



THE UNIVERSITY of EDINBURGH
School of Engineering

Institute for Energy
Systems

VOILAb
Vortex
Interaction
Laboratory

Circular Arc Aerodynamics and Applications to Downwind Yacht Sails and Wind Assisted Ships

Jean-Baptiste R. G. Soupezz & Ignazio Maria Viola

IX International Conference on Computational Methods in Marine Engineering (Marine 2021)
Edinburgh, Scotland, UK
2-4 June 2021

Thin Airfoil

Thickness/chord $\sim 10^{-2}$

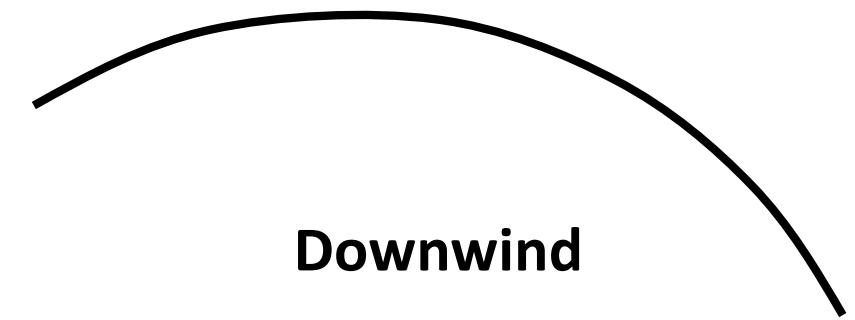


Yacht Sail

Thickness/chord $\sim 10^{-4}$

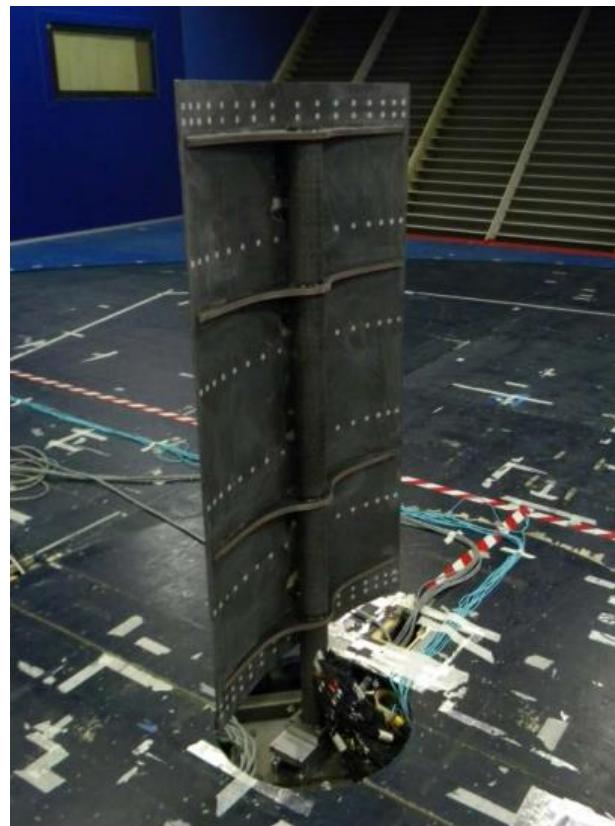
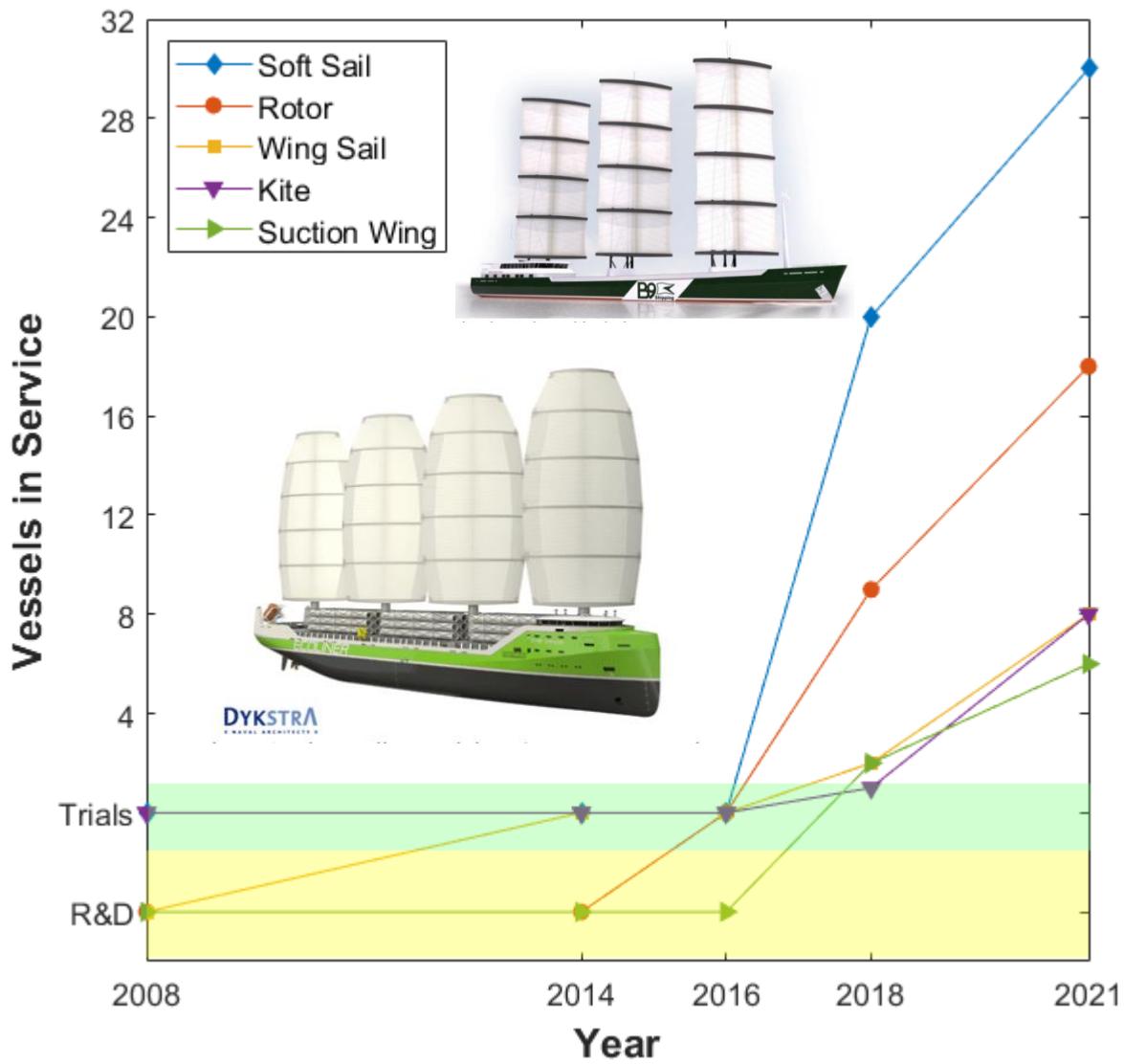


