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Landing trajectory determination from FDM parameters

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Presentation overview

- Introduction
- Landing trajectory
- Air Distance
- New algorithm for estimating lateral deviation
- Applications and examples
- Conclusions

Introduction

- Study performed in the context of the EU Future Sky Safety program
- In cooperation mainly with Cranfield university and TU Berlin
- Main objective (P3) is to develop algorithms for the identification veer-off risk factors using flight data:
  - What are the risk factors?
  - How can they be measured using routine flight data?
  - How can they be used in FDM programs?

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Veer-off risk factors

Based on accident/incident analysis:

- Crew performance inaccurate (56% of cases), refers to improper crew handling and non-optimal response, leading to e.g. long/soft landings, lateral deviations.
- Wet/contaminated runway (25% of cases)
- Crosswind (24% of cases)
- Hard landing (7% cases)

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Landing trajectory

Landing trajectory is an important element in veer-off risk.

In particular,

- Lateral deviations at touchdown reducing the margin to the runway edge
- Lateral deviations during ground control
- Long landings, leading to significant braking and reduced lateral controllability
- Influencing factors, such as crosswind and runway friction

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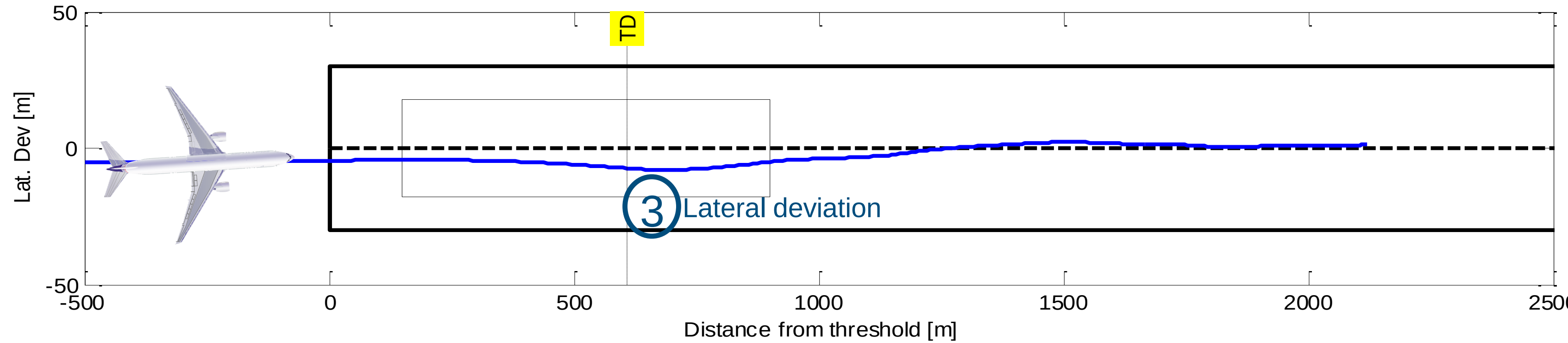
Landing trajectory, key elements

*see NLR Veer-off Workshop 2018



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Why not using GPS???

- Accuracy: In general 5-10m, but susceptible to several error sources (nr. of satellites, atmospheric effects, multipath, etc.)
- GPS Resolution
  (.000172 deg -> ~30 m)
- Update frequency: 1 Hz

=> GPS not usable

Alternative approach

- Assume use of the ILS for the final approach and landing
- Characteristics of the ILS are well known
  - ICAO Annex 10
  - ICAO Doc 9274, specifies error model

