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# On Highly Cambered Thin Circular Arcs at Low Reynolds Numbers


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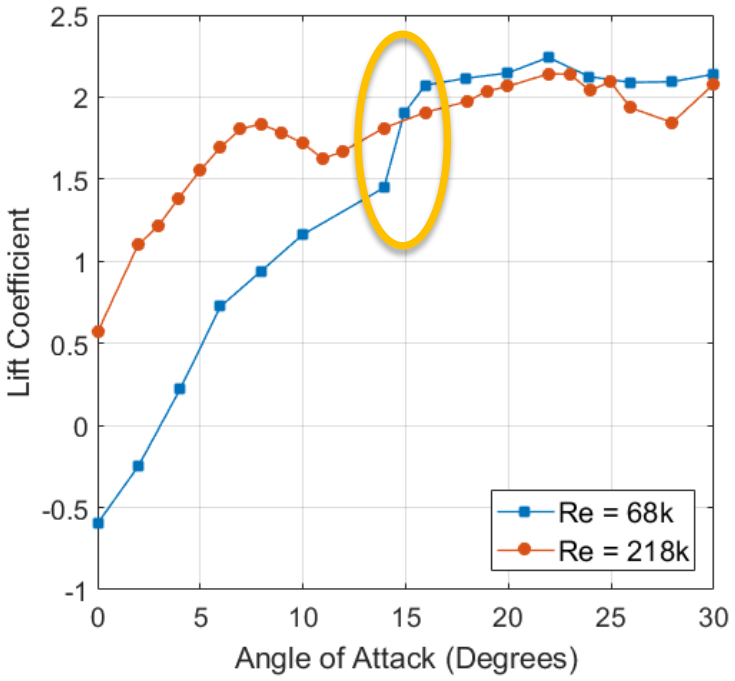
# BACKGROUND - SPINNAKERS

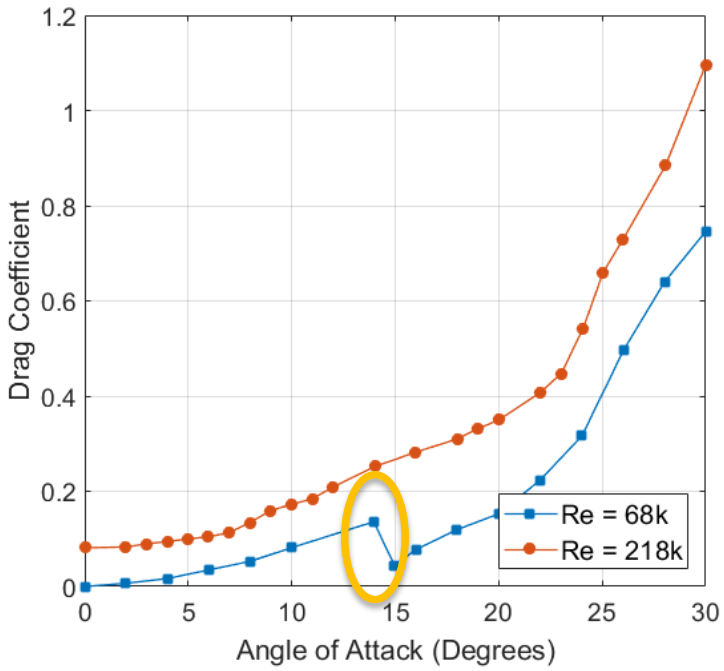
# BACKGROUND - WIND TUNNEL TESTING

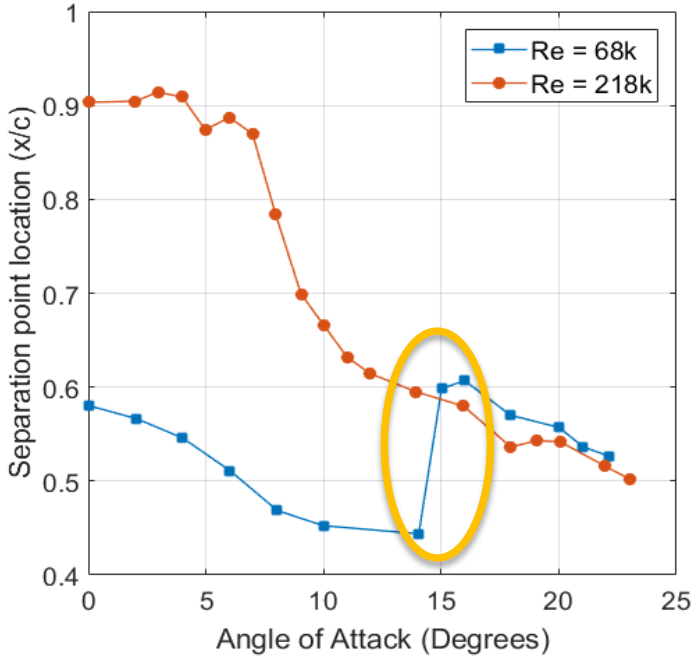
- **Wind Tunnel assumption:** the flow around the spinnaker is turbulent (at the scales typically tested in dedicated wind tunnel facilities).
- Inconsistencies noticed in the pressure distribution on wind tunnel tested models.
- Potential evidence of transition occurring in the literature.
- Highly 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).



