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Investigation of the effect of wind uncertainty/fluctuation on wake vortex transport NGE/IGE

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WakeNet3-Europe Workshop

Short-Term Weather Forecasting for Probabilistic Wake-Vortex Prediction

Institut für Physik der Atmosphäre, DLR Oberpfaffenhofen

10/11 May 2010

WakeNet3-Europe
A network on Aircraft Wake Turbulence

Overview of the presentation

Introduction

1. Influence on the WV transport of the distribution of $V_{10}\ [m/s]$ (crosswind speed at an altitude of 10m)
2. Influence on the WV transport of the distributions of both $V_{10}\ [m/s]$ and the aircraft altitude $h_0\ [m]$
3. Influence on the WV transport of the distribution of the orientation of the crosswind $\alpha\ [-]$

Introduction

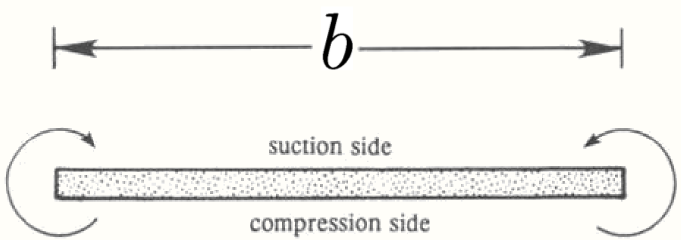
Aircraft wake vortices

$$L = \rho U_\infty b_0 \Gamma_0 = M g$$

$$\Gamma_0 = \frac{M g}{\rho U_\infty b_0} \quad \text{circulation}$$

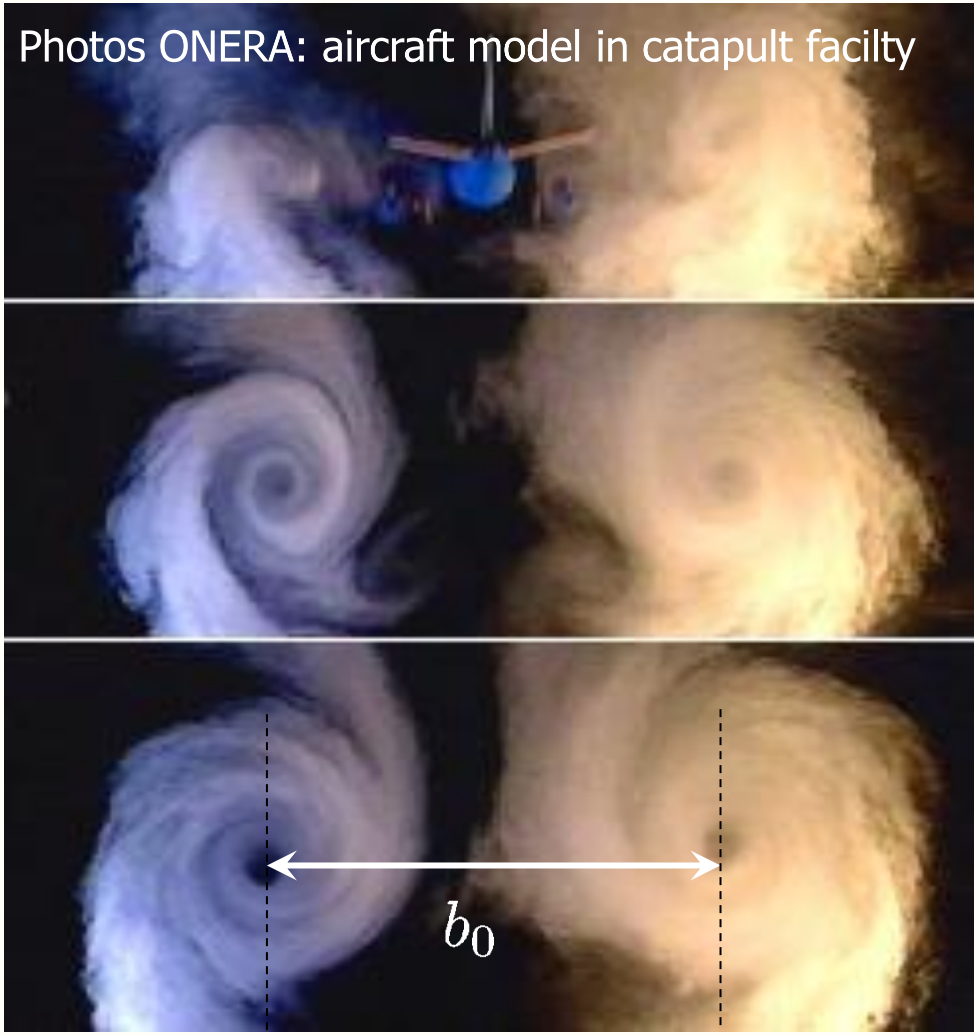
$$V_0 = \frac{\Gamma_0}{2\pi b_0} \quad \text{sink velocity}$$

$$t_0 = \frac{b_0}{V_0} \quad \text{reference time}$$



$$b_0 = 0.72 \ldots 0.84\, b$$

depending on a/c and on wing configuration



Introduction

Operational modeling of WV behavior (transport and decay)

The Deterministic wake Vortex Model (DVM) is a wake vortex predictor software developed by UCL.

It integrates, in time, various physical models so as to forecast, in real-time, the transport and decay of the wake vortices in one computational gate (i.e., one slice of space along the flight path).

It includes models of:

- time-to-demise evaluation (with EDR and stratification effects)
- two-phase decay (choice between two EDR-based models and one TKE-based model)
- near-ground effects (NGE)
- in-ground effects (IGE)
- wind shear effects
- stratification effects

It takes, as inputs:

- the aircraft characteristics (altitude, weight, TAS, span and wing loading factor)
- the met. conditions: wind (cross and head), turbulence and stratification profiles

Operational modeling of WV behavior (cont.)

Probabilistic modeling and assessment of WV is what is operationally required.

The Probabilistic wake vortex model (PVM) is an upper software layer that is based on a Monte-Carlo approach, using the DVM as a subtool.

For each PVM run, many deterministic runs are performed, with variations on the impact parameters:

- met. conditions,
- a/c characteristics,
- coefficients of the physical models

An operationally usable statistical analysis (PDF, mean, variance, confidence envelopes) is then obtained from the results.

(1) Influence of $V_{10}\ \ [m/s]$ distribution

- Classical logarithmic profile: $\dfrac{V(z)}{V_\tau} = \dfrac{1}{\kappa}\log\left(\dfrac{z+z_0}{z_0}\right),$

  with $\kappa = 0.40\ \ [-]$ the von Karman constant,

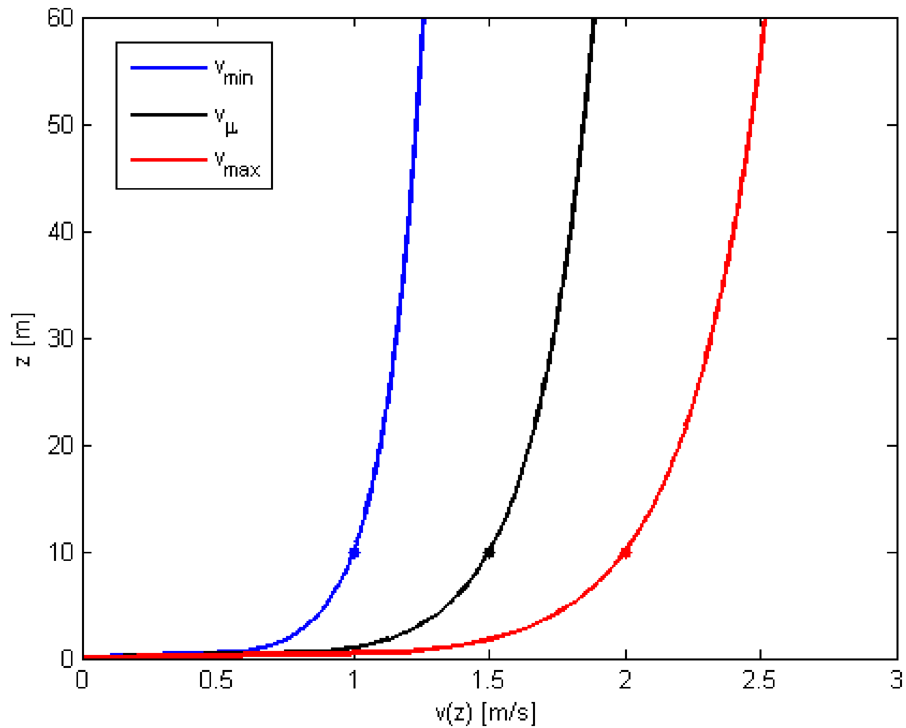
  z_0 the roughness height (typically $z_0 = 0.01\ \ [m]$ for short grass) and

  V_τ the friction speed (determined by $V_{10} = V(z=10)$)
- Two investigated distributions: uniform and normal
- Identical μ and σ for both distributions
- Uniform distribution:

$$\begin{aligned} V_{10_{\min}} &= 1.00\ \ [m/s] \\ V_{10_{\max}} &= 2.00\ \ [m/s] \end{aligned}$$

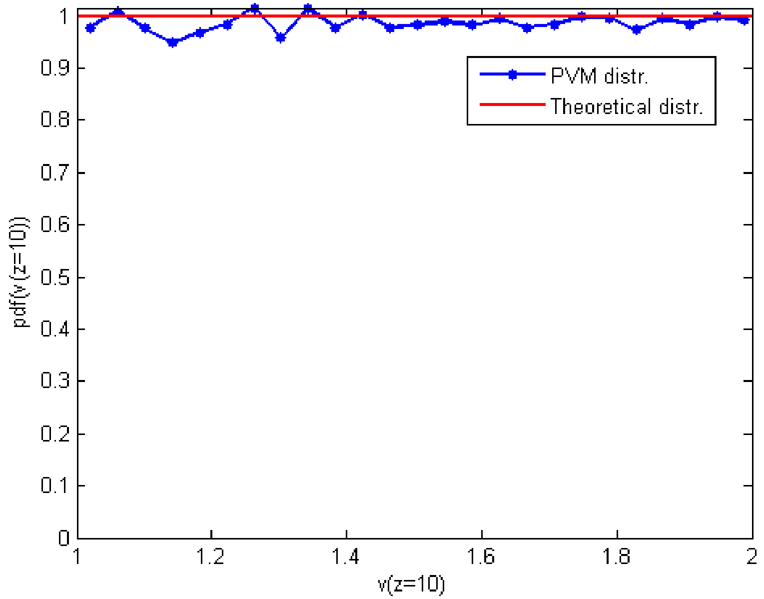
- Normal distribution:

$$\begin{aligned} \mu(V_{10}) &= 1.50\ \ [m/s] \\ \sigma(V_{10}) &= 0.29\ \ [m/s] \end{aligned}$$

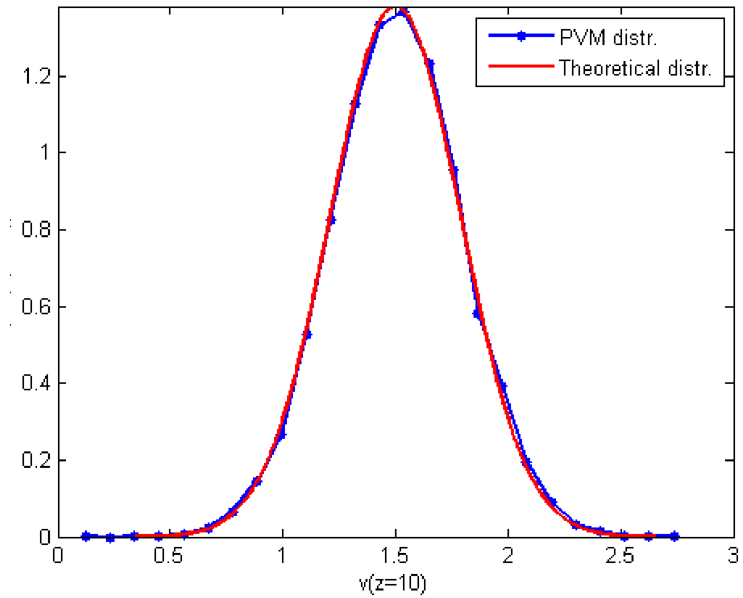


(1) Influence of $V_{10}\ [m/s]$ distribution

- Studied case (IGE) : $$\begin{aligned} b &= 60.3\ [m],\ M = 180\,000\ [kg], s = b_0/b = 0.75\ [-], \\ h_0 &= 40.0\ [m],\ TAS = 70.0\ [m/s] \end{aligned}$$
- Everything is deterministic, apart from the crosswind
- PVM simulations: 100 000 runs for each distribution
- Discrete inputs PDF obtained by random picking in the continuous PDF:



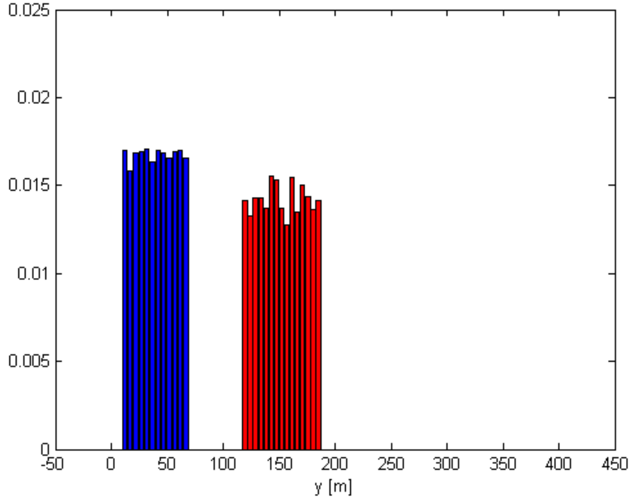
Uniform distribution

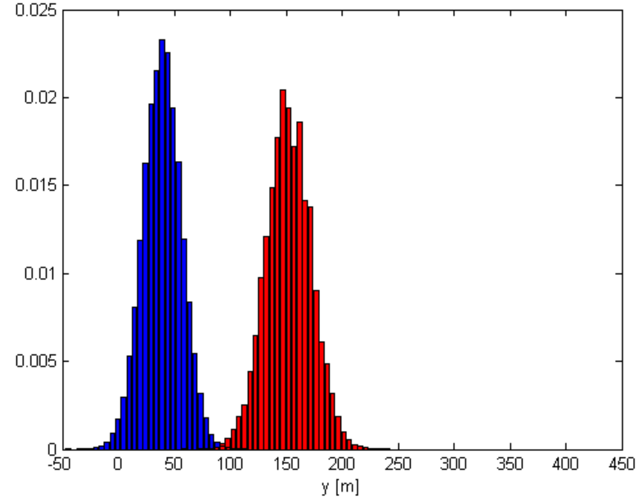


Normal distribution

Effect on the lateral position of the vortices: discrete PDF

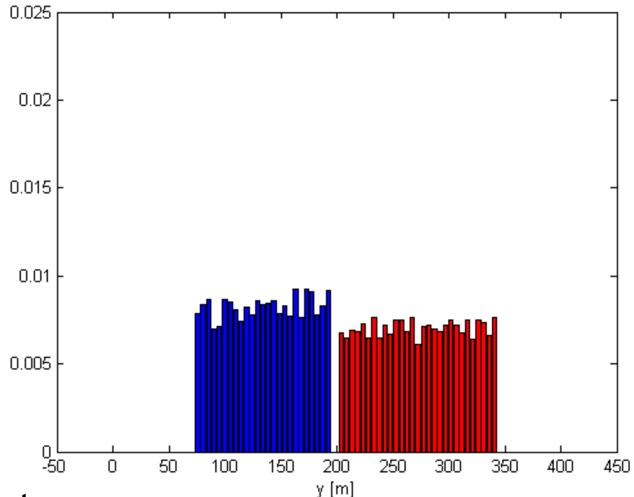
- After $t = 60 \ [s]$ (left/right : uniform/normal distribution of V_{10}) :

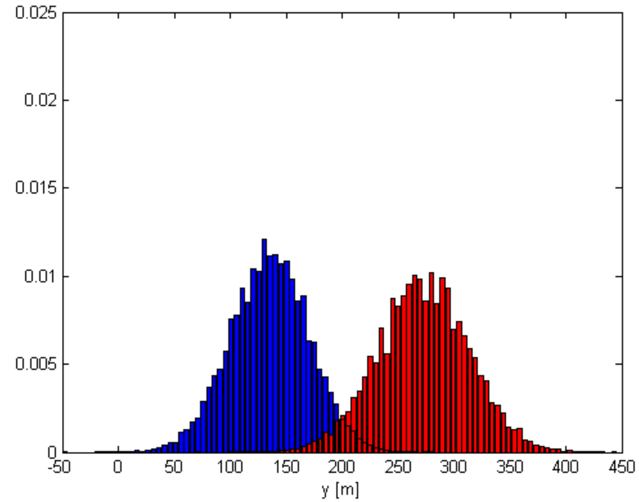




Bin size = 5m

- After $t = 120 \ [s]$:



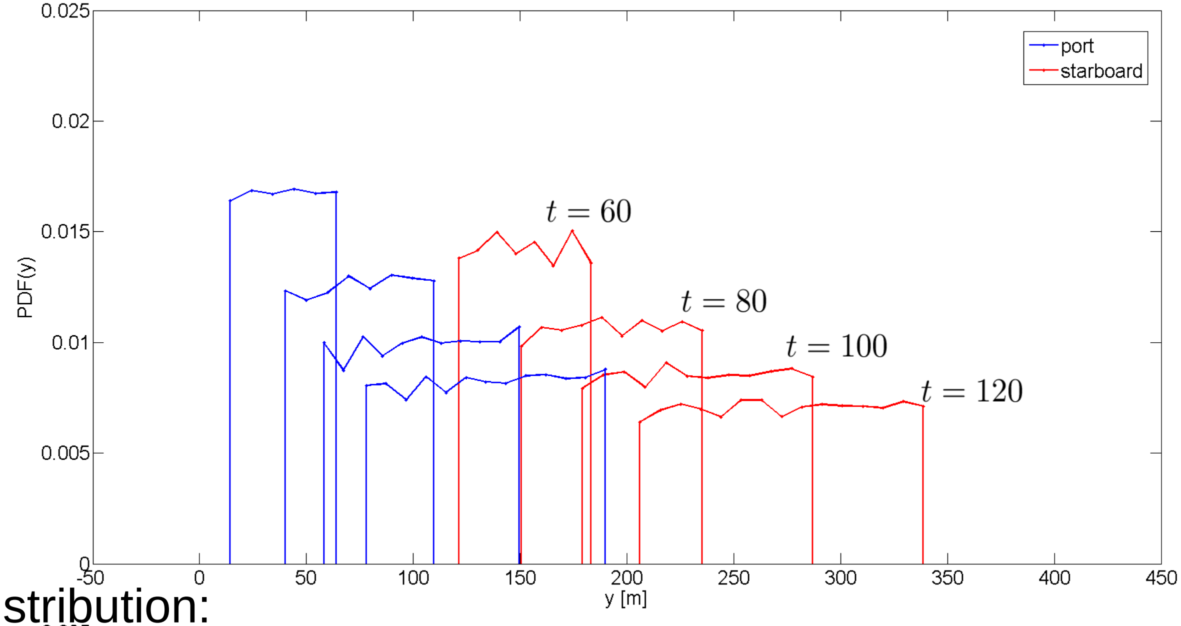


Blue: port vortex

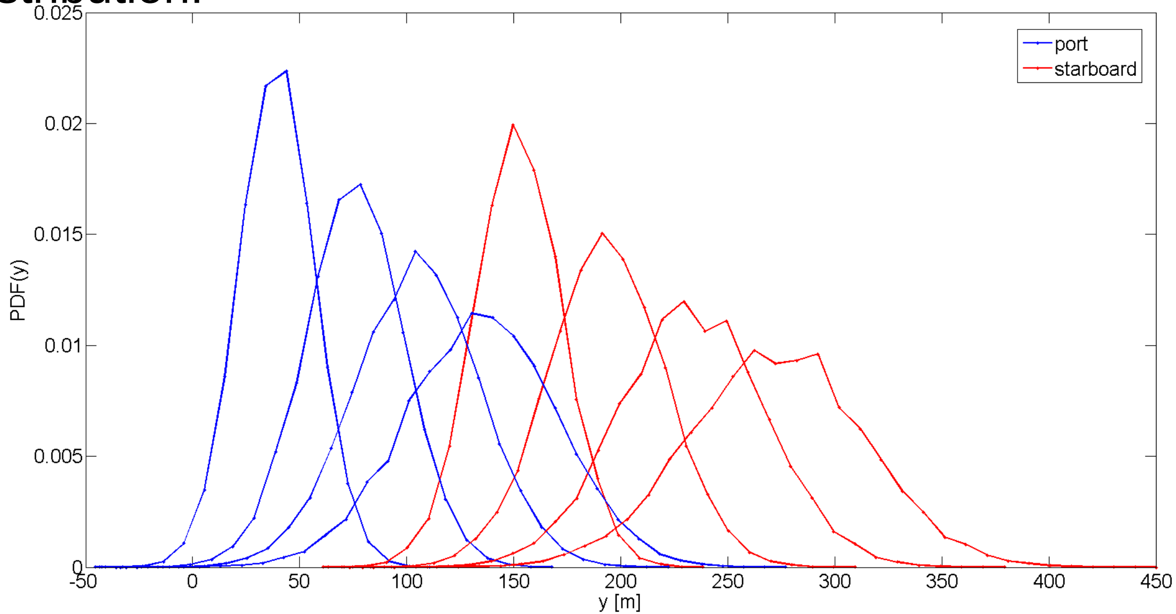
Red: starboard vortex

Evolution of the lateral position discrete PDF

- Uniform distribution:



- Normal distribution:



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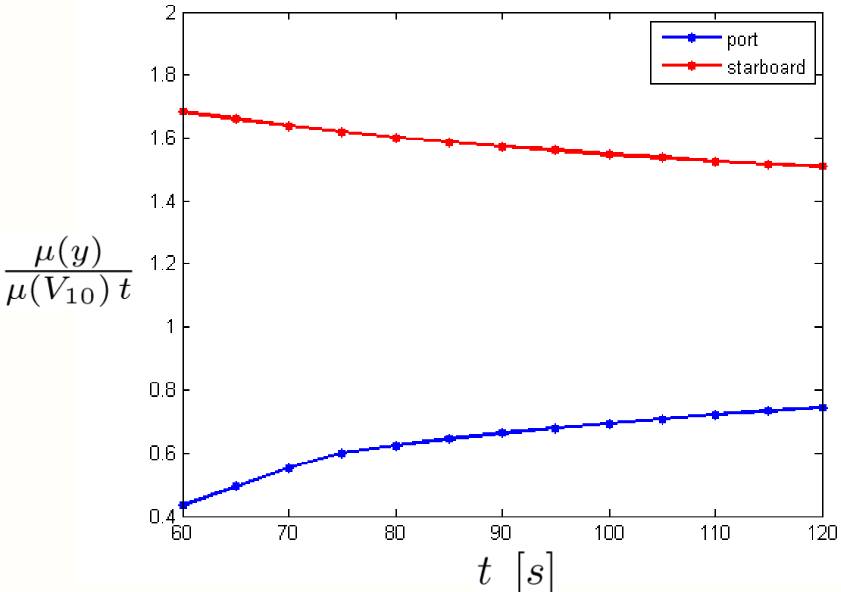
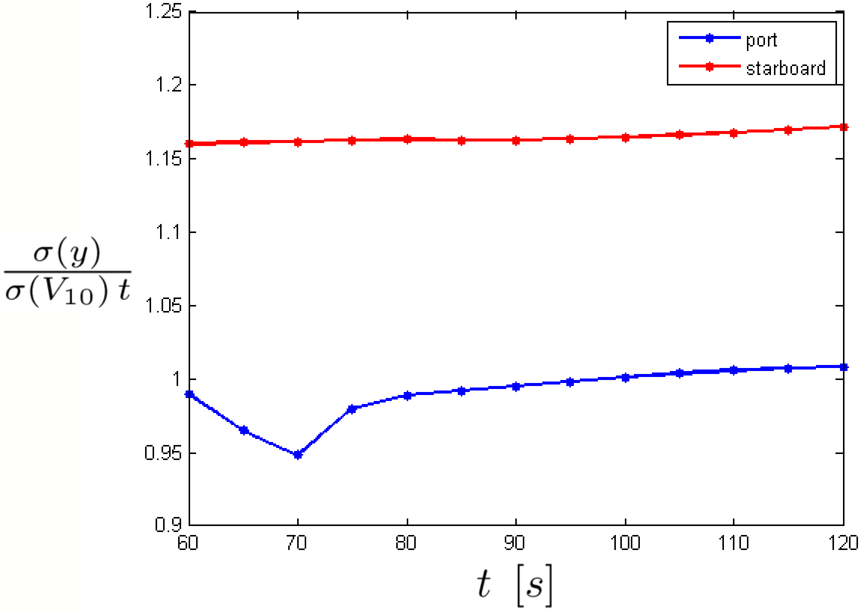
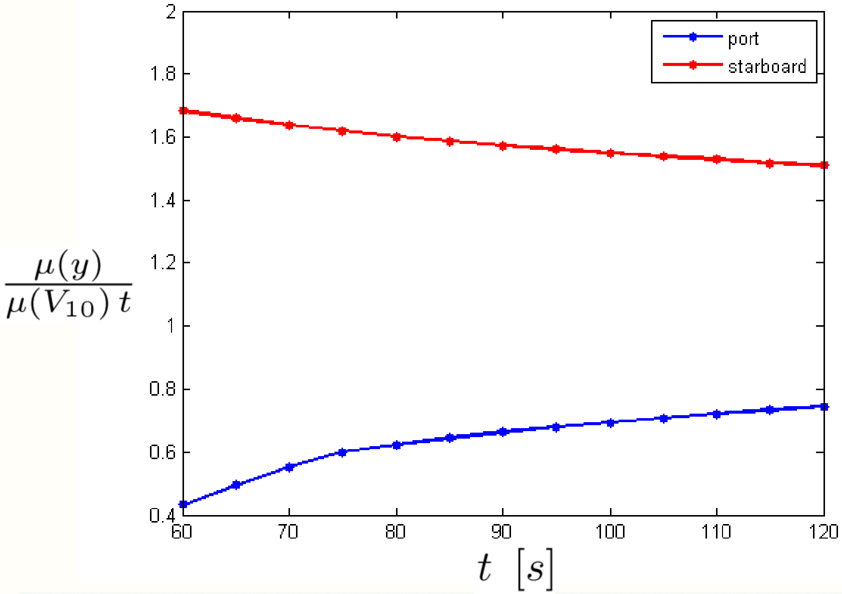
Evolution of normalized mean (left) and standard deviation (right) of the lateral position

