Influence of bridge deck shape on extreme buffeting forces

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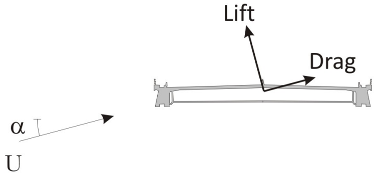
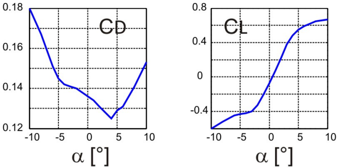
Illustrative Example





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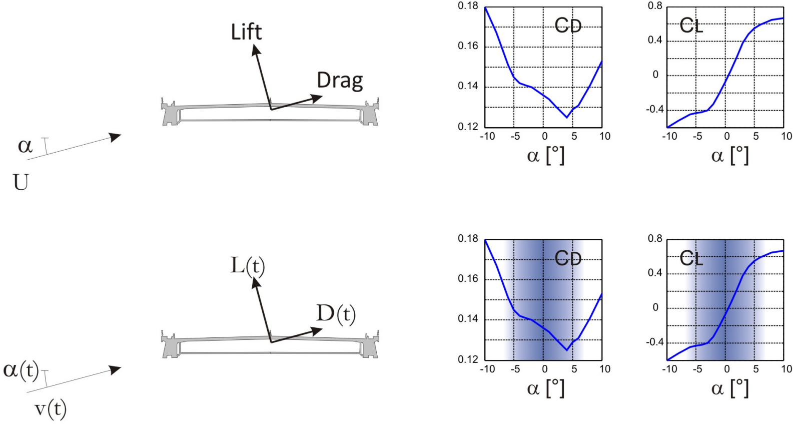

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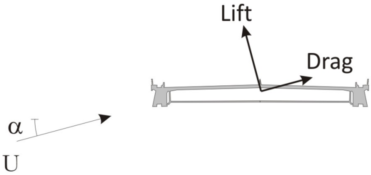

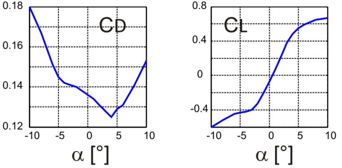

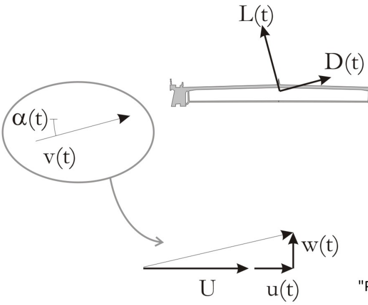

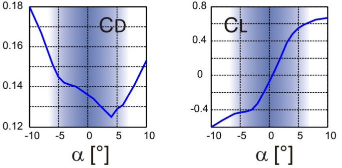

Solari, G. and G. Piccardo (2001).
"Probabilistic 3-D turbulence modeling for gust buffeting of structures
Probabilistic Engineering Mechanics **16**(1): 73-86.

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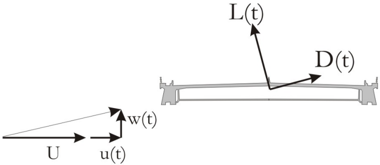

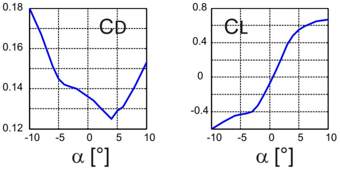

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$$\frac{f}{\frac{1}{2}\rho C_{D,0} B U^2} = \left(1 + \frac{2u}{U} + u^2 + w^2\right)\frac{C_D}{C_{D,0}}$$

$$\sigma_u/U = 0.1$$
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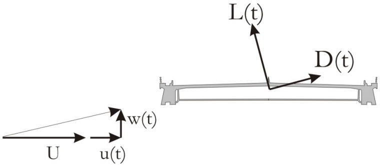