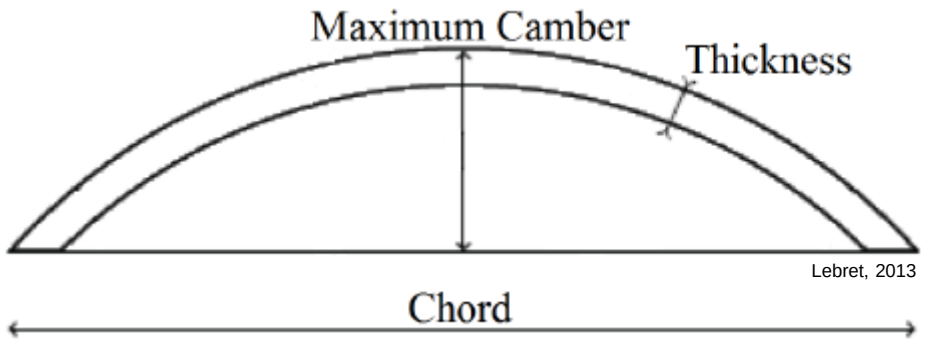




- **<u>Hypothesis:</u>** there is a combination of critical Reynolds Number and critical Angle of Attack that will trigger transition.

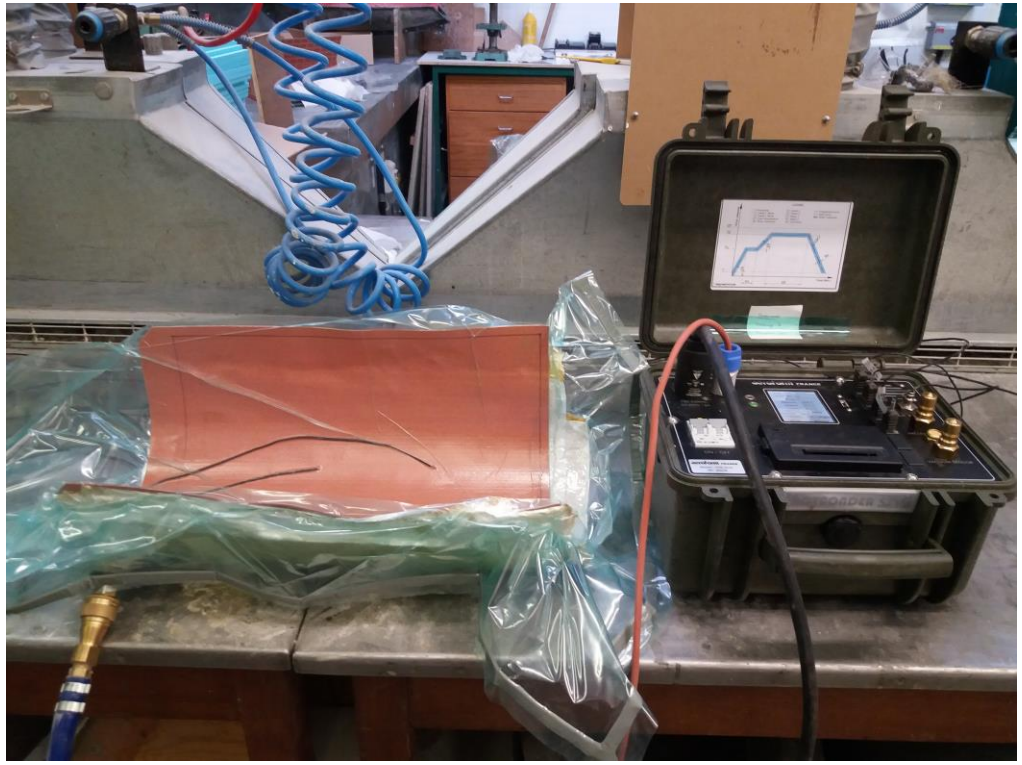
# CIRCLAR ARC GEOMETRY AND MANUFACTURING

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



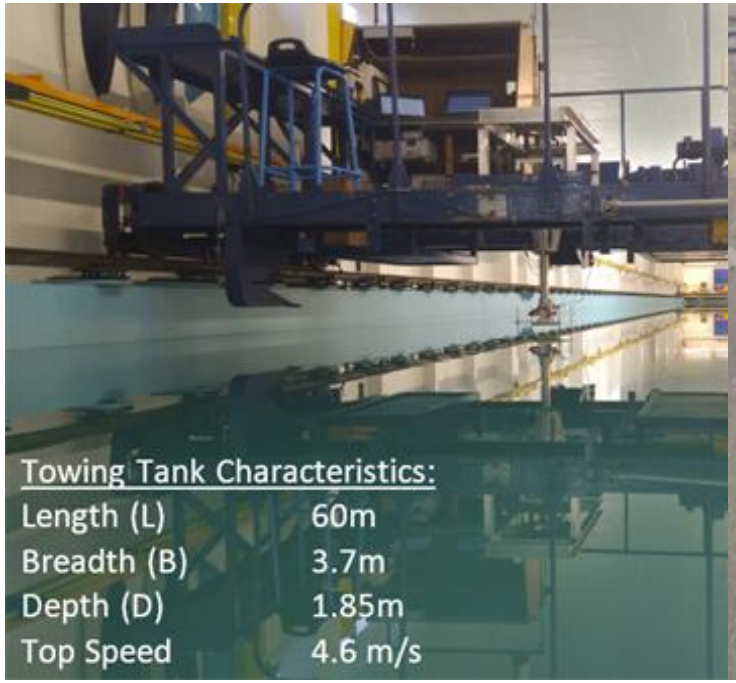
Lebret, 2013