Upwind



Downwind



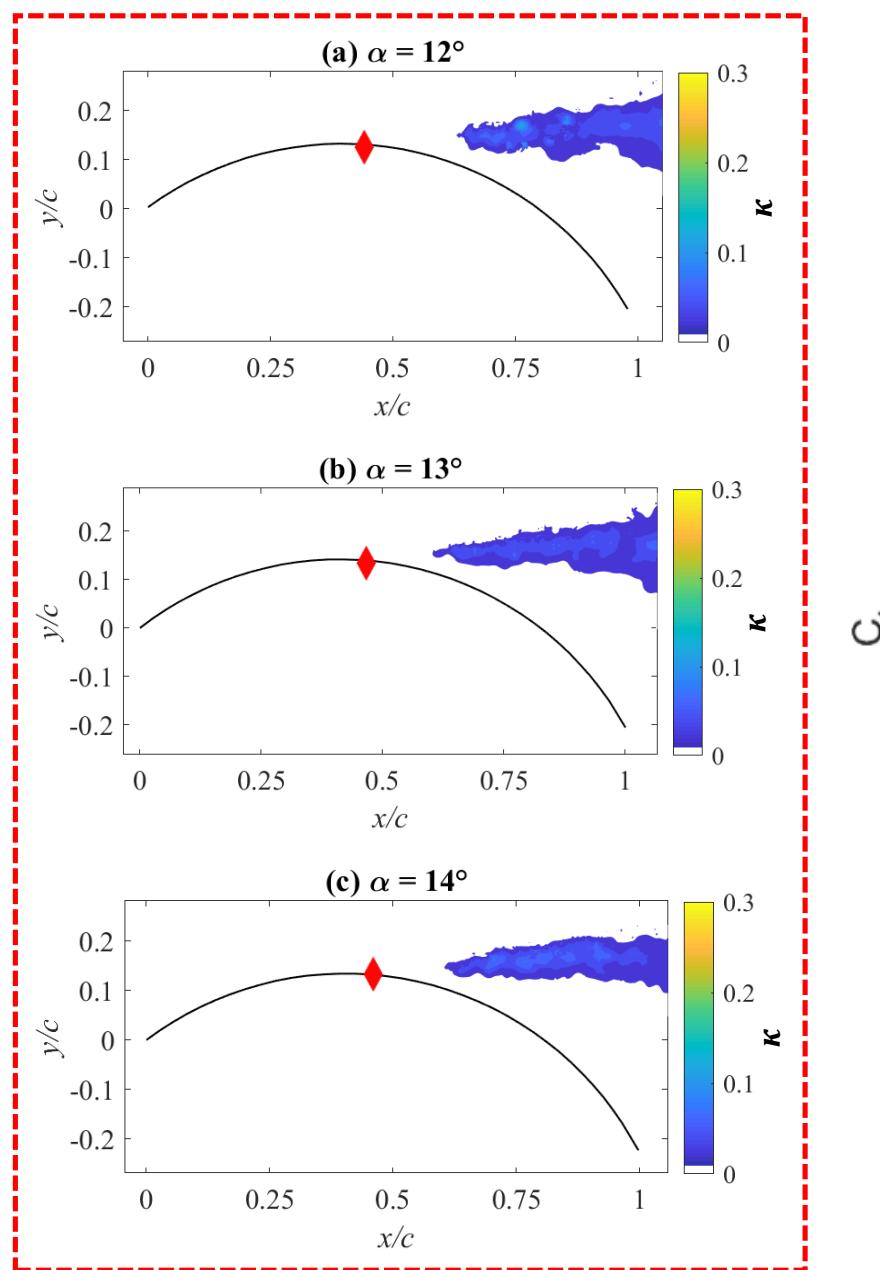


Bordogna et al., International Shipbuilding Progress, 2018



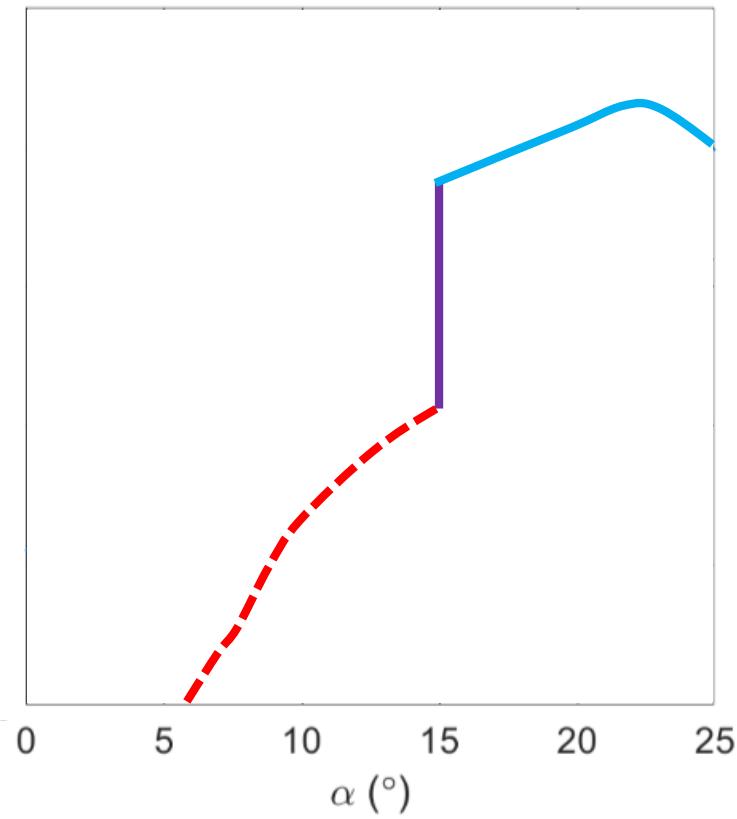
