SOLENT
UNIVERSITY

ON THE EXPERIMENTAL TESTING OF DOWNWIND YACHT SAILS

HERE COMES THE MATHS… SORRY!

21ST SEPTEMBER 2019

~~Jean Baptiste R. G. Souppez~~ JB

Senior Lecturer in Yacht Design and Composite Engineering

UK Principal Expert in Small Craft Structures | British Standards Institution
Visiting Professor and Research Supervisor | University of Liege, EMship +
Deputy Editor-in-Chief | SNAME Journal of Sailing Technology
Research Supervisor | University of Plymouth, MLA
Stanley Gray Research Fellow | IMarEST

jean-baptiste.souppez@solent.ac.uk

Celebrating 50 Years of Yacht Design at Solent

SOLENT UNIVERSITY

CONTENTS

BACKGROUND

Continuity $$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} + \frac{\partial W}{\partial z} = 0$$

X-momentum
$$\rho\left(\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} + W\frac{\partial U}{\partial z}\right) = -\frac{\partial P}{\partial x} + \rho g_x + \mu\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2}\right)$$

Y-momentum
$$\rho\left(\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} + W\frac{\partial V}{\partial z}\right) = -\frac{\partial P}{\partial y} + \rho g_y + \mu\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}\right)$$

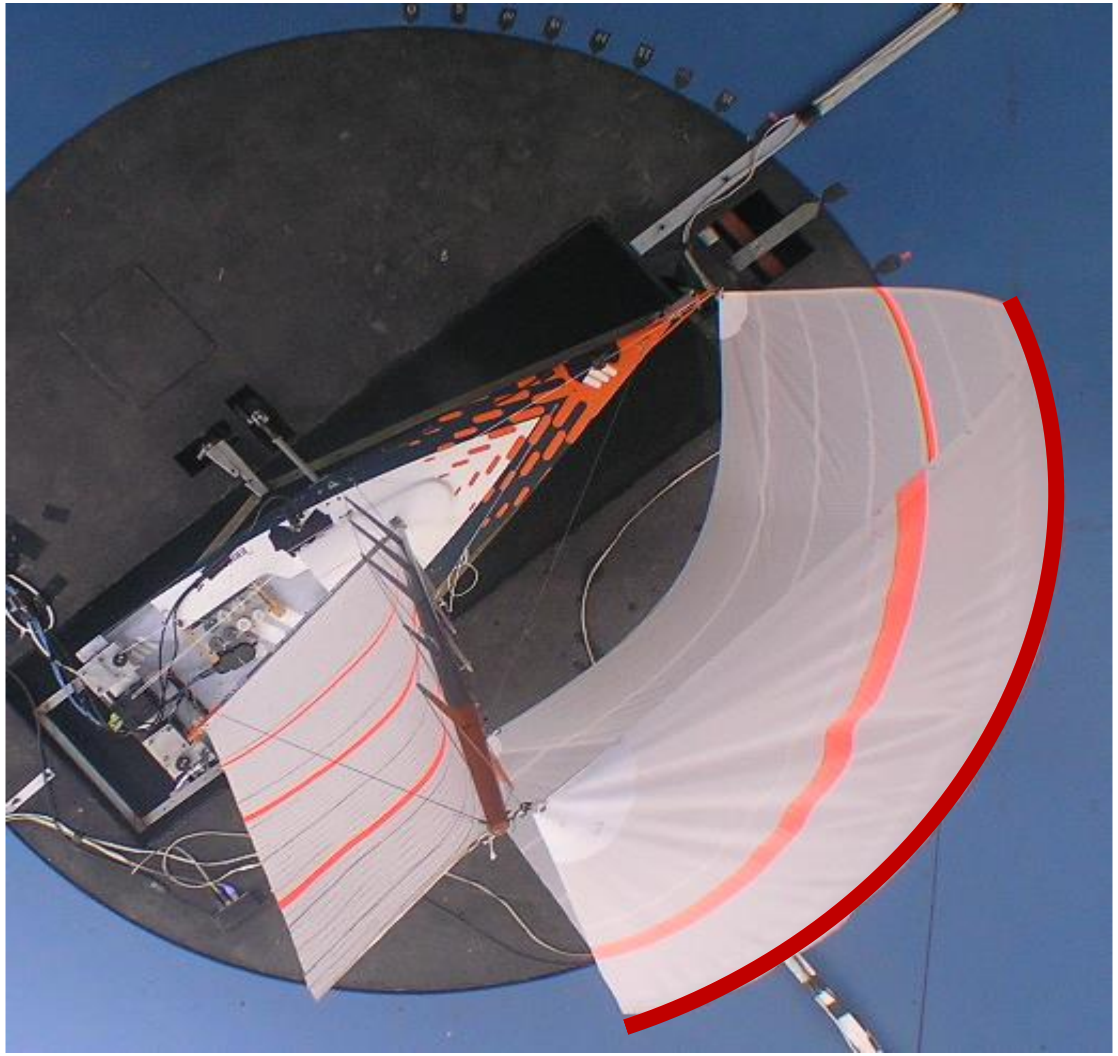
Z-momentum
$$\rho\left(\frac{\partial W}{\partial t} + U\frac{\partial W}{\partial x} + V\frac{\partial W}{\partial y} + W\frac{\partial W}{\partial z}\right) = -\frac{\partial P}{\partial z} + \rho g_z + \mu\left(\frac{\partial^2 W}{\partial x^2} + \frac{\partial^2 W}{\partial y^2} + \frac{\partial^2 W}{\partial z^2}\right)$$