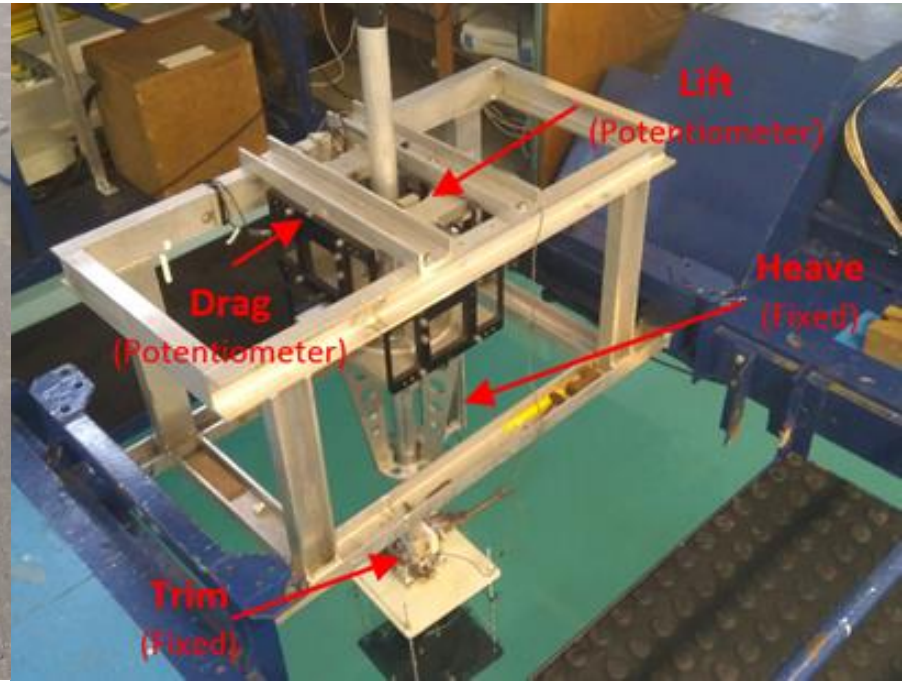
- **Manufacturing:**
  - Carbon prepreg



# TOWING TANK EXPERIMENTAL SETUP

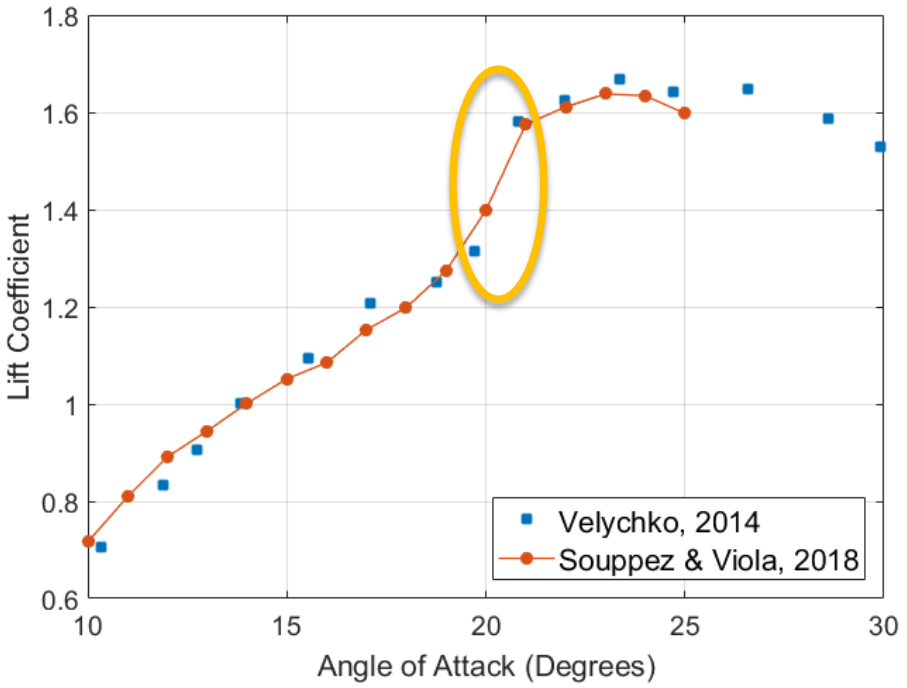
- Force measurements undertaken in Solent University's Hydrodynamic Test Centre:
  - Reynolds numbers: 53k, 68k, 150k and 220k
  - Angles of Attack: 5 to 20 (5 to 25 at 53k) in 1 degree increments
  - Angle of attack of 11 degrees for 130k < Re < 160k

