Ocean Engineering EU conference (OEE2021): CFD for simulating tidal turbine cavitation

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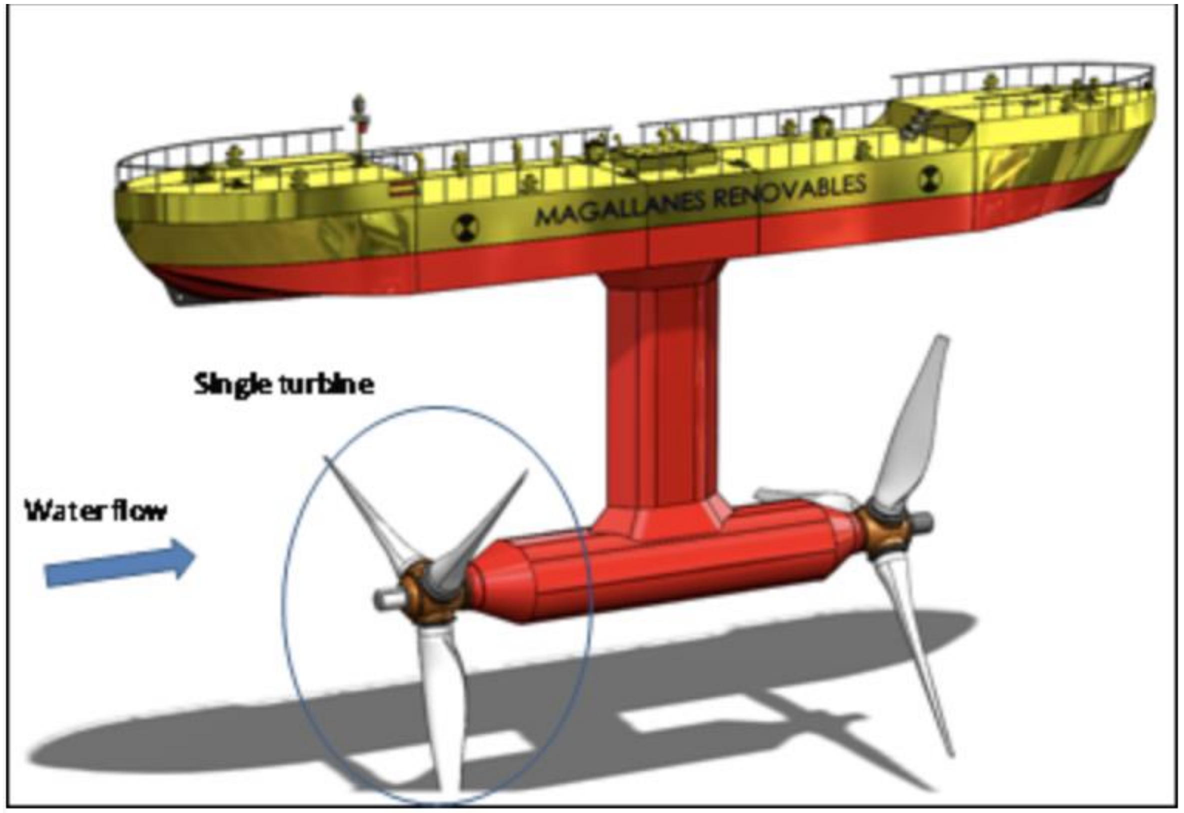
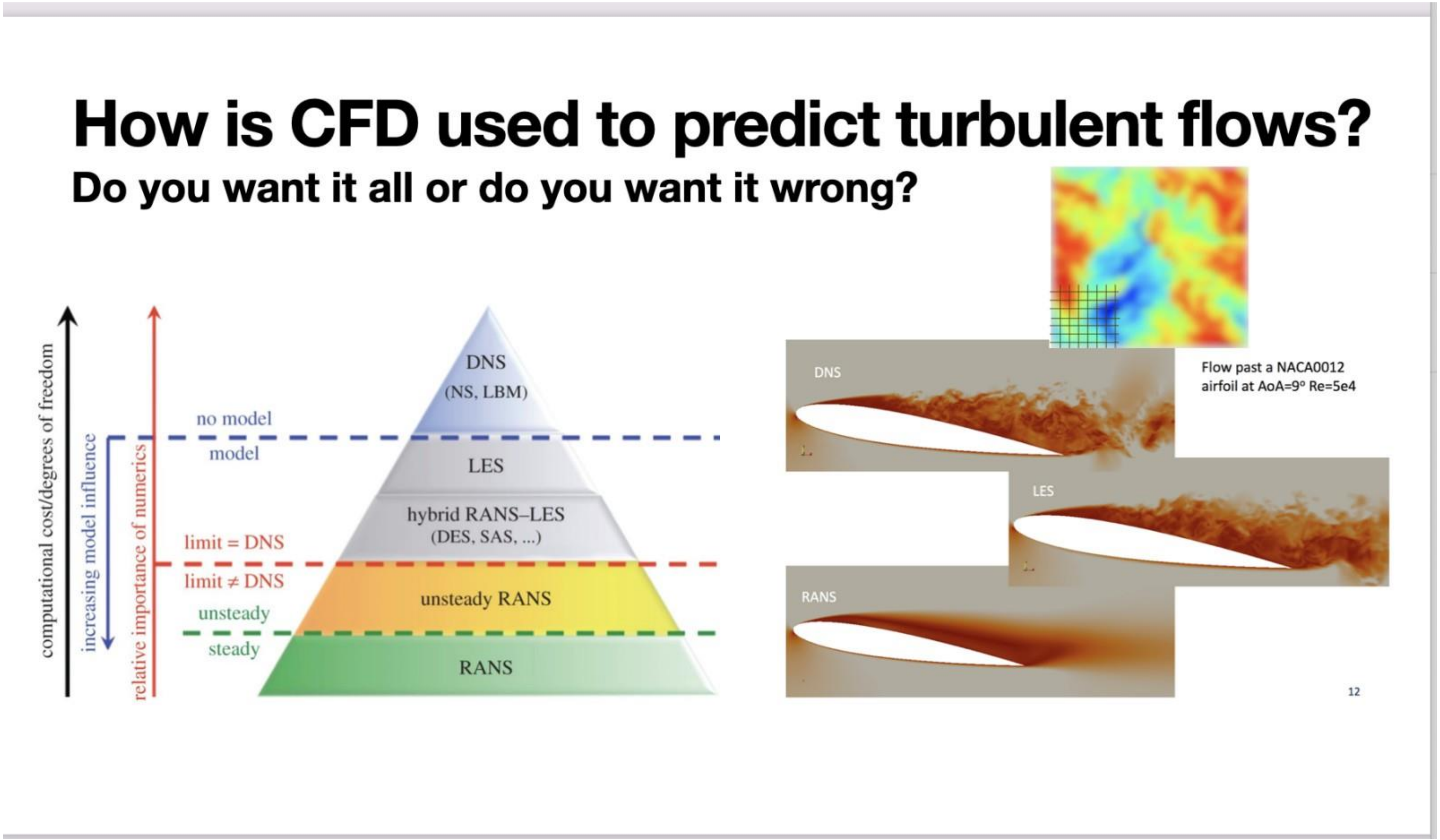
NEMMO
MAKING BLADES BETTER

NEMMO: Opportunity and challenges



- Dual tidal turbine powering the ship.
  - Upstream and downstream are mirror image
  - Rotating in opposite direction
- Massive turbines: 19.5 m diameter
- Problem of cavitation!

