



**HAL**  
open science

# Aerodynamic behavior of an airfoil under extreme wind conditions

Ingrid Neunaber, Caroline Braud

► **To cite this version:**

Ingrid Neunaber, Caroline Braud. Aerodynamic behavior of an airfoil under extreme wind conditions. The Science of Making Torque from Wind (TORQUE 2020), Sep 2020, On-line due to COVID (organisation: TU-Delft ), Netherlands. hal-03437757

**HAL Id: hal-03437757**

**<https://hal.science/hal-03437757v1>**

Submitted on 20 Nov 2021

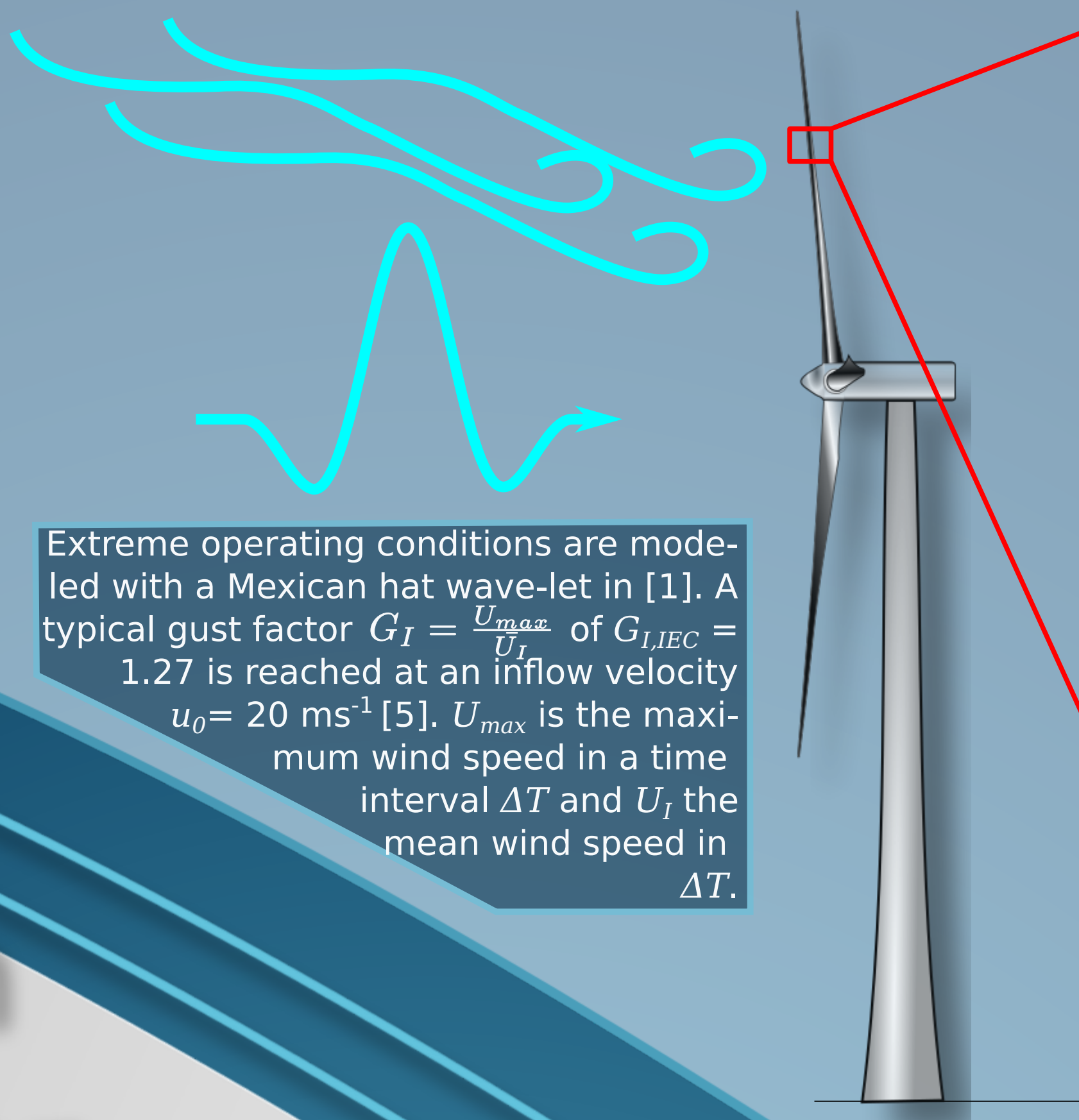
**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