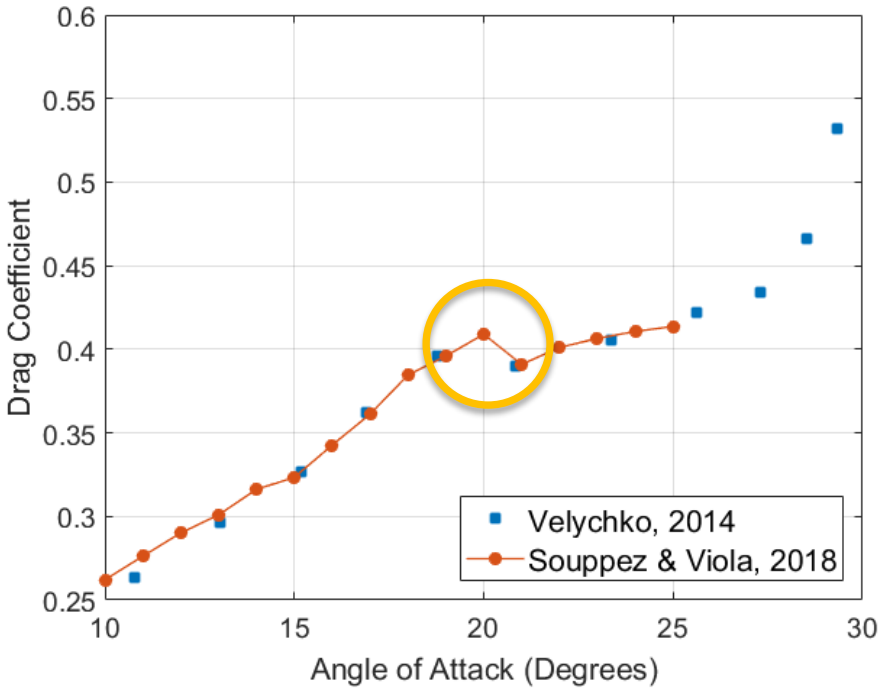


# TOWING TANK RESULTS - RE = 53K

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