BACKGROUND

- **Wind Tunnel assumption:** the flow around the spinnaker is turbulent (at the scales typically tested in dedicated wind tunnel facilities).

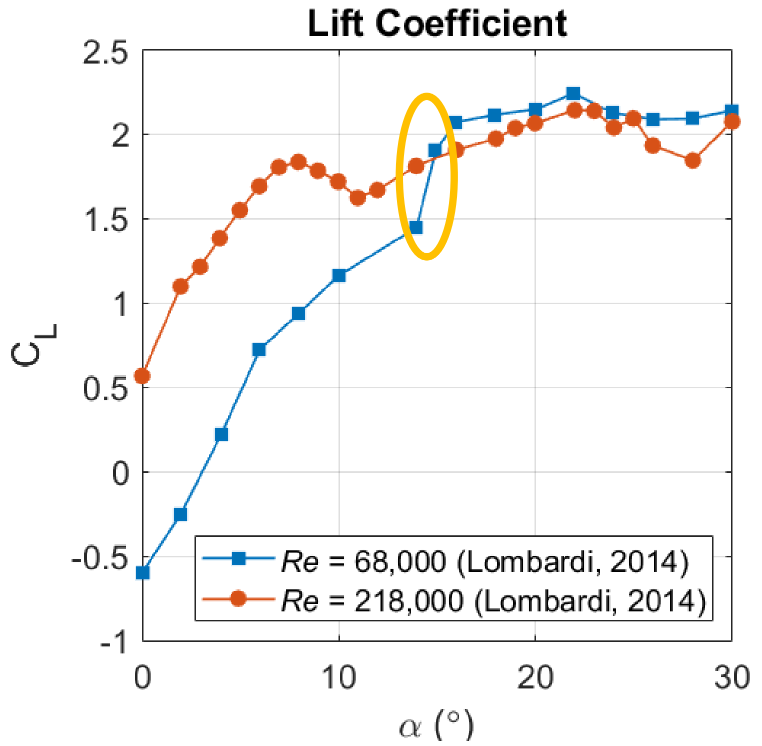
- Inconsistencies noticed in the pressure distribution on wind tunnel tested models.