# Motivation

- wind in the atmosphere is turbulent  $\Rightarrow$  turbulence increases loads [1]
- wind turbine safety and durability guaranteed by design requirements from IEC-61400-1 norm: extreme wind conditions are accounted for [2]
- interaction between complex, rapid flow structures and the rotor blade is not well understood: aerodynamic behavior of an airfoil is highly dependent on dynamic variations of the angle of attack between the flow and the blade



Extreme operating conditions are modeled with a Mexican hat wave-let in [1]. A typical gust factor  $G_I = \frac{U_{max}}{U_I}$  of  $G_{I,IEC} = 1.27$  is reached at an inflow velocity  $u_0 = 20 \text{ ms}^{-1}$  [5].  $U_{max}$  is the maximum wind speed in a time interval  $\Delta T$  and  $U_I$  the mean wind speed in  $\Delta T$ .

**A: regular inflow**  
The flow is attached to the airfoil and the wind turbine operates normally. The control can account for changes in the inflow.

**B: gust**  
A sudden change in the inflow velocity, i. e. a **gust**, causes a sudden change in the angle of attack at the rotor blade which leads to an overshoot in lift due to **dynamic stall** and results in **high loads**. Control mechanisms do not operate fast enough to avoid this.

Example of the lift coefficient in static and dynamic inflow conditions (after [3]).