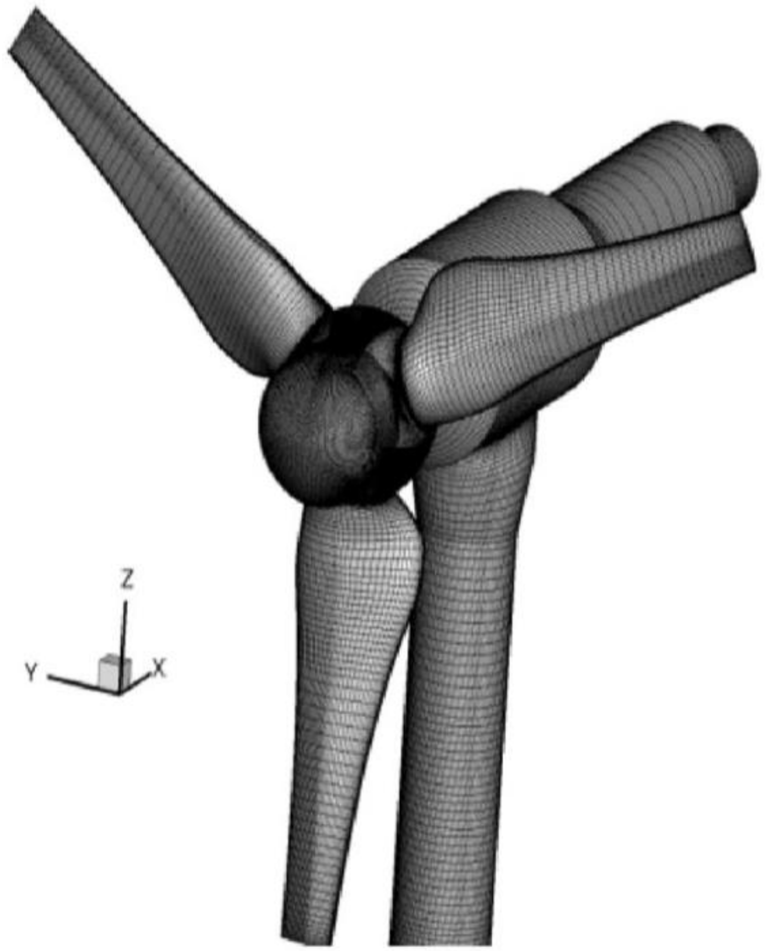
CFD for turbulent flows: “Why turbulence and why relativity” -- Werner Heisenberg (Nobel prize, 1932)



How is CFD used to predict turbulent flows?

Do you want it all or do you want it wrong?

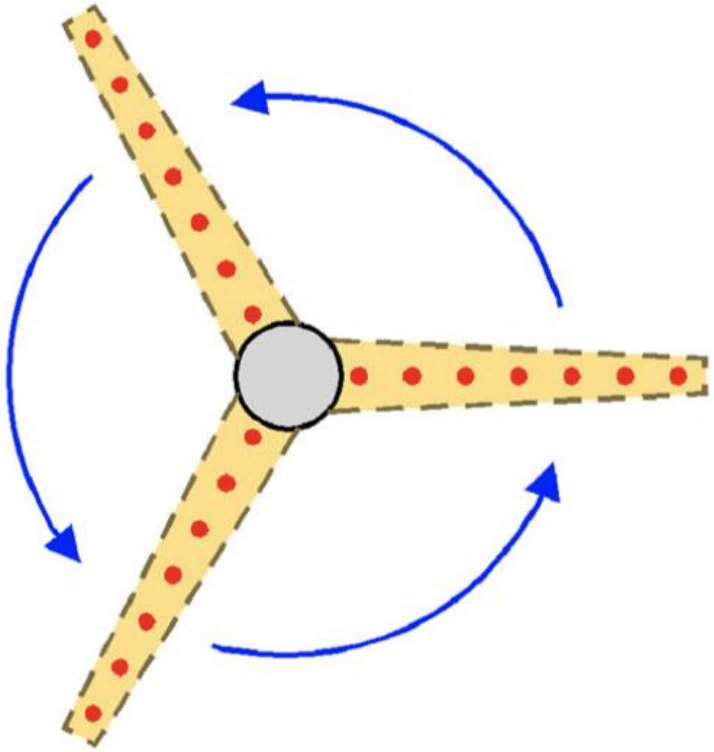
Explorations of LES-ALM for tidal turbine blade simulations



Blade-resolved, Apsley et al. 2018

- Liu et al., 2016 predicted that using 32 cores x 32 GB RAM in a week only RANS calculation could be done– Computationally prohibited to perform **LES (Large Eddy Simulations) using blade resolved simulations!**
- Complexity in terms of **meshing** and **computational expenses**.

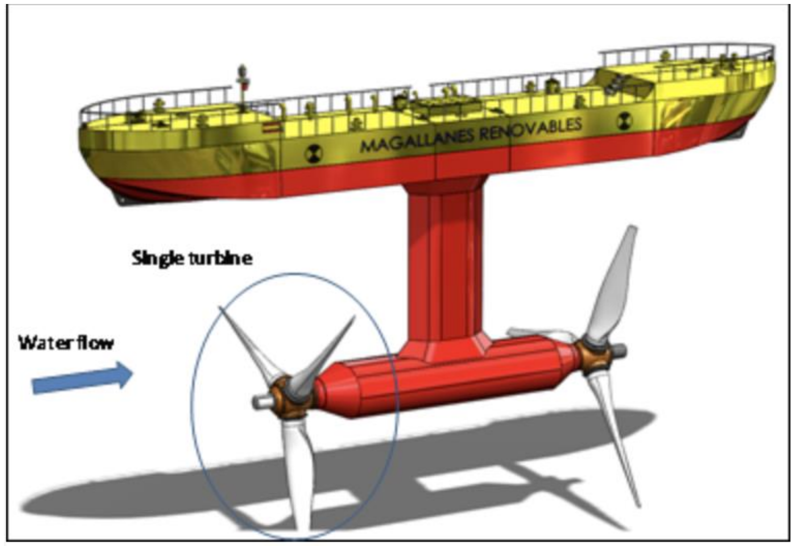
Explorations of LES-ALM for tidal turbine blade simulations

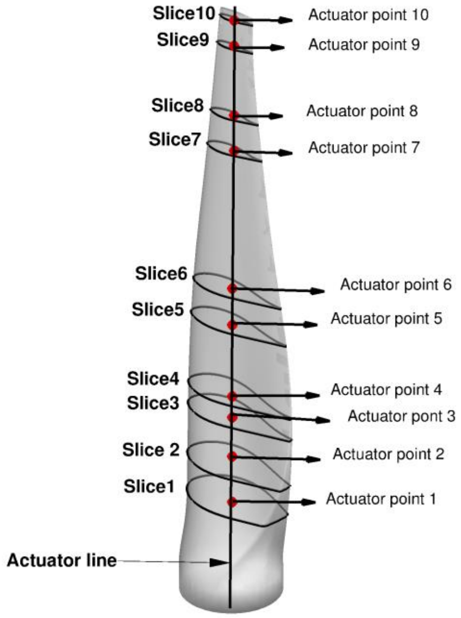


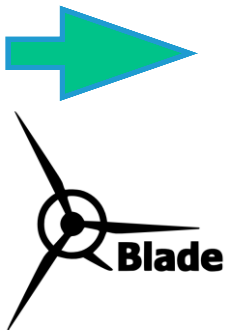
Actuator line method, Apsley et al. 2018

