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On Highly Cambered Thin Circular Arcs at Low Reynolds Numbers

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- CIRCULAR ARC GEOMETRY
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BACKGROUND - SPINNAKERS

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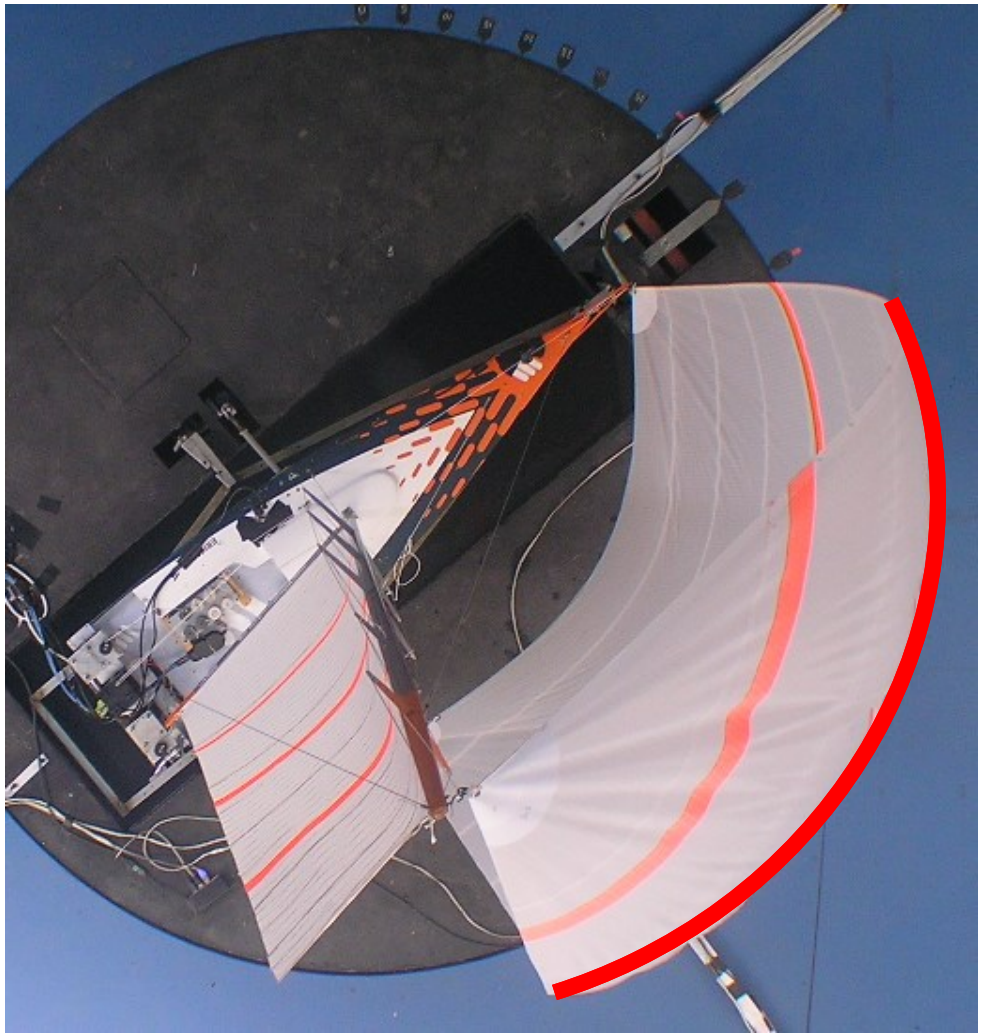
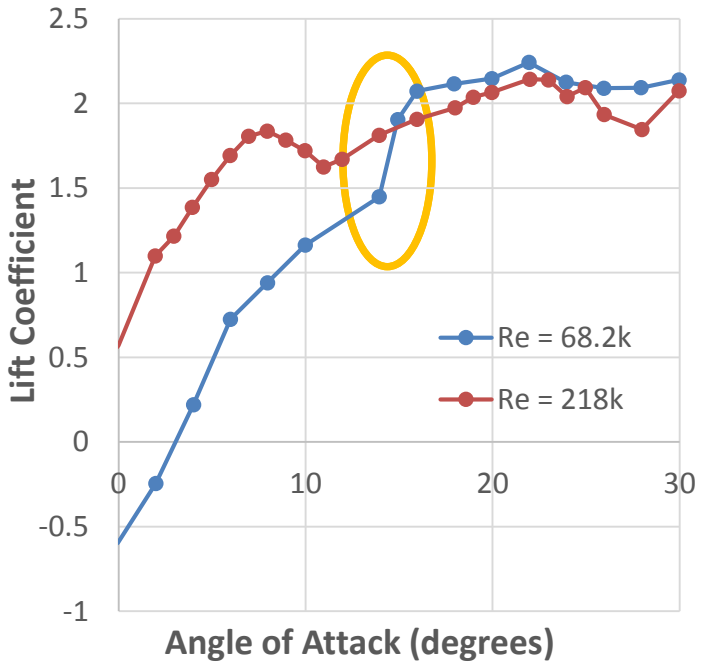
BACKGROUND – WIND TUNNEL TESTING