# Aerodynamic behavior of an airfoil under extreme wind conditions

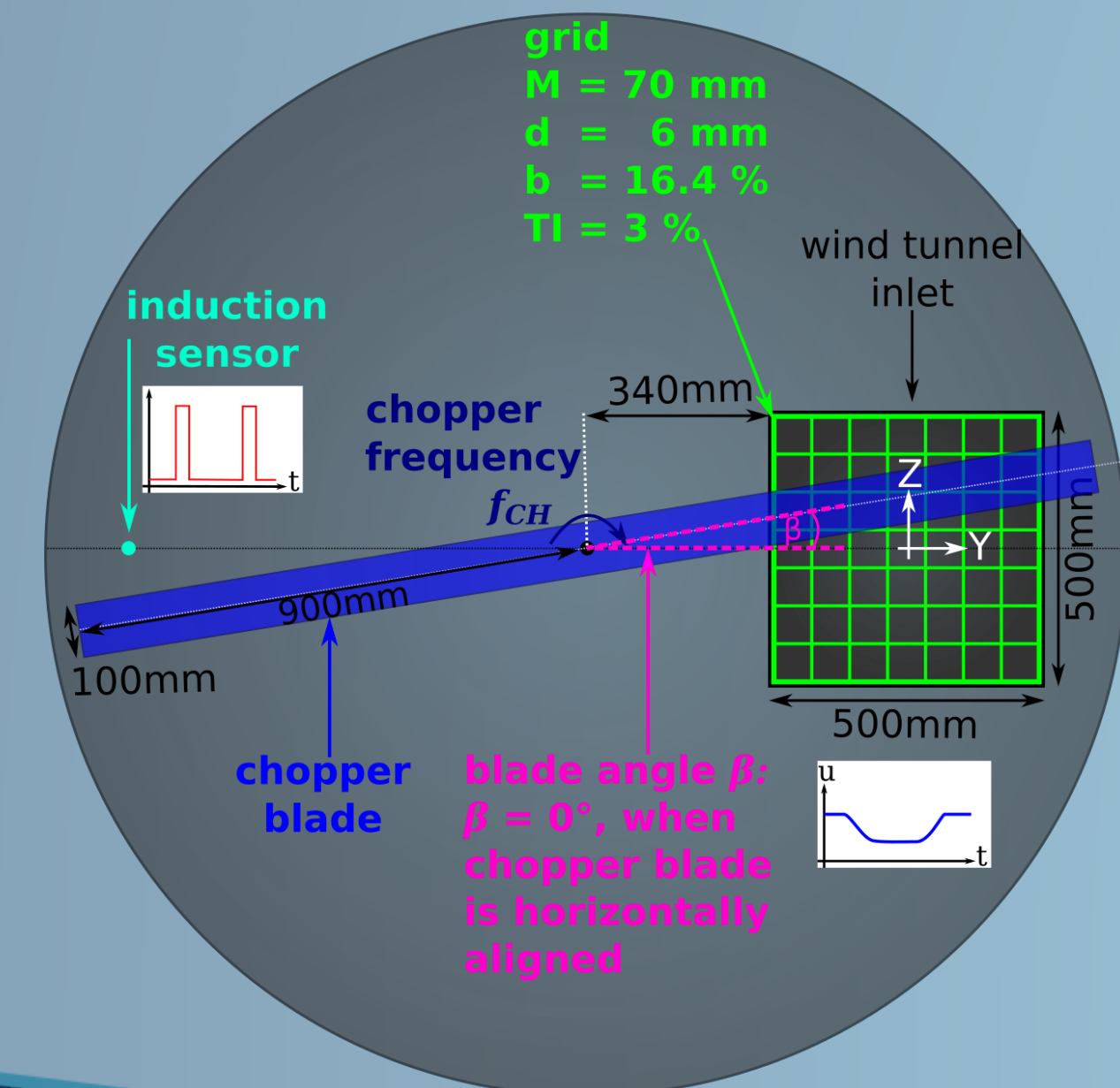
Ingrid Neunaber & Caroline Braud

## Setup

**The Chopper**  
Strong, rapid flow perturbations are generated by a rotating bar that cuts through the inlet of the wind tunnel [4]. Turbulence is added by a regular grid