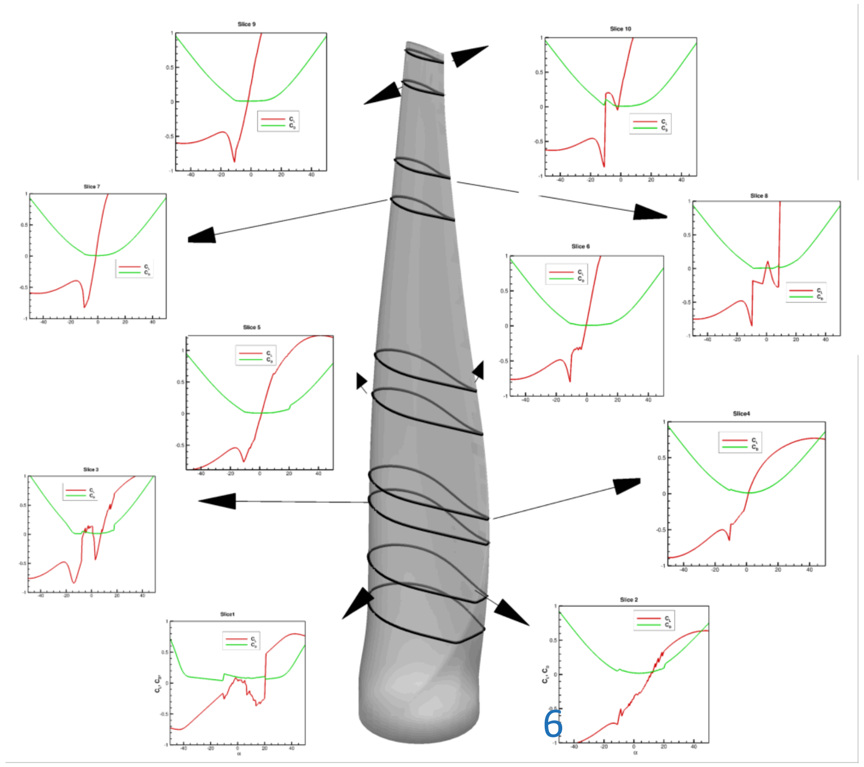
- Blades are modeled as actuator lines and each line comprises of different points, where the coefficient of lift and drag are known.
- **Computationally inexpensive:** Bachant et al. 2016 found that Actuator Line Method (ALM) could reduce the computational expenses by **fourth order** when compared against the blade resolved simulations.
- **Accuracy:** Pierella et al. 2014 documented the results from blind test 2 for NTNU-Norway and marked that "from the current comparisons it seems that a LES method coupled with an actuator line method is at present the best option."