Receiver centering

Beam bends

Angular error equation: $$\phi = \frac{-I_0 + BB}{K_1 K_2} + \phi_0$$

Beam centering

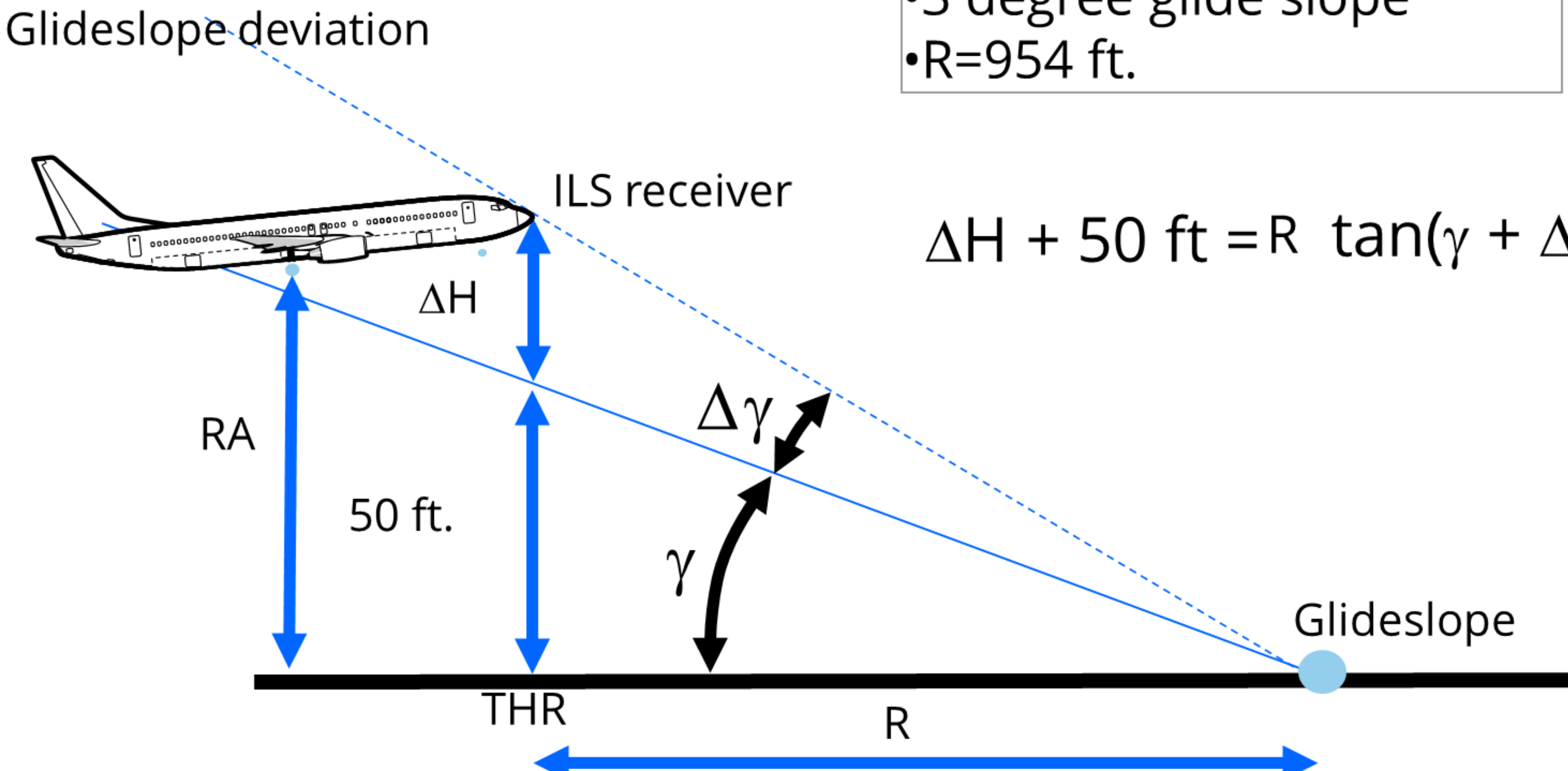
Beam sensitivity

Receiver sensitivity

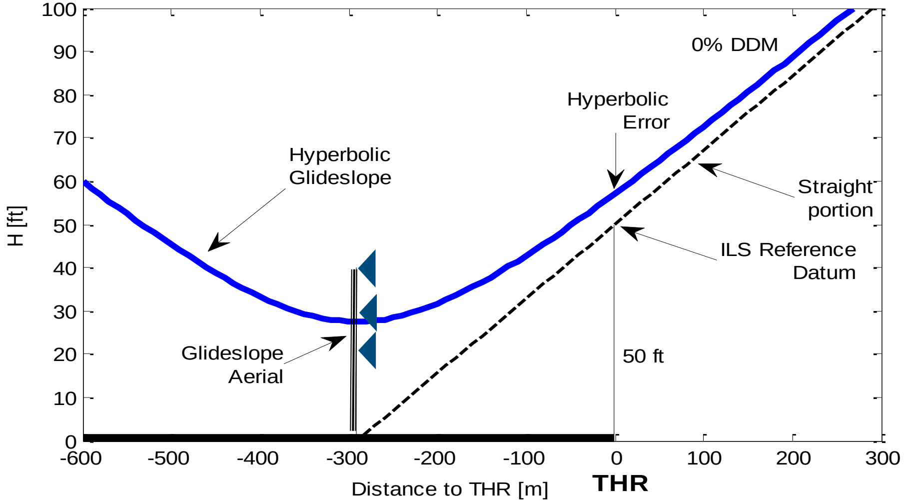
Threshold crossing

- 3 degree glide slope
- R=954 ft.

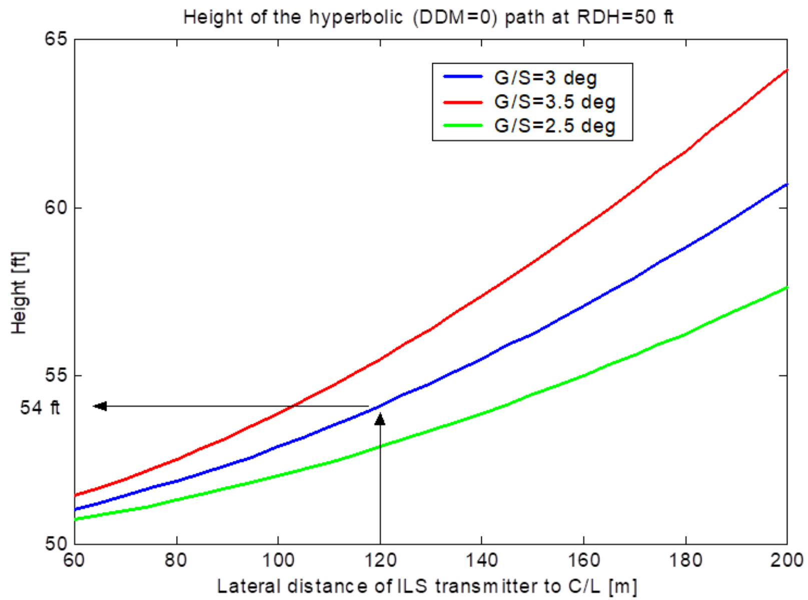
$$\Delta H + 50\ \text{ft} = R\ \tan(\gamma + \Delta\gamma)$$



Hyperbolic error



$$H_{Hyperbole} = z_{gp} + \tan(\gamma_{gs}) \cdot \sqrt{(x - x_{gp})^2 + (y - y_{gp})^2}$$



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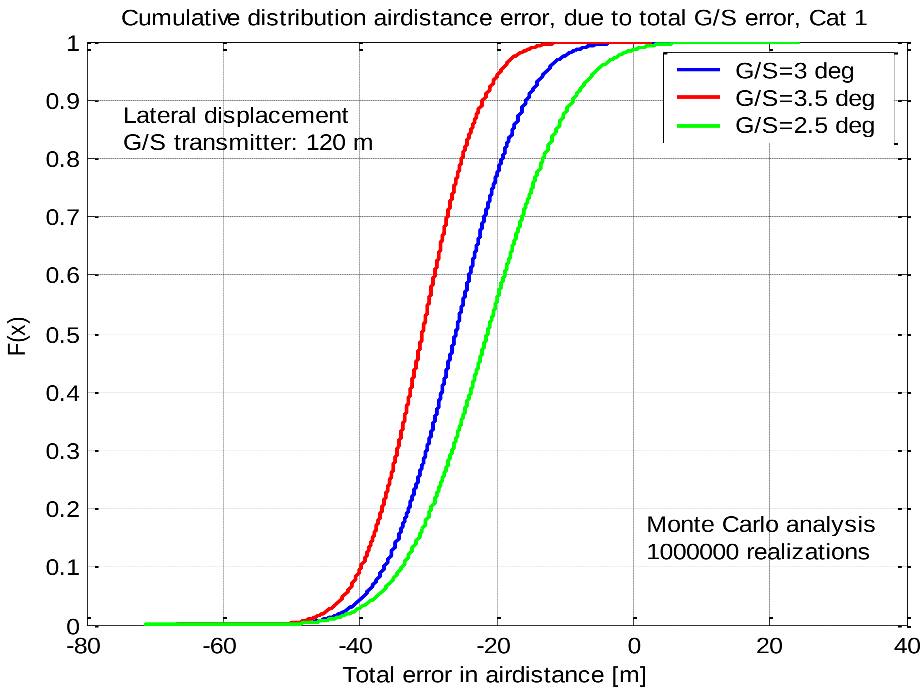
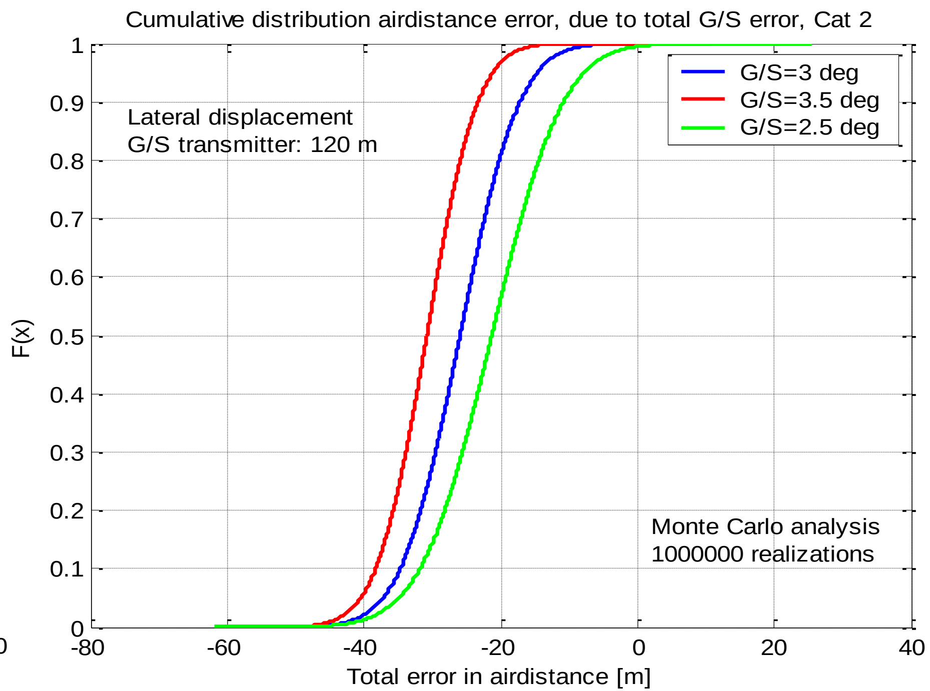
Airdistance accuracy due to total system error