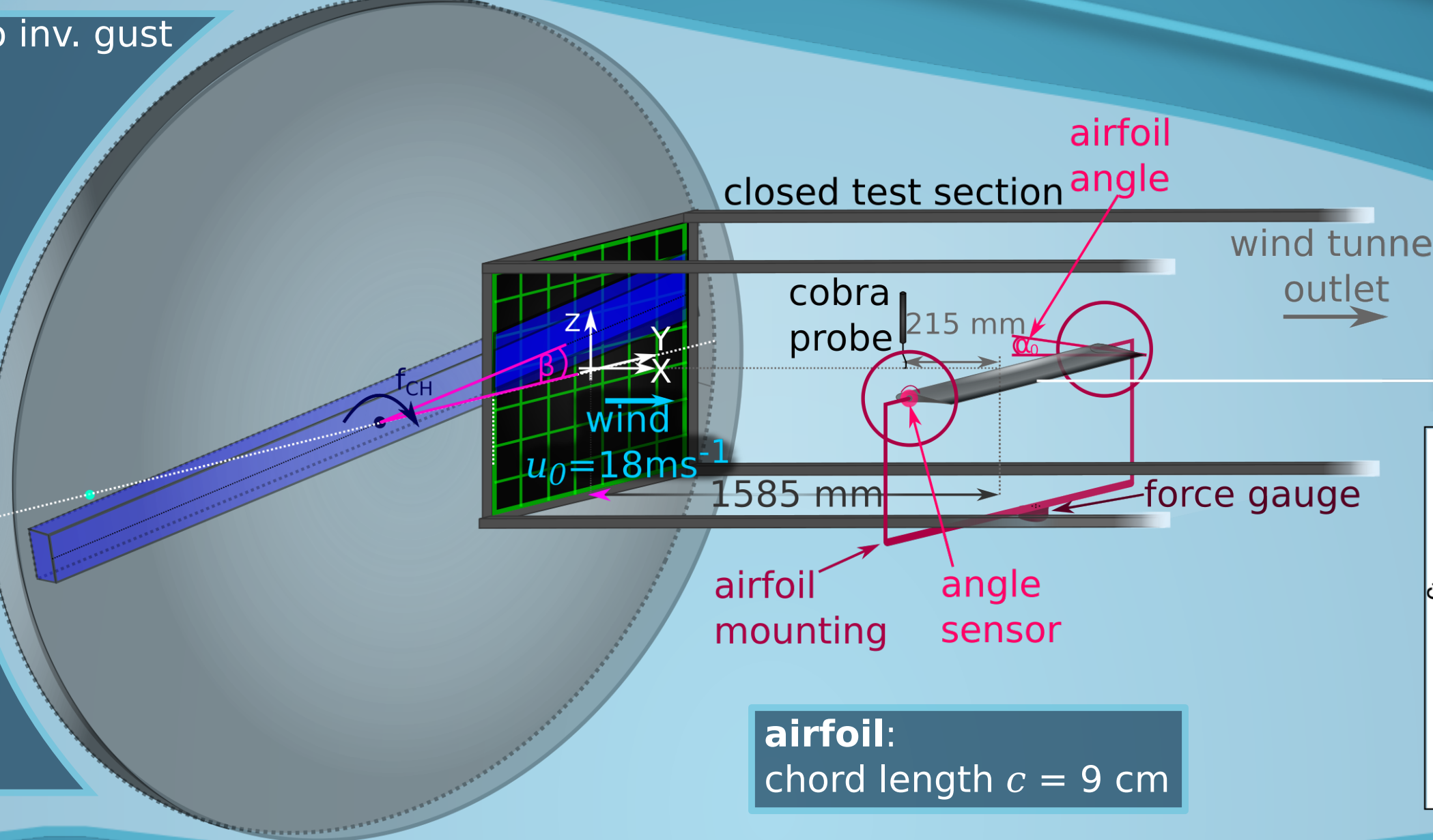


### A. Front view



### B. Setup

- Airfoil exposed to inv. gust
- 3 airfoil angles:  $\alpha_{01} = 0^\circ$ ,  $\alpha_{02} = 8^\circ$ ,  $\alpha_{03} = 12^\circ$
  - 2 chopper frequencies:  $f_{CH1} = 0.04 \text{ Hz}$  ( $t = 600 \text{ s}$ ),  $f_{CH2} = 0.4 \text{ Hz}$  ( $t = 120 \text{ s}$ )
  - inflow measured with cobra probe at  $f_s = 2.5 \text{ kHz}$
  - inflow velocity  $u_0 = 18 \text{ ms}^{-1}$



## Objectives

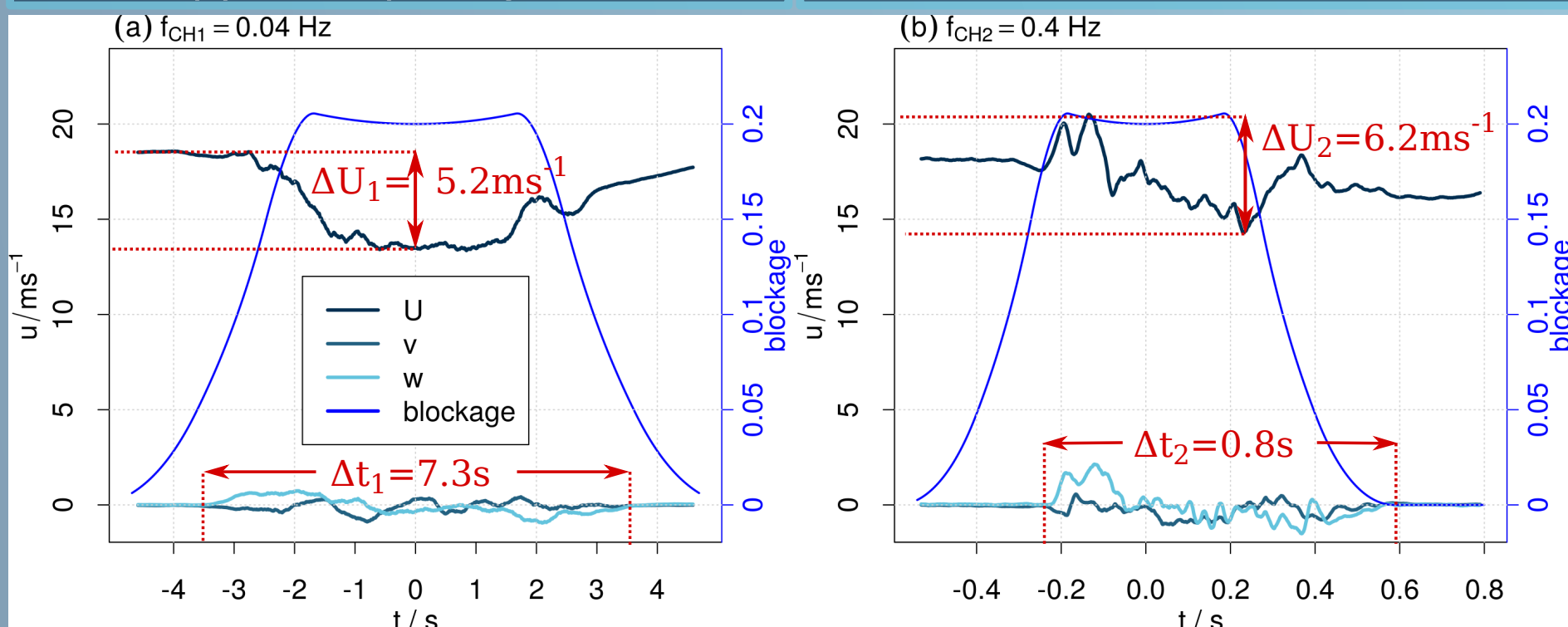
- introduce a **setup** capable of producing strong, rapid flow variations while also including **turbulence**
- **characterize** the flow generated by this setup
- **expose an airfoil** to the inflow and investigate the impact of extreme flow variations on the lift response of the airfoil