OpenFOAM:
LES-ALM tidal turbines

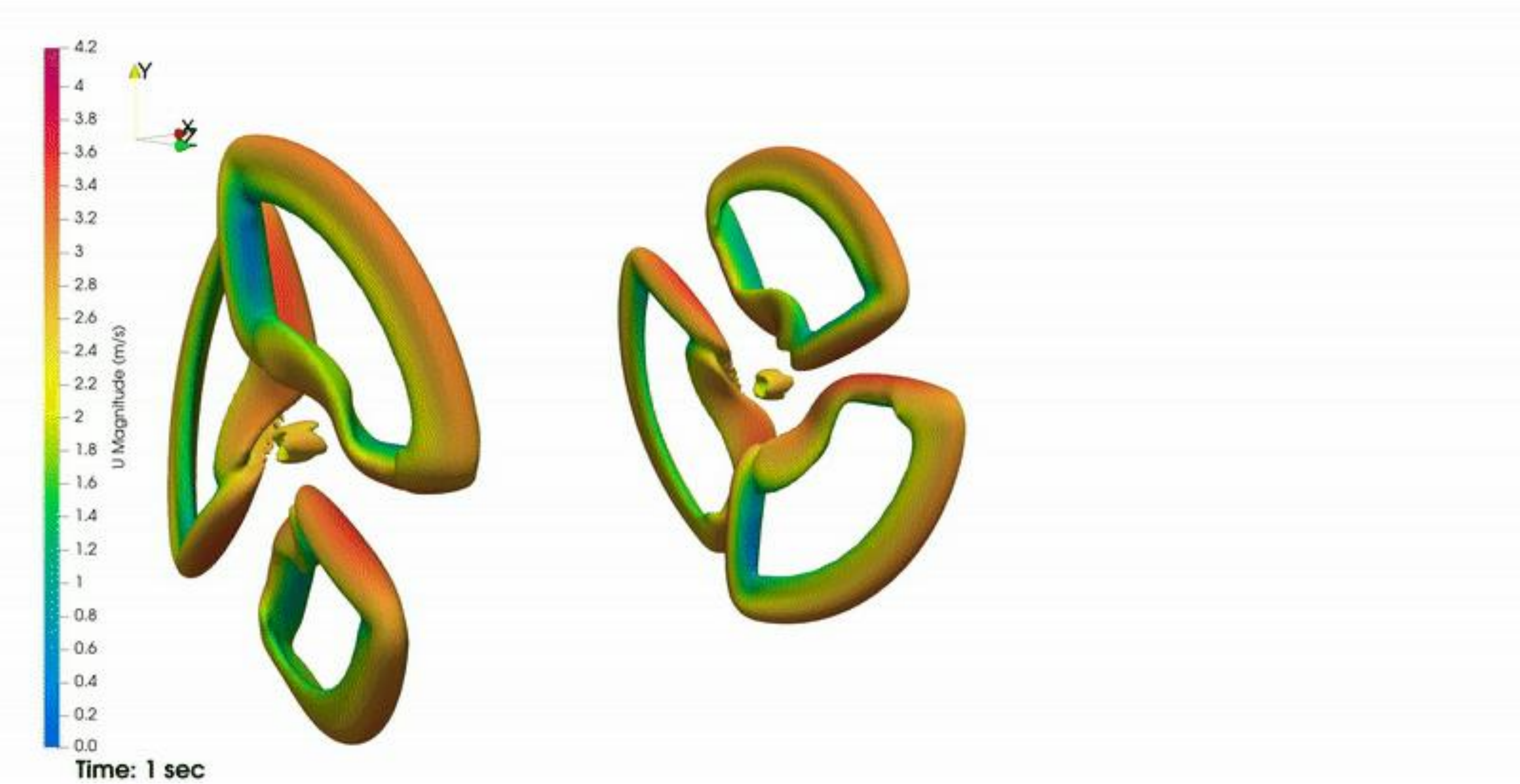


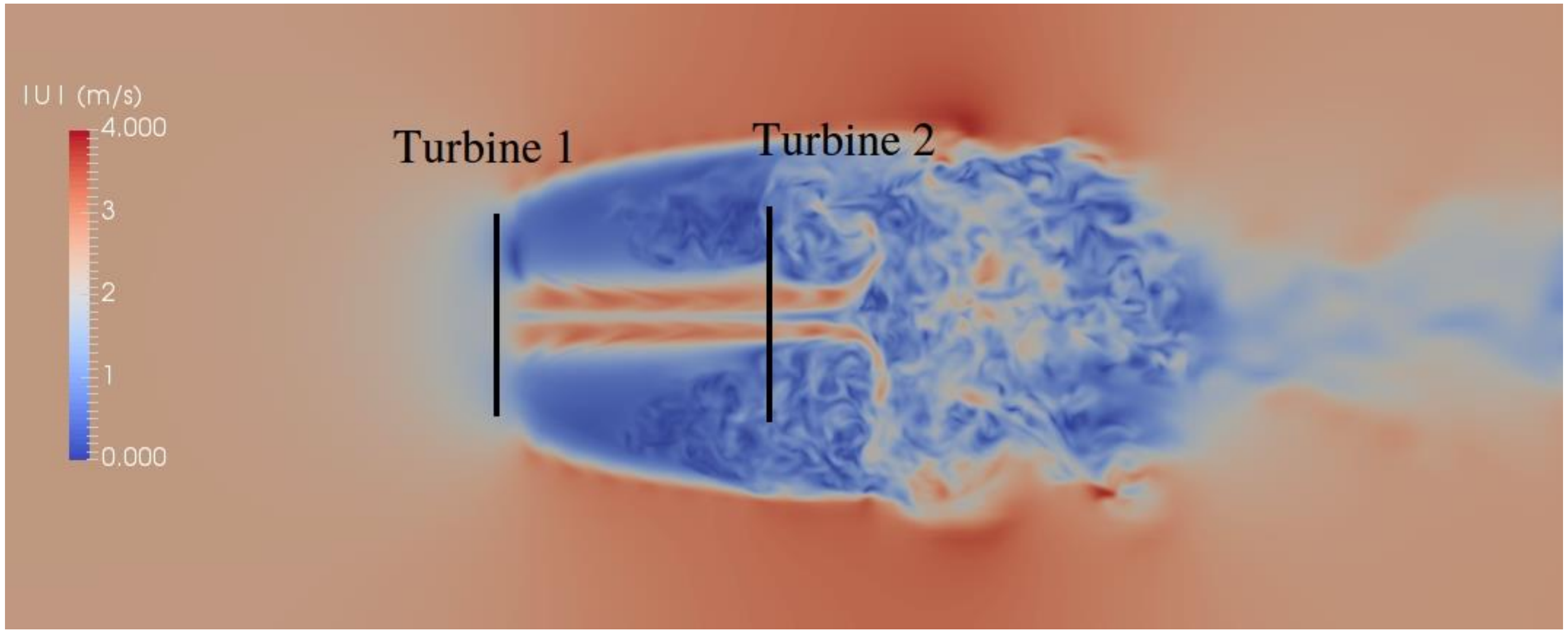


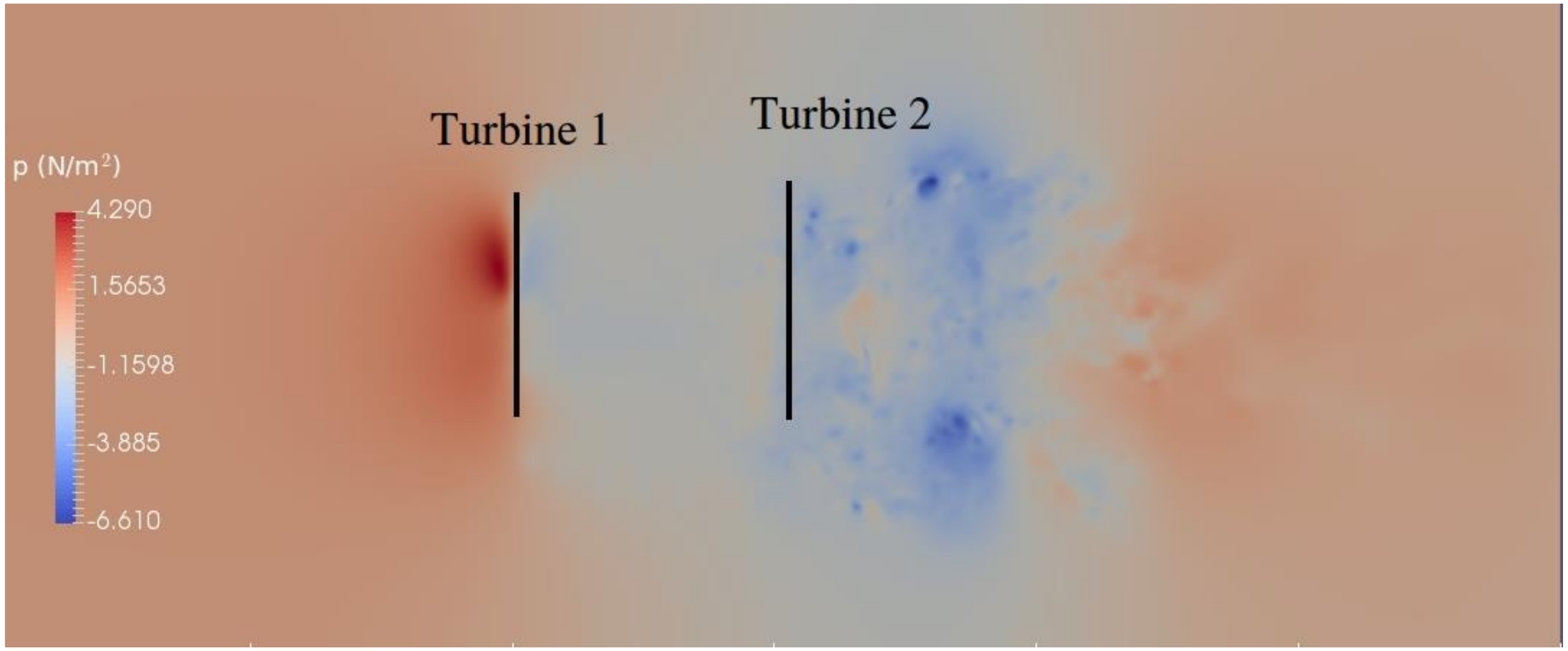




OpenFOAM LES-ALM: Magallanes tidal turbine



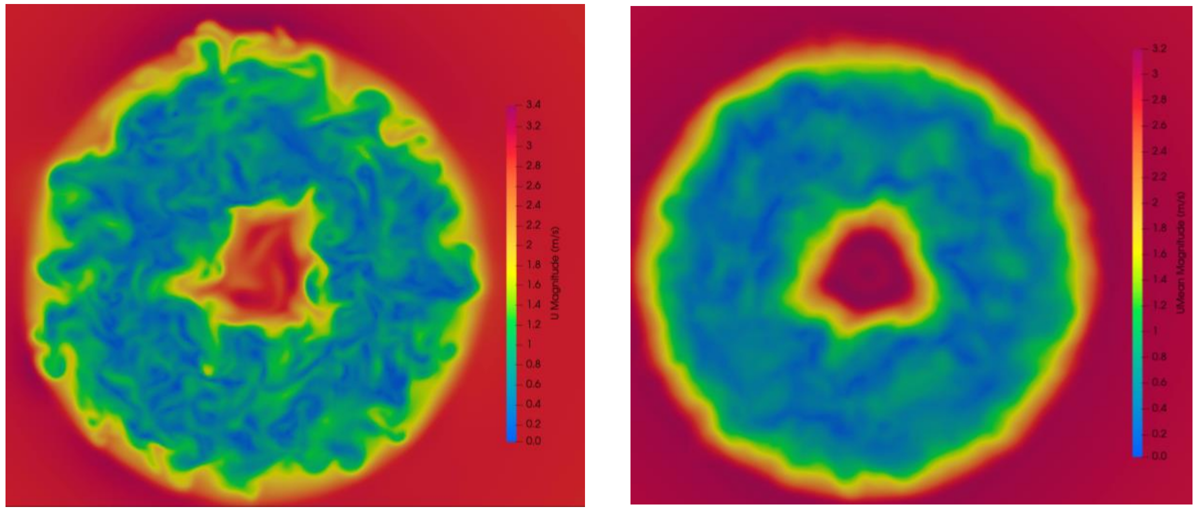




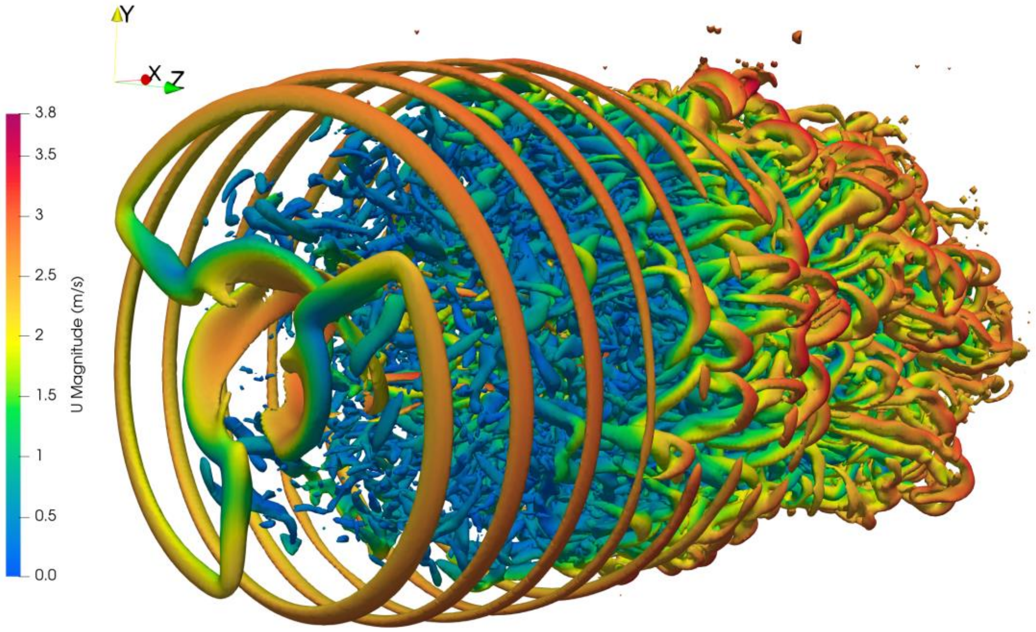
Note: Non-similar turbine wakes imply power/torque imbalance!