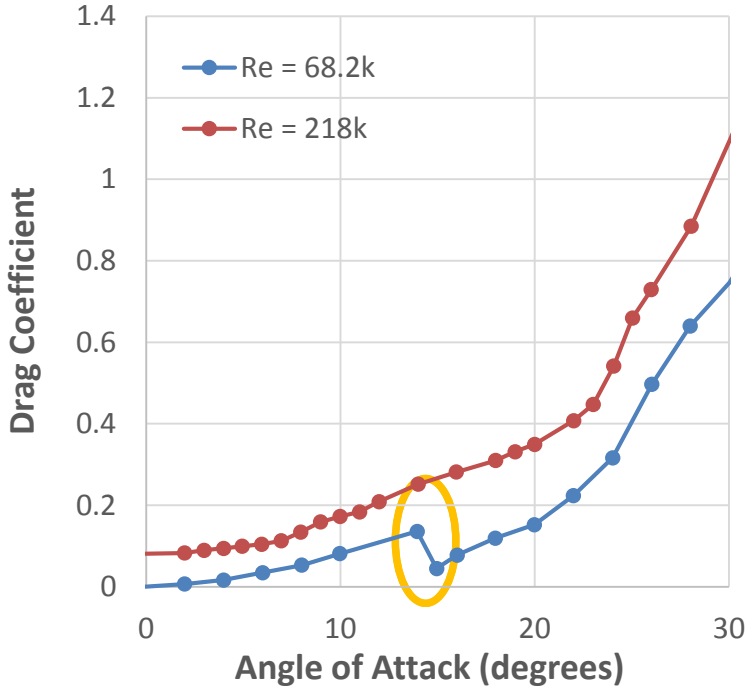
- **Wind Tunnel assumption:** the flow around the spinnaker is turbulent.
- Inconsistencies noticed in the pressure distribution on wind tunnel tested models.
- Potential evidence of transition occurring in the literature.
- Highly cambered thin circular arc as a simplified cross section through a spinnaker.

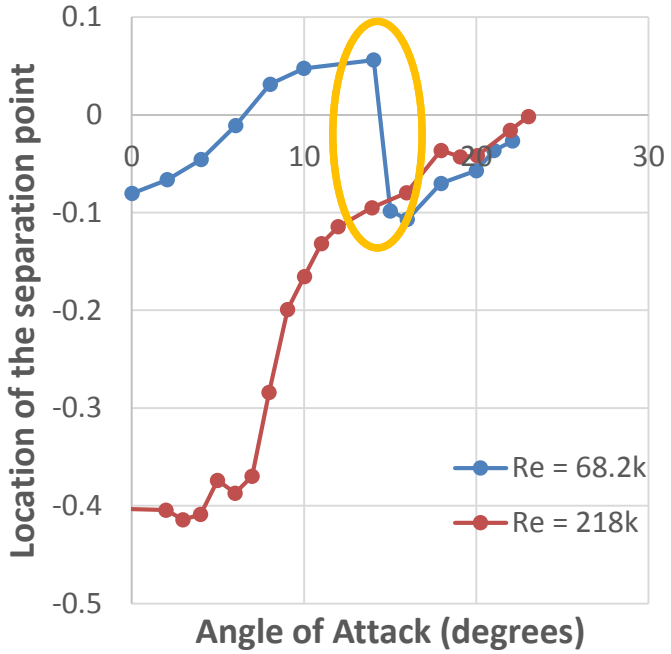


CIRCULAR ARCS IN THE LITERATURE

- At low Reynolds number, evidence of a discontinuity in the lift and drag (Lombardi, 2014).
- Abrupt change in the location of the separation point at the same angle (Martin, 2015).