## Results: Inflow

### The inverse Gust

- large, rapid velocity deficit in  $U$  induced by chopper:  $\Delta U_1 = 5.2 \text{ ms}^{-1}$  /  $\Delta U_2 = 6.2 \text{ ms}^{-1}$
- shape of inverse gust depends on chopper frequency

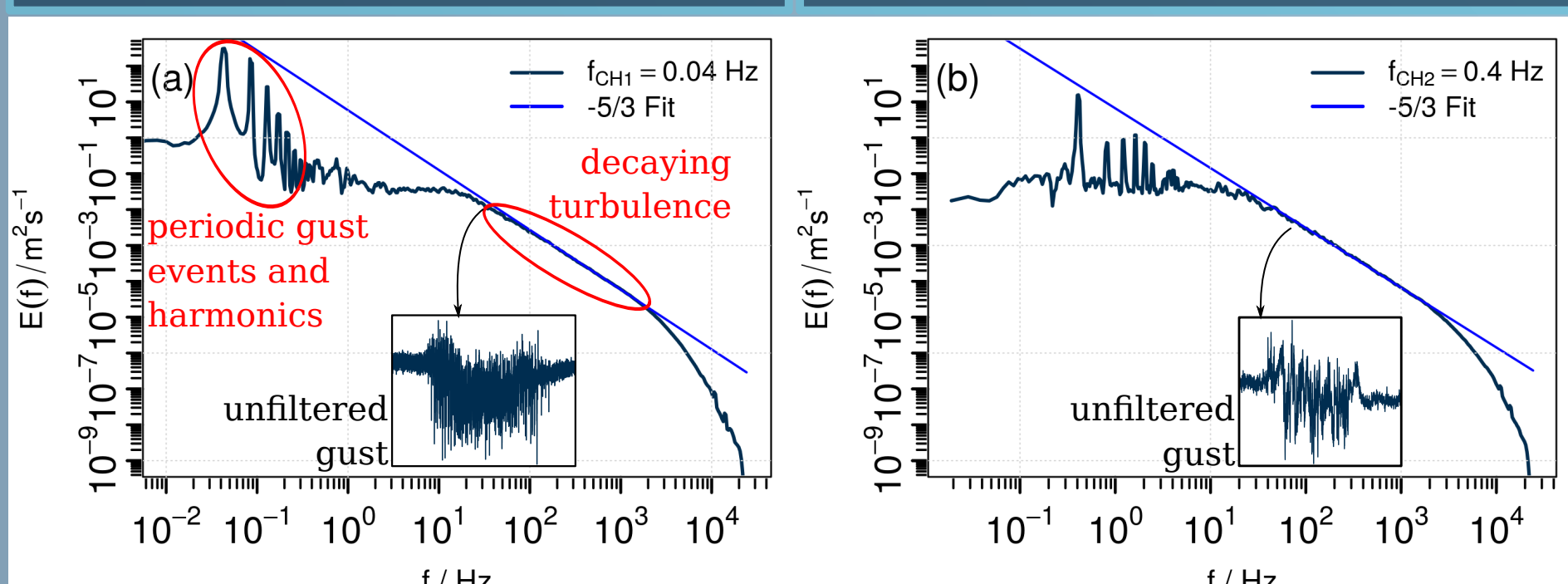
- variations in  $v$  and  $w$  component
- gust duration  $\Delta t \sim$  anti-proportional to chopper frequency:  $\Delta t \approx 7.3s(f_{CH1})$  /  $\Delta t \approx 0.8s(f_{CH2})$
- $TI \approx 17\%$  ( $f_{CH1}$ ) /  $TI \approx 13\%$  ( $f_{CH2}$ )
- $G_I \approx 1.16$  ( $f_{CH1}$ ) /  $G_I \approx 1.2$  ( $f_{CH2}$ )