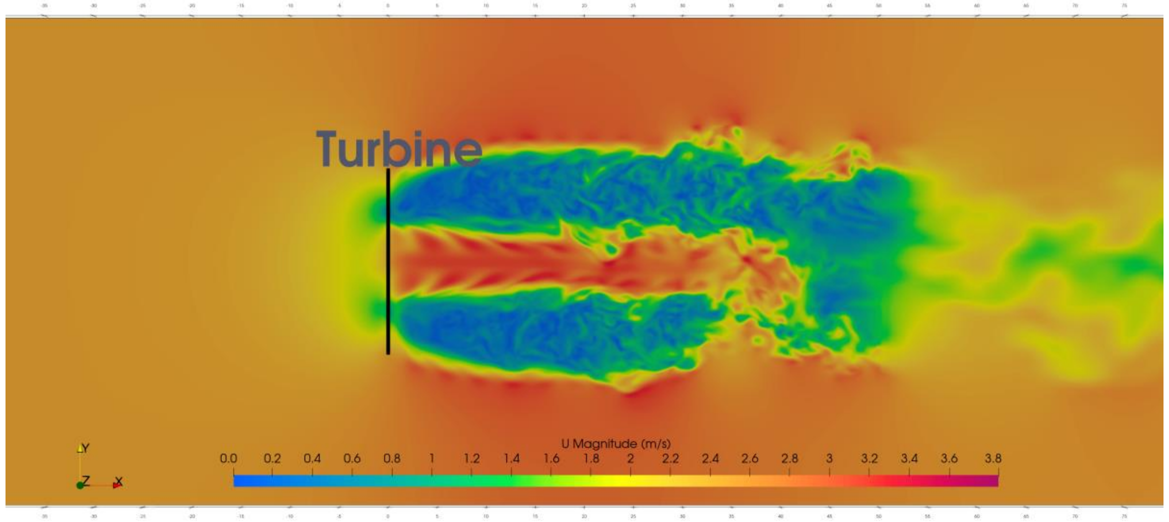
Improving power balance: Effect of upstream blade twist angle

- Only upstream tidal turbine blade considered
- *Varied upstream blade pitch angle*
- *Reduced power produced by first turbine* and
- *Generated more uniform wake for second turbine*



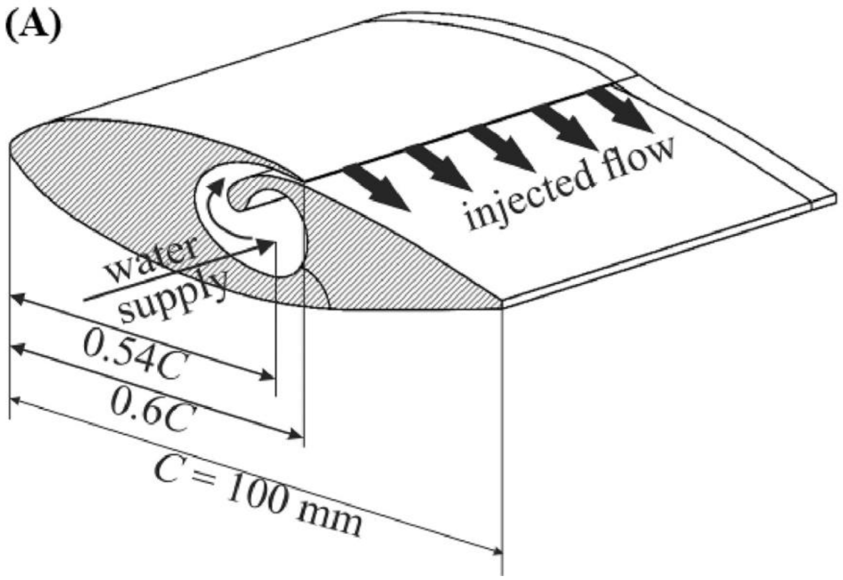
Sr No	Name	External pitch (in degree)	Results (C_P, C_T)
1	BDA_P0	0	$C_P = 0.46$, $C_T = 0.65$
2	BDA_P2	2	$C_P = 0.38$, $C_T = 0.52$
3	BDA_P4	4	$C_P = 0.28$, $C_T = 0.39$
4	BDA_P6	6	$C_P = 0.17$, $C_T = 0.24$

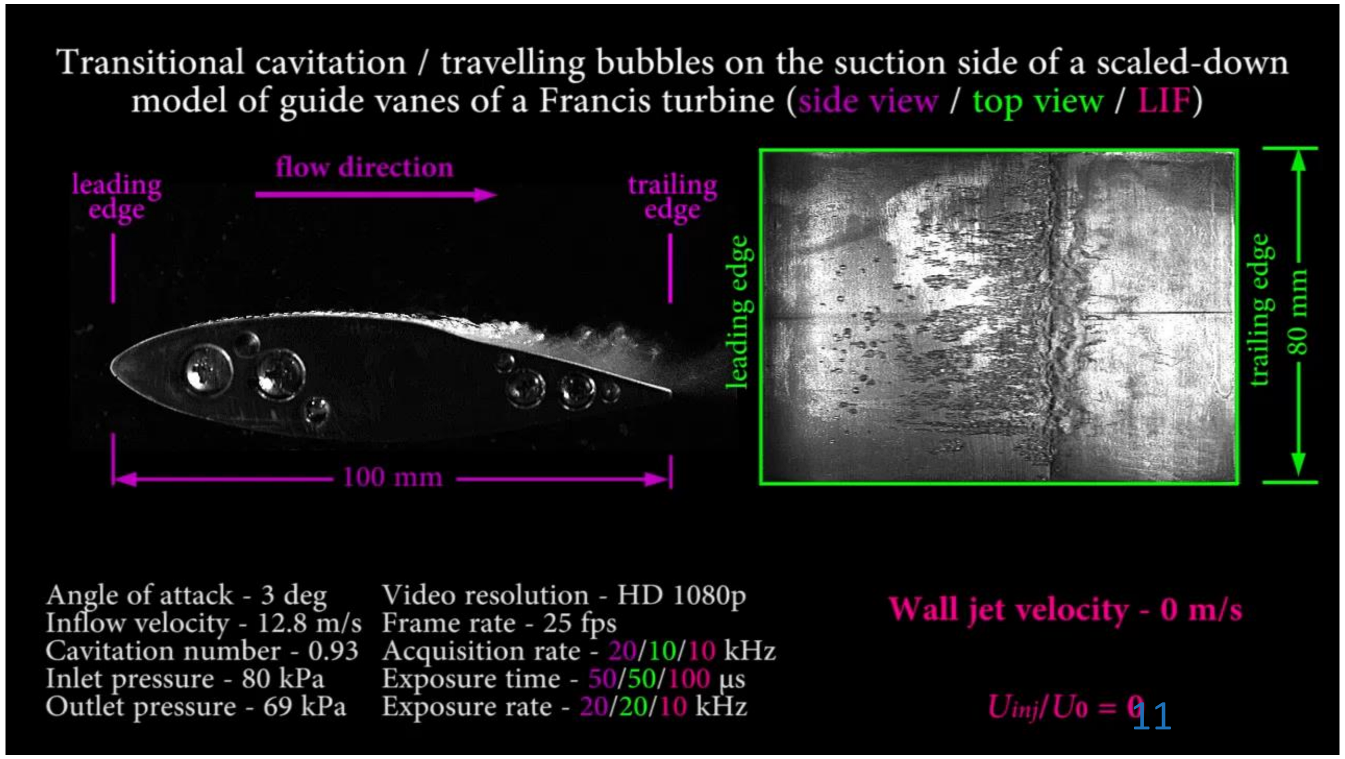




Cavitation and cavitation control

Cavitation and cavitation control: Validation/demo: Timoshevskiy et al. 2018




Transitional cavitation / travelling bubbles on the suction side of a scaled-down model of guide vanes of a Francis turbine (side view / top view / LIF)