Soupeze et al., HPYD, 2021

Subcritical Regime



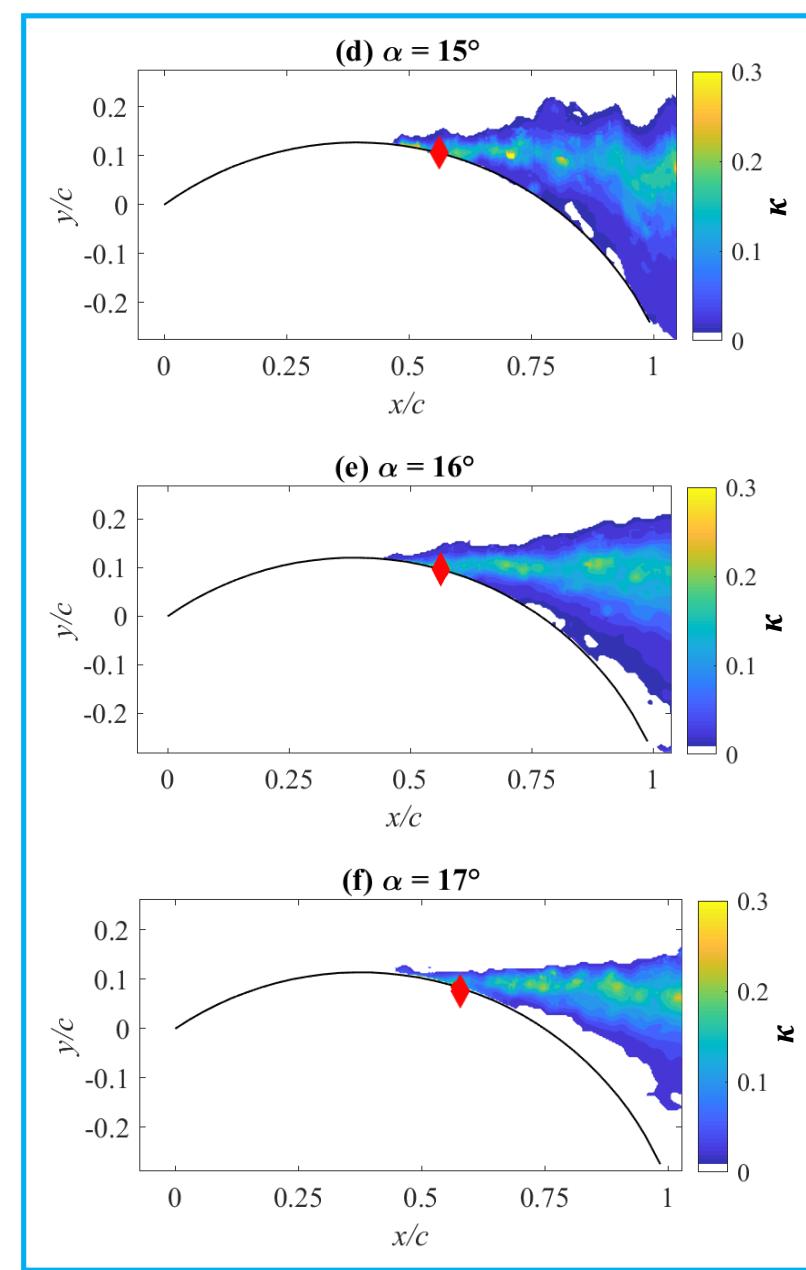
$$\kappa = \frac{\overline{(u')^2} + \overline{(v')^2}}{2U_\infty^2}$$