### The energy spectral density

- hot-wire measurement with  $f_s = 50 \text{ kHz}$  for high resolution

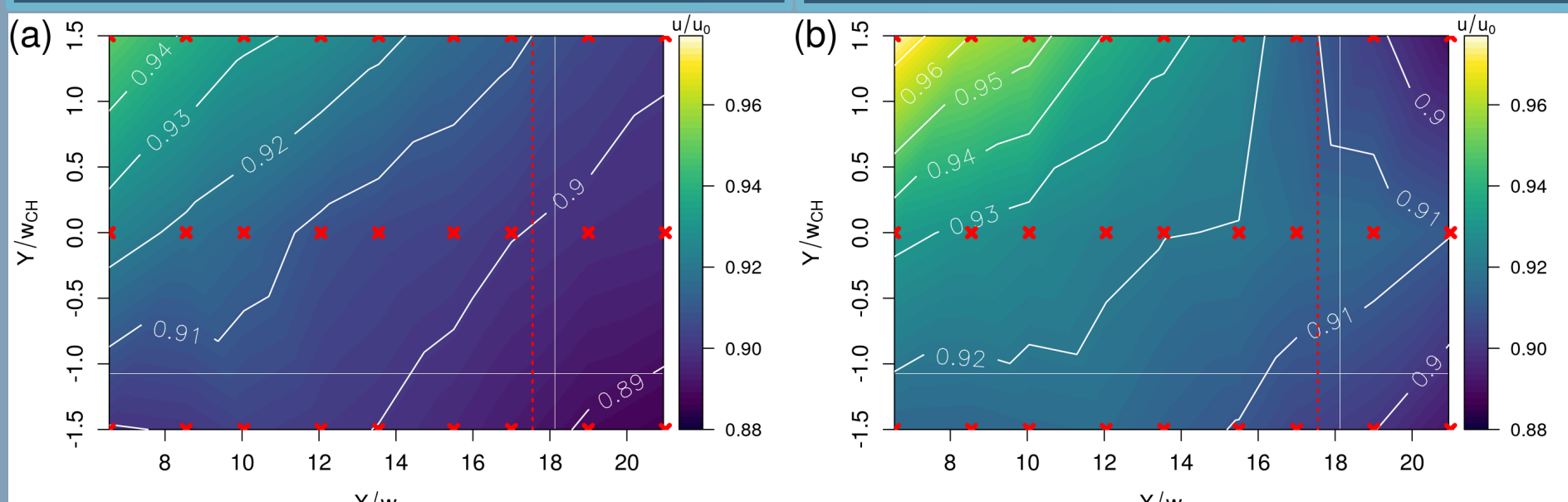
- periodic gust events in time series visible as peaks with  $f_{CH}$
- turbulence in the gust decays [4]



### The mean flow field

- flow field in complete test section scanned with cobra probes - fig.3:interpolated contour plot of

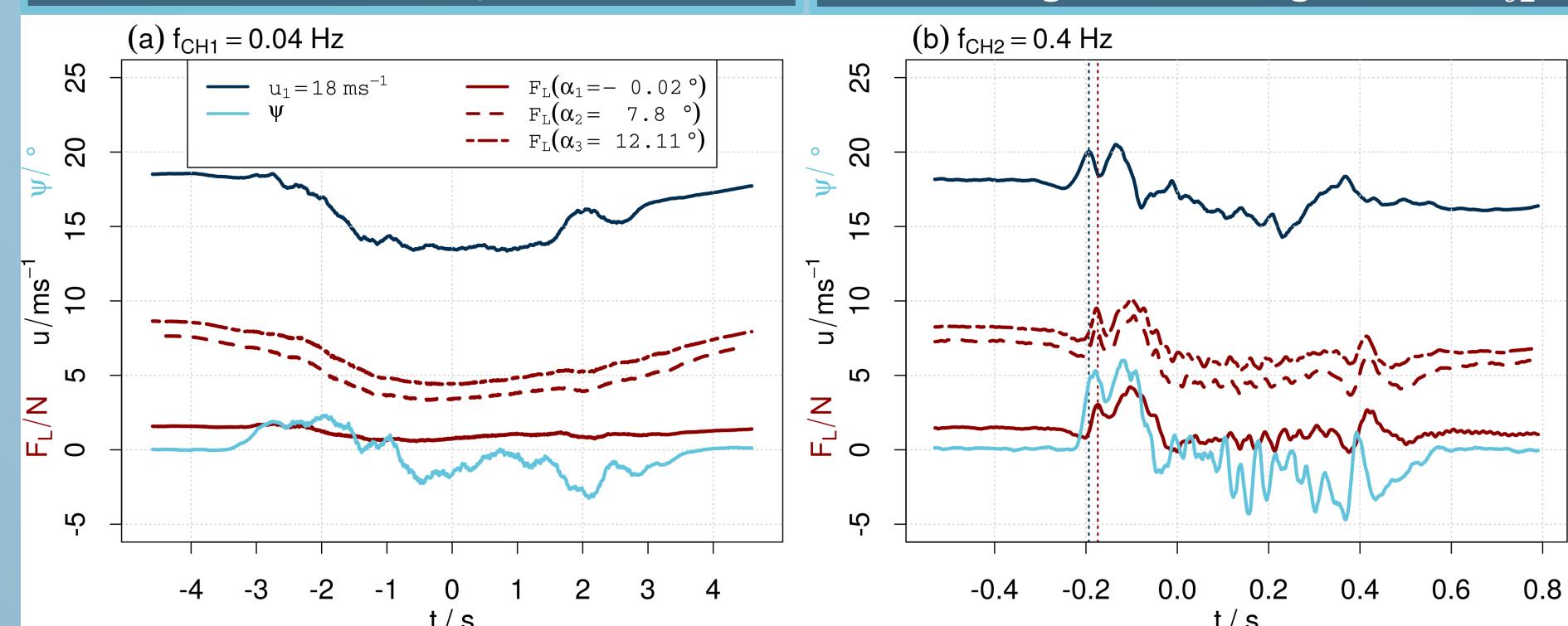
- normalized mean gust velocity - flow inhomogeneous close to the inlet but more homogeneous downstream at airfoil position



