CIRCULAR ARC AERODYNAMICS AND APPLICATIONS TO DOWNWIND YACHT SAILS AND WIND ASSISTED SHIPS

Jean-Baptiste R. G. Souppez* and Ignazio Maria Viola†

* School of Engineering, Institute for Energy Systems
University of Edinburgh
Kings Buildings, West Main Road, Edinburgh, EH9 3JW
jean-baptiste.souppez@ed.ac.uk

† School of Engineering, Institute for Energy Systems
University of Edinburgh
Kings Buildings, West Main Road, Edinburgh, EH9 3JW
i.m.viola@ed.ac.uk

ABSTRACT

Upwind yacht sails, characterized by a low camber and largely attached flow, have long been successfully analysed using inviscid methods. Conversely, inviscid approaches are unsuitable for highly cambered wings, such as those employed for downwind sailing and some wind-assisted ships due to the highly separated flow. Furthermore, despite recent numerical and experimental advances on downwind sails [1], certain flow features and their effect remain to be fully understood. Indeed, spinnakers are typically trimmed so that the stagnation point is at the leading edge, where the flow separates, reattaching shortly downstream, forming a leading-edge separation bubble (LESB). This flow feature sets the beginning of the boundary layer, whose separation further downstream is paramount for the global aerodynamic forces on the sail.

To provide further insights into the aerodynamics of highly cambered thin wings, a quasi-steady two-dimensional approach is considered, as the governing fluid mechanics may be represented locally by the flow around a highly cambered circular arc with a sharp leading edge [2]. This study focusses on the impact of the LESB on the boundary layer regime and downstream flow separation.

Particle image velocimetry is employed to portrait the flow field around highly cambered circular arcs and investigates the effect of the LESB on the boundary layer regime and trailing-edge separation. The existence of the combination of a critical Reynolds number and a critical angle of attack to trigger turbulent separation is demonstrated. Remarkably, a turbulent LESB followed by a laminar boundary layer is observed in sub-critical regime, with evidence of relaminarisation occurring. Conversely, in a post-critical condition, a turbulent LESB ensued by a turbulent boundary layer is detected, the latter continuing all the way to trailing-edge separation.

These findings reveal the critical effect of the leading-edge vortical structures on the global flow field and forces experienced by cambered wings with leading-edge separation. Thus, it is envisaged that these results will contribute to better address the experimental challenges associated with the planning and testing of highly cambered sails, namely preventing an incorrect prediction of the full-scale forces should the essential flow features not be replicated at model-scale. Eventually, these findings will support the design and performance of modern downwind yacht sails, as well as wind assisted ships configurations, such as DynaRigs, that play a vital role in the decarbonisation of the shipping industry.

REFERENCES

[1] J.-B. R. G. Souppez, A. Arredondo-Galeana and I. M. Viola, "Recent advances in numerical and experimental downwind sail aerodynamics", *Journal of Sailing Technology*, Vol. **4**, pp. 45-65, 2019. 10.5957/jst.2019.4.1.45

[2] J.-B. R. G. Souppez, P. Bot and I. M. Viola, On the effect of the leading-edge separation bubble on the aerodynamics of spinnakers, 7th High Performance Yacht Design Conference, Auckland 11-12 March 2021.