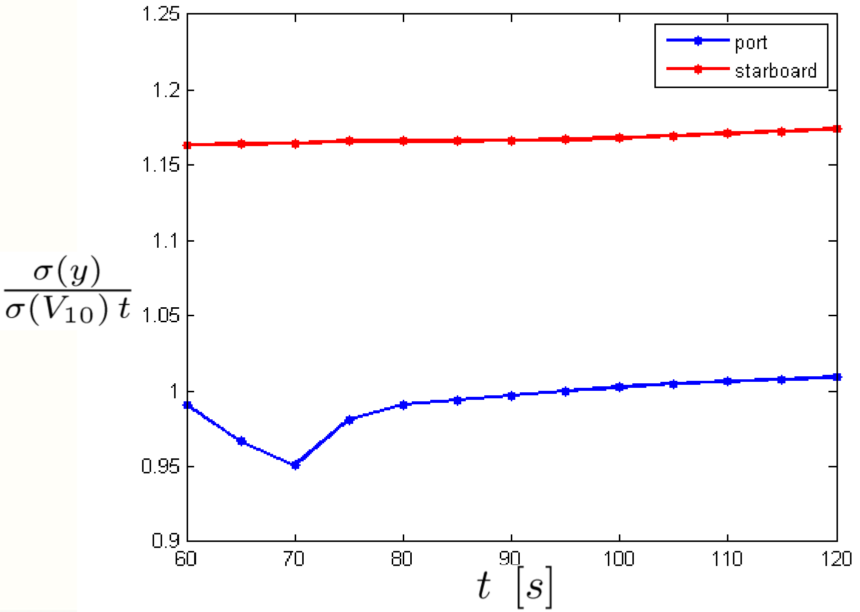
- Uniform distribution:





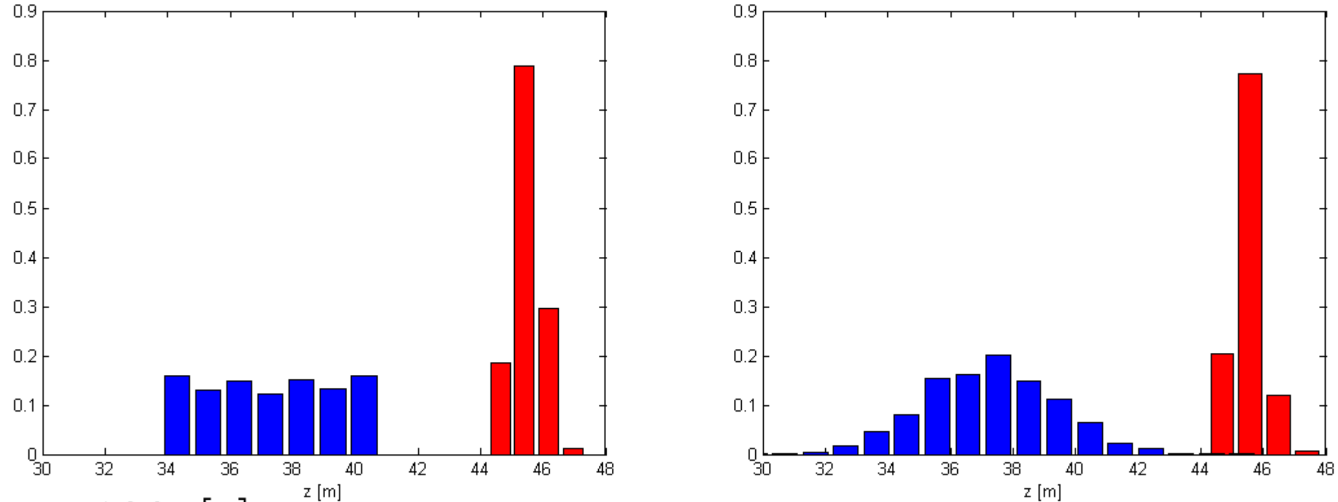
- Normal distribution:





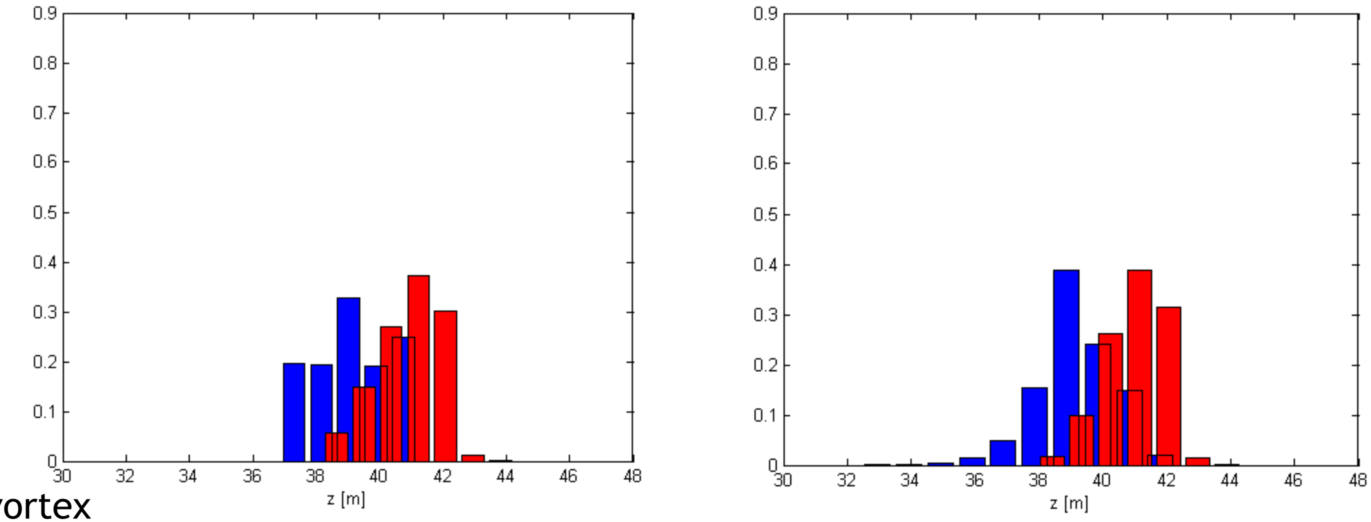
Effect on the altitude position of the vortices

- After $t = 60 \ [s]$ (left/right : uniform/normal distribution of V_{10}) :



- After $t = 120 \ [s]$:

Bin size = 1m

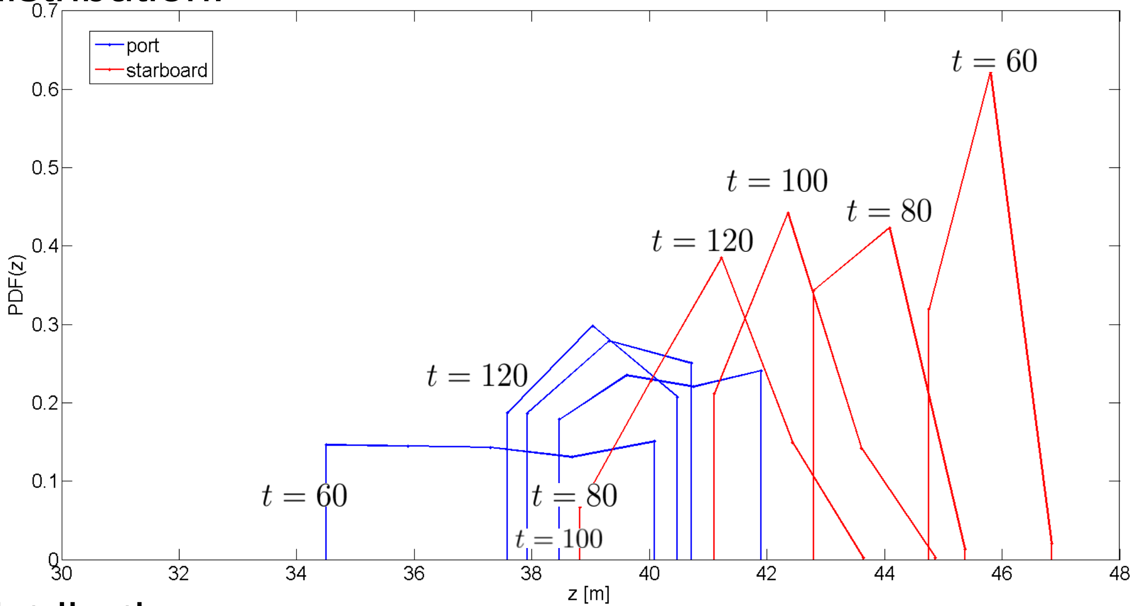


Blue: port vortex

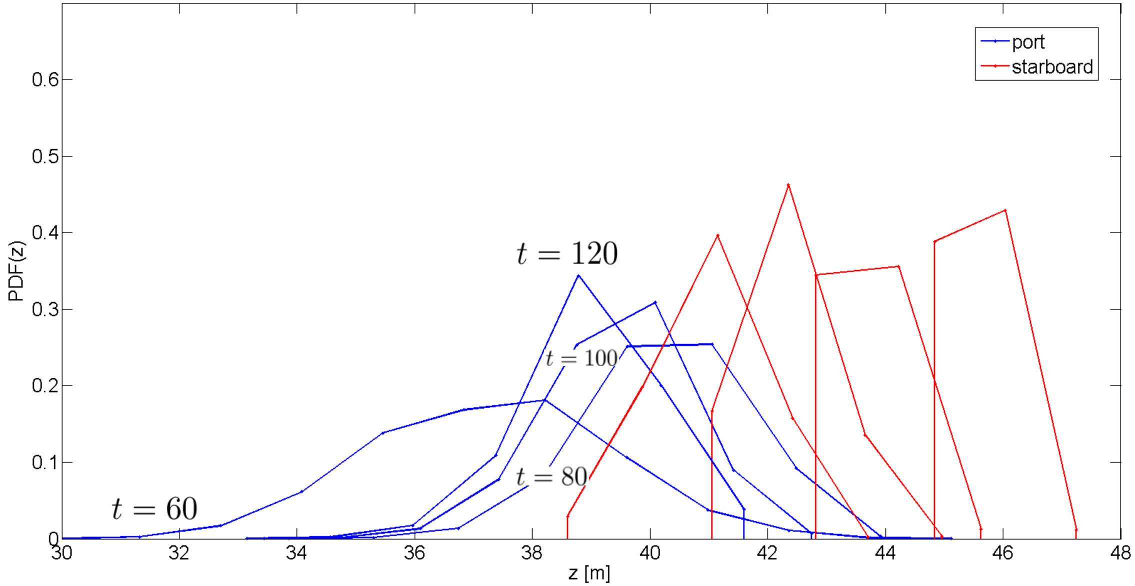
Red: starboard vortex

Evolution of the altitude position discrete PDF

- Uniform distribution:

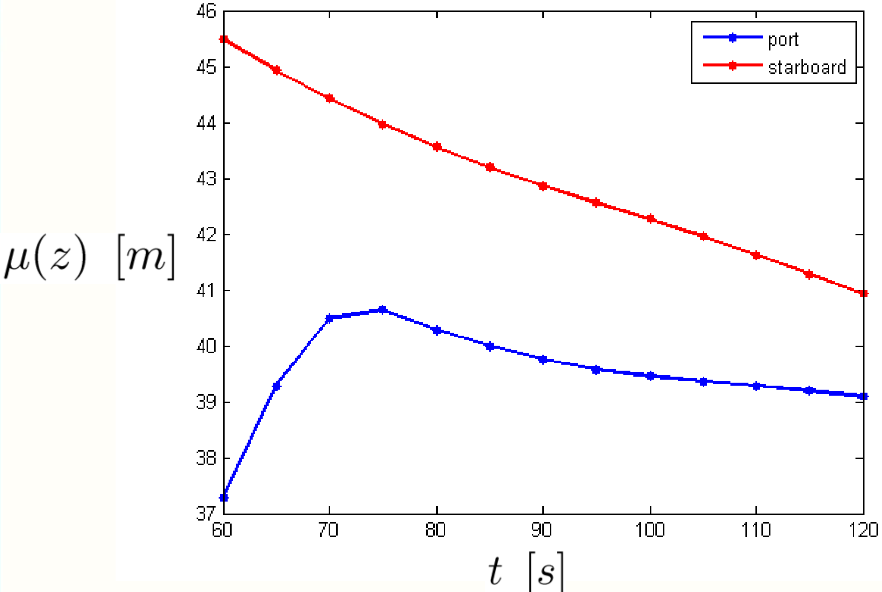


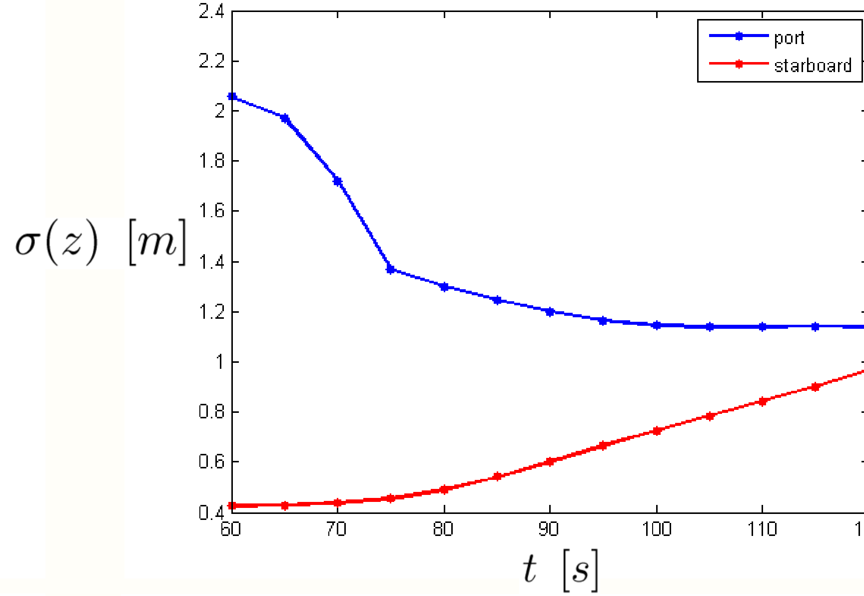
- Normal distribution:



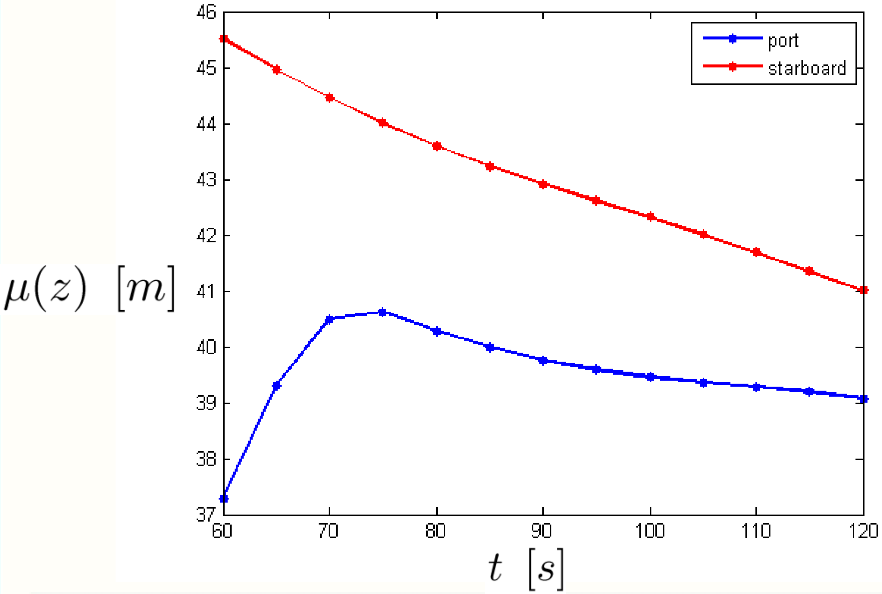
Evolution of mean (left) and standard deviation (right) of the altitude position

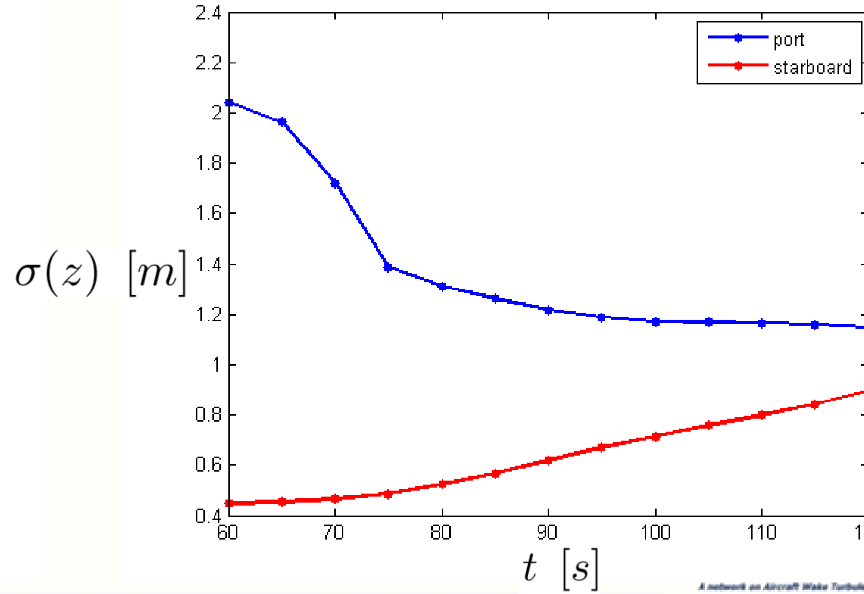
- Uniform distribution:





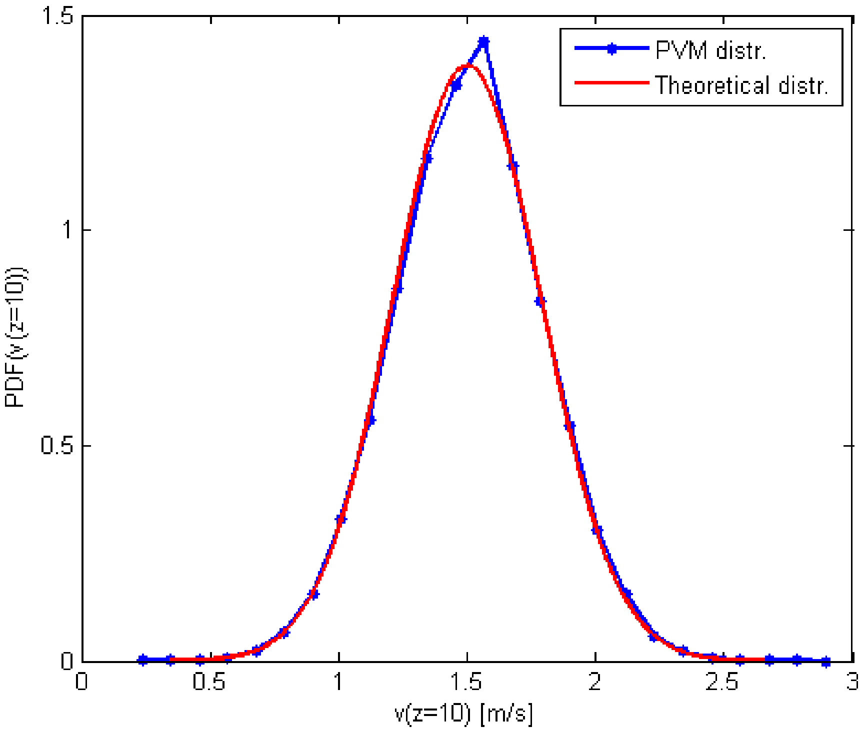
- Normal distribution:

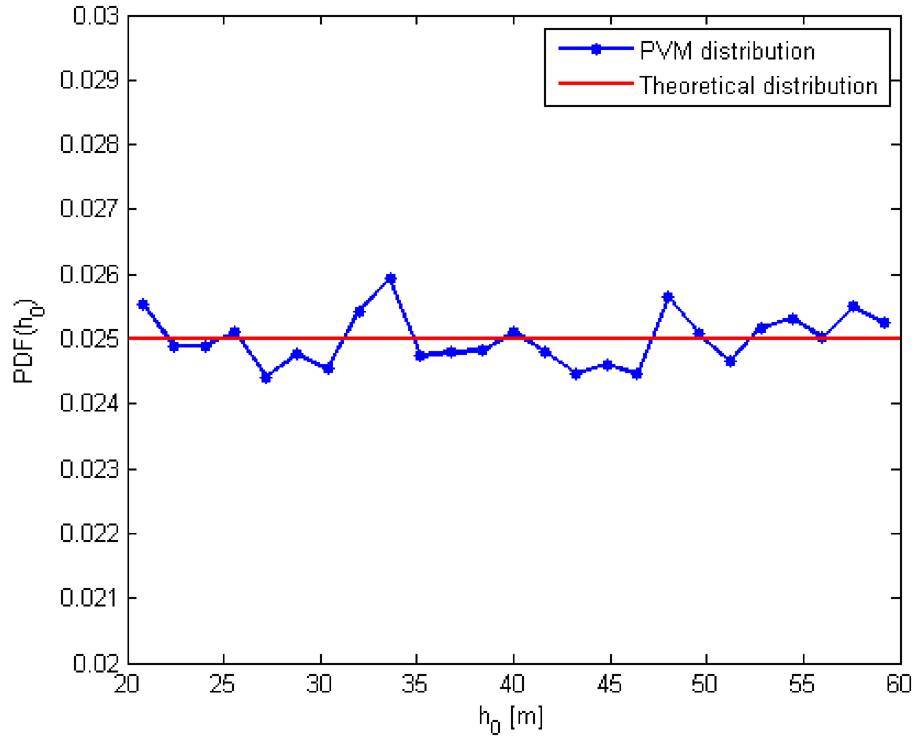




(2) Influences of both V_{10} $[m/s]$ and h_0 $[m]$ distributions

- One investigated case: V_{10} normal (left) and h_0 uniform (right)





$$\mu(V_{10}) = 1.50 \ [m/s]$$
$$\sigma(V_{10}) = 0.29 \ [m/s]$$

$$h_{0_{\min}} = 20.0 \ [m]$$
$$h_{0_{\max}} = 60.0 \ [m]$$

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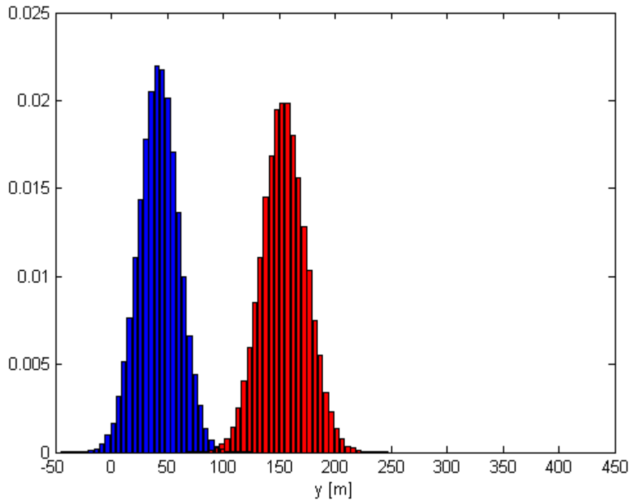
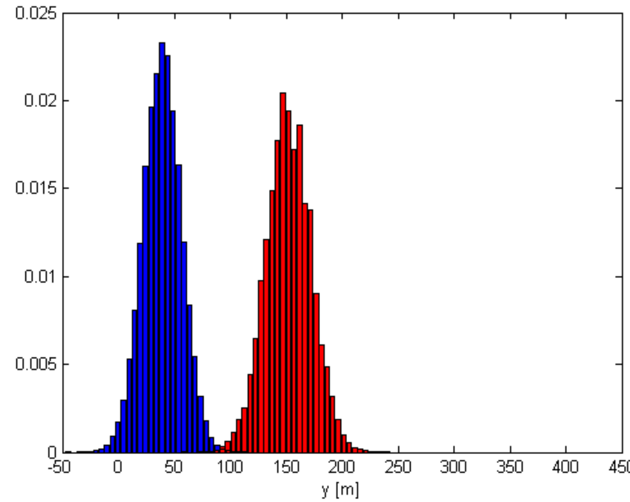
Effect on the lateral position of the vortices

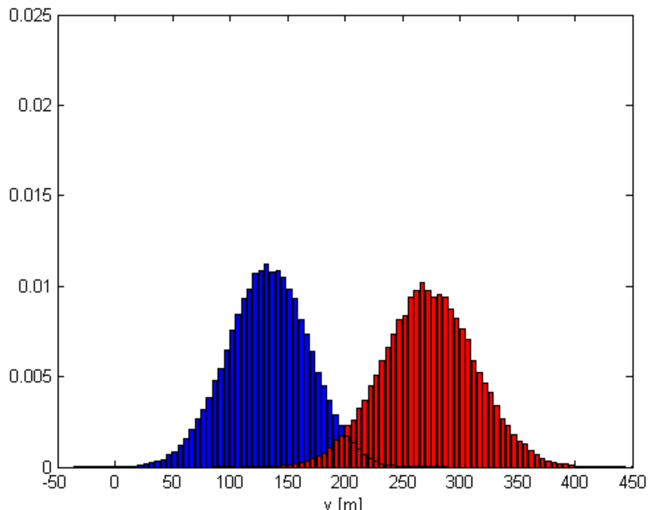
- After $t = 60 \ [s]$ (left: present case, right: previous case) :