## Results: Airfoil

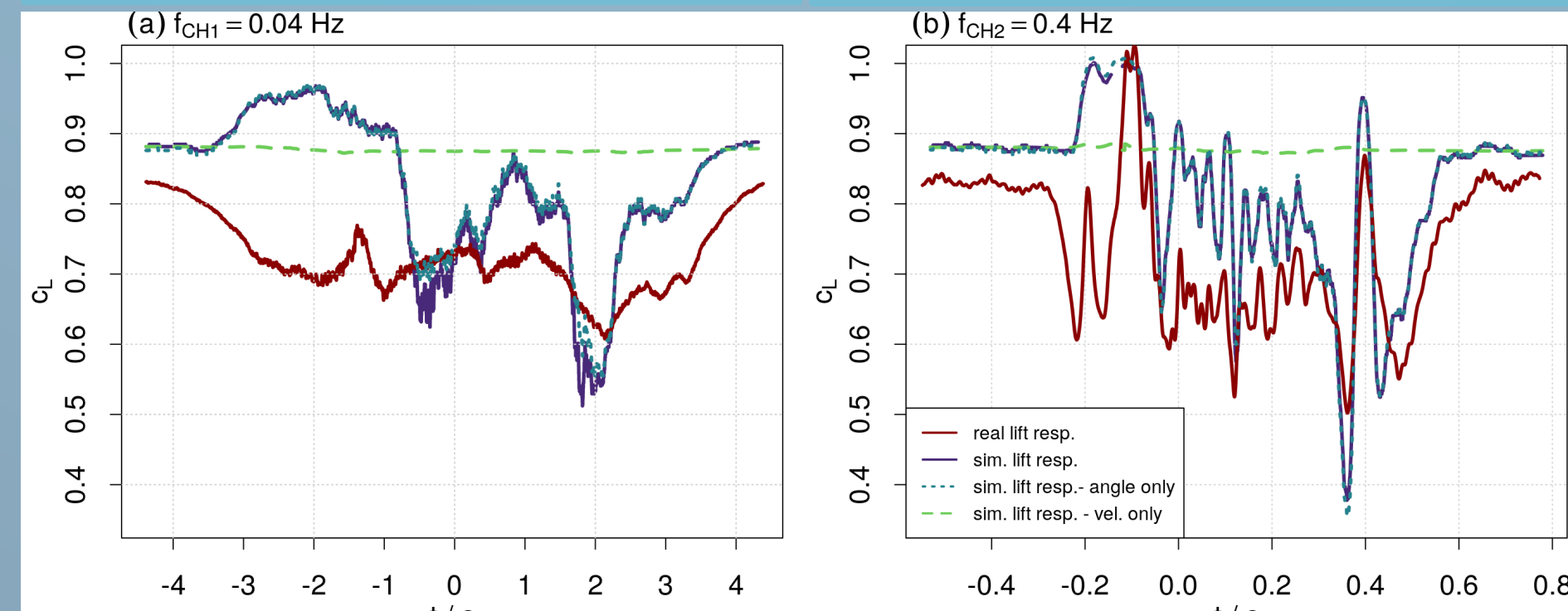
### The airfoil response

- fig. 4 shows the response of the phase-averaged, smoothed lift force  $F_L$  to the gust for the three airfoil angles, the inflow velocity and the flow pitch angle  $\psi$
- $\Rightarrow$  **angle of attack:  $\alpha = \alpha_0 + \psi$**
- the higher  $\alpha_0$ , the higher  $F_L$
- lift response follows mean flow component  $U$  of the inverse gust
- small influence of  $\psi$  on  $F_L$