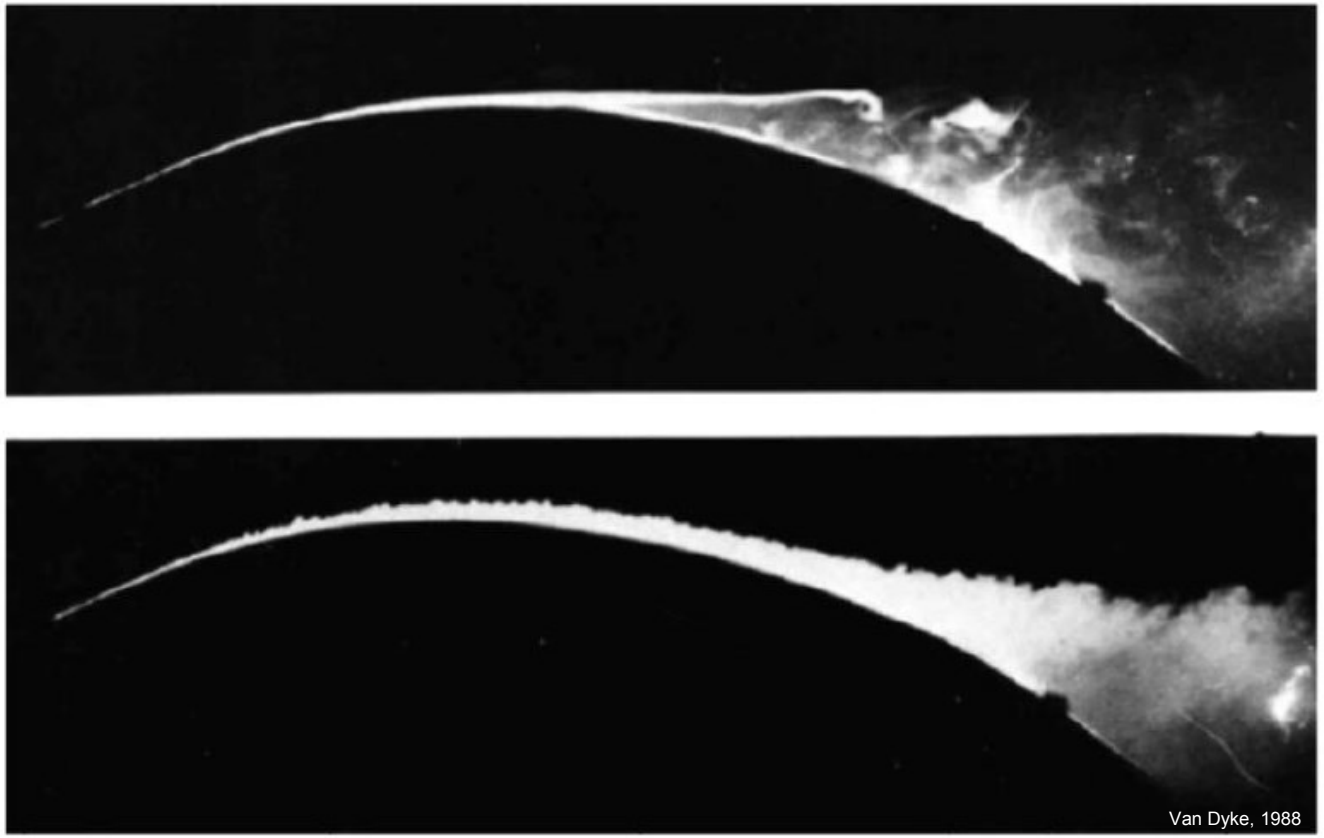






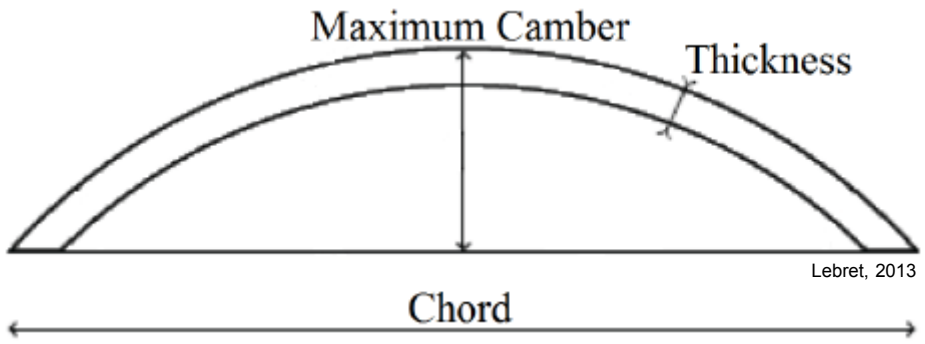
CIRCULAR ARCS IN THE LITERATURE

- **Hypothesis:** these is a combination of critical Reynolds Number and critical Angle of Attack that will trigger transition.