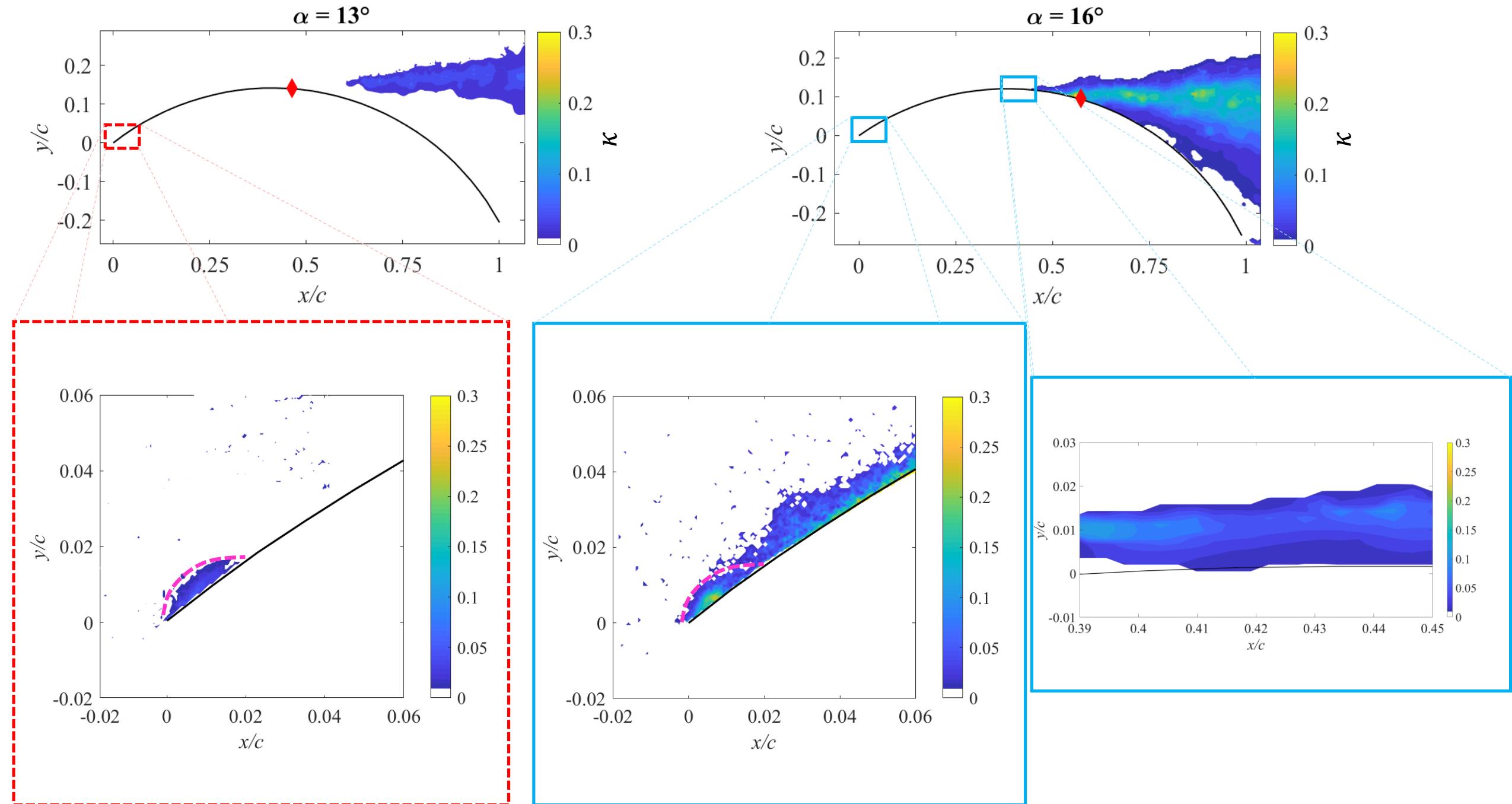
C_L



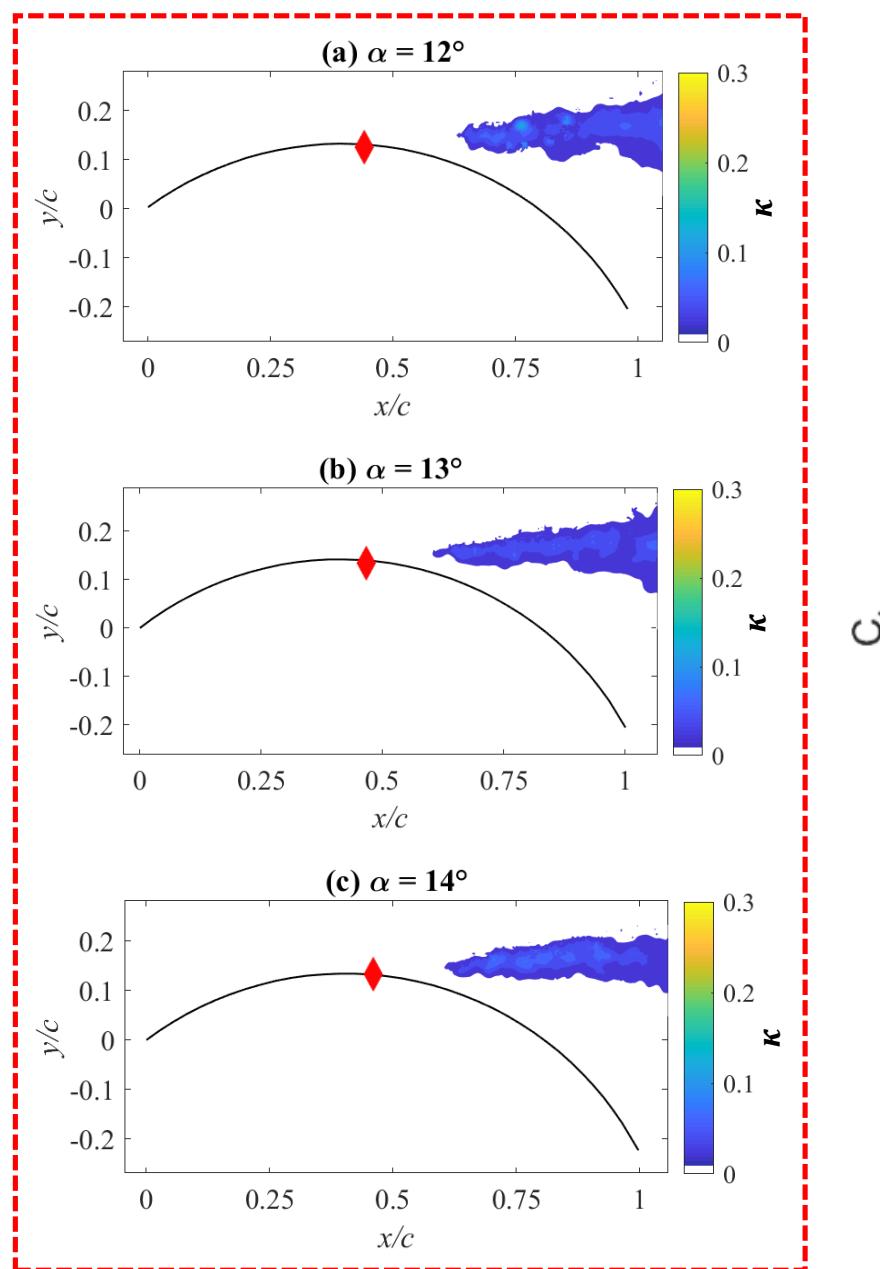
◆ Separation point