### Simulated airfoil response

- further investigation of the influence of  $U$  and  $\psi$  on the lift response of the airfoil
- interpolated surface fit of  $c_L(\alpha, u_0)$  (cf. setup) used to calculate expected response of  $c_L$  to gust
- figure 5: influence of  $U$  and  $\psi$  can be separated by calculating  $c_L$  with respect to  $U$  (-),  $\psi$  (-), and both  $U$  and  $\psi$  (-) for  $\alpha_{02}$  - additionally: measured  $c_L$  (—)



### The airfoil response: numbers

$\alpha_0 / ^\circ$	$f_{CH1}$	$f_{CH2}$
$\Delta U / \text{ms}^{-1}$	5.2	6.2
$\Delta \psi / ^\circ$	5.6	10.7
$\Delta F_L / N$	-0.02	1.23
	7.8	4.33
	12.11	4.26

- for  $f_{CH1}$ ,  $\Delta F_L$  is significantly smaller for  $\alpha_{01}$  than for  $\alpha_{02}$  and  $\alpha_{03}$
- for  $f_{CH2}$ ,  $\Delta F_L$  is similar for all airfoil angles but largest for  $\alpha_{02}$

### Main results

- the simulated  $c_L$  response is determined by change of  $\alpha$
- with respect to only  $U$ ,  $c_L$  would be constant
- the simulated and measured  $c_L$  are in the same order of magnitude but differ significantly in case of  $f_{CH1} \Rightarrow$  dynamic aerodynamic effects present
- for the rapidly changing flow of  $f_{CH2}$ ,  $\alpha$  does determine evolution

## Conclusions

- **new setup** for generation of complex, strong, turbulent flow changes for aerodynamic investigations presented: the *chopper*
- 2 different chopper frequencies investigated
- main **flow features** include
  - rapid strong inverse gust
  - decaying turbulence within gust (cf. [4])
  - changes of the mean velocity of over  $5 \text{ ms}^{-1}$  in less than  $2s$  ( $f_{CH1}$ ) /  $0.4s$  ( $f_{CH2}$ )
  - variation of  $v$  and  $w$  flow component during gust  $\Rightarrow$  dynamic angle of attack changes investigatable!
- the **response of the airfoil** to the gust
  - appears to be mainly determined by mean velocity
  - a comparison with the simulated gust response shows that dynamic effects that cannot be explained by the static lift curve are present
- in the **future**, we plan to
  - further customize the setup to also generate increasing gusts
  - investigate the dynamic effects using non-intrusive flow measurements (PIV) and local aerodynamic characterization

## Sources

- [1] Frandsen S (2007) Turbulence and turbulence generated structural loading in wind turbine clusters, Phd thesis, DTU - Risø National Laboratory
- [2] IEC 61400-1-4 (2019) Wind energy generation systems - Part 1: Design requirements, Report, International Electrotechnical Commission
- [3] Choudhry A, Leknys R, Arjomandi M and Kelso R (2014) An insight into the dynamic stall lift characteristics, *Experimental Thermal and Fluid Science* **58**
- [4] Neunaber I, Braud C (2020) First characterization of a new perturbation system for gust generation: The Chopper, *Wind Energy Science*, **5**
- [5] Bardal L M and Sætran L R (2016) Wind gust factors in a coastal wind climate, *Energy Procedia* **94** 417-424
- [6] Soulier A, Braud C, Voison D and Podvin B (2020) Ability of the e-TellTale sensor to detect flow features over wind turbine blades: flow stall/reattachment dynamics, *Wind Energy Science*, in review

## Acknowledgements

This work was carried out within the research projects ASAPe with the funding from region Pays-de-Loire, Centrale Nantes, and Ville de Nantes (grant no. 2018 ASAPe) and ePARADISE with the funding from ADEME/region Pays-de-Loire (grant no. 1905C0030). The authors would like to thank WEAMEC. The authors would like to thank CSTB for providing measurement equipment.