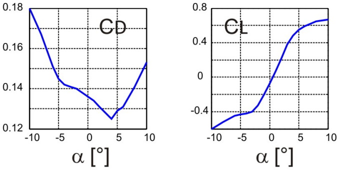

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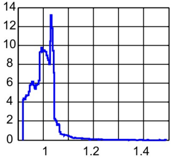

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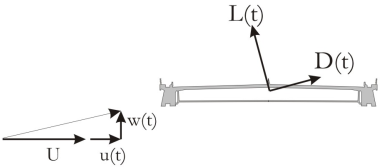

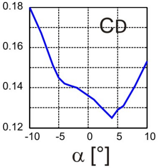

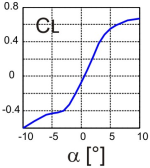

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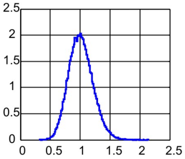

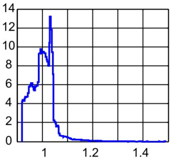

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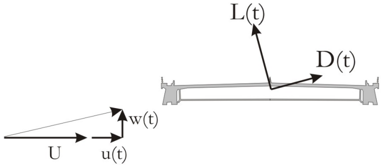

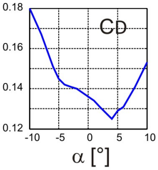

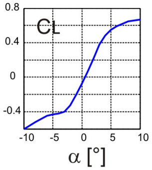

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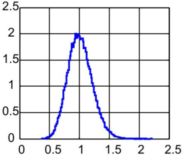

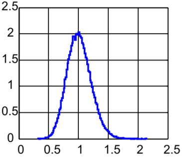

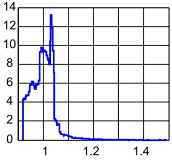

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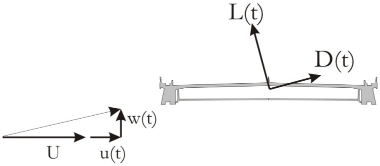

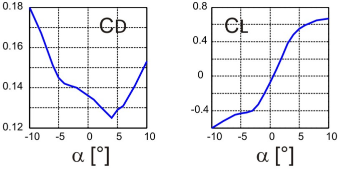

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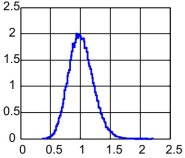

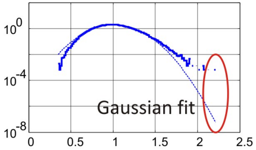

Objectives

For a given bridge deck (C_D, C_L, C_M) & turbulence characteristics (σ_u, σ_w, ρ_{uw}):

How big is the skewness of the resulting loading ?

(extremes and peak factors)

Assumptions:

- quasi-steady loading
- no aeroelastic effect, no admittance, no aerodynamic damping

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Scope: Decks for which a complete wind-tunnel or CFD assessment is not affordable

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Classification of bridge decks

Expected (stationary) aerodynamic coefficient for a new bridge deck ?

- CFD / wind-tunnel;
- search literature for a similar *generic* section;
- search codes for C_D, C_L, C'_D, C'_L
- ...

→ Classification of deck sections and related aerodynamic coefficients

all measured in the wind-tunnel at the CSTB (Nantes)