Angle of attack - 3 deg
Inflow velocity - 12.8 m/s
Cavitation number - 0.93
Inlet pressure - 80 kPa
Outlet pressure - 69 kPa

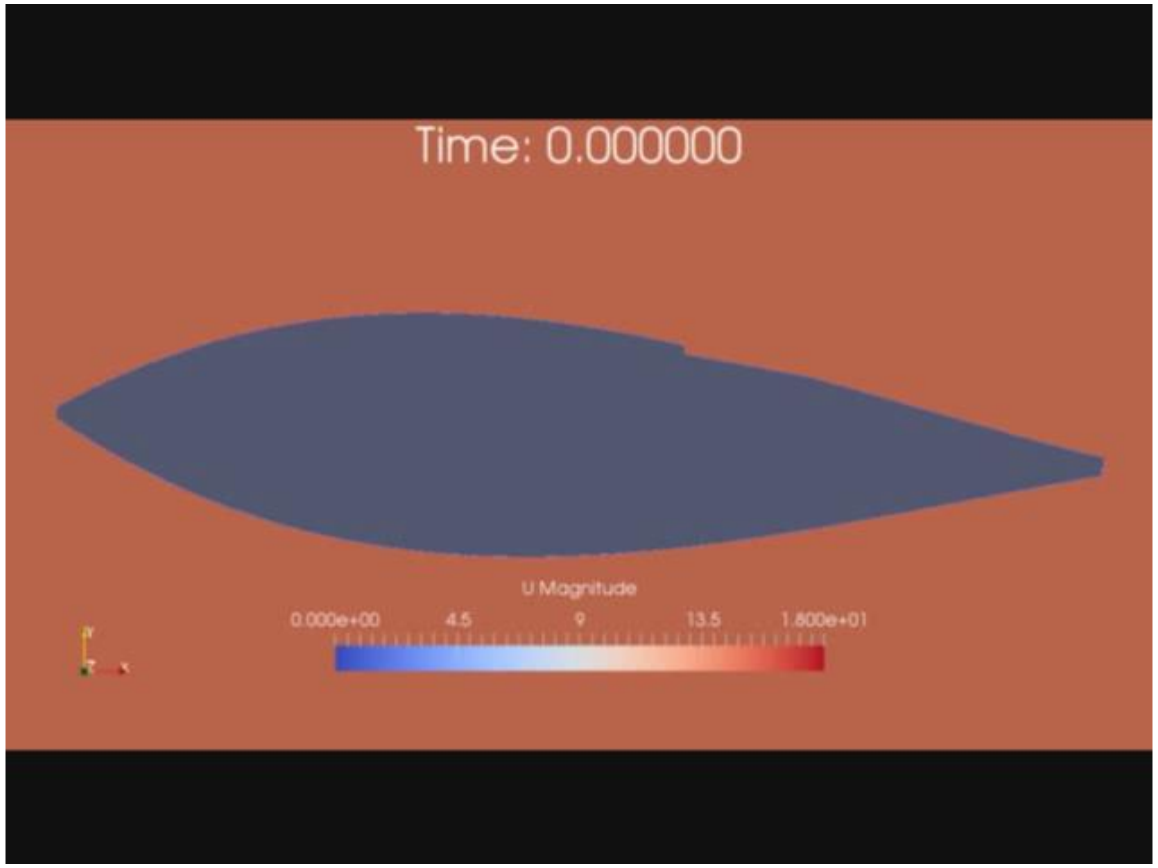
Video resolution - HD 1080p
Frame rate - 25 fps
Acquisition rate - 20/10/10 kHz
Exposure time - 50/50/100 µs
Exposure rate - 20/20/10 kHz

Wall jet velocity - 0 m/s

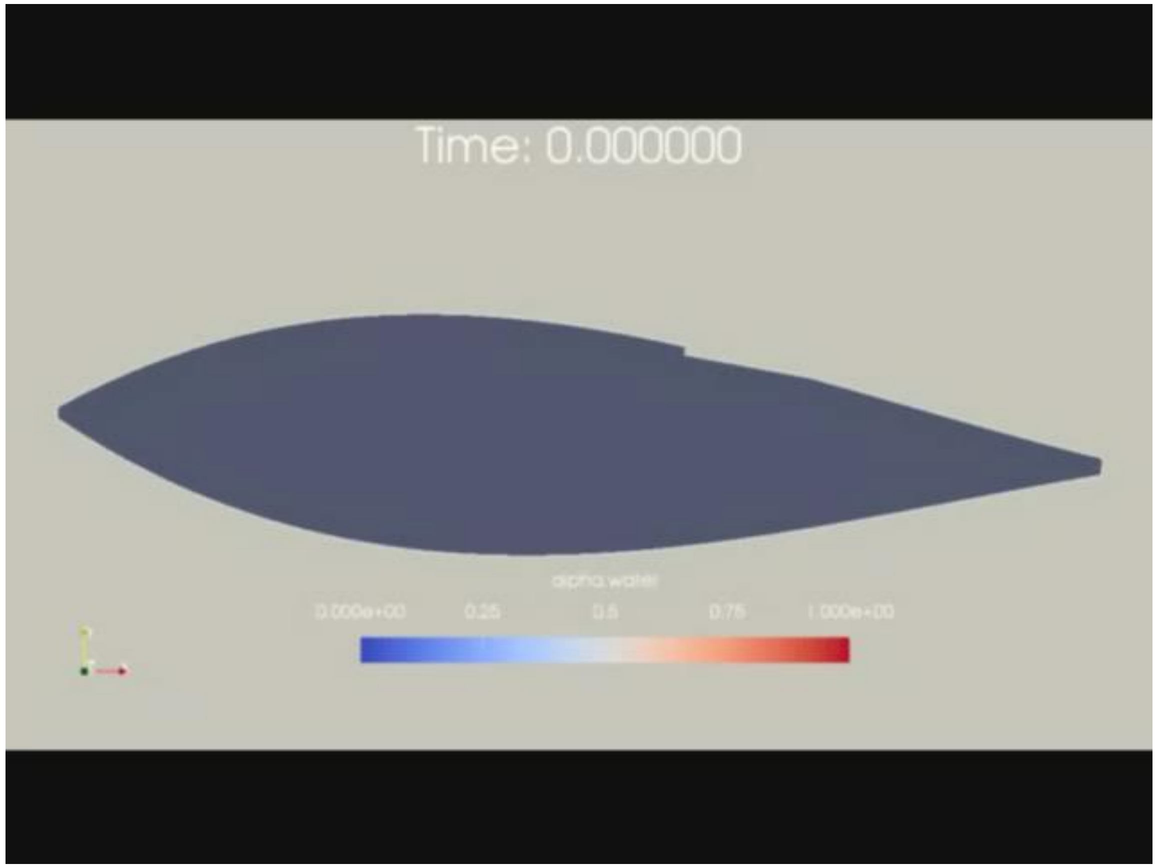
$U_{inj}/U_0 = 0$

Hydrofoil cavitation control: @60%c (for Angle Of Attack 3º)

