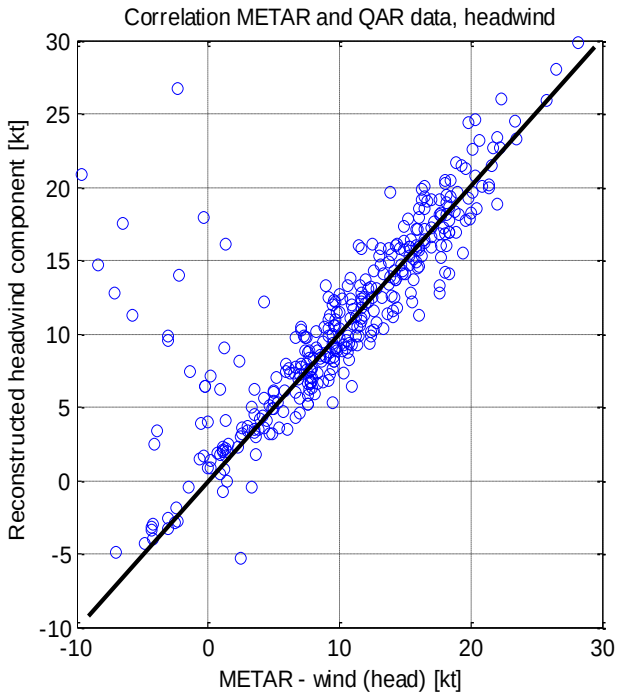
METAR data vs. reconstructed wind

METAR data matches well with flight data, but.... with significant outliers.

Crosswind



Headwind



Conclusions

- For determination of instantaneous cross- and tailwind during the landing phase, neither METAR-data, nor FMS-wind are well suited
- ADIRS-wind is near instantaneous, but without sideslip correction and low sample rate (cross/tailwind accuraccy = ~3 kt resp. 4 kt)
- Instantaneous wind can be reconstructed from flight data parameters, compensating for bias-errors and sideslip with fair accuracy (~2 kt)
- Reconstructed cross- and tail-wind can be used to monitor actual encountered wind conditions in relation to applicable limits or guidelines.

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Fully engaged

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