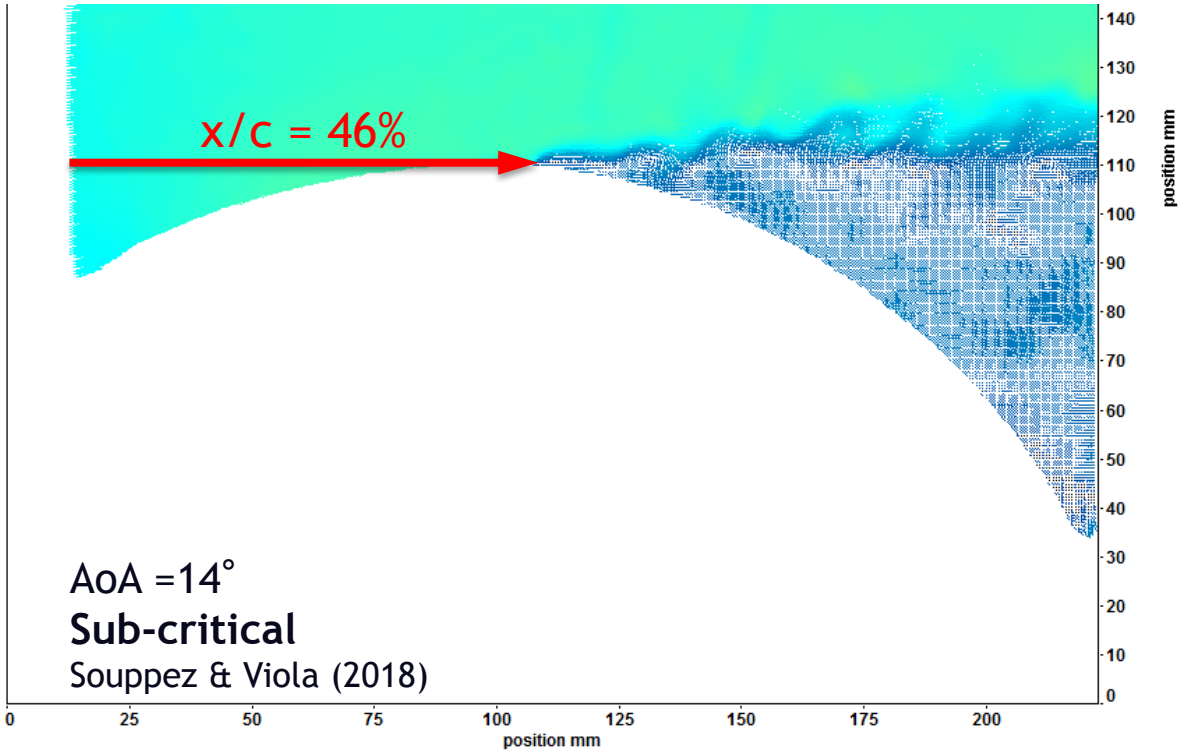



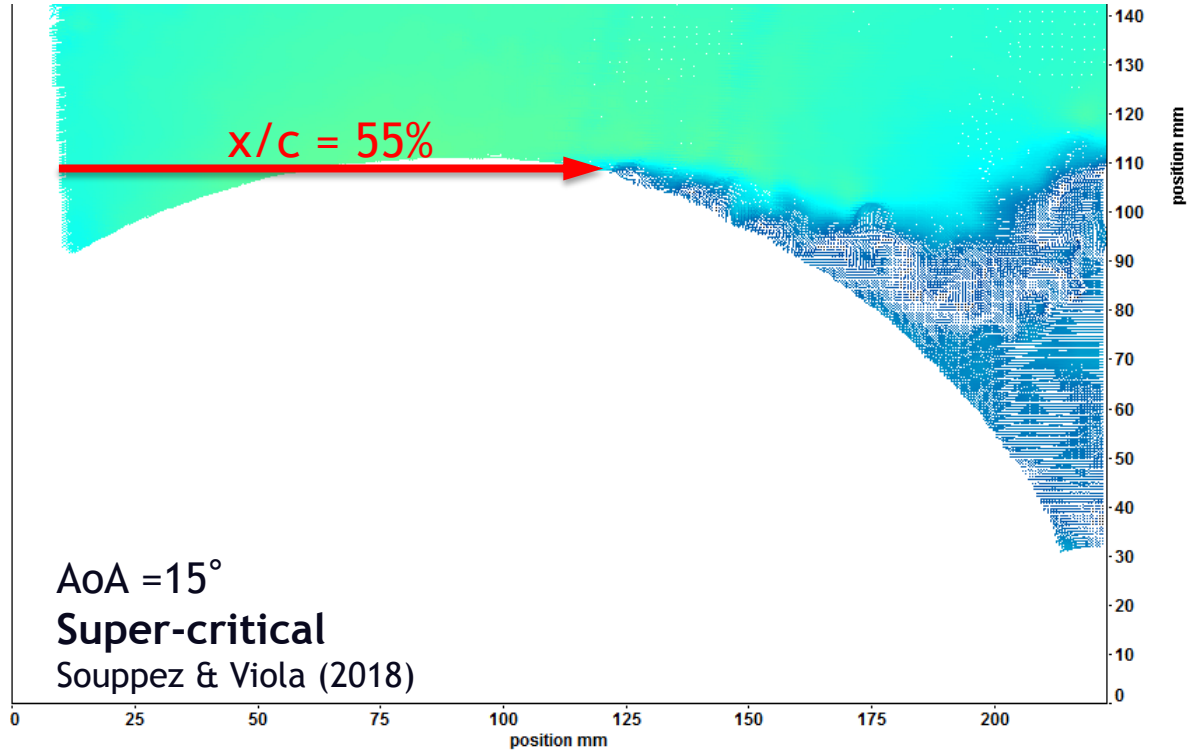


- Good agreement between the towing tank and the wind tunnel.