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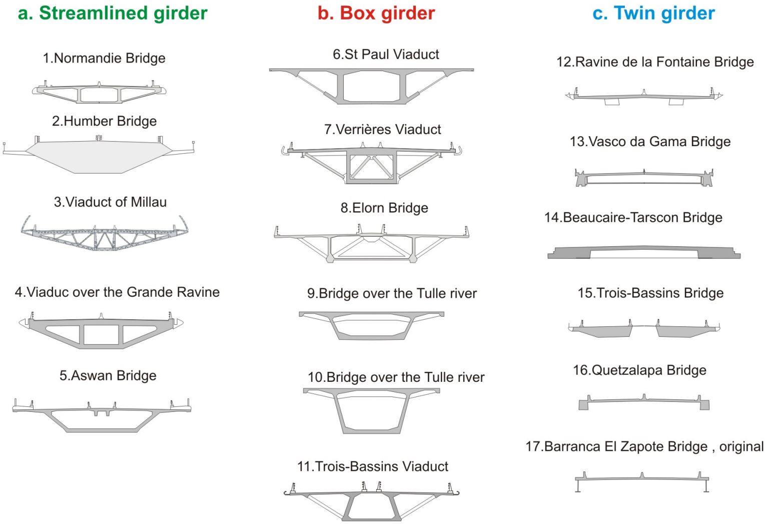
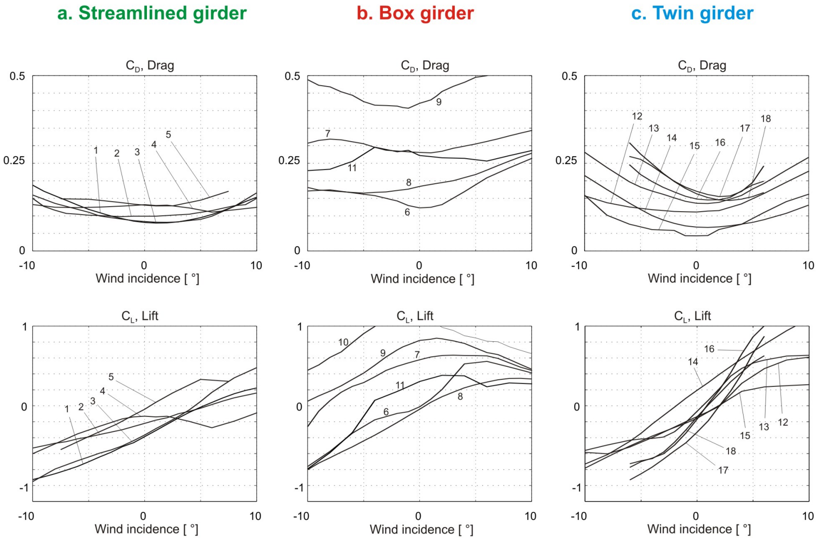
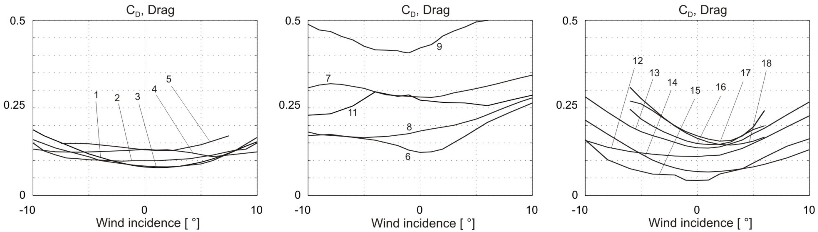



a. Streamlined girder
b. Box girder
c. Twin girder
C$_D$, Drag
C$_L$, Lift
Wind incidence [°]

Classification

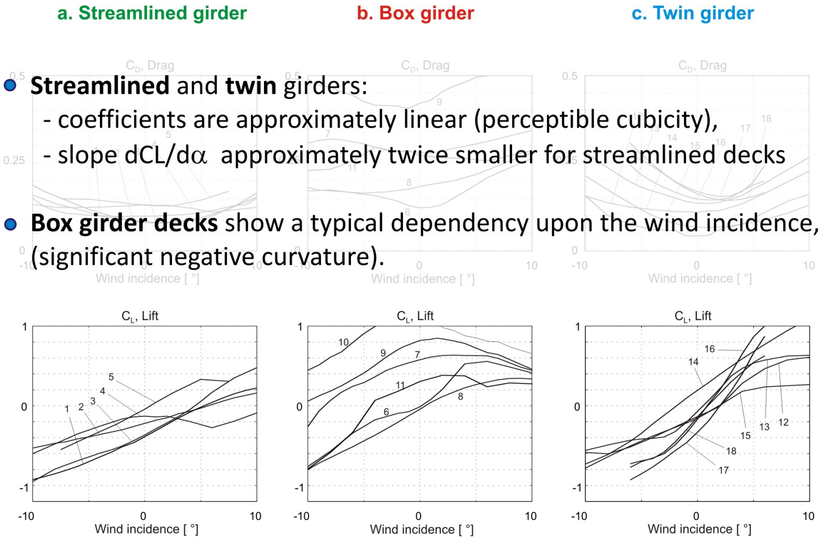
a. Streamlined girder **b. Box girder** **c. Twin girder**