Postcritical Regime

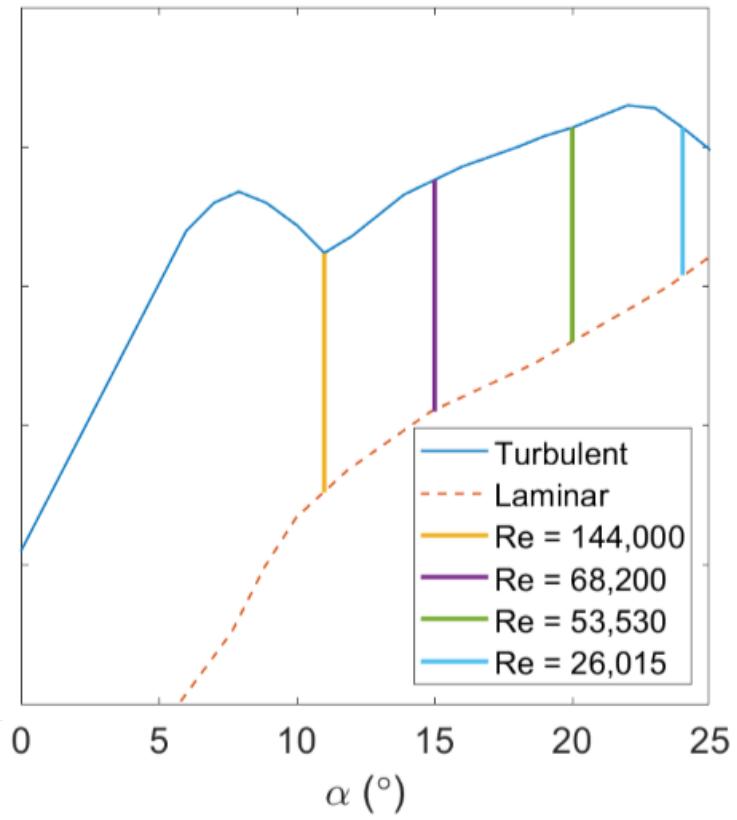




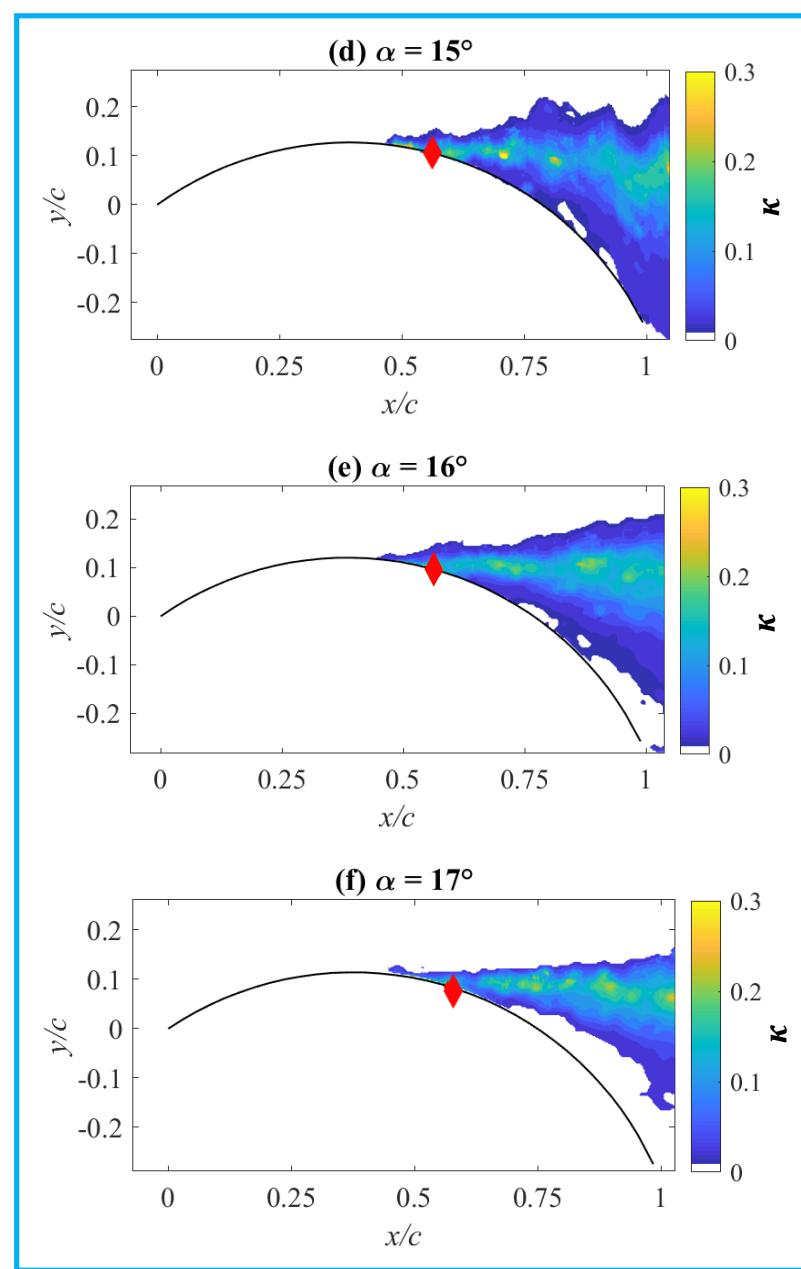