# TRANSITION: SEPARATION AND WAKE SIZE - RE = 68K

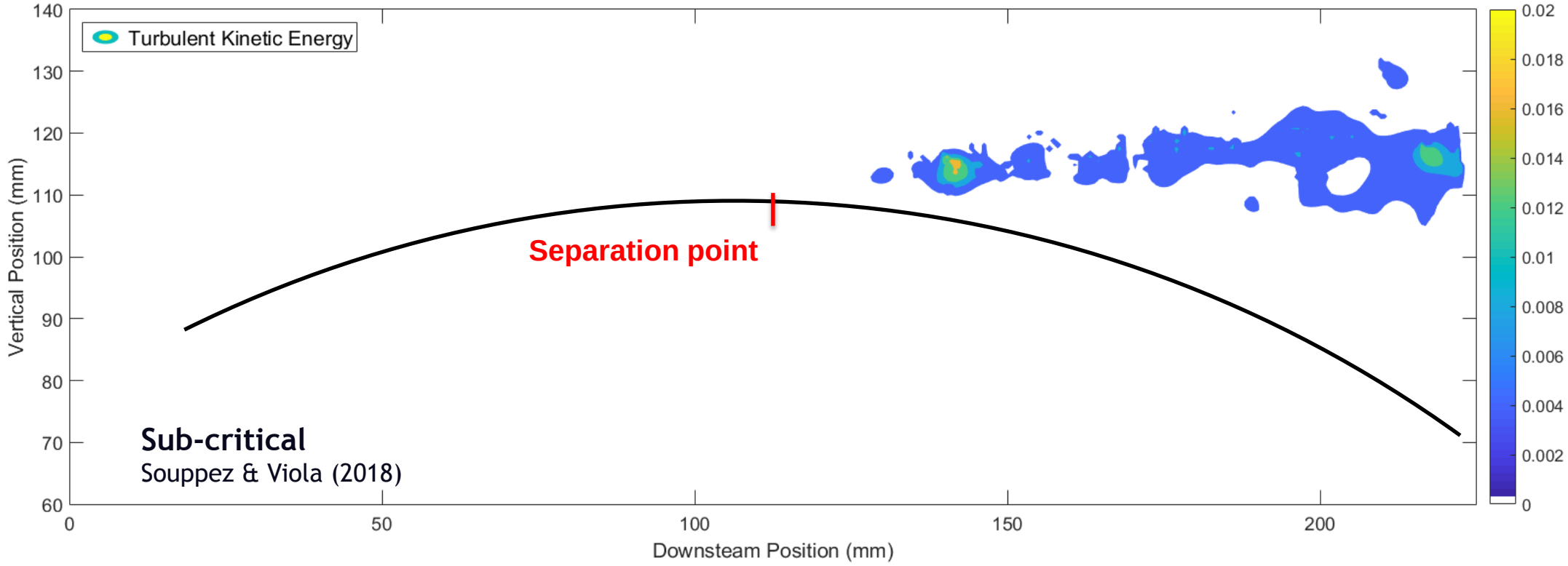
- Delayed separation consistent with the values of Martin (2015) and reduced wake, characteristic of laminar to turbulent transition



# TRANSITION: TURBULENT KINETIC ENERGY - RE = 68K

- Further evidence of the transition can be found by computing the TKE.