- Drag is minimum for zero-incidence (positive curvature)
- Streamlined girders show the lowest drag coefficients (small height/width ratios & normalization of aerodynamic forces with respect to the deck width B)
- Box girder decks show the largest variability of drag coefficients.

Classification

- **Streamlined** and **twin** girders:
  - coefficients are approximately linear (perceptible cubicity),
  - slope dCL/dα approximately twice smaller for streamlined decks
- **Box girder decks** show a typical dependency upon the wind incidence, (significant negative curvature).



Pattern Space Representation (c_0, c_1, c_2)

Aim: Collapse information to a set of scalars

We fit a polynomial aerodynamic law of the form[1]

$$C(\alpha) = \sum_{k=0}^{p} \frac{c_i}{k!} \alpha^k .$$

In this work, $p = 2$. We thus have

- c_0, c_1, c_2 for each deck
- statistics of c_0, c_1, c_2 for each deck typology

(1) for details, see:
Denoël, V. (2009). "Polynomial approximation of aerodynamic coefficients based on the statistical description of the wind incidence." Probabilistic Engineering Mechanics 24(2): 179-189..

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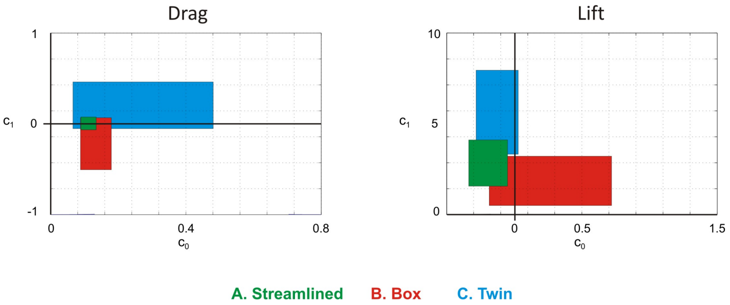

(Boxes represent the mean +/- one std of the deck sections in each catergory)

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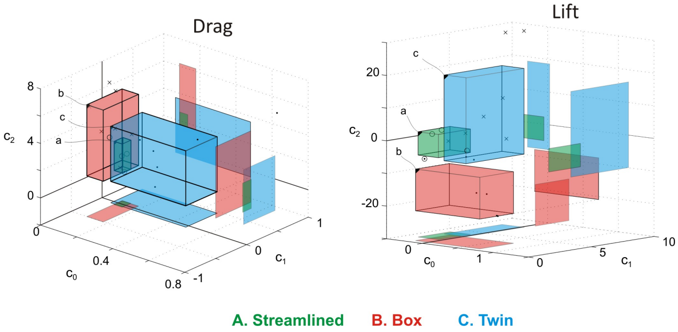

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Skewness of the quasi-steady loading

1. Assume a Gaussian turbulence

$$p_{uw}(u,w) = \frac{1}{2\pi I_u I_w U^2 \sqrt{1-\rho^2}} e^{\frac{-1}{2(1-\rho^2)U^2}\left(\frac{u^2}{I_u^2} - \frac{2\rho uw}{I_u I_w} + \frac{w^2}{I_w^2}\right)}$$

2. Assume a quasi-steady loading

$$F(t) = \frac{1}{2}\rho C[\alpha(t)] B V^2(t).$$

with $\alpha(t)$ and $V(t)$ are functions of u and w.