Relaminarization

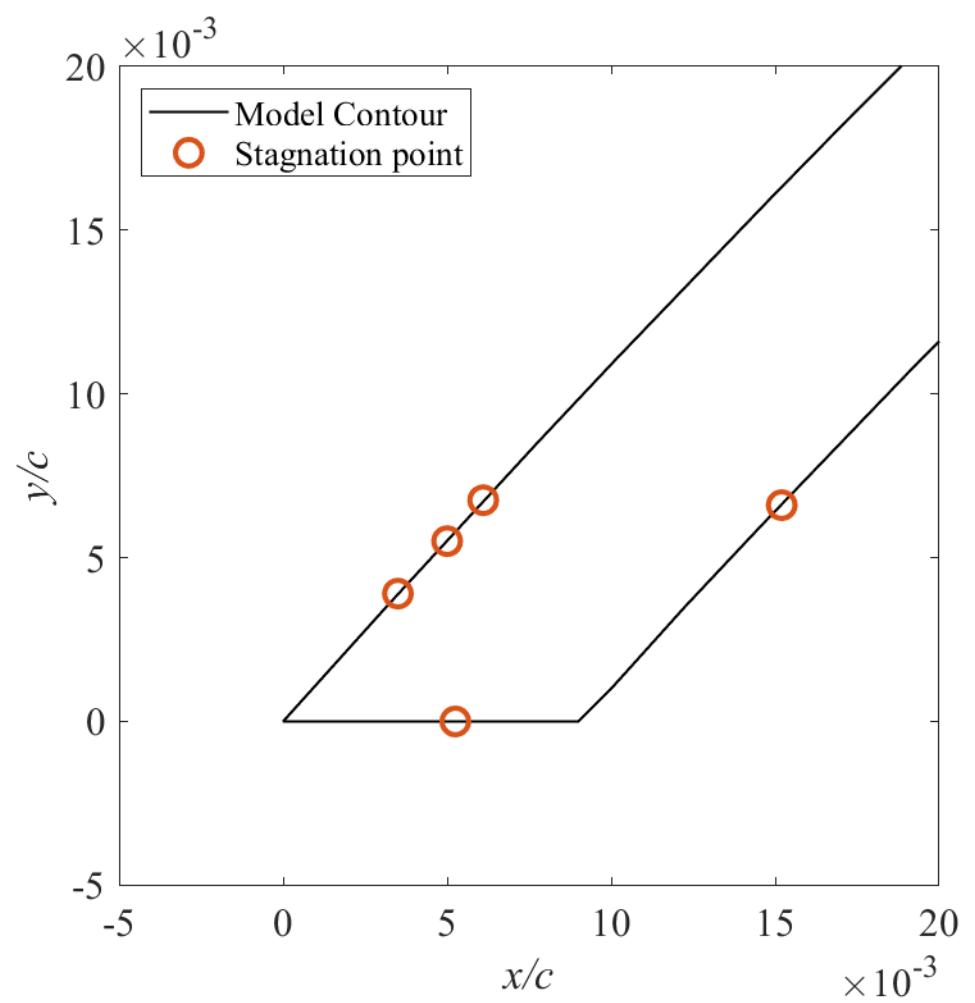
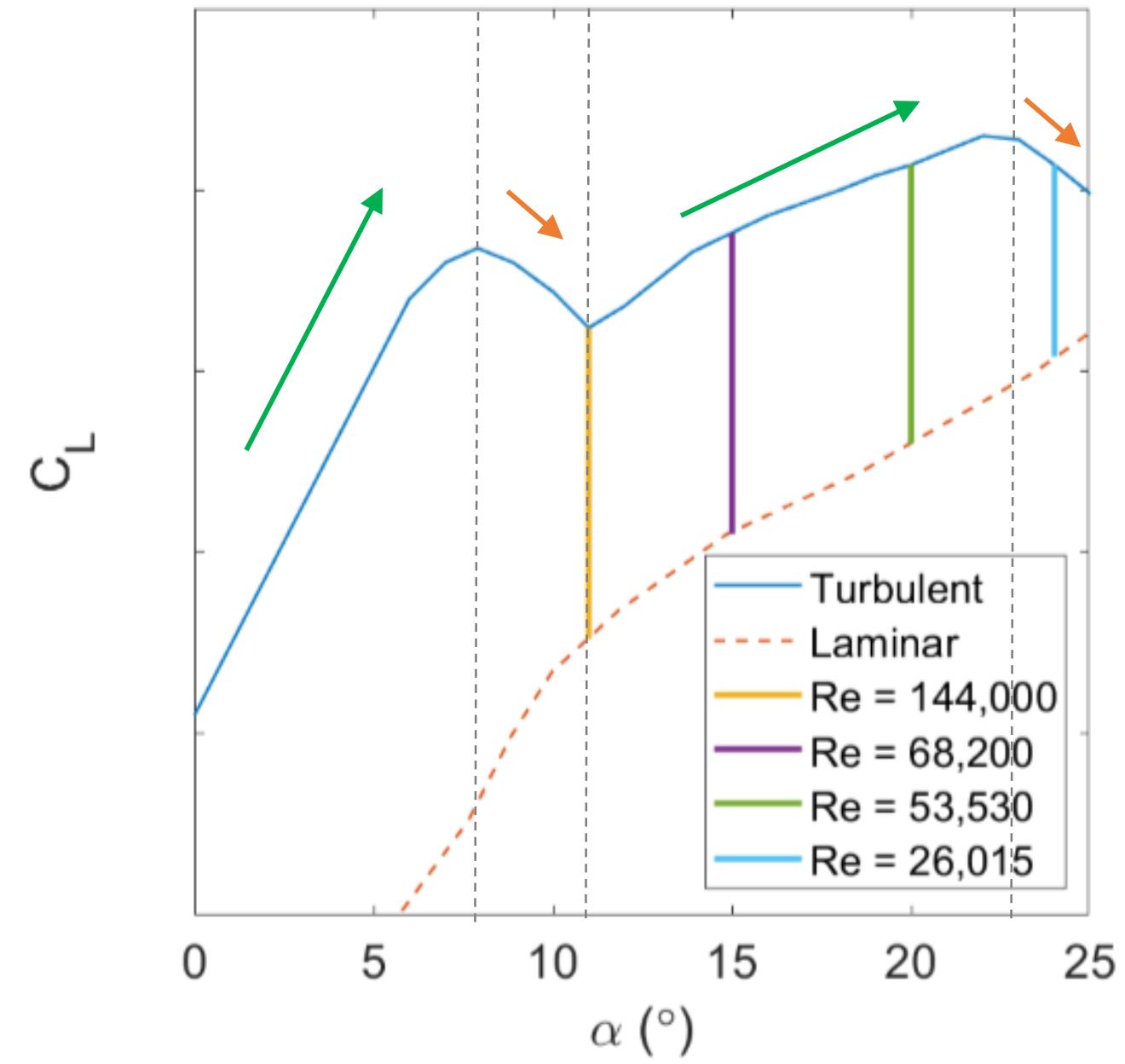