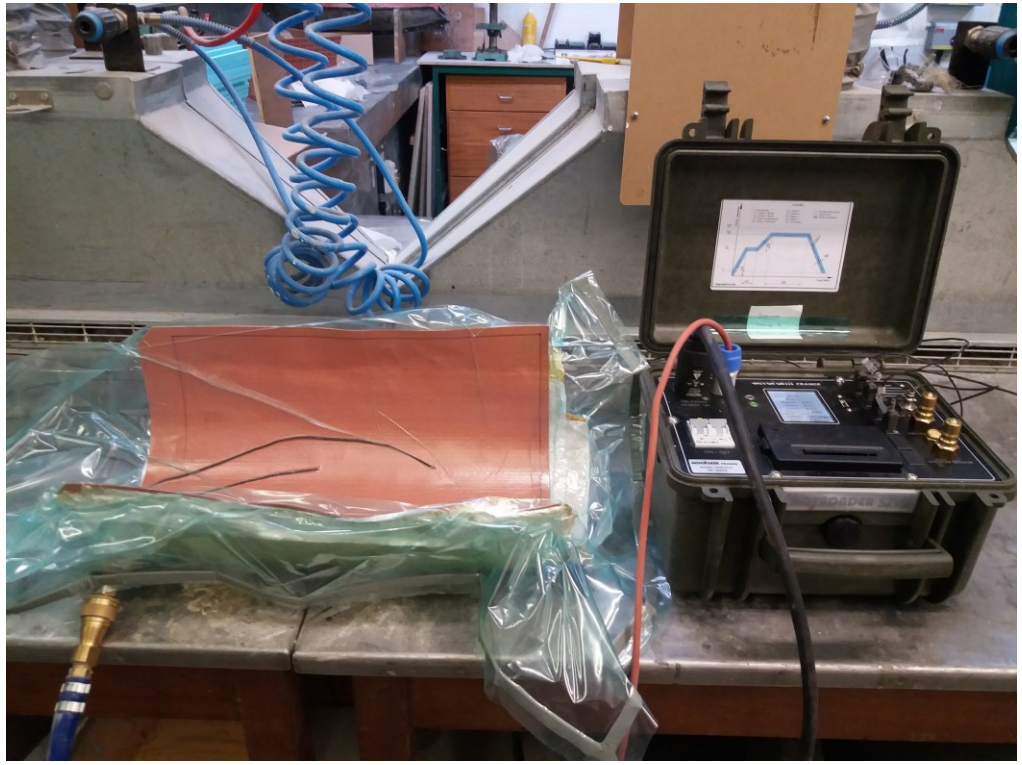
CIRCLAR ARC GEOMETRY AND MANUFACTURING

- **Specifications:**
  - Highly cambered: (22.32%)
  - Thin: (1.8mm thickness)
  - Chord: 200m
  - Sharp leading edge