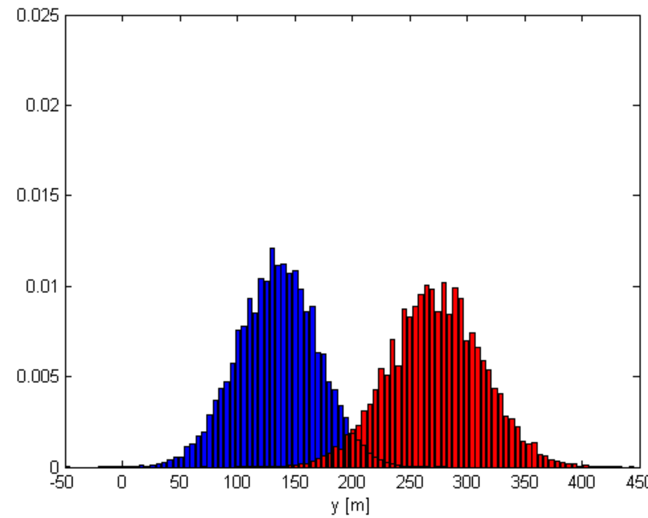




Bin size = 5m

- After $t = 120 \ [s]$:





Blue: port vortex

Red: starboard vortex

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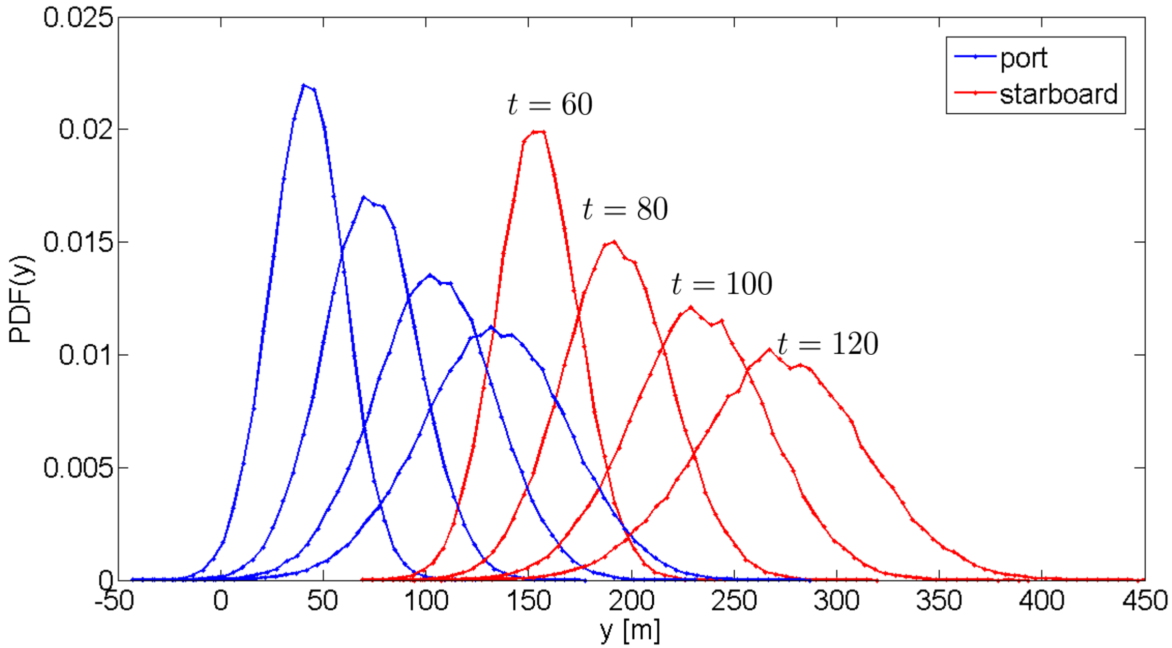
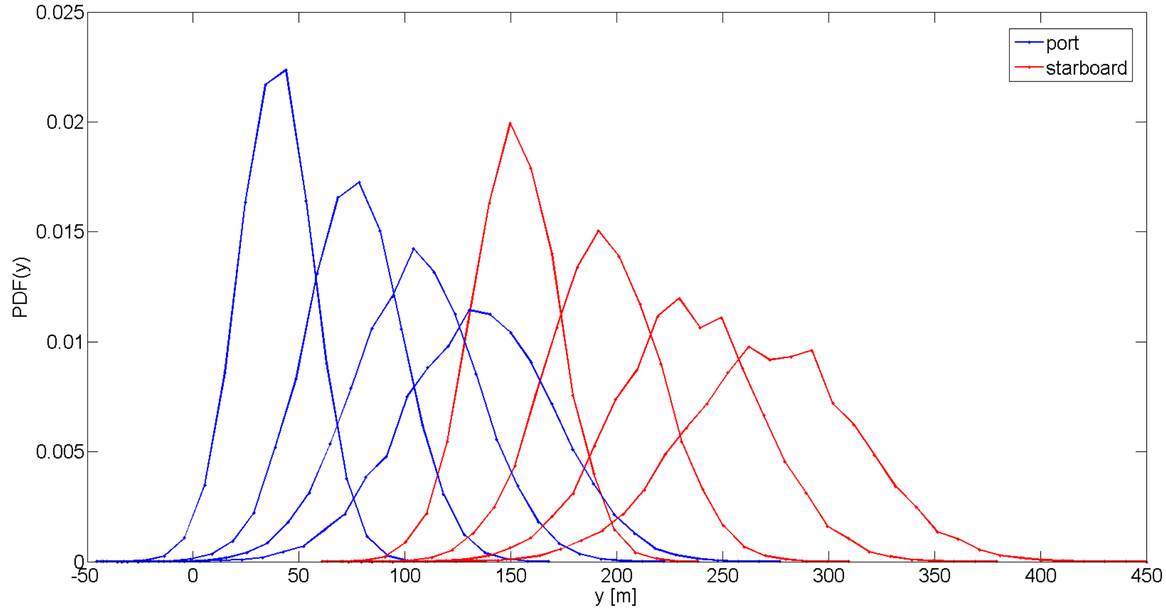
Evolution of the lateral position discrete PDF

- present case:

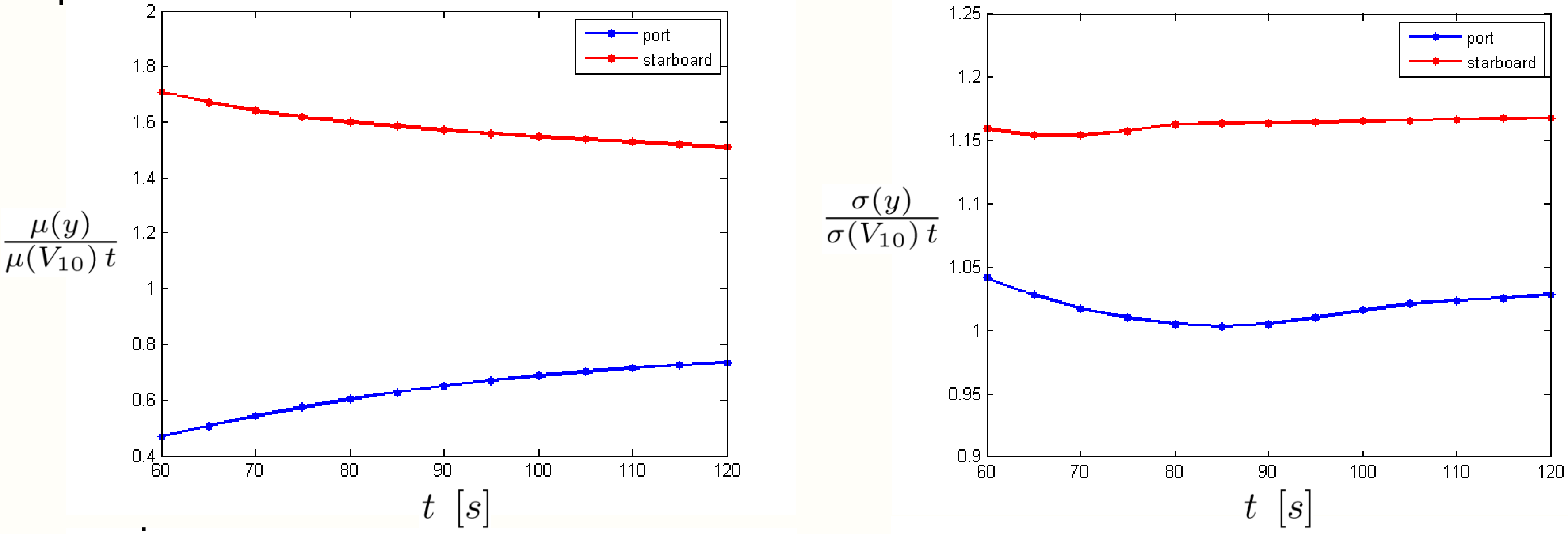


- previous case:

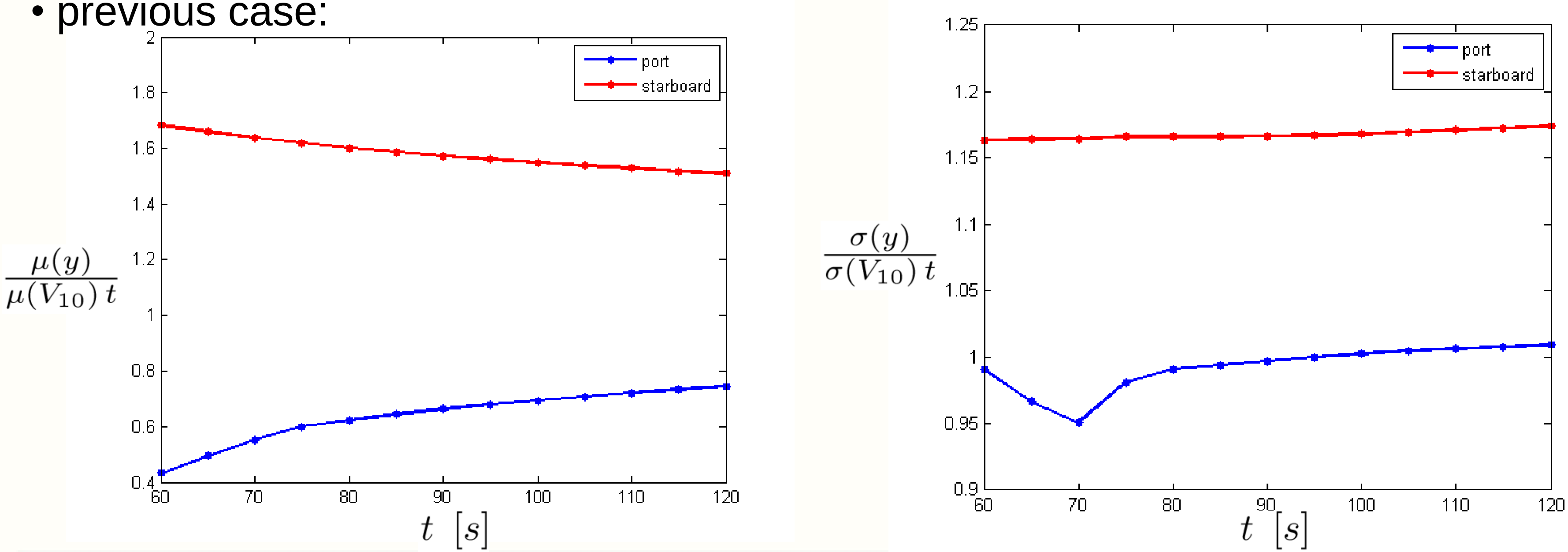


Evolution of normalized mean (left) and standard deviation (right) of the lateral position

- present case:



- previous case:



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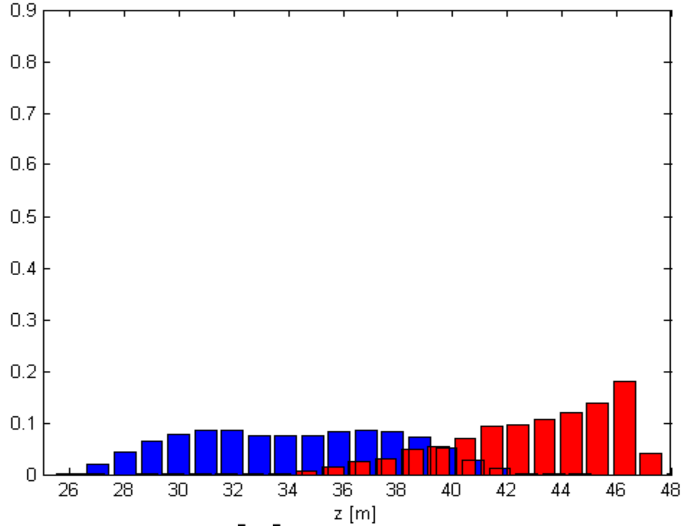
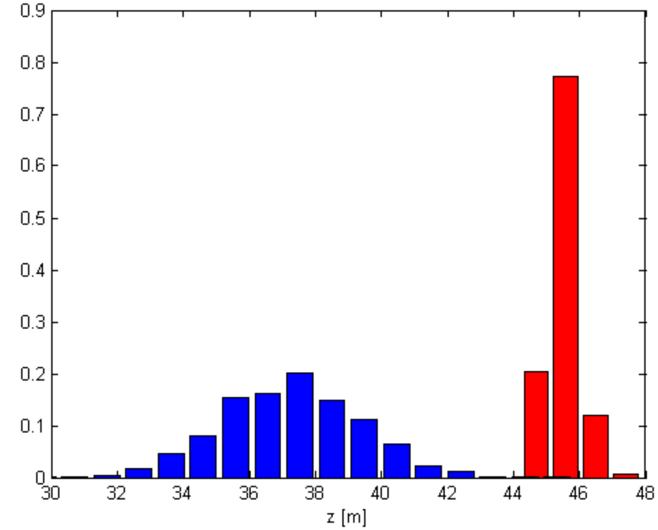
Effect on the altitude position of the vortices