For G/S=3 deg: mean=-26m (due to hyperbolic error)

Cat 1: std.dev.=8.1m, Cat 2: std.dev.=6.9 m

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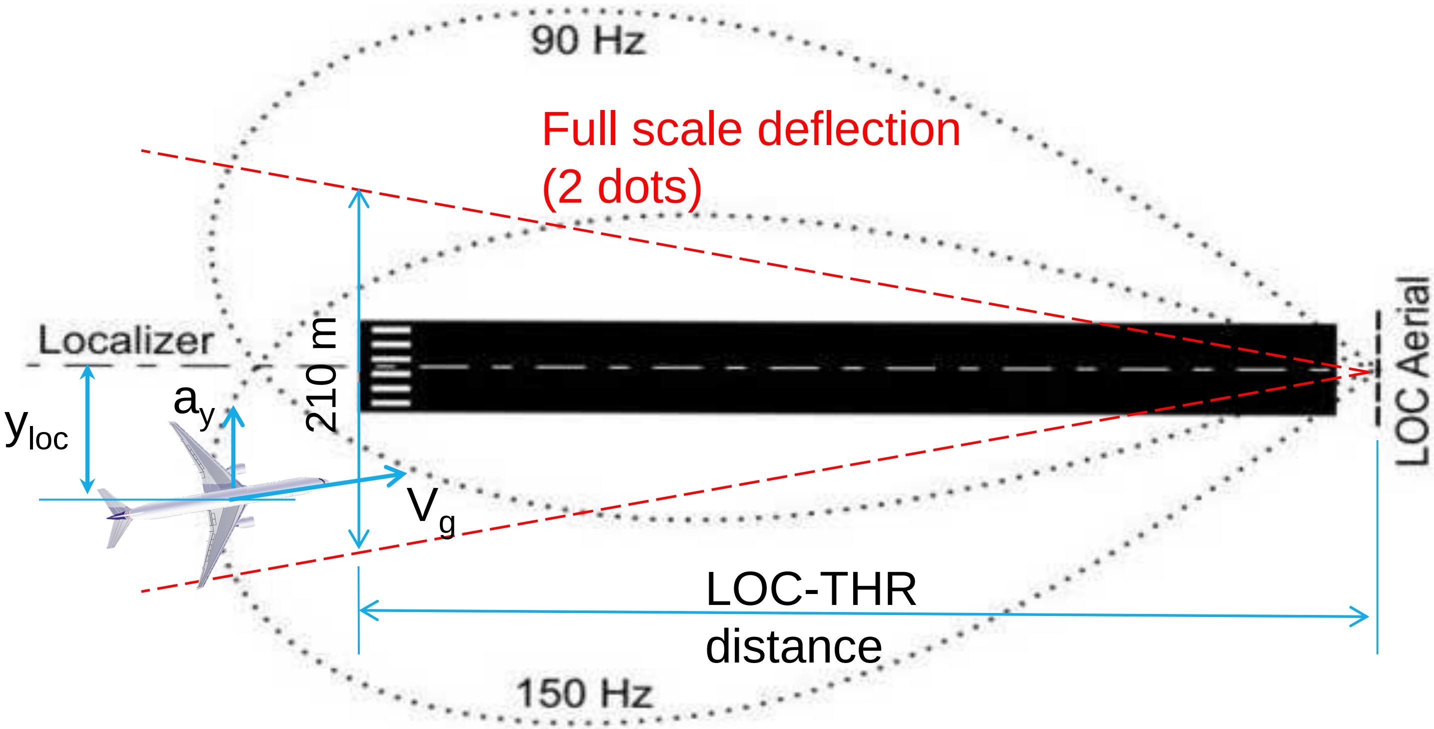
Lateral deviation



Three complementary methods

1. Double integration of lateral acceleration
   - High sample rate (4-8Hz)
   - Noisy signal
   - Very sensitive to bias
2. Single integration of lateral velocity
   - Moderate sample rate (1Hz)
   - Sensitive to bias
3. Derived from localizer deviation
   - Dependent on geometry and sensor accuracy

$$\iint A_y \, dt^2$$

$$\int V_g \sin \Delta\chi \, dt$$

Localizer accuracy

Basic lateral accuracy (ICAO Annex 10/Doc 9274):

- 1-2 meter in touchdown zone

Localizer – THR distance

- Information not generally available to FDM programs
- Reasonable estimate: 300m beyond DER (just outside recommended RESA)

THR aperture width is defined in ICAO Annex 10, depending on $D_{thr\text{-}llz}$, usually 210 meter

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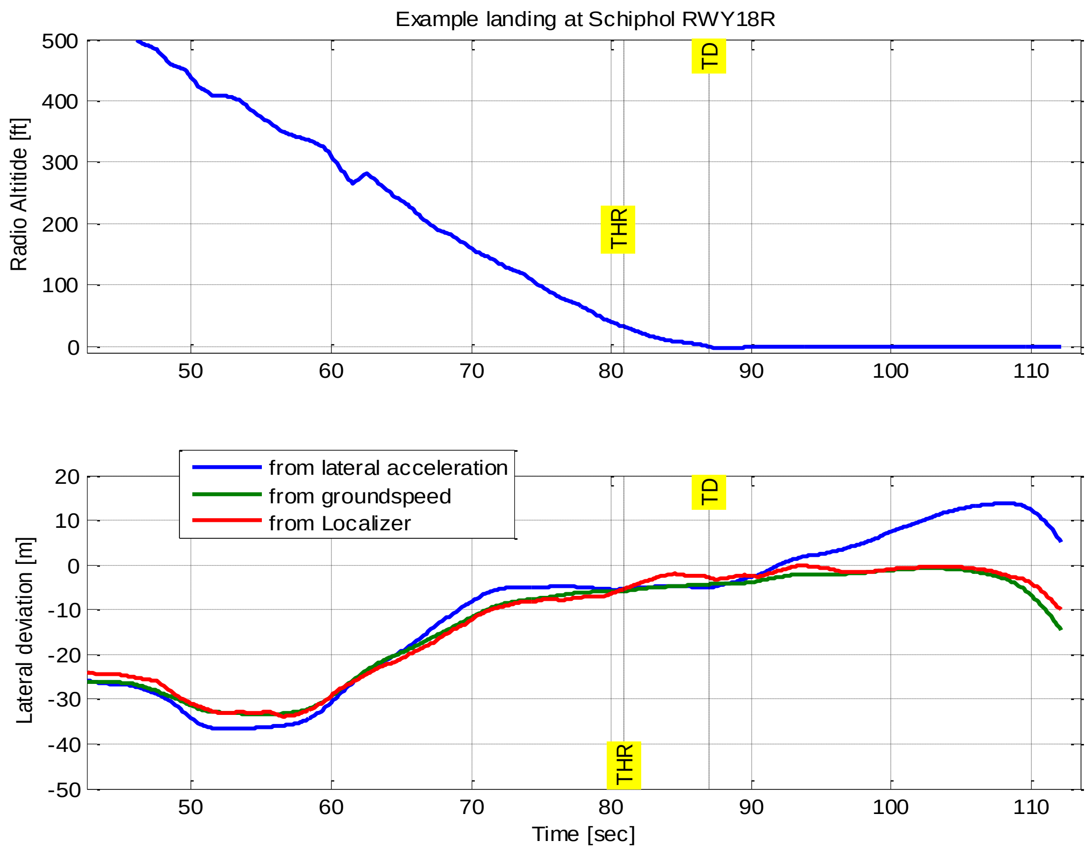
Example 1: landing at SPL RWY18R