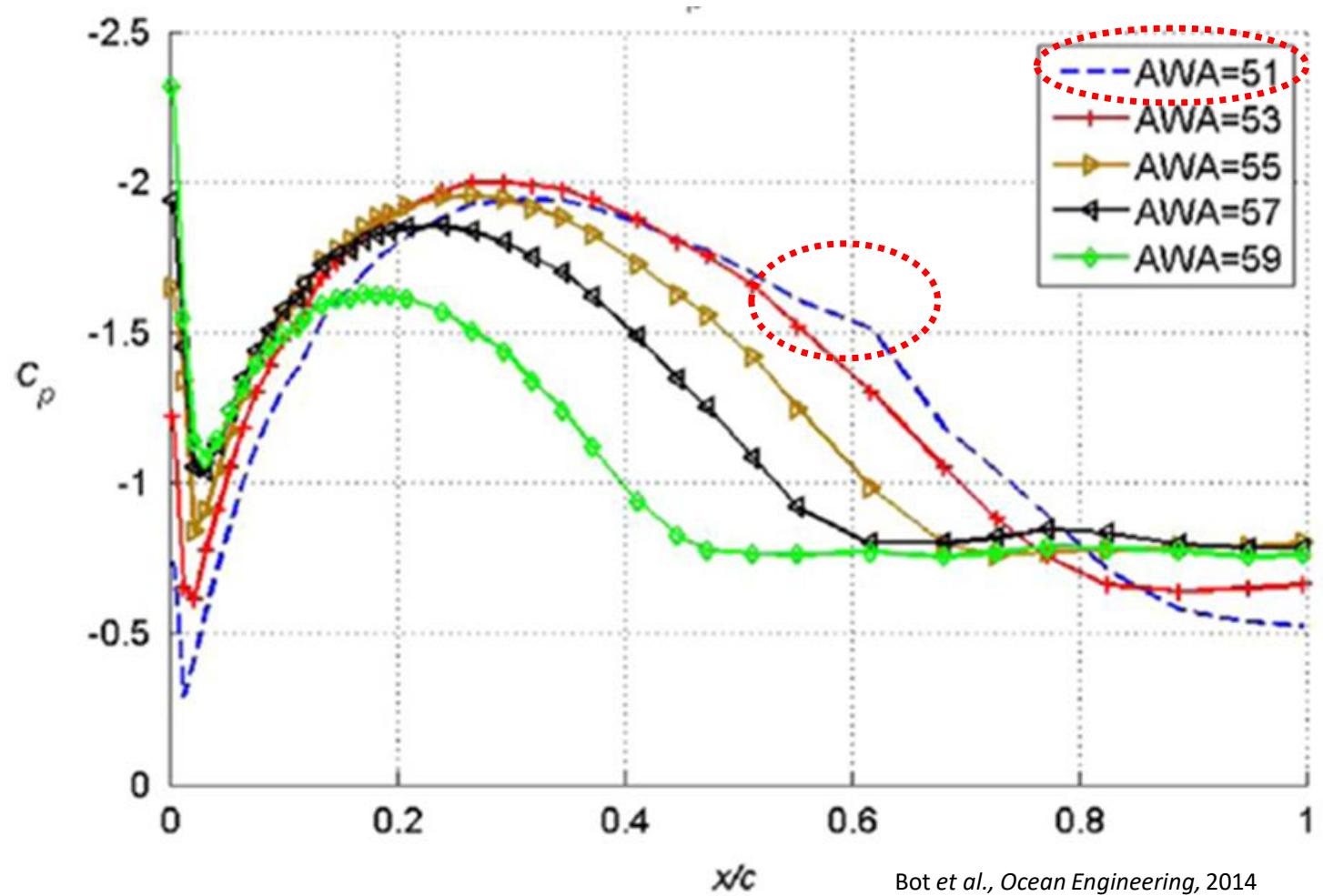
C_L



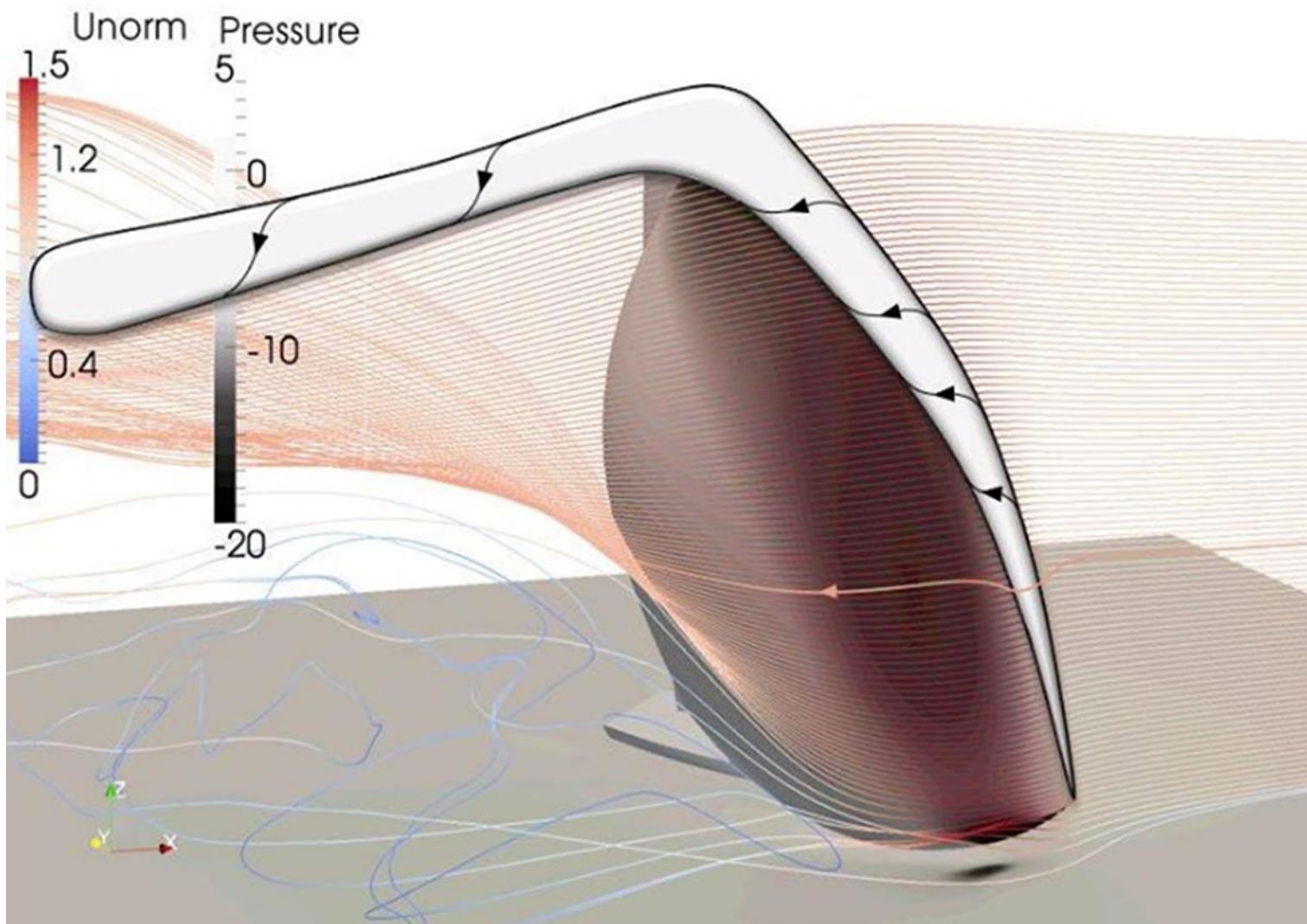
Boundary Layer







Bot et al., Ocean Engineering, 2014



Soupperez et al, Journal of Sailing Technology, 2018

Conclusions

1. Combination of a critical Reynolds number and a critical angle of attack triggers transition, and replicate full-scale flow regime.
2. Minimum Reynolds number needed for model-scale testing.
3. Leading-edge separation bubble:
 - **Pre-critical regime:** relaminarization occurs at the reattachment point.
 - **Post-critical regime:** reattached boundary layer is turbulent all the way to trailing-edge separation.

Thank you

Jean-Baptiste R. G. Soupezz
jean-baptiste.soupezz@ed.ac.uk



References:

- Bordogna, G., Keuning, J. A., Huijsmans, R. H. M. & Belloli, M., (2018), "Wind-tunnel experiments on the aerodynamic interaction between two rigid sails used for wind-assisted propulsion", *International Shipbuilding Progress*, 65, pp. 93-125. DOI 10.3233/ISP-180143