3. PDF of a continuous function $f(u,w)$:

$$p_f(f) = \lim_{df \to 0} \frac{1}{df} \iint_{f<f(u,v)<f+df} p_{uv}(u,v)dudv.$$

Impractical results → asymptotic series expansion for small I_u, I_w

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Impractical results $\rightarrow$ asymptotic series expansion for small I_u, I_w

After some developments ...(1)

$$m_{1,f} \equiv \mu_f \simeq \left(\frac{1}{2}\rho B U^2\right)\left(c_0 + \frac{c_2}{2} I_v^2.\right) \qquad (1)$$

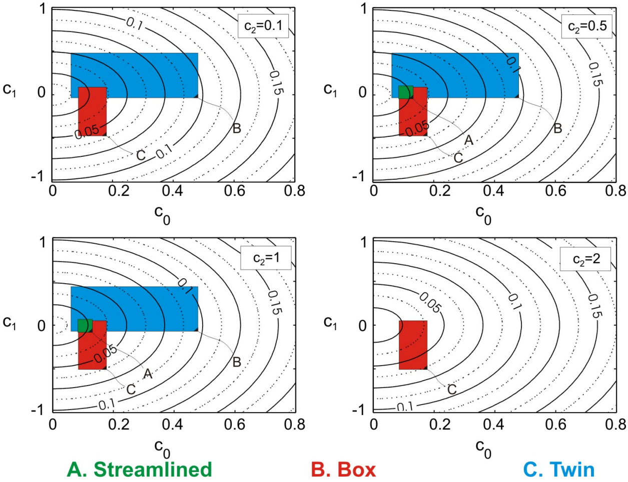
$$m_{2,f} \equiv \mu_f^2 + \sigma_f^2 \simeq \left(\frac{1}{2}\rho B U^2\right)^2 \left(c_0^2 + c_1^2 I_w^2 + \frac{3}{4} c_2^2 I_w^4 + c_0 c_2 I_w^2 + 6 c_0 c_1 I_u I_w\right). \qquad (2)$$

$$m_{3,f} \simeq \left(\frac{1}{2}\rho B U^2\right)^3 \left(c_0^3 + \frac{9}{2} c_1^2 c_2 I_w^4 + \frac{15}{8} I_w^6 c_2^3 + \frac{3}{2} c_0^2 c_2 I_w^2 + 3 c_0 c_1^2 I_w^2 + \frac{9}{4} I_w^4 c_0 c_2^2\right) \qquad (3)$$

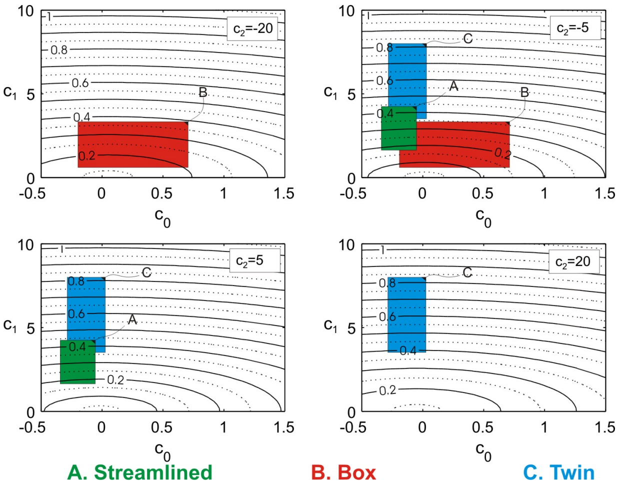
(Results are given for $\rho_{uw} = 0$)

(1) for details, see:
Denoël, V. (2009). "Limit analysis of the statistics of quasi-steady non-linear aerodynamic forces for small turbulence intensities." Probabilistic Engineering Mechanics 24(4): 552-564..

