On Highly Cambered Thin Circular Arcs at Low Reynolds Numbers

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Credit: http://fast40class2018.com/pictures
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.
- 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.

[Image of circular arcs]
CIRCLAR ARC GEOMETRY AND MANUFACTURING

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

- **Manufacturing:**
  - Carbon prepreg

[Image: Diagram of circular arc geometry with labels for maximum camber, thickness, and chord. Image credit: Lebret, 2013.]
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 Characteristics:
- Length (L): 60m
- Breadth (B): 3.7m
- Depth (D): 1.85m
- Top Speed: 4.6 m/s
TOWING TANK RESULTS - RE = 53K

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

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

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