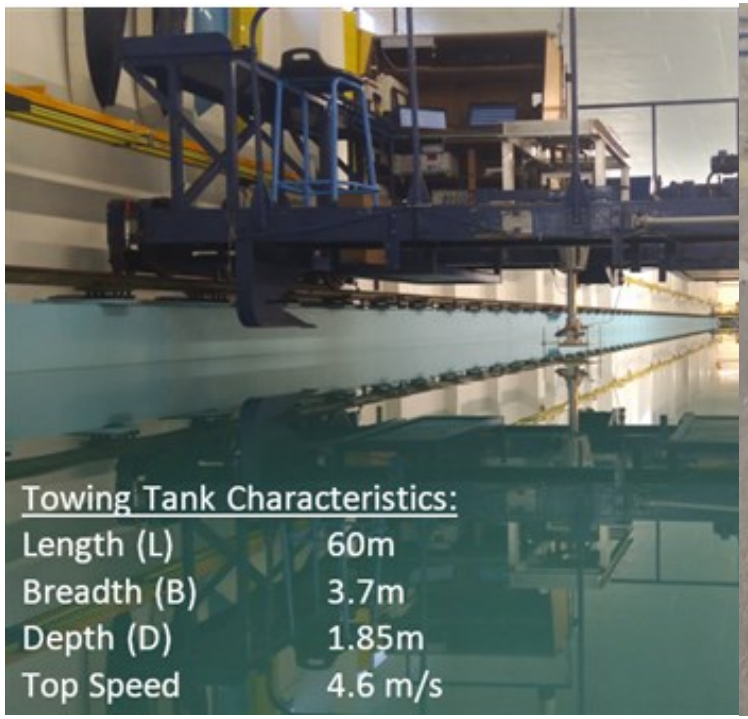
Lebret, 2013

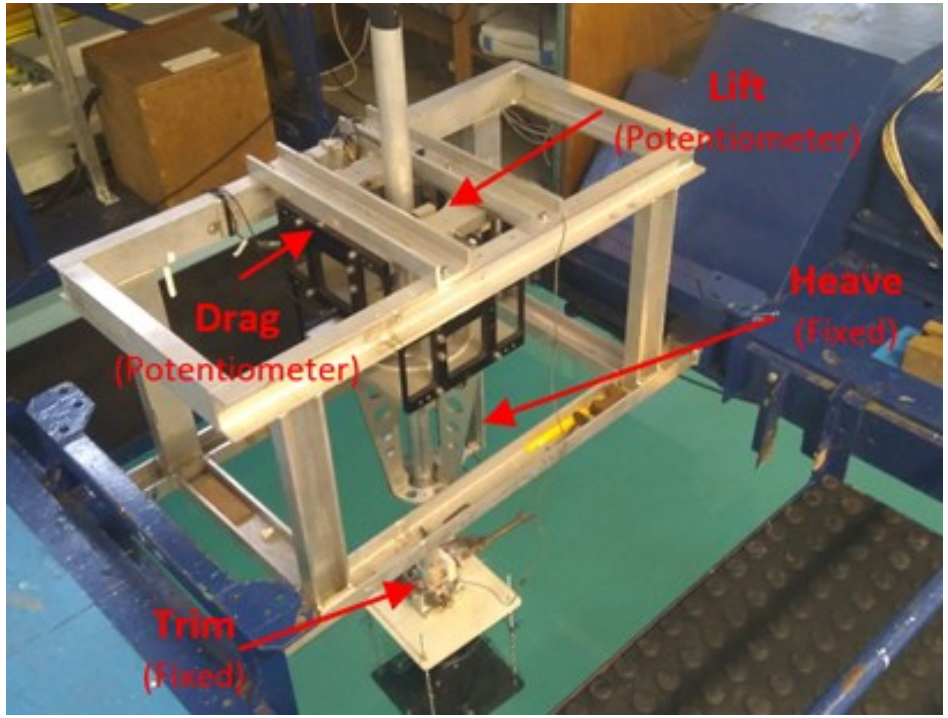
- **Manufacturing:**
  - Carbon prepreg



TOWING TANK EXPERIMENTAL SETUP

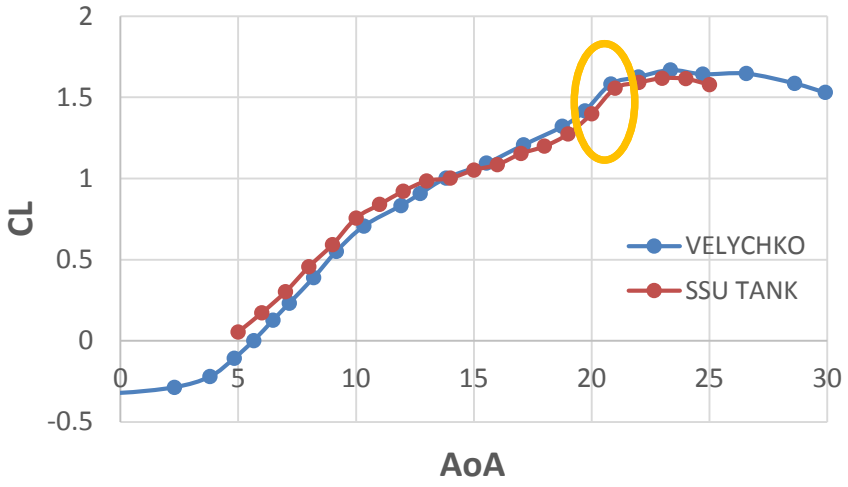
- Force measurements undertaken in Solent University's Hydrodynamic Test Centre:
  - Reynolds numbers of: 53k, 68k, 150k and 220k.
  - Angles of Attack: 5 to 20 (5 to 25 at 53k) in 1 degree increments.