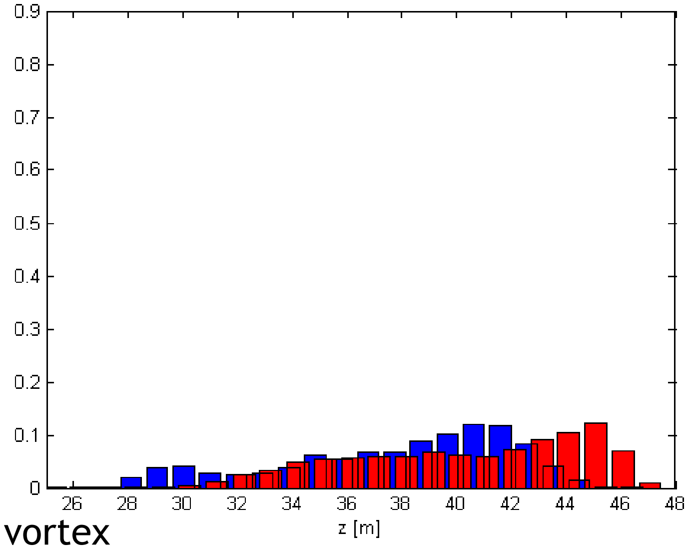
- After $t = 60 \ [s]$ (left: present case, right: previous case) :

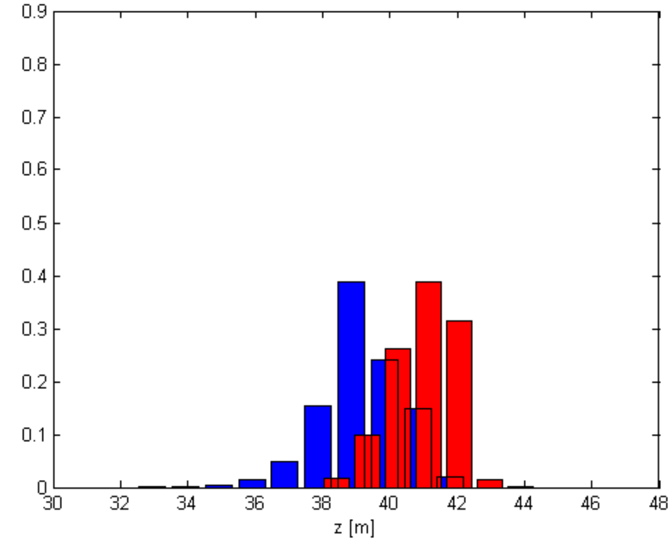




Bin size = 1m

- After $t = 120 \ [s]$:





Blue: port vortex

Red: starboard vortex

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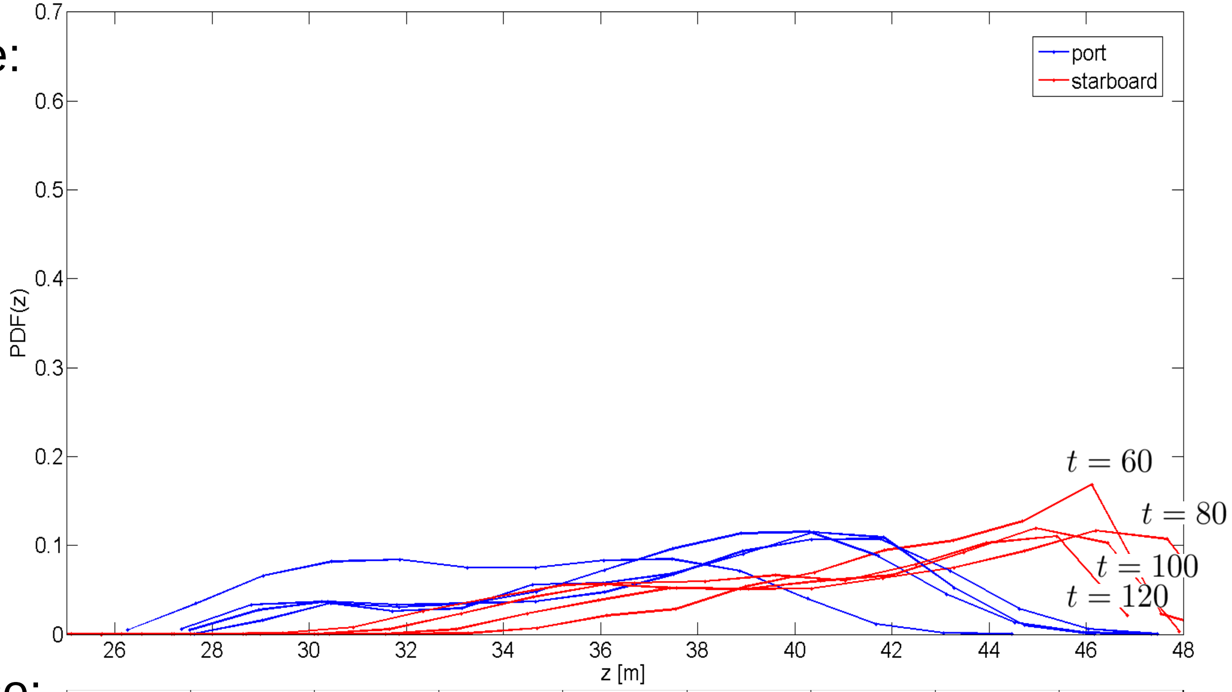
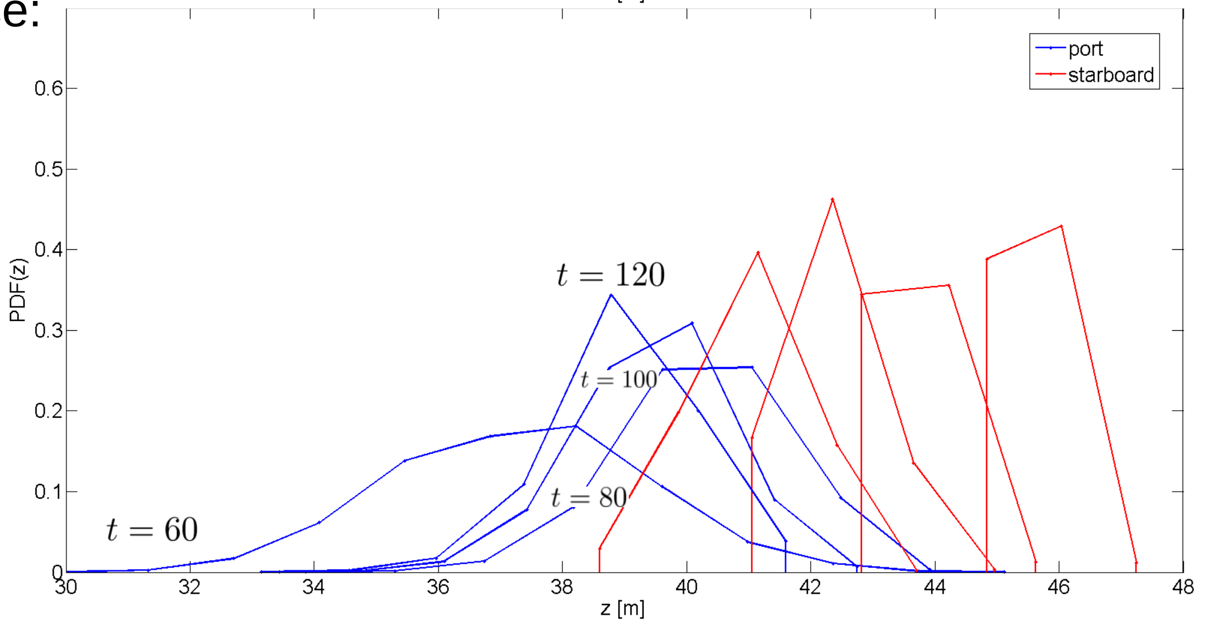
Evolution of the altitude position discrete PDF

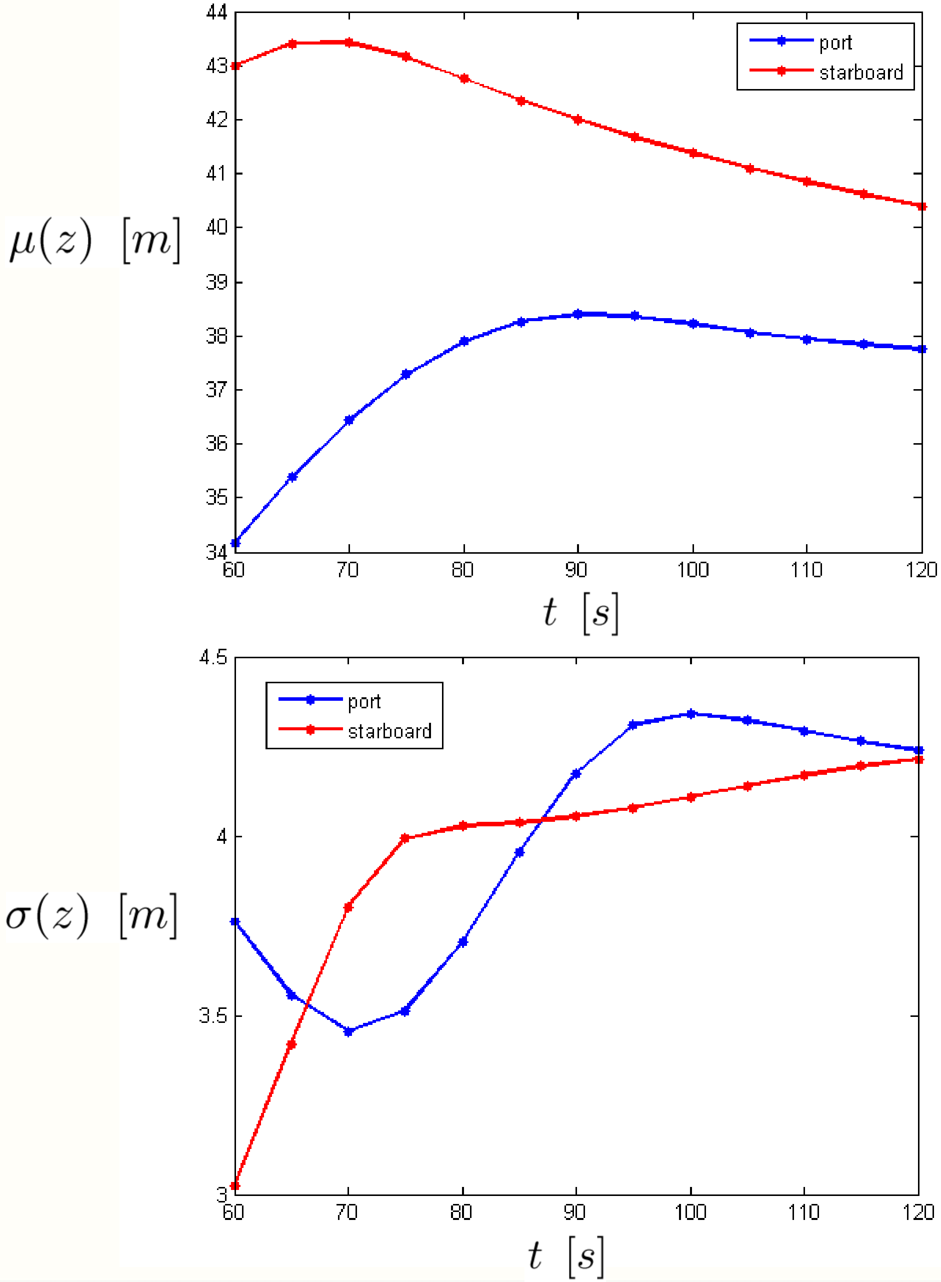
- present case:



- previous case:



Evolution of mean (top) and standard deviation (bottom) of the altitude position



(3) Influence of the distribution of wind orientation α

- Headwind component:

$$\vec{u}_{loc} = V \sin(\alpha)\, \vec{e_x}$$

- Crosswind component:

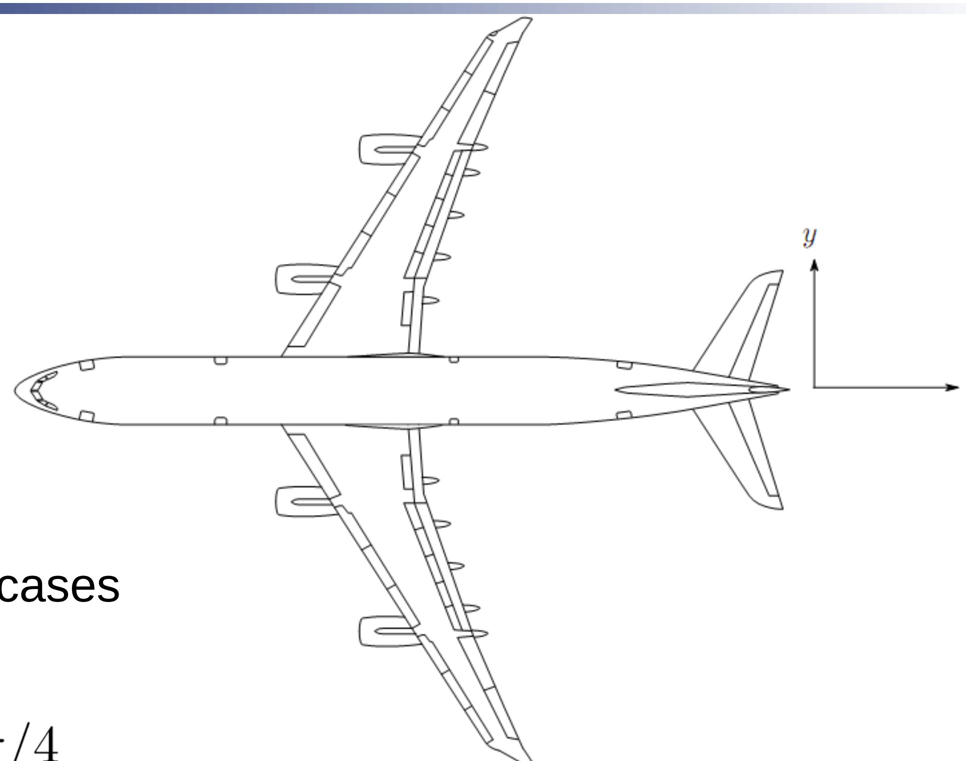
$$\vec{v}_{loc} = V \cos(\alpha)\, \vec{e_y}$$

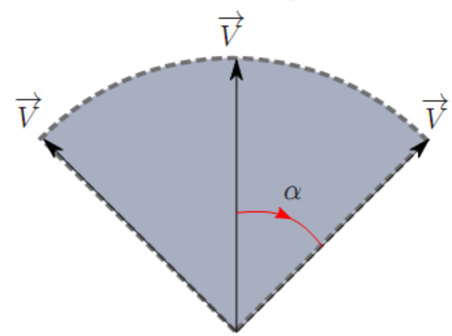
- Uniform distribution: 3 investigated cases

(i)
$$\begin{aligned} \Delta\alpha &= \pi/2 \\ \alpha_{\min} &= -\pi/4,\ \alpha_{\max} = \pi/4 \end{aligned}$$

(ii)
$$\begin{aligned} \Delta\alpha &= \pi/4 \\ \alpha_{\min} &= -\pi/8,\ \alpha_{\max} = \pi/8 \end{aligned}$$

(iii)
$$\begin{aligned} \Delta\alpha &= \pi/6 \\ \alpha_{\min} &= -\pi/12,\ \alpha_{\max} = \pi/12 \end{aligned}$$



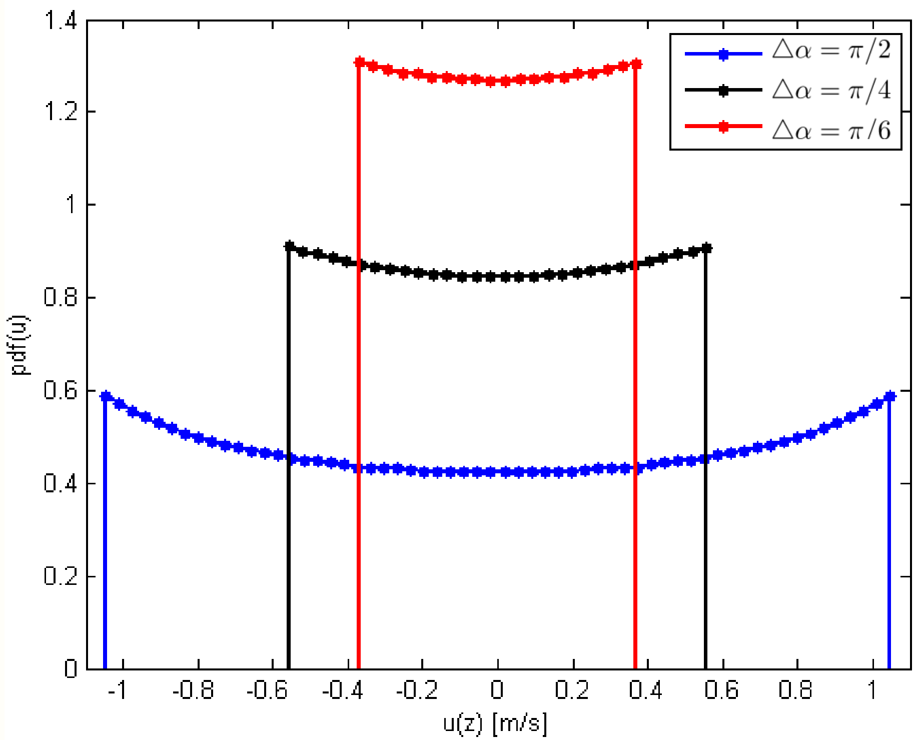


$$\vec{V} = \vec{u}_{loc} + \vec{v}_{loc}$$

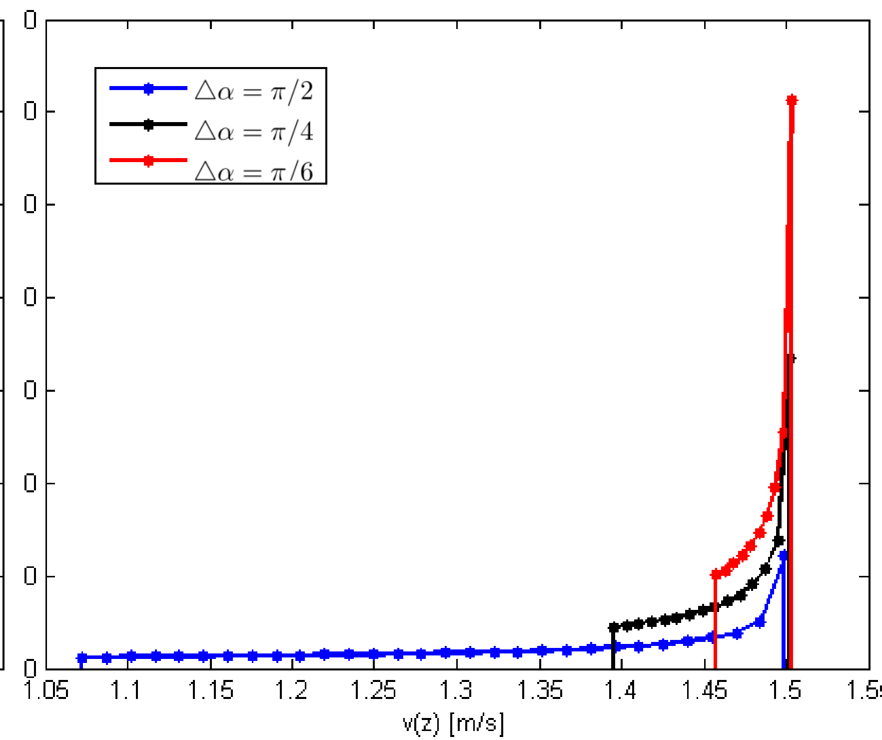
(3) Influence of the distribution of wind orientation α

- Everything else is deterministic
- PVM simulations: 10 000 runs for each of the 3 cases
- Discrete inputs PDF of head- and crosswind:

Headwind distribution at $z = 10$



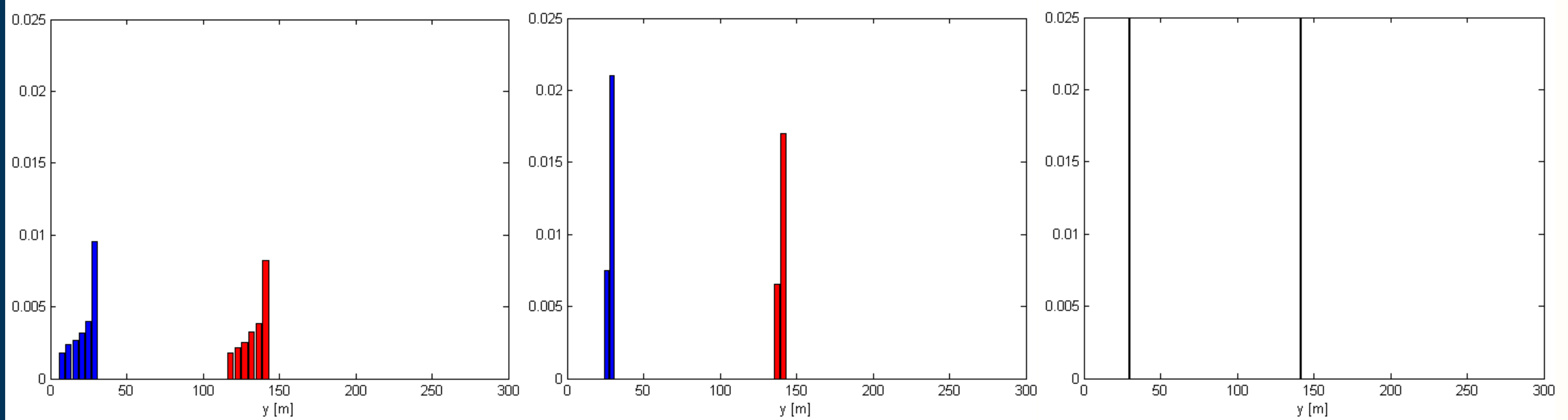
Crosswind distribution at $z = 10$



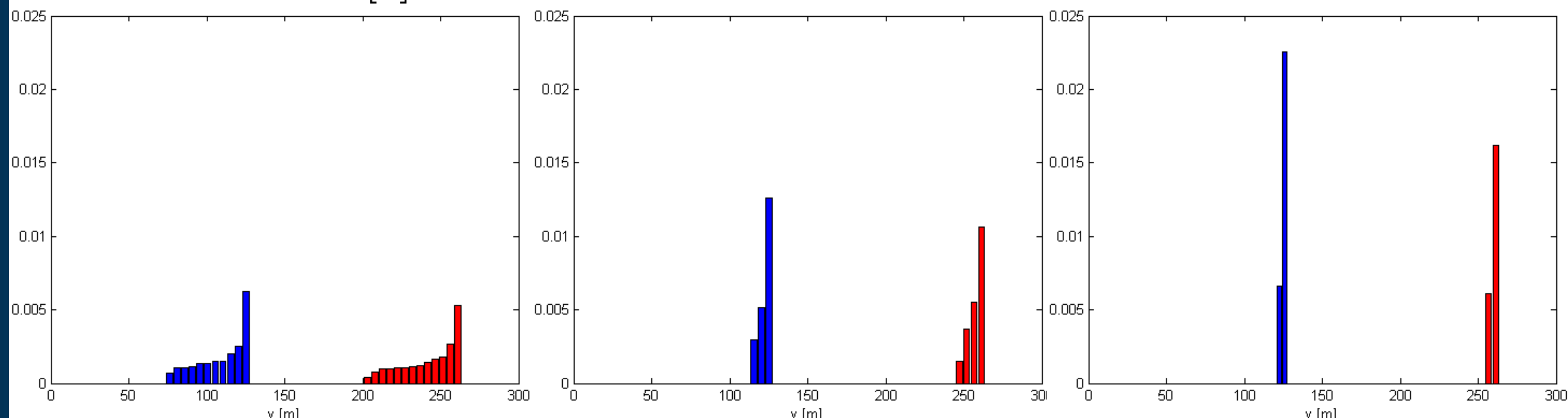
Bin size = 5m

Effect on the lateral position of the vortices

- After $t = 60 \ [s]$ (left: $\triangle\alpha = \pi/2$, middle: $\triangle\alpha = \pi/4$, right: $\triangle\alpha = \pi/6$) :



- After $t = 120 \ [s]$:

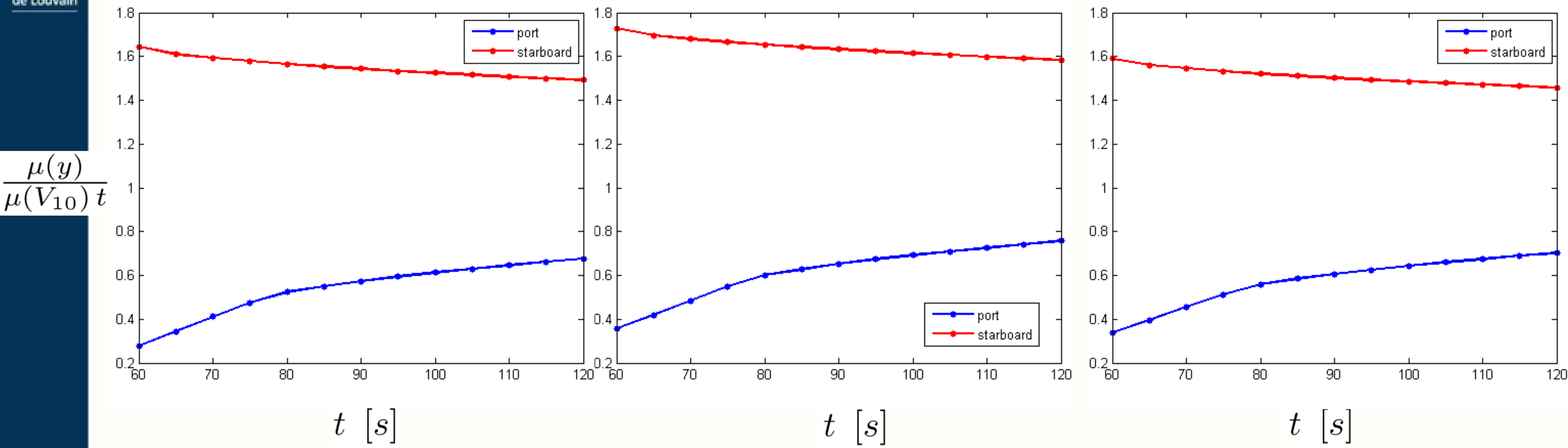


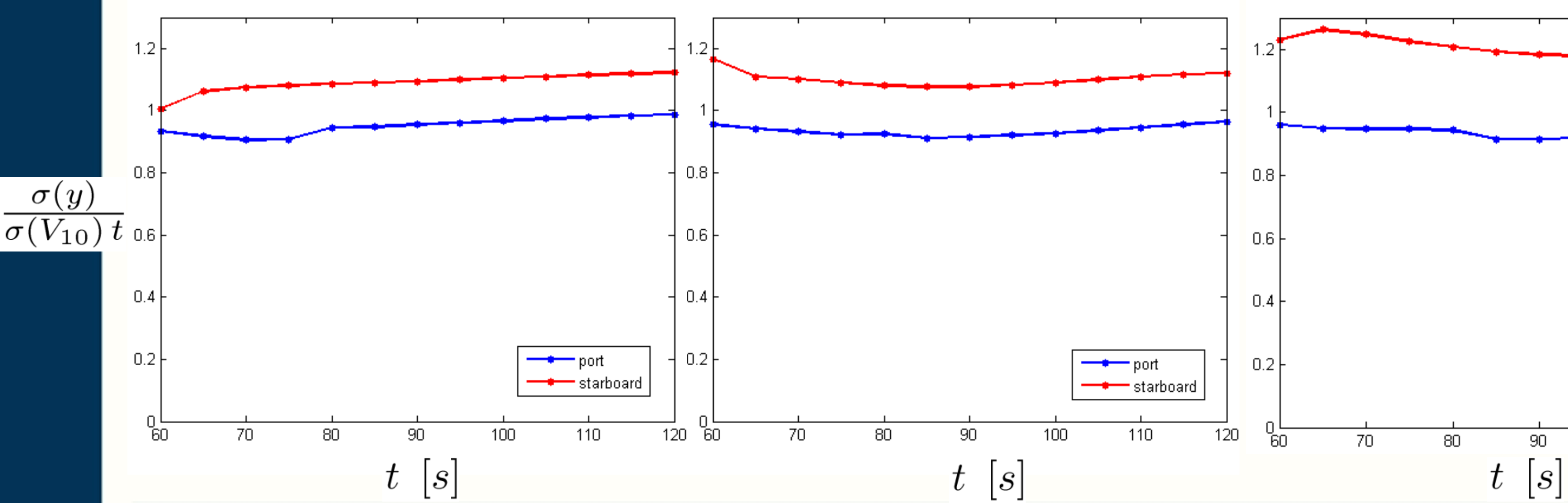
Blue: port vortex

Red: starboard vortex

Evolution of normalized mean (top) and standard deviation (bottom) of the lateral position

(left: $\triangle\alpha = \pi/2$, middle: $\triangle\alpha = \pi/4$, right: $\triangle\alpha = \pi/6$) :

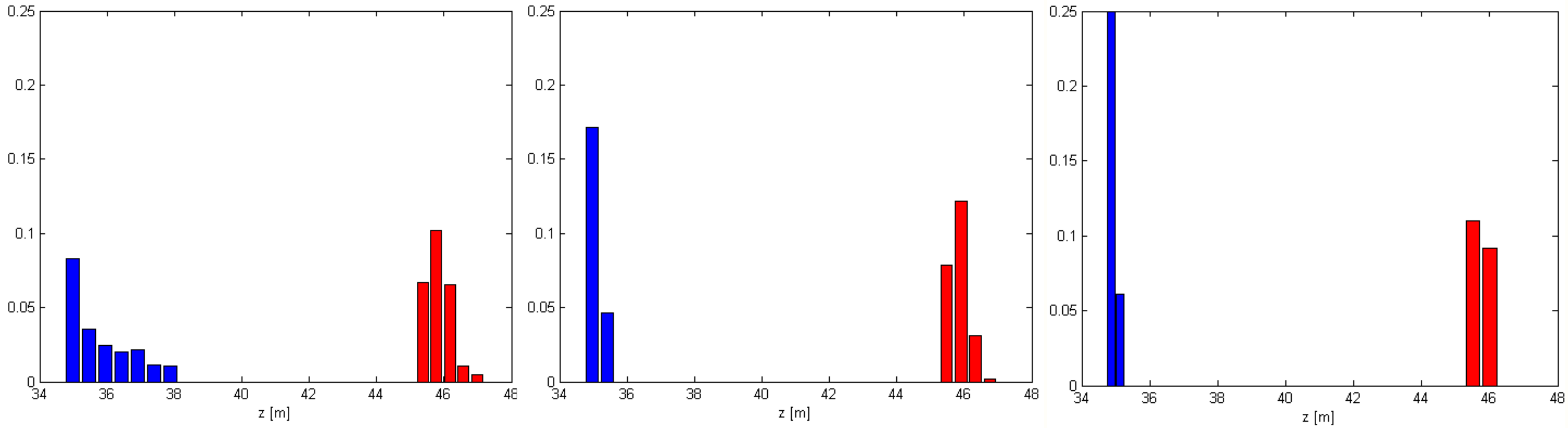




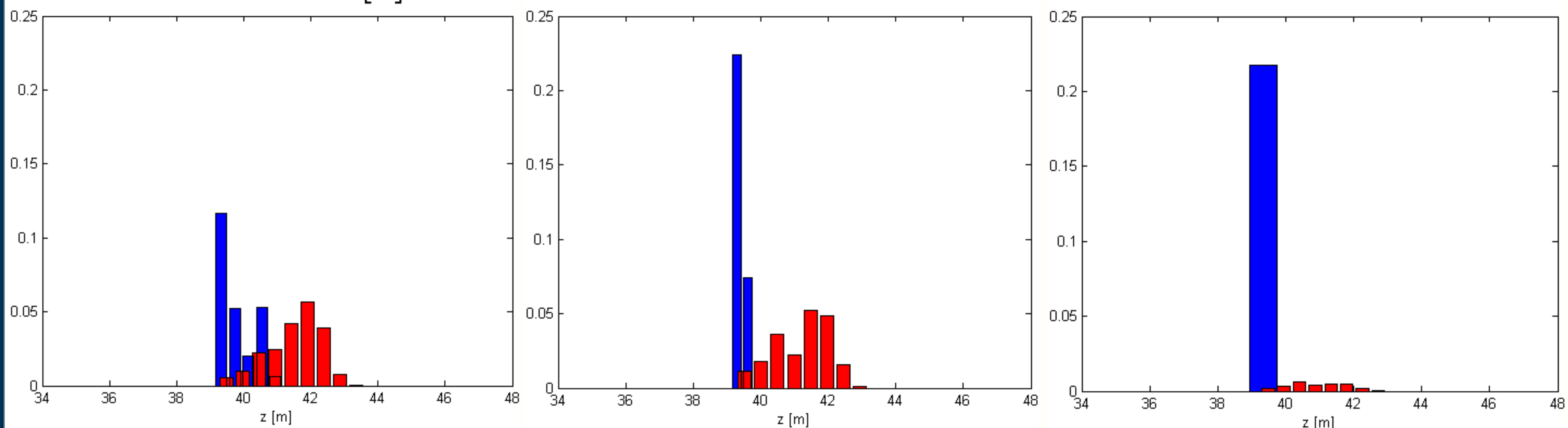
Effect on the altitude position of the vortices

Bin size = 0.5m

- After $t = 60 \ [s]$ (left: $\triangle\alpha = \pi/2$, middle: $\triangle\alpha = \pi/4$, right: $\triangle\alpha = \pi/6$) :



- After $t = 120 \ [s]$:



Blue: port vortex

Red: starboard vortex

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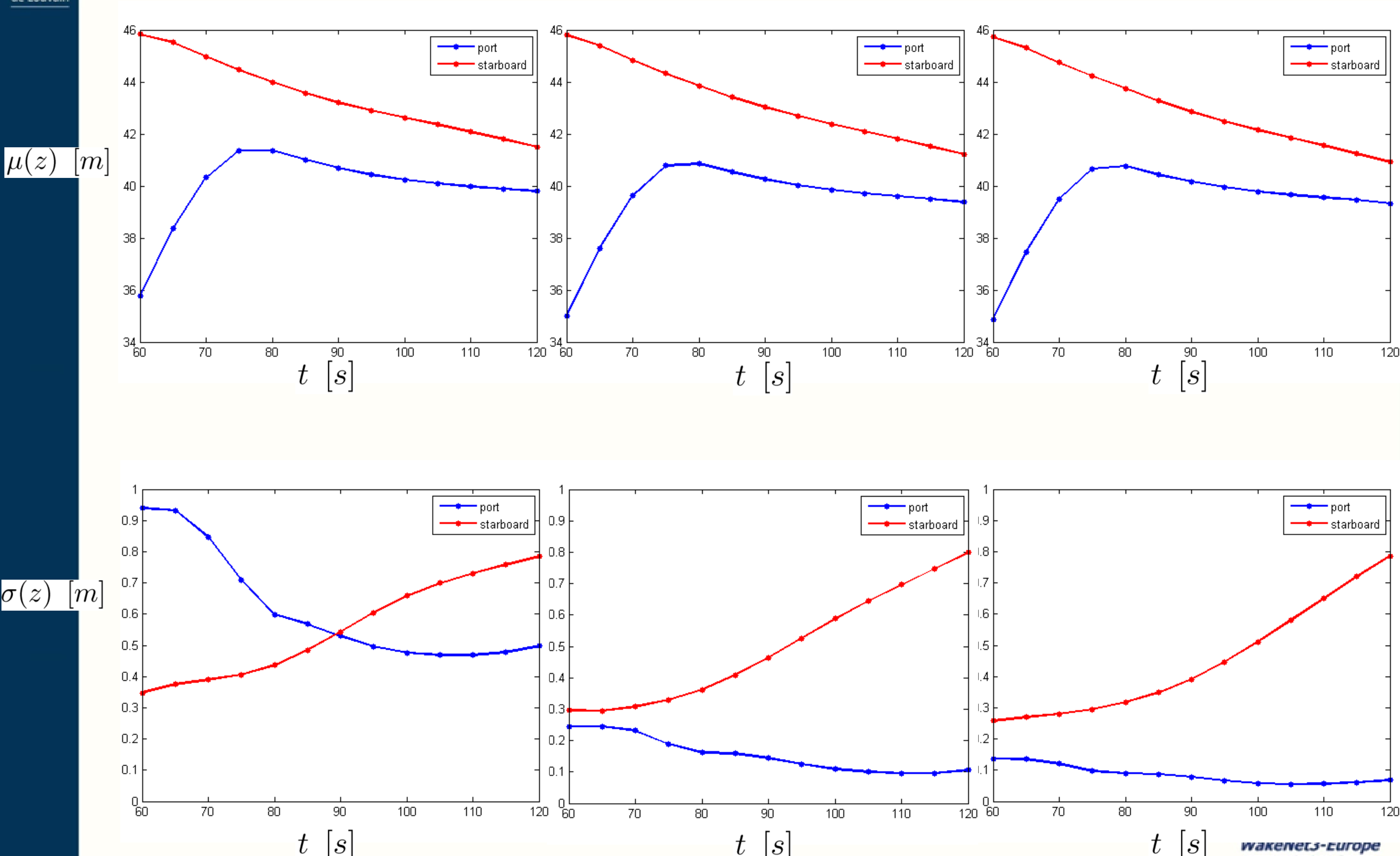
Evolution of mean (top) and standard deviation (bottom) of the altitude position

(left: $\triangle\alpha = \pi/2$, middle: $\triangle\alpha = \pi/4$, right: $\triangle\alpha = \pi/6$) :



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