- Bot, P., Viola, I. M., Flay, R. G. J. & Brett, J. S., (2014), "Wind-tunnel pressure measurements on model-scale rigid downwind sails", *Ocean Engineering*, 90, pp. 84-92. 10.1016/j.oceaneng.2014.07.024
- Khan, L., Macklin, J. J. R., Peck, B. C. D., Morton, O., & Soupezz J.-B. R. G., (2021), "A review of wind-assisted propulsion for sustainable commercial shipping: latest developments and future stakes, *RINA Wind Propulsion 2021 Conference*, London, 29-30 September 2021.
- Soupezz, J.-B. R. G., Arredondo-Galeana, A., & Viola I. M., (2019), ""Recent Advances in Numerical and Experimental Downwind Sail Aerodynamics", *Journal of Sailing Technololoy*, 4, pp. 45–65. <https://doi.org/10.5957/jst.2019.4.1.45>
- Soupezz, J.-B. R. G., Bot, P. & Viola, I. M., (2021), "On the effect of the leading-edge separation bubble on the aerodynamics of spinnakers", *7th High Performance Yacht Design (HPYD7) Conference*, Auckland, 11-12 March 2021.
- Viola, I. M., Bartesaghi, S., Van-Renterghem, T. & Ponzini, R., (2014), "Detached eddy simulation of a sailing yacht", *Ocean Engineering*, 90, pp. 93-103. <https://doi.org/10.1016/j.oceaneng.2014.07.019>