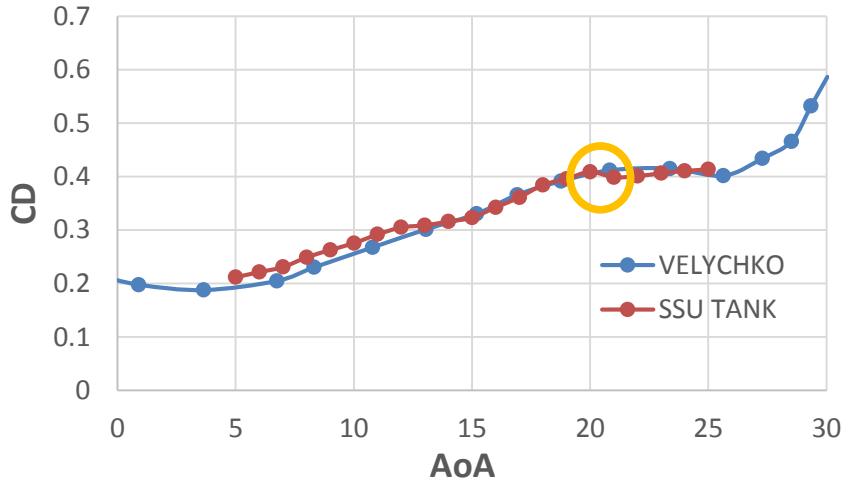


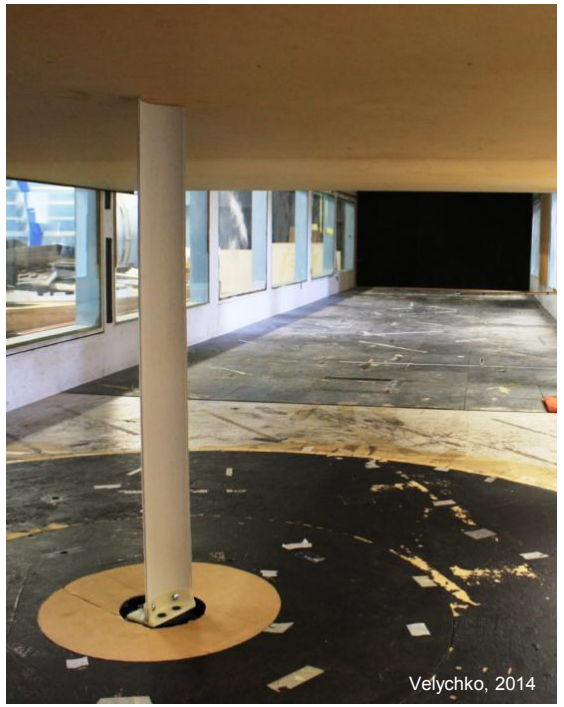


TOWING TANK RESULTS - RE = 53K

- Compared with Velychko's (2014) wind tunnel experiment.