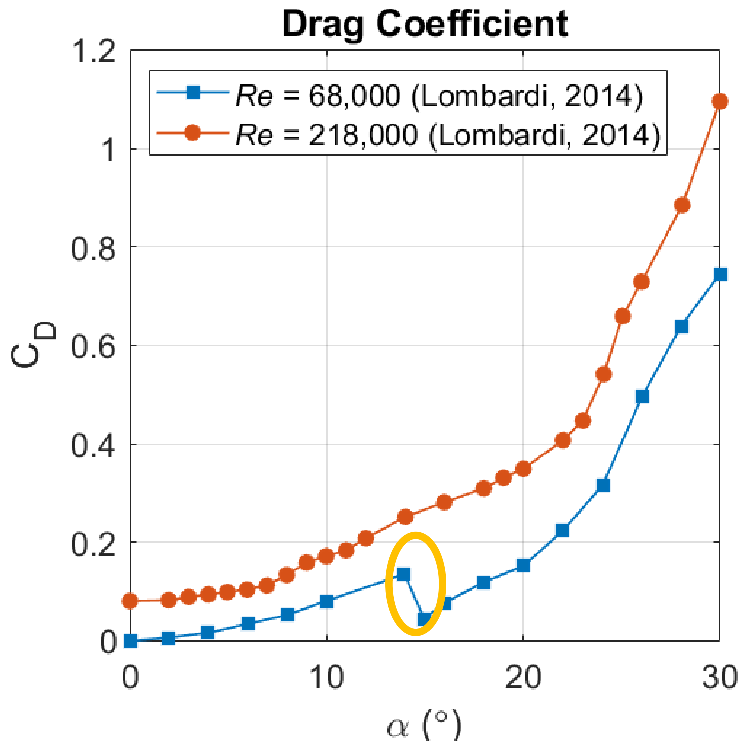
- ***Highly-cambered thin*** *circular arc with a* ***sharp leading-edge***, as a simplified cross section through a spinnaker.

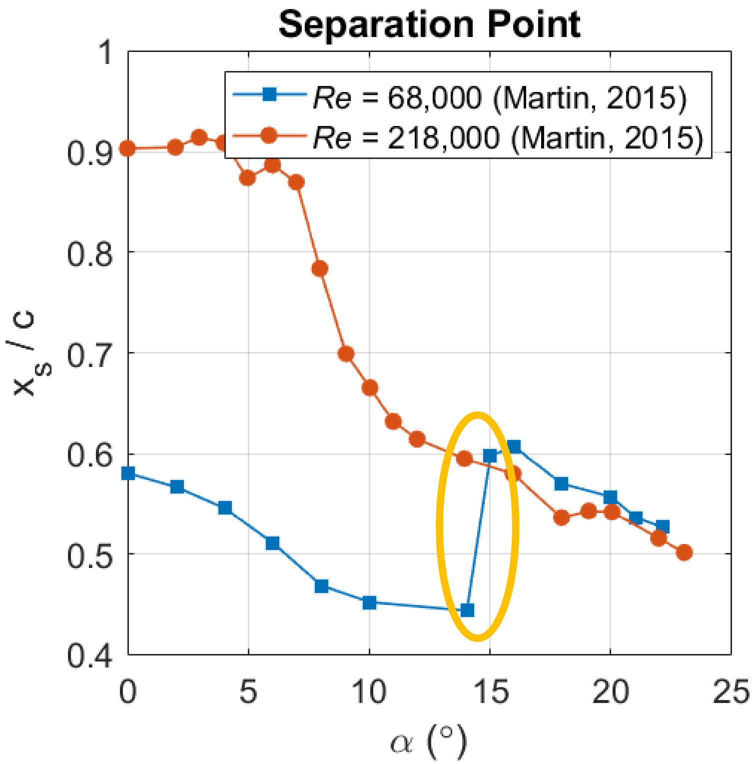


CIRCULAR ARC AERODYNAMICS

- Low Reynolds number: discontinuity in the lift and drag (Lombardi, 2014)
- Separation point further downstream at the same angle (Martin, 2015)