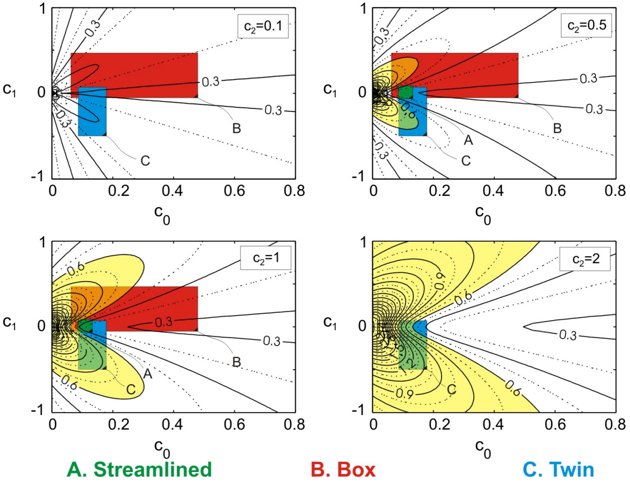
Standard Deviation of Drag Force



Standard Deviation of Lift Force



Skewness Coefficient of Drag Force



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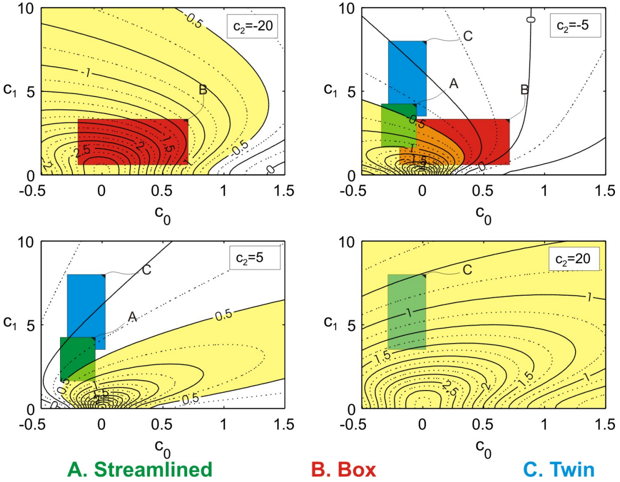
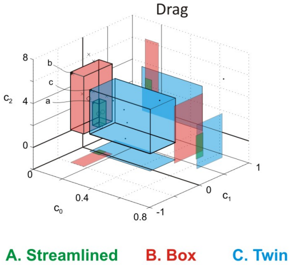


Summary of main contributions

- Ranges of variation of coefficients c_0 , c_1 and c_2 associated to three different deck typologies



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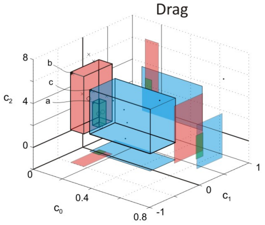
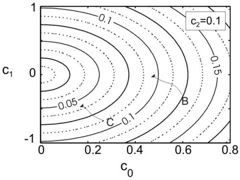
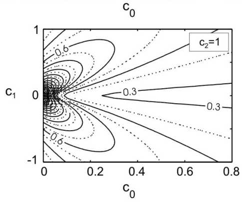


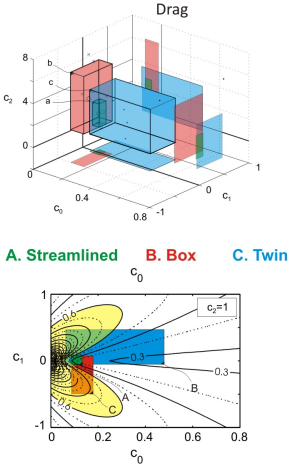
A. Streamlined B. Box C. Twin





Summary of main contributions

- Ranges of variation of coefficients c_0 , c_1 and c_2 associated to three different deck typologies
- Computation of “universal” variance and skewness plots in the pattern space
- Computation of the skewness of the aerodynamic loading for three dierent deck typologies
  - **Streamlined:** linear Gaussian but...
  - **Box:** drag is not skewed & lift is “well” skewed
  - **Twin:** most susceptible to provide a skew load



Thank you for your attention ...

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Contact me: v.denoel@ulg.ac.be

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