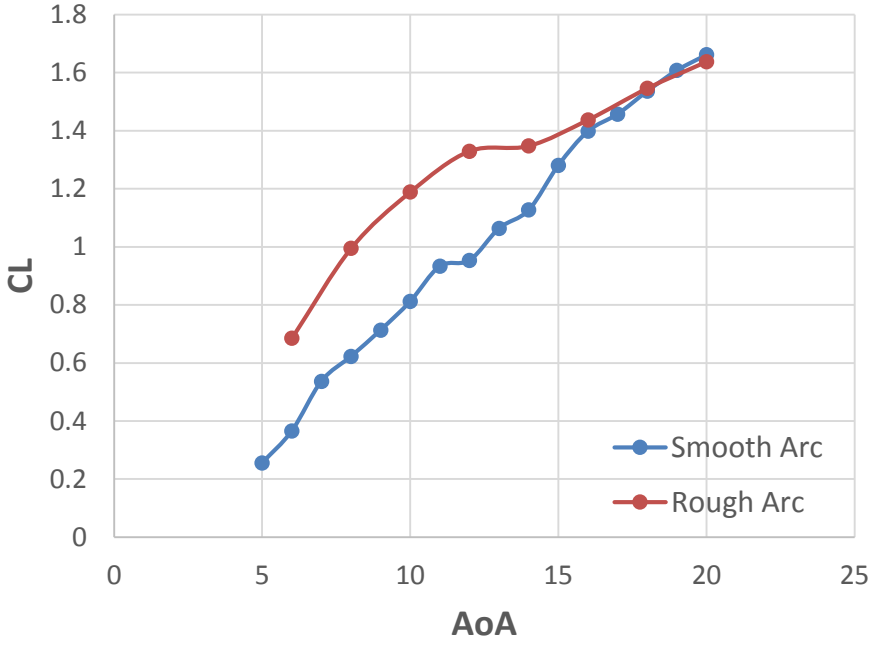


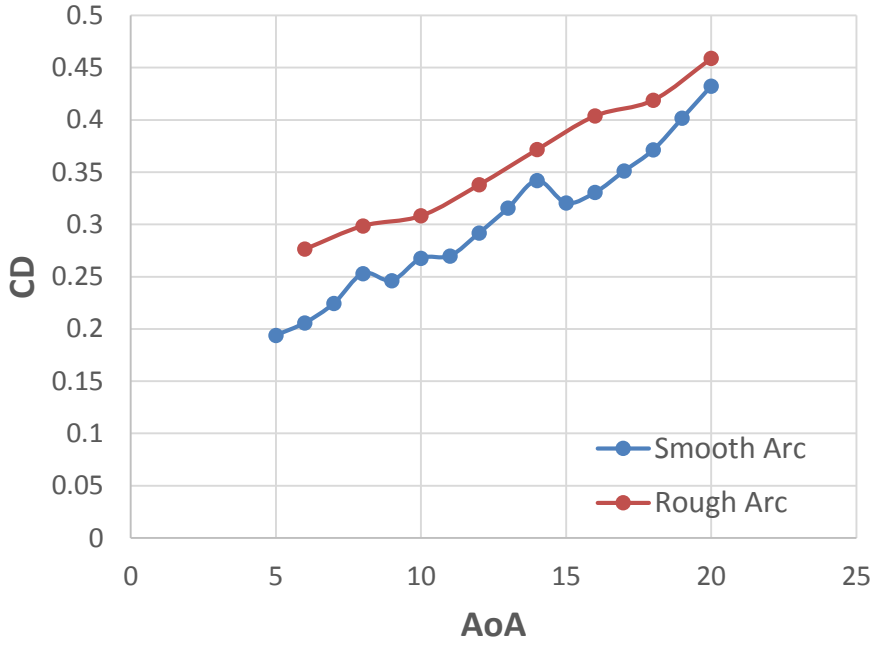


- Good agreement between the towing tank and the wind tunnel.

EFFECT OF ROUGHNESS

- To help validate the hypothesis that transition causes the jump in lift, an arc was tested with a sand paper strip at the leading edge to trigger transition.





- Results would suggest the transition is indeed responsible for the abrupt changes.
  - Consistent with Velychko (2014).