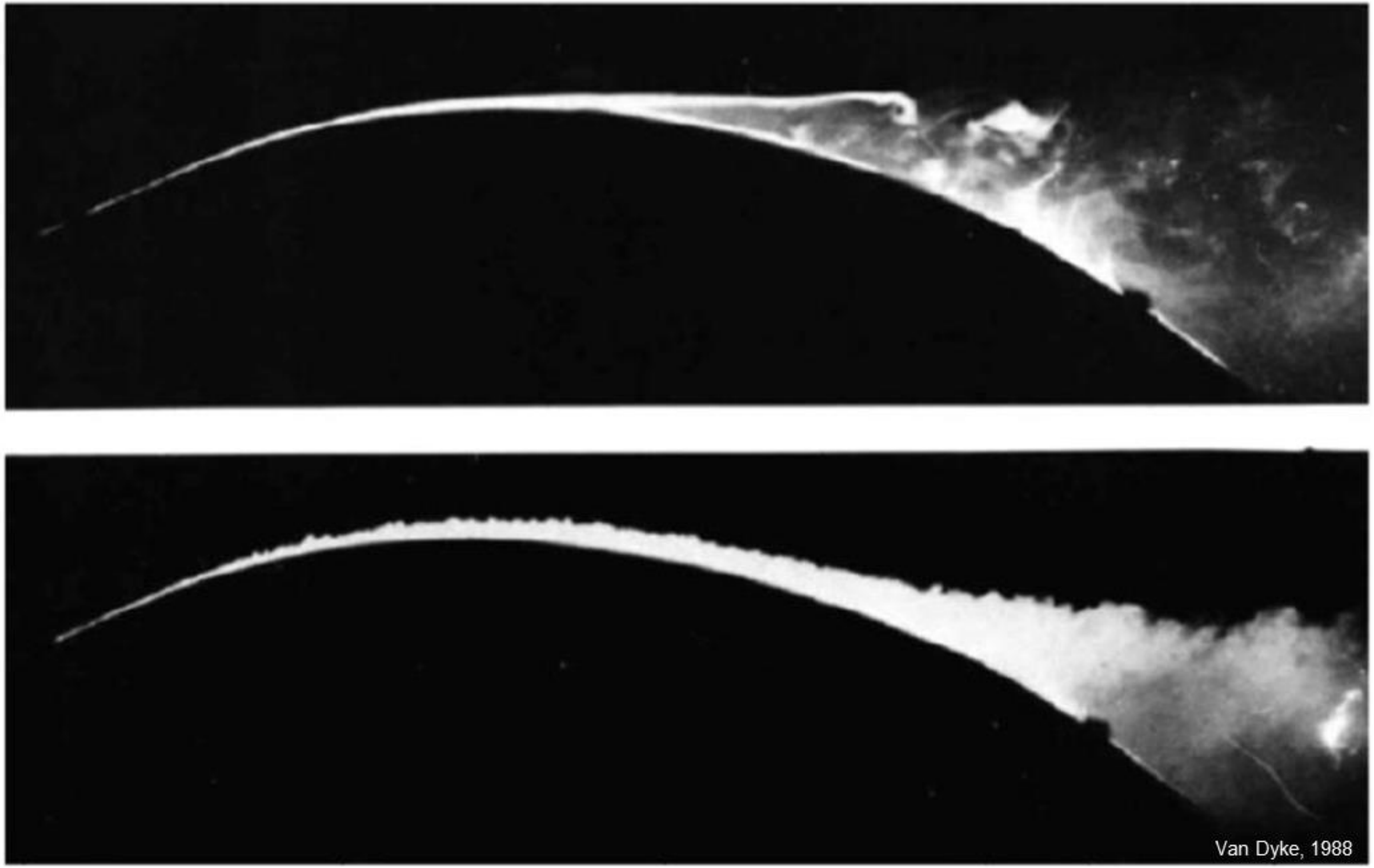






- <u>**Hypothesis:**</u> these is a combination of critical Reynolds number and critical angle of attack that will trigger transition (and thus a laminar regime can exist).