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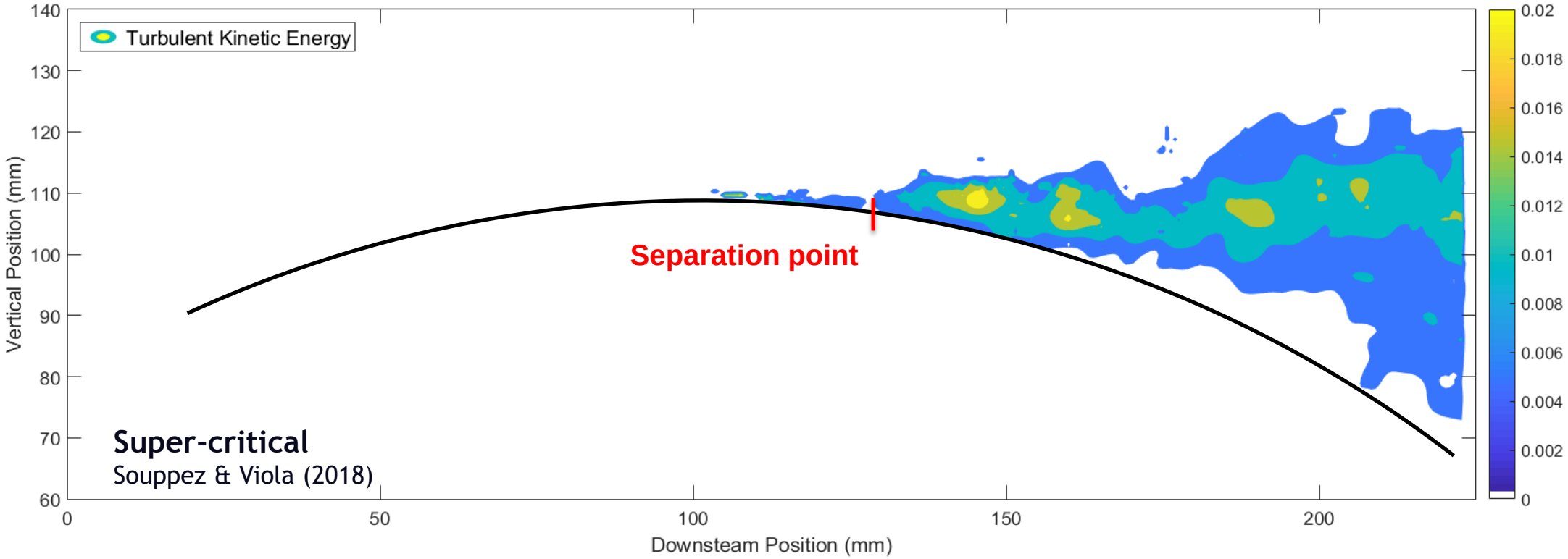
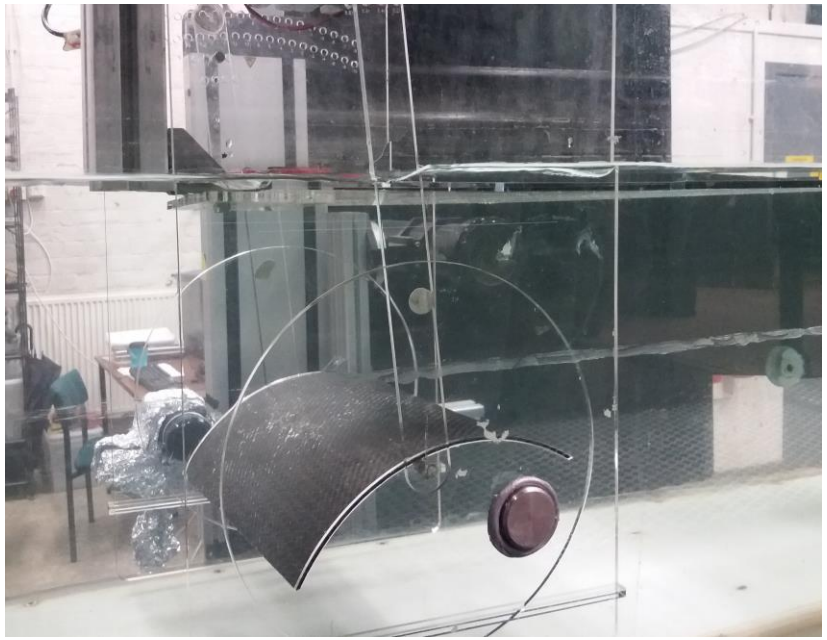
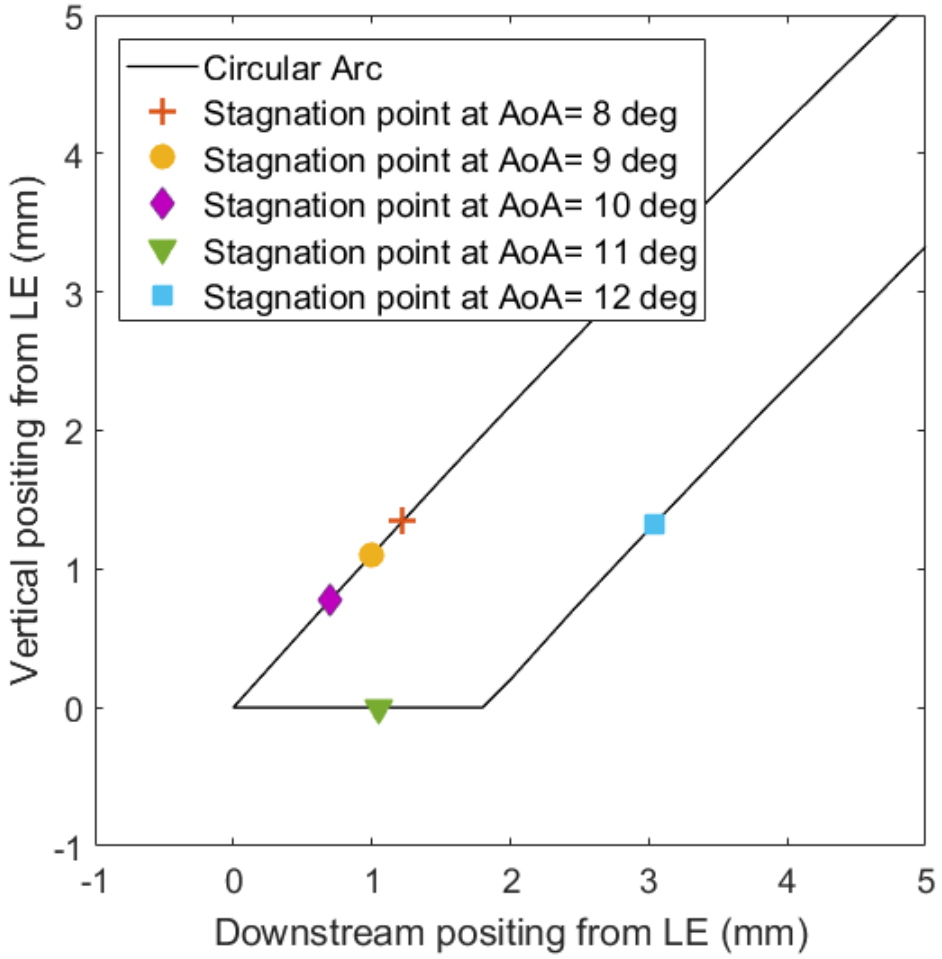