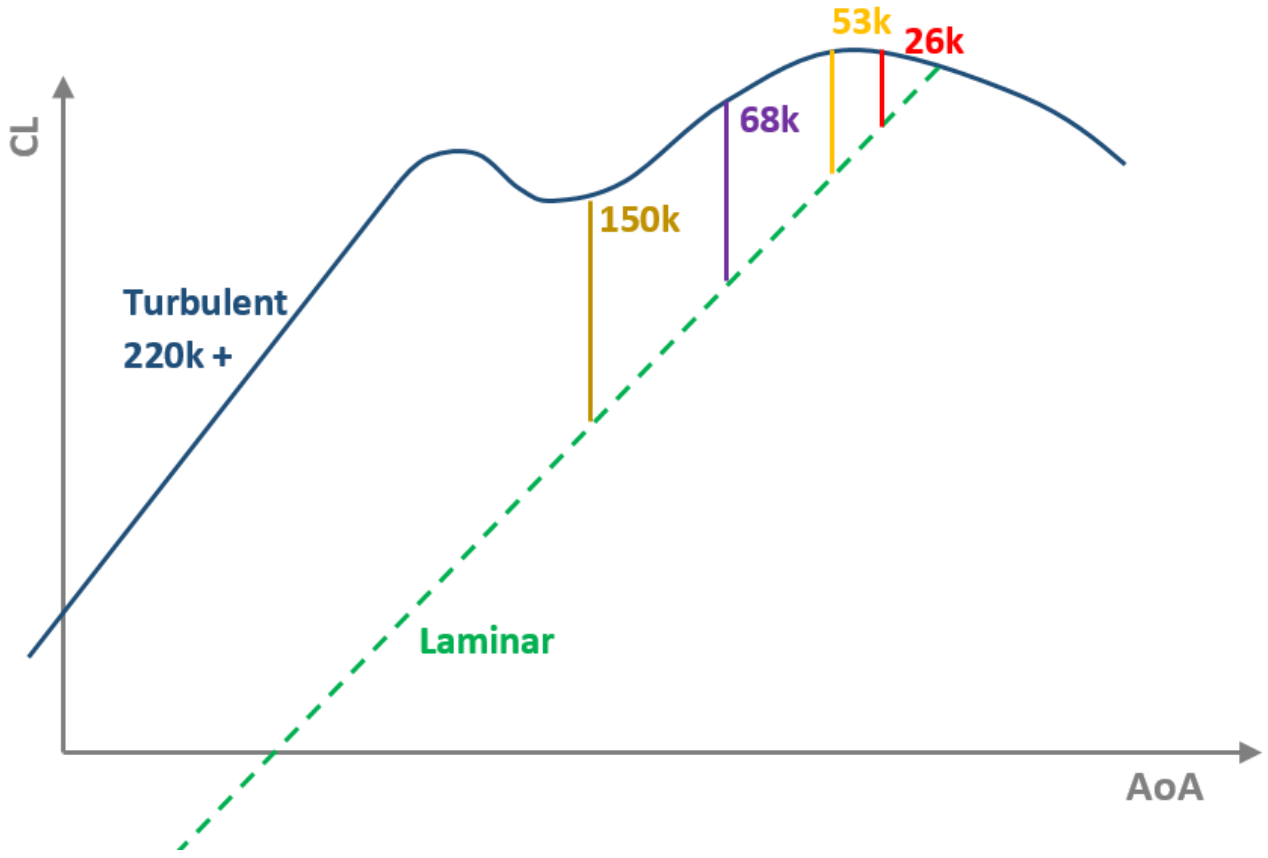
FINDINGS

- Highly cambered thin circular arc as a simplification for the section of a spinnaker.

- Tank testing experiment providing further evidence that:
  - The flow is turbulent above a critical Reynolds number of 220k irrelevant of the angle of attack.
  - Below 220k, there is a combination of Reynolds number and angle of attack that will induce transition.
  - If the flow is made turbulent (roughness strip test) there is no more jump in lift and drag.

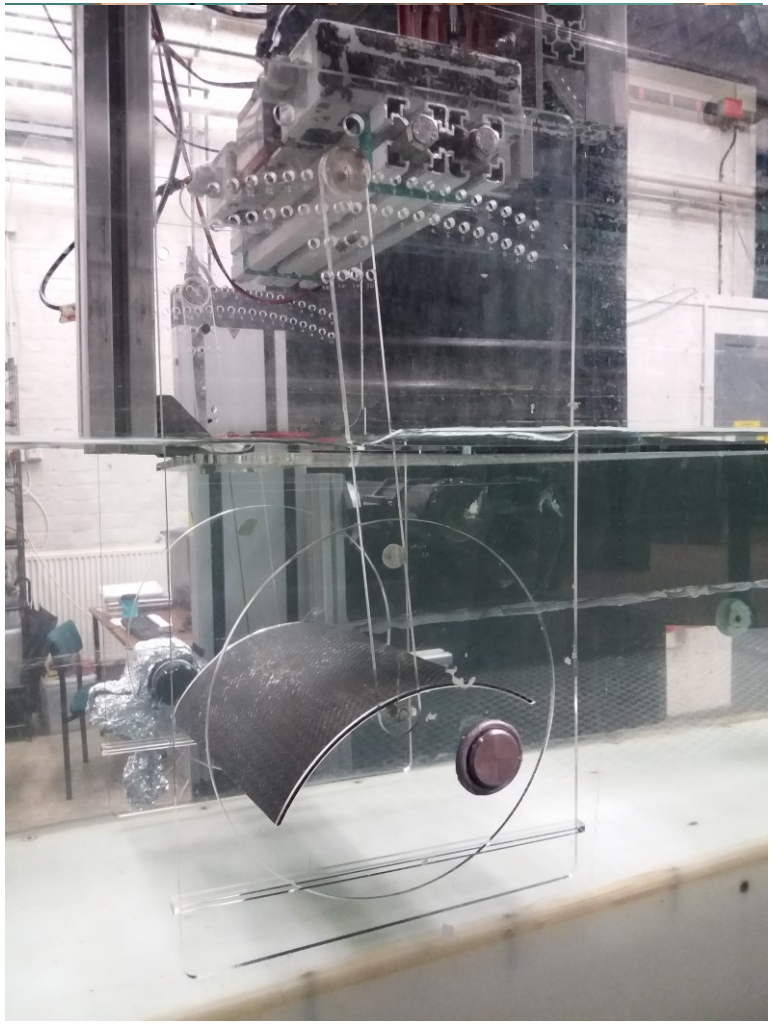
IMPACT

- Idealised model for the lift coefficient of highly cambered thin circular arcs.
- Offers a new interpretation of the data gathered in previously tested yacht sails.
- Challenges current knowledge and practice in Wind Tunnel Testing of downwind yacht sails.
  - Aims to define the minimum Reynolds number at which model-scale sails can be tested assuring a turbulent boundary layer at every relevant angle of attack.



CURRENT RESEARCH QUESTIONS AND OBJECTIVES

- Find the Reynolds number so that the critical angle of attack is **11 degrees**.
  - Significant as it is the ideal angle of attack and necessary to inflate a soft membrane such as a spinnaker.
- Develop a blockage correction that would allow results from different facilities to be compared.
- Provide flow diagnostics evidence of the transition occurring.
- **Use LDA to detect transition.**



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Thank You

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