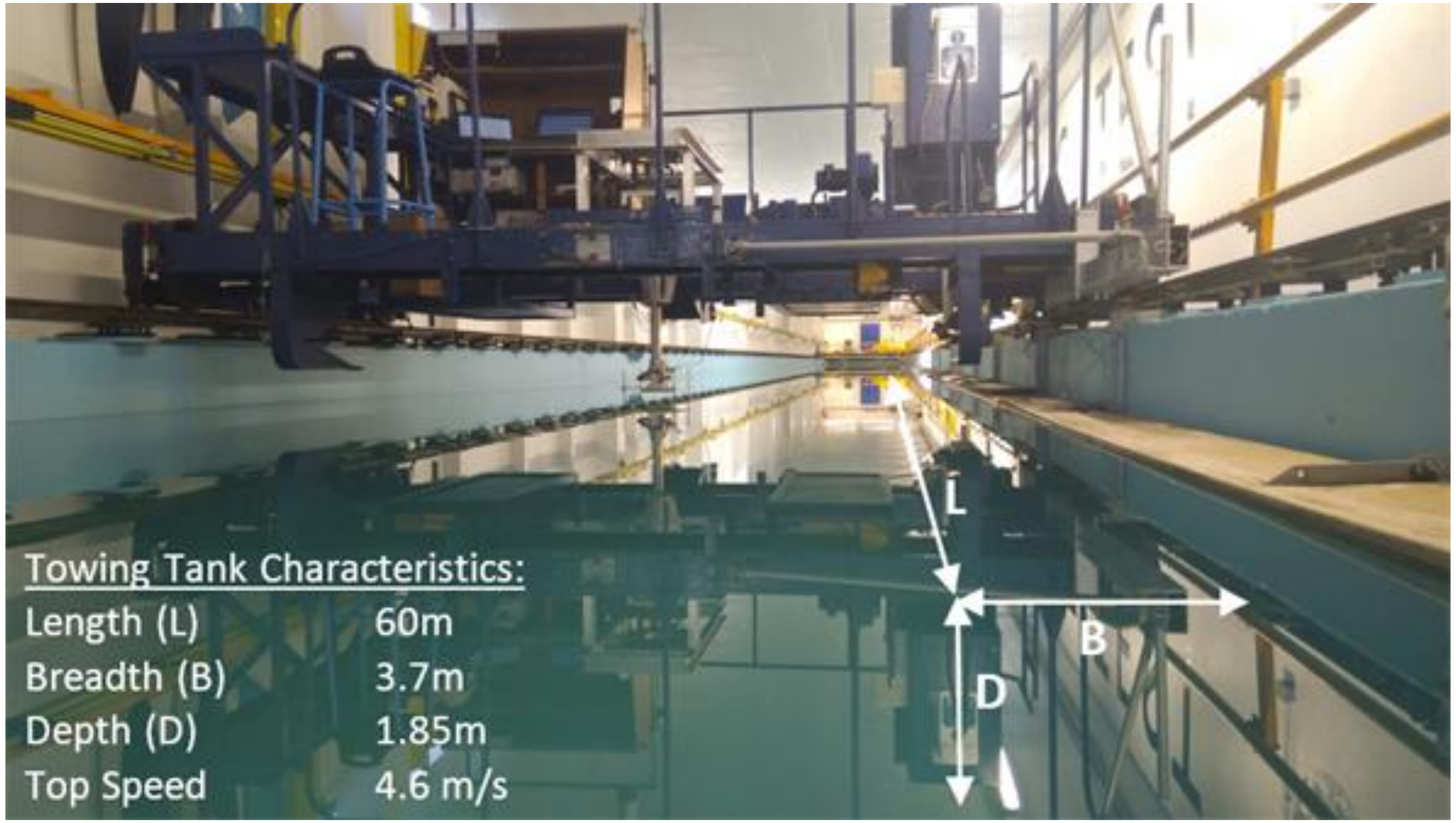
HYPOTHESIS