Velocity magnitude

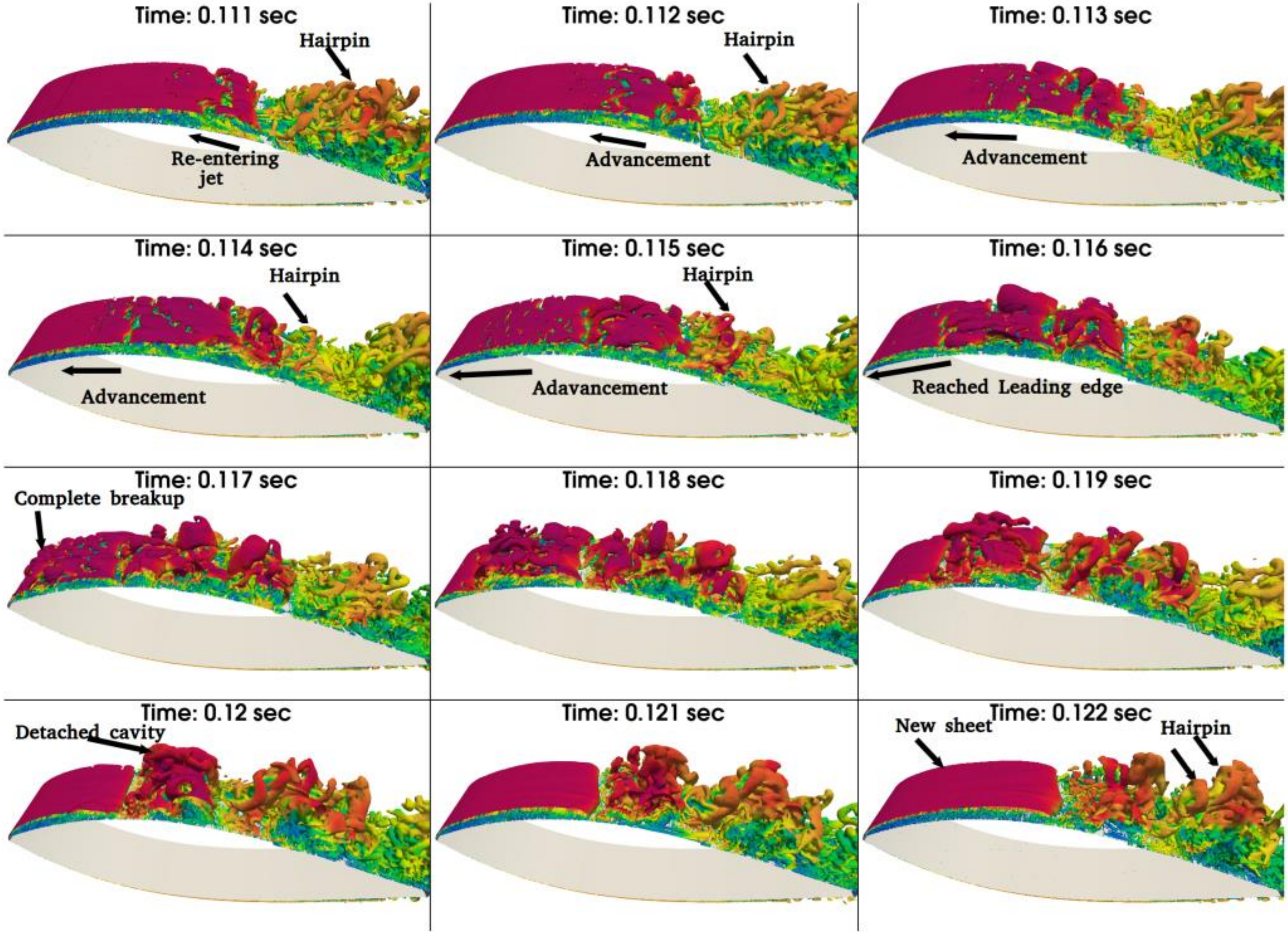


Void fraction

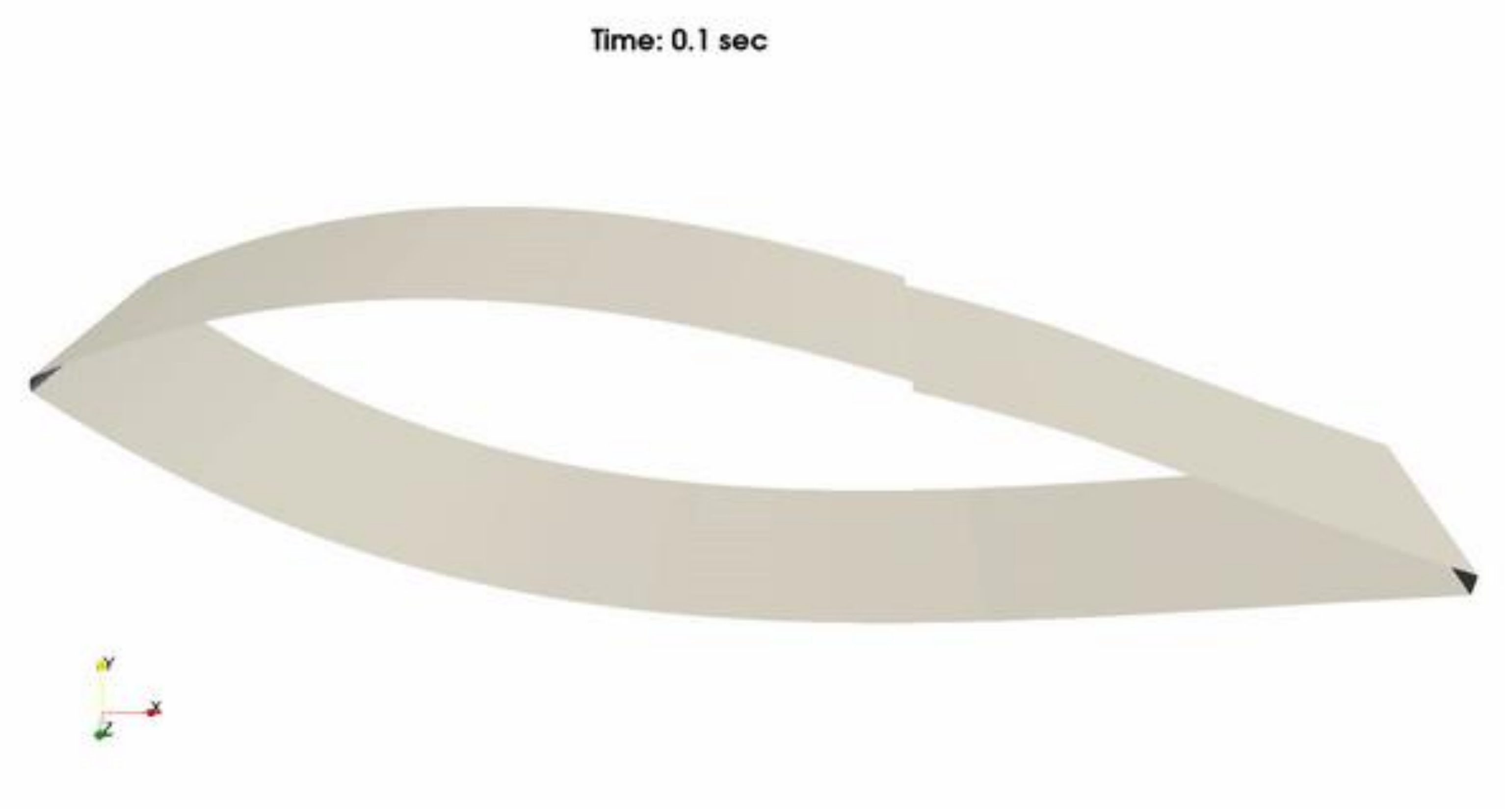


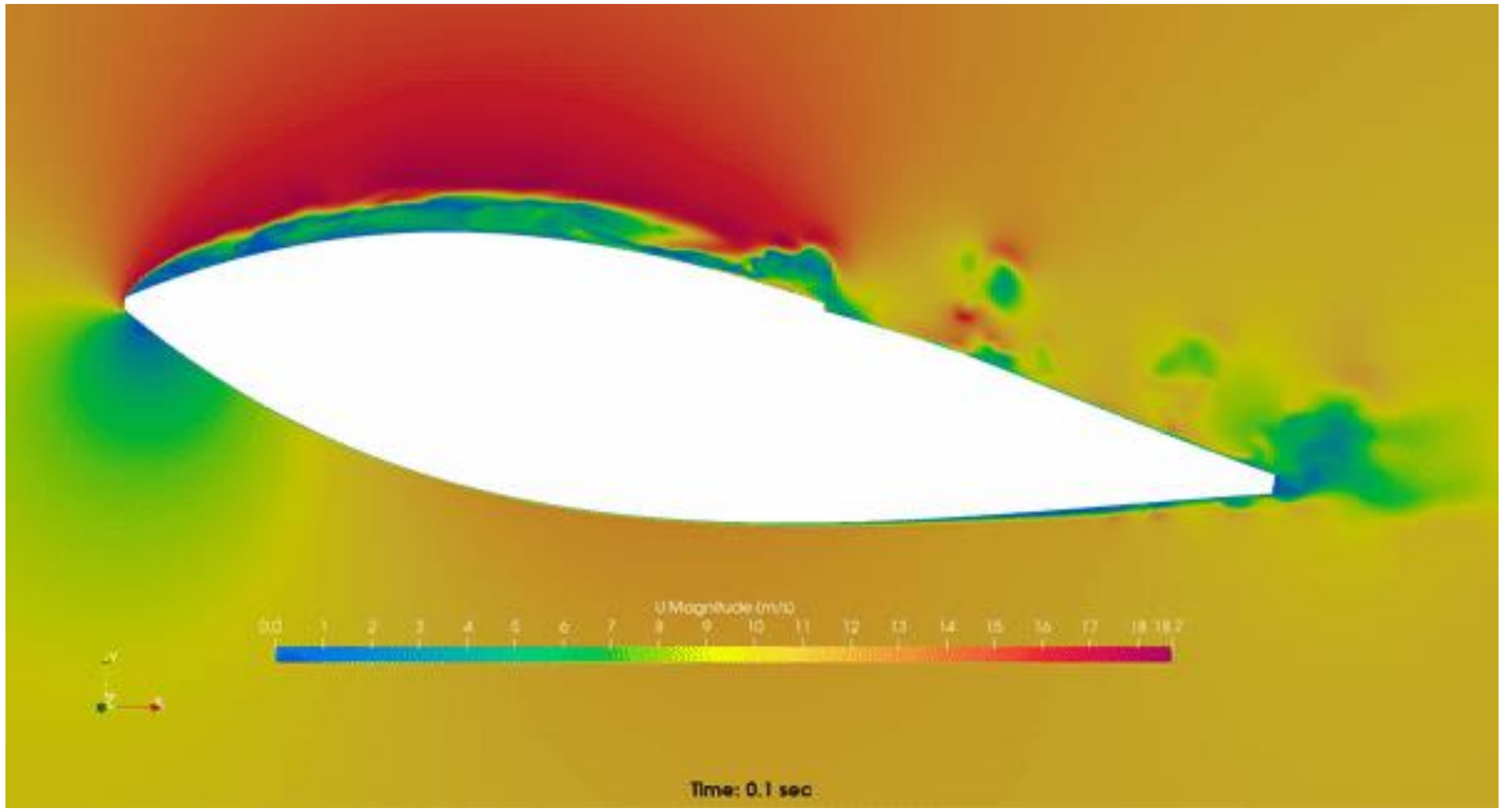
t=0.0-0.2s (no blowing)
t=0.2-0.4s (hi-blowing)
t=0.4-0.6s (lo-blowing)

No flow control (Angle of Attack 9º, Pant and Frankel, 2021)

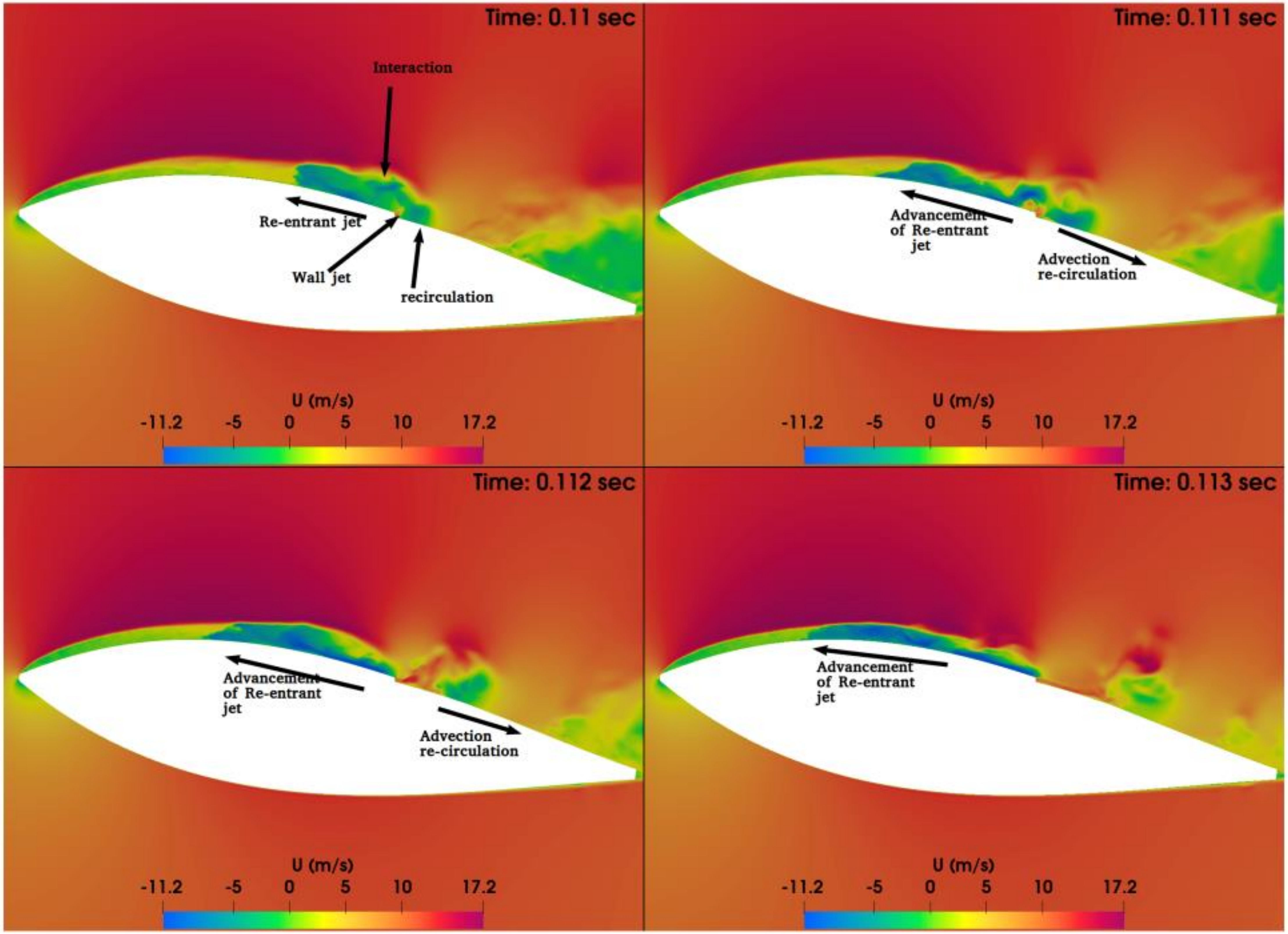


With flow control (Angle of Attack 9°)





With flow control (Angle of Attack 9º , Pant and Frankel, 2021)



Conclusion

- For low angle of attack, lower wall jet injection could mitigate the (unsteady) cavitation
  - But effect the hydrodynamic performance of hydrofoil. (Pant et al. 2020, Processes)
- For higher angle of attack, wall jet injection is not a feasible solution to mitigate.
  - Possible because of the interaction between the re-entry jet and wall jet. (Pant and Frankel 2021, Ocean Engineering)
- Thus, wall jet injection for cavitation control should be used with caution!

THANK YOU