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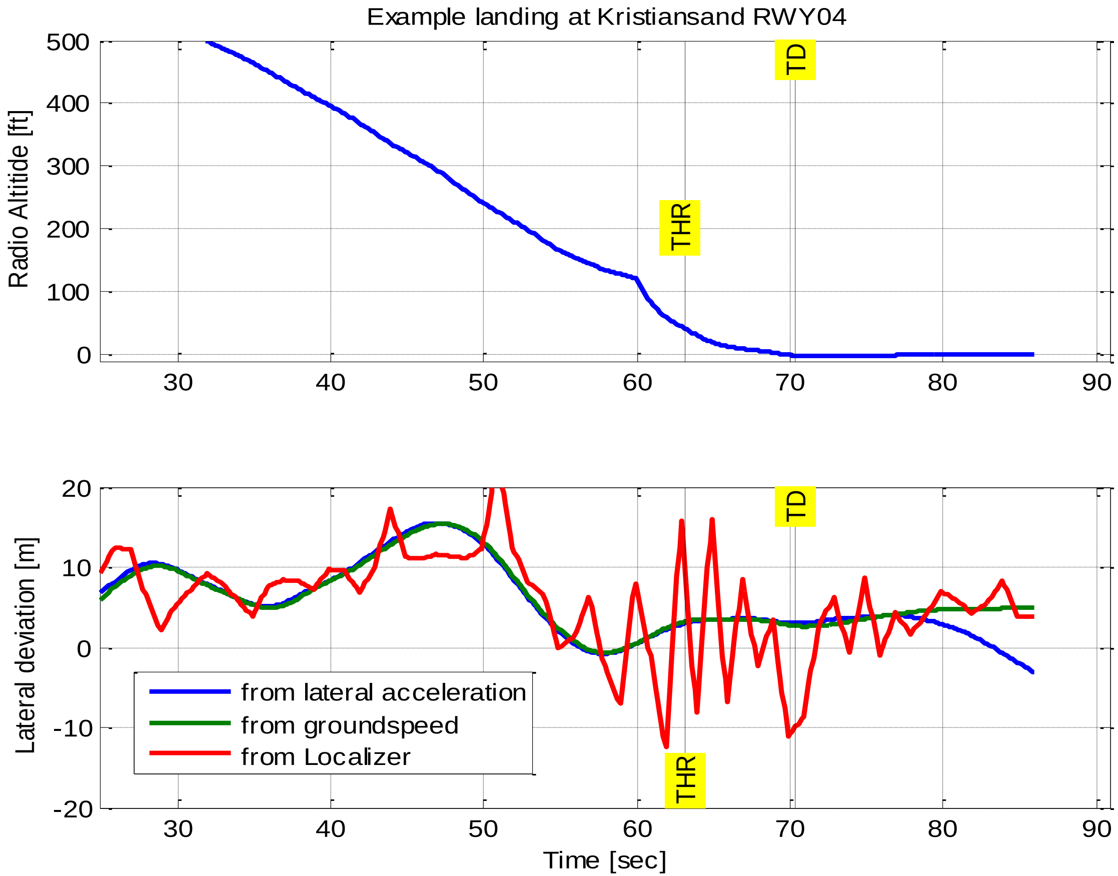
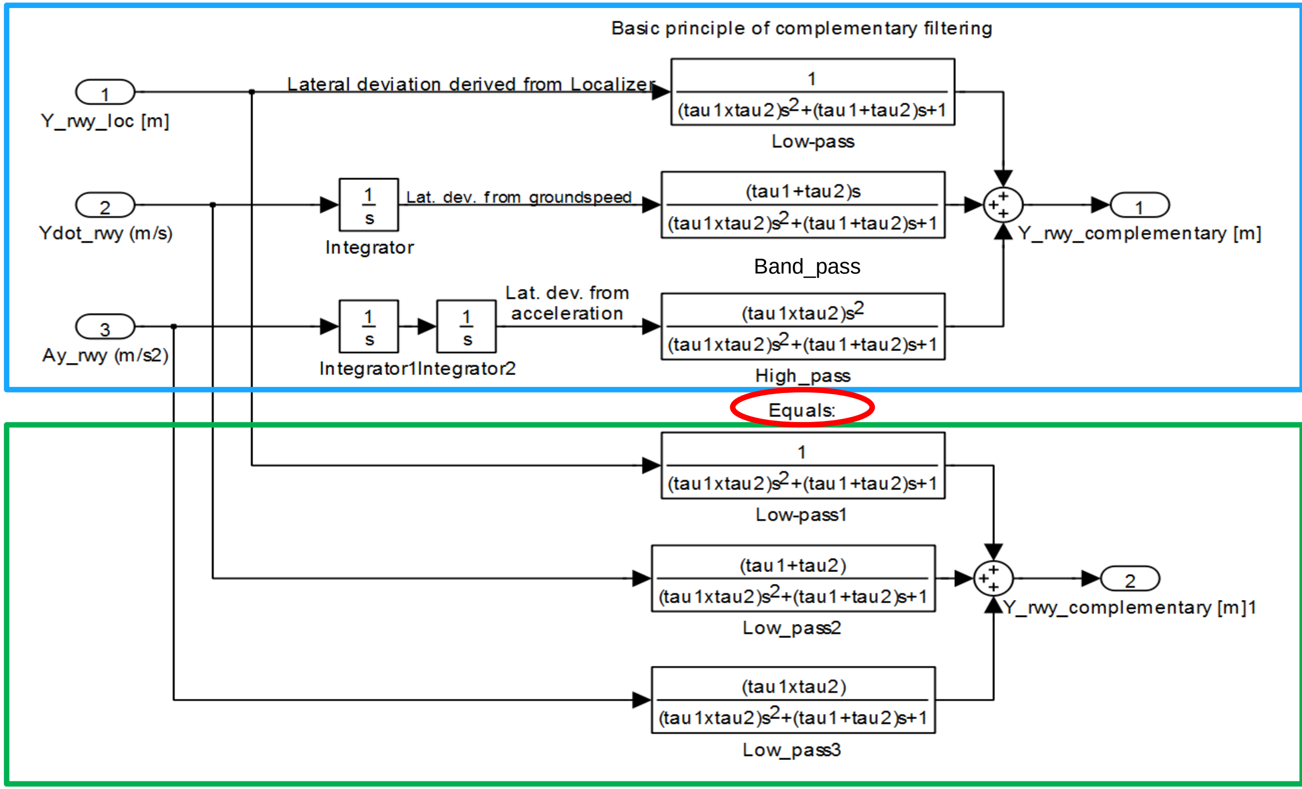
Example 2: Landing at Kristiansand RWY04



The solution: complementary filtering

- Uses each of the composing signals in the appropriate frequency range.