# IDEAL ANGLE OF ATTACK

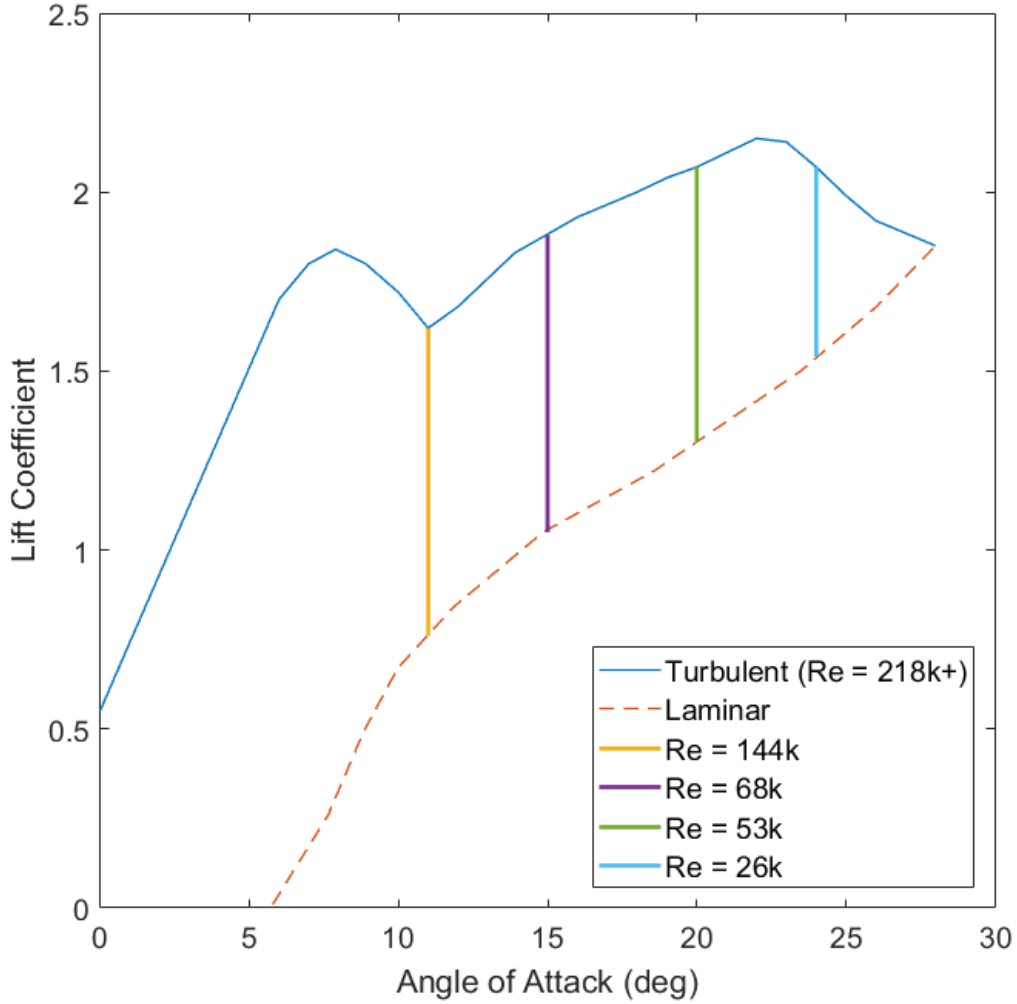
- PIV employed to locate stagnation points at 8, 9, 10, 11 and 12 degrees angle of attack.
- Revealed 11 degrees is the ideal angle of attack, i.e. the minimum required to inflate a soft membrane such as a spinnaker.





# FINDINGS

- Below Re = 218k, there is a combination of Reynolds number and angle of attack that will induce transition, demonstrated with PIV.
- Ideal angle of attack occurs a 11 degrees, with a critical Reynolds number of 144k.
- 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.



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# Thank You


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