- Integration of bias is avoided



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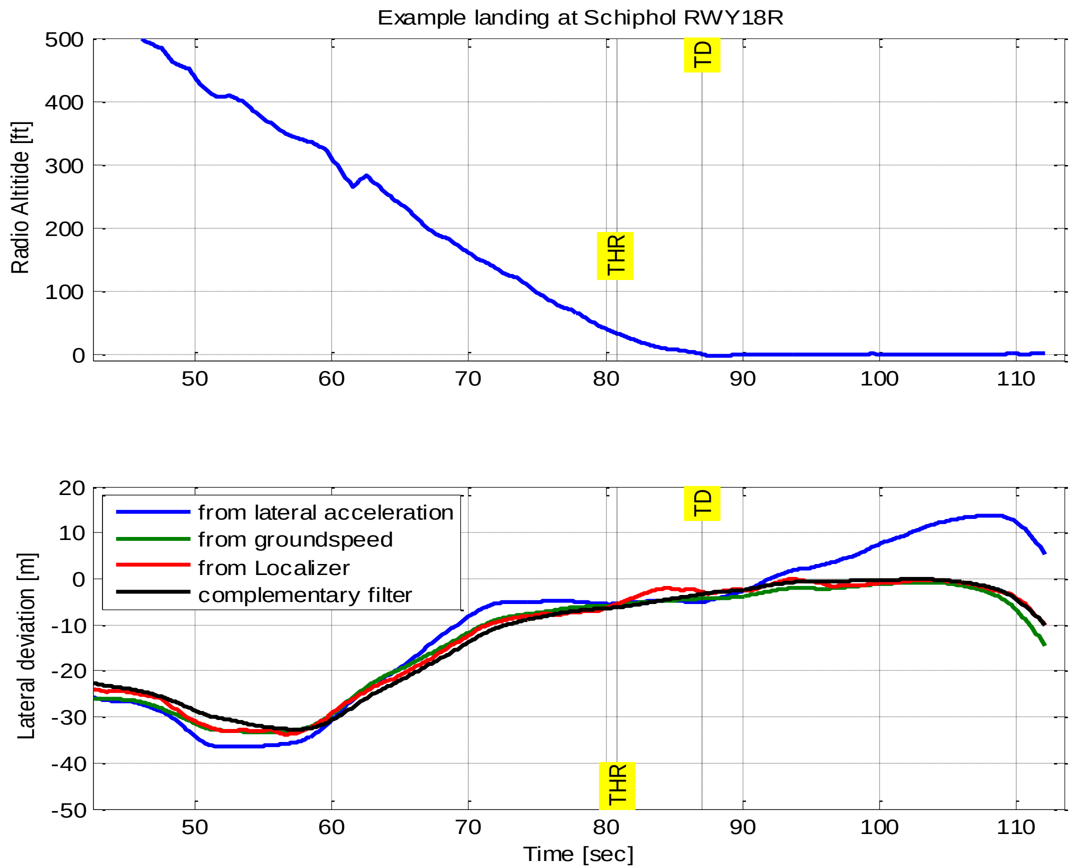
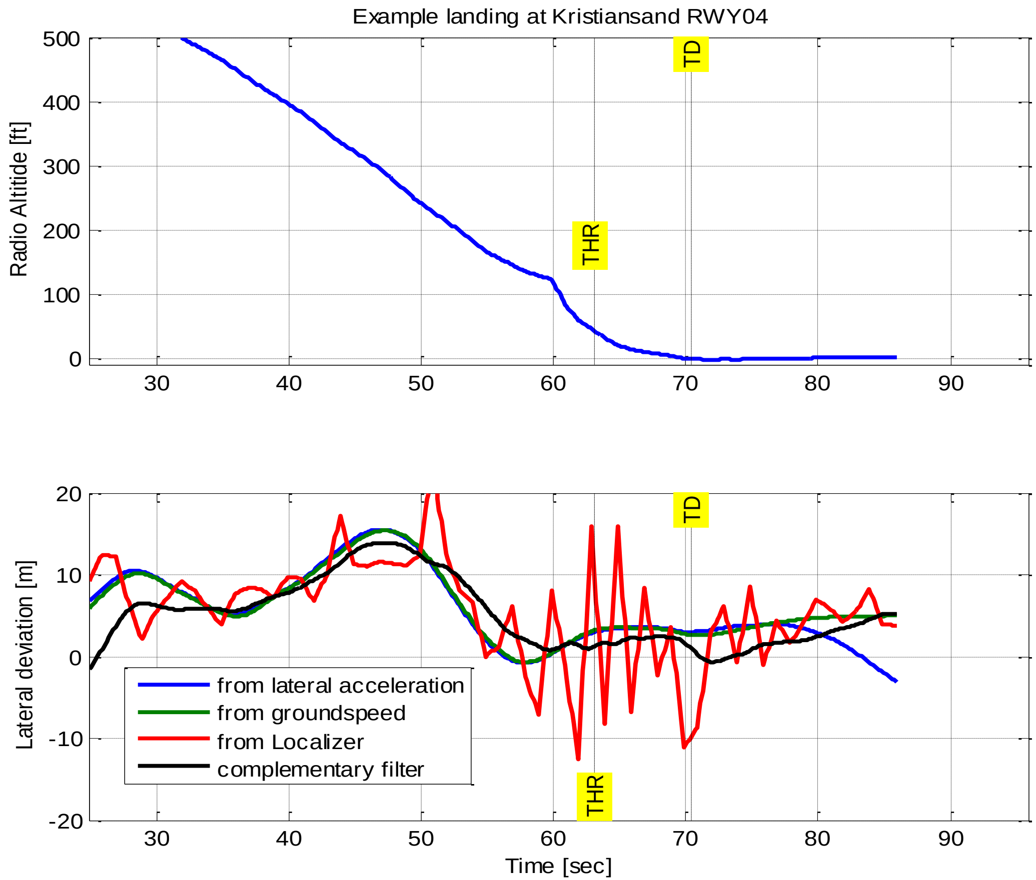
Example 1



Example 2

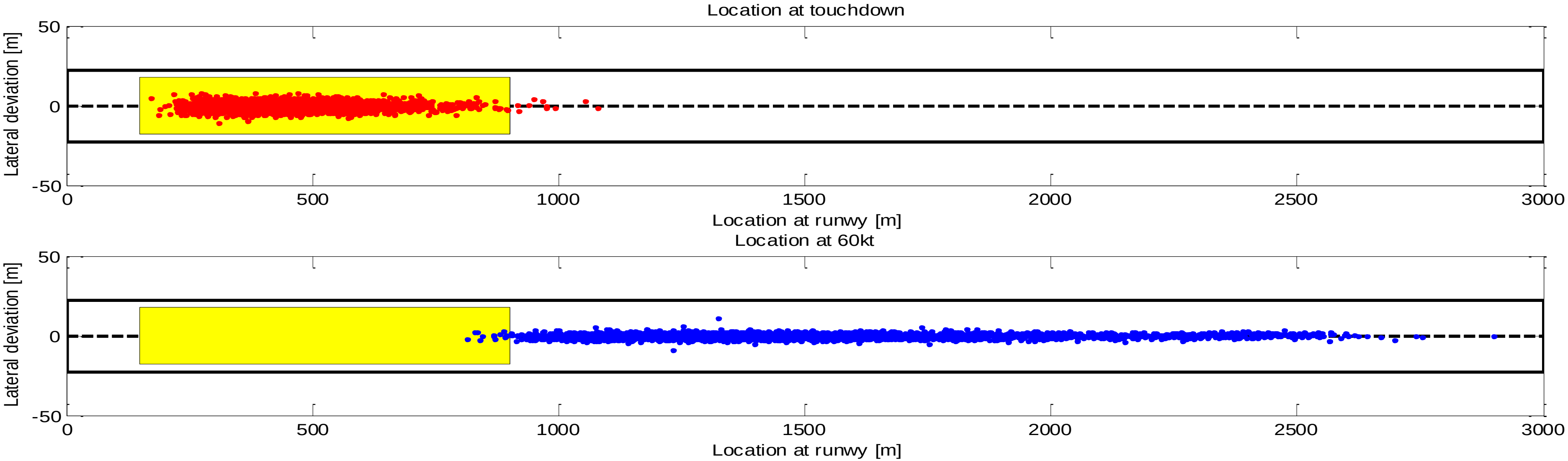


Example landing at Kristiansand RWY04
Radio Altitide [ft]
Lateral deviation [m]
Time [sec]
THR
TD
from lateral acceleration
from groundspeed
from Localizer
complementary filter

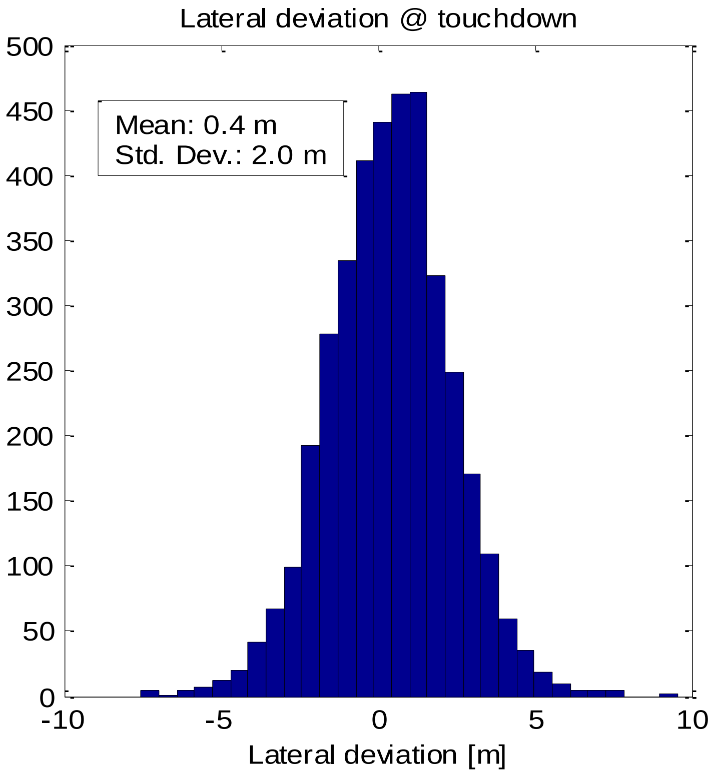
Filter Integrity

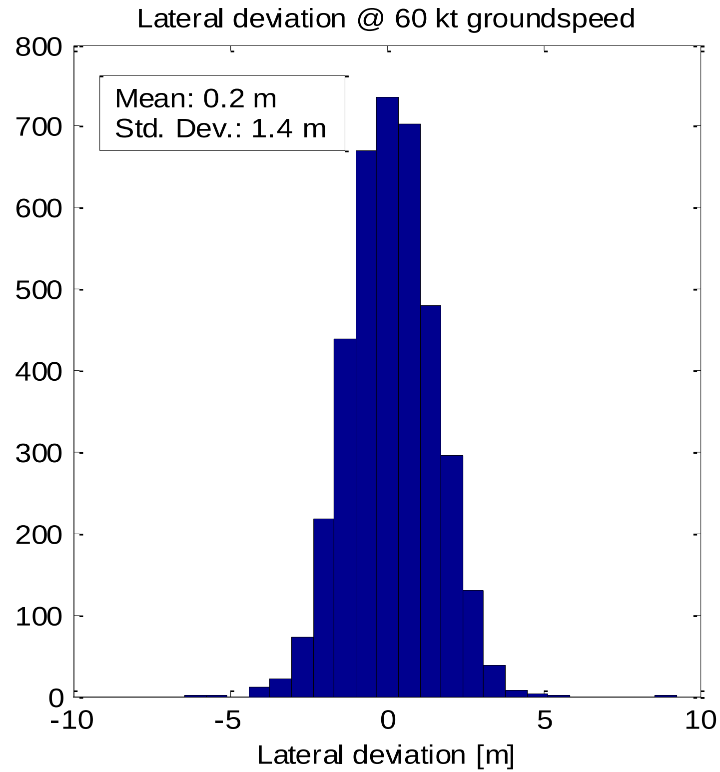
- Consistency of composing signals is internally computed
- Consistency is expressed in a Figure of Merit (FOM)
- FOM > 1 indicates significant discrepancies among the composing signals
- FOM > 1 may be caused by LOC signal anomalies
- FOM > 1 is a warning to FDM specialists to be reluctant to use results of the filter.
- Current experience shows 10-20% cases with FOM>1

Example: Touchdown and roll-out dispersion

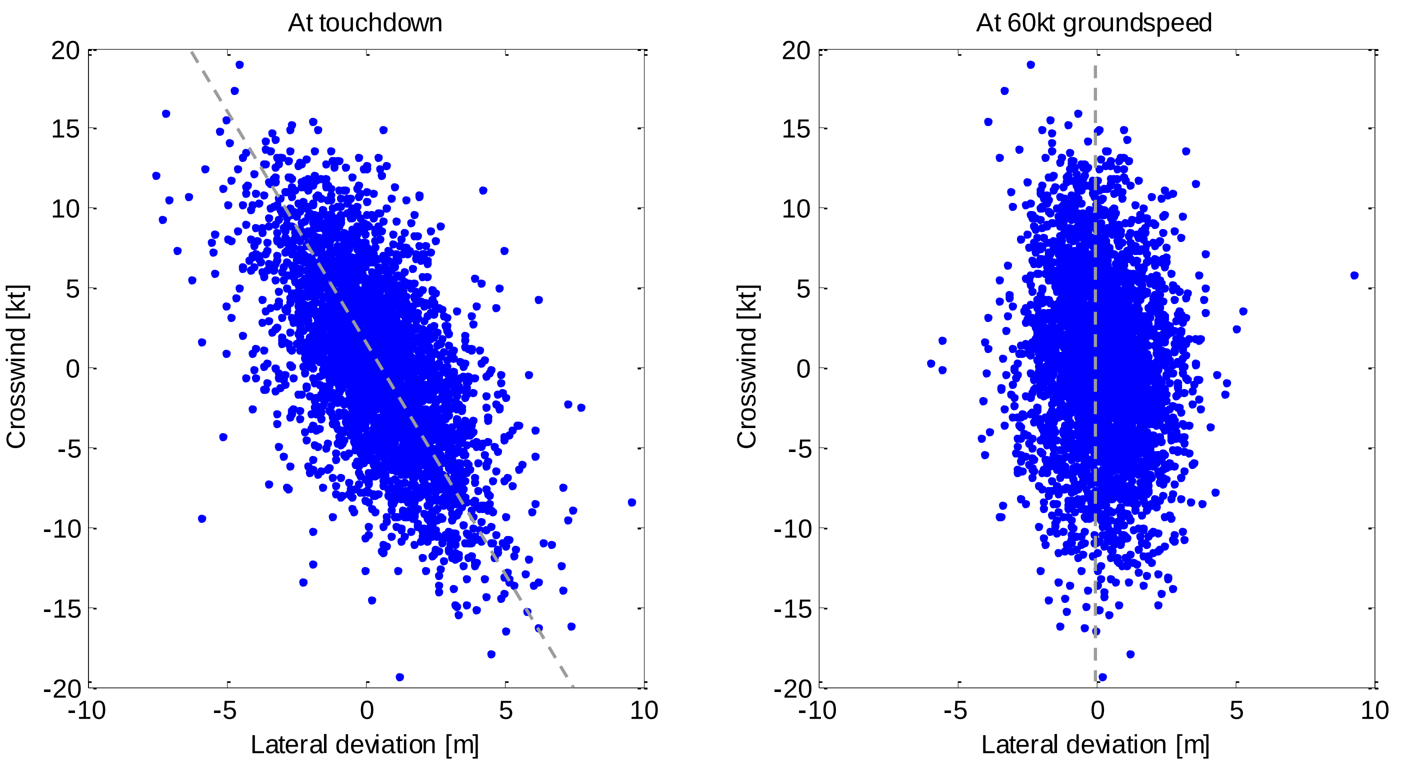


Lateral dispersion

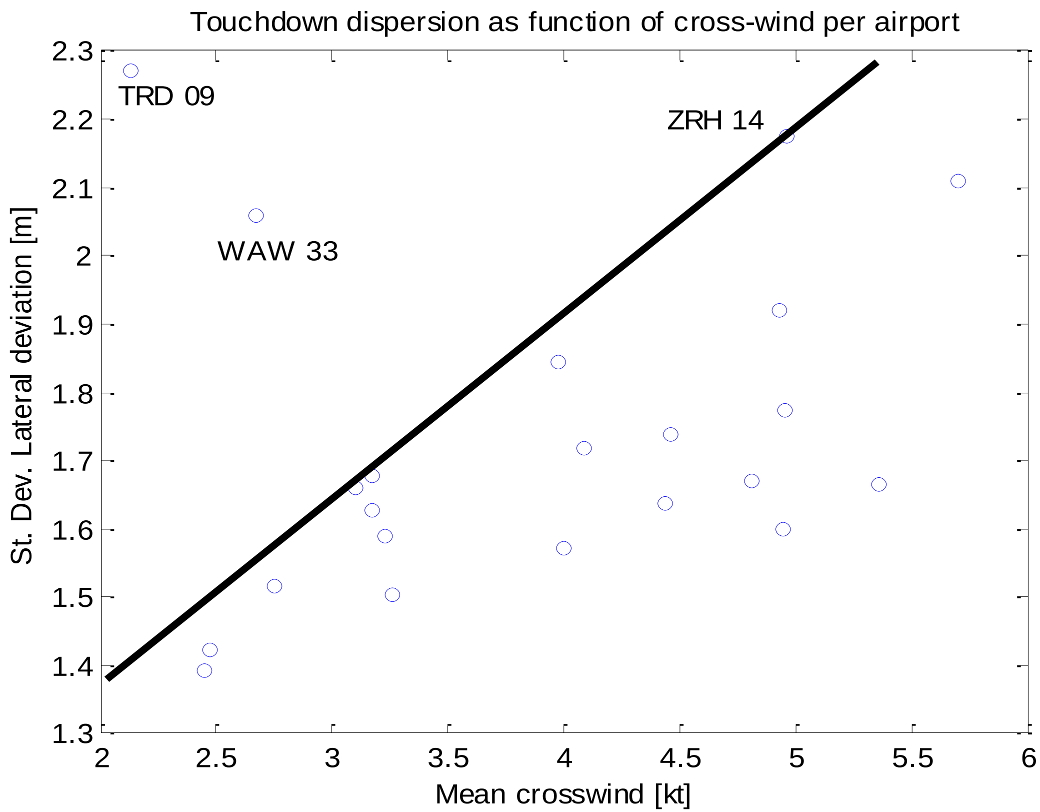




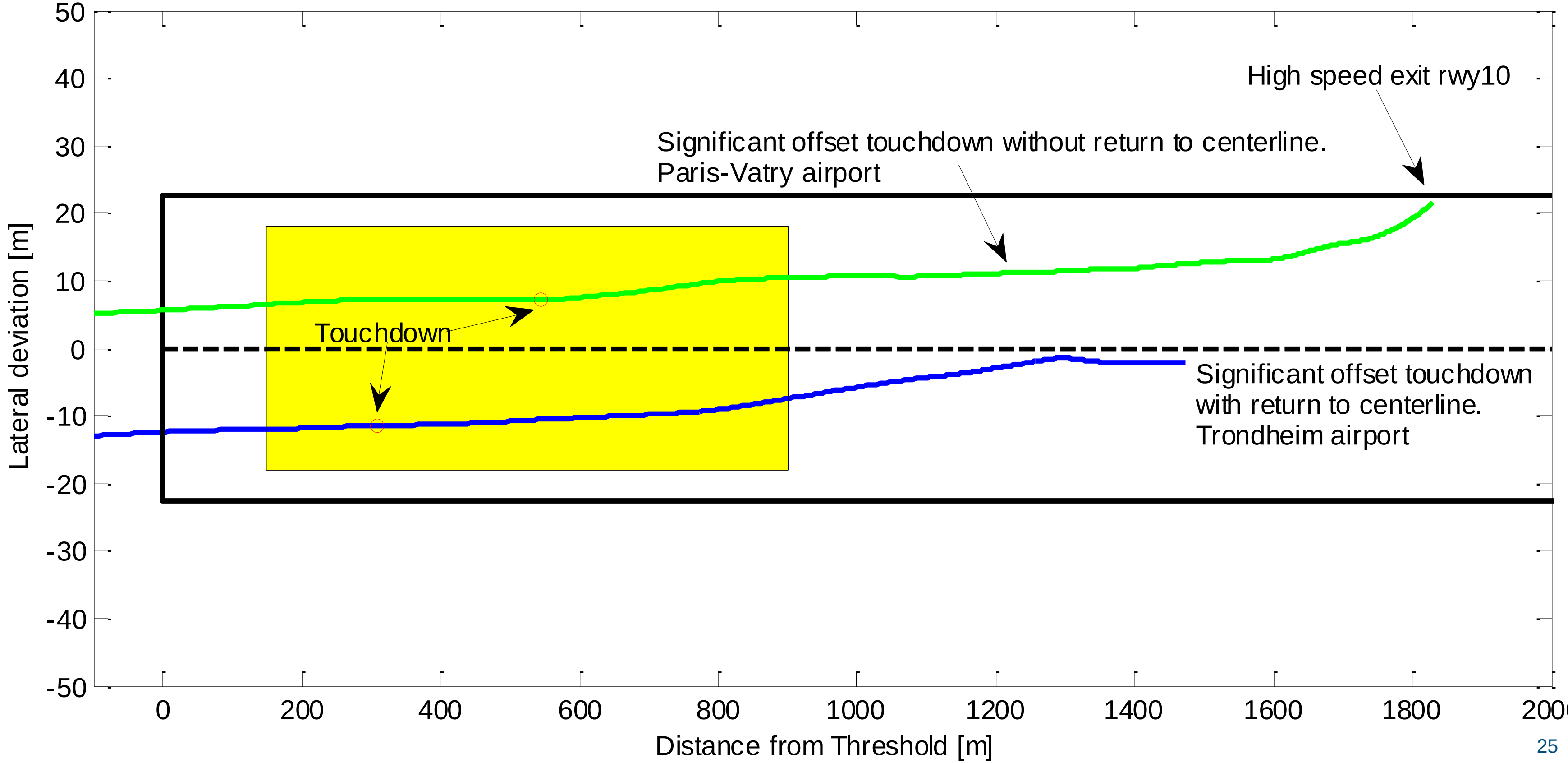
Effect of crosswind



Airport comparison

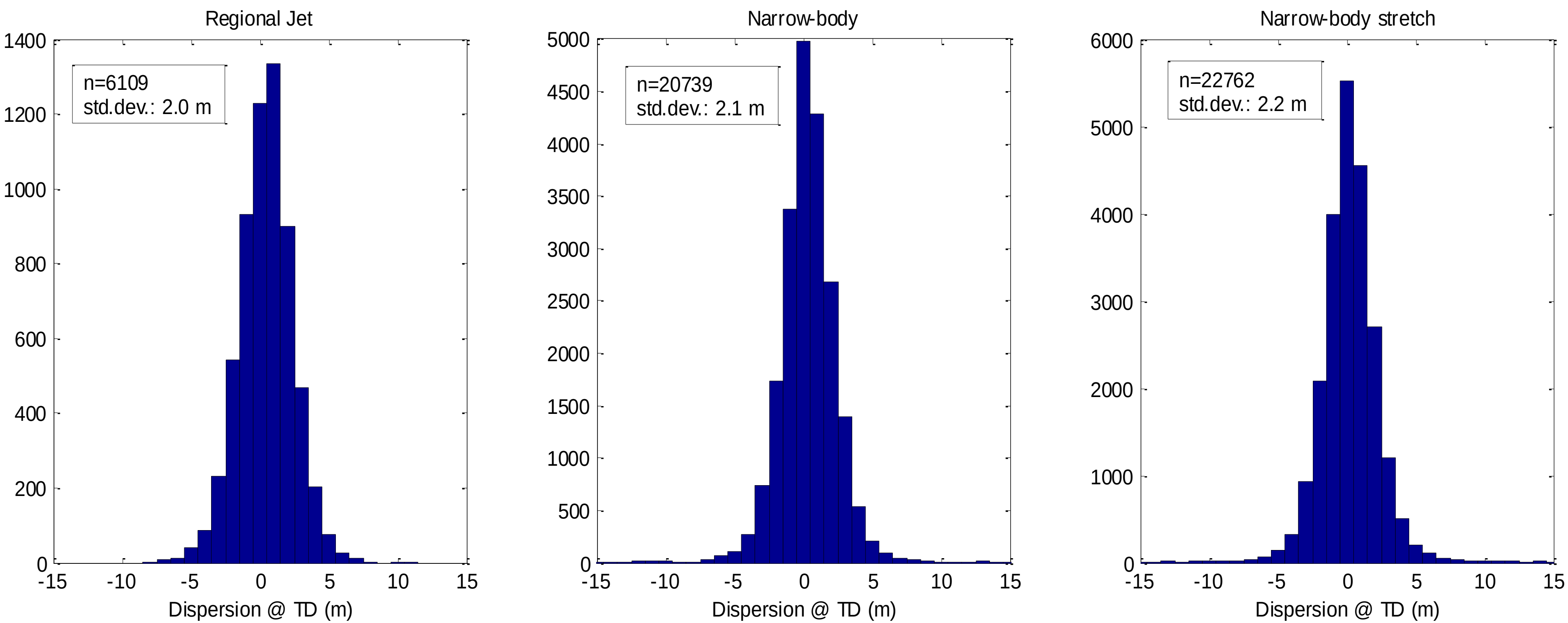


Individual cases

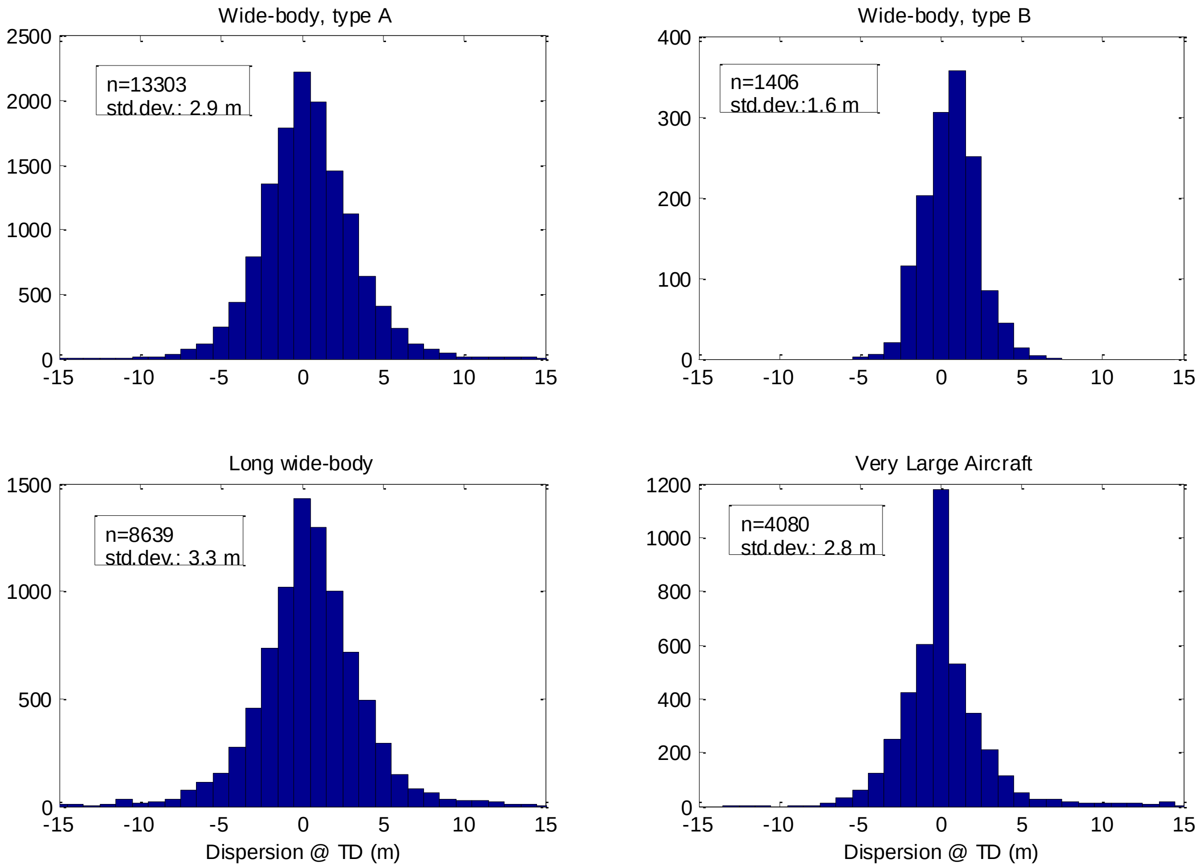


Inter-type comparison

Regional Jet, Medium & Large Narrow -body



Inter-type comparison, wide-body



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Conclusions

- Use of complementary filter to accurately estimate landing trajectory seems feasible
- Expected accuracy in the order of a few meters, but may depend on the facility (Cat I/II, location of the LOC, etc.)
- Figure of merit provides an indication of the integrity of the results
- Results may be used in assessing runway veer-off risk
  - By determining normal performance and significant deviations
  - Identifying airports with potentially higher risk
  - Scrutinizing individual cases
  - ???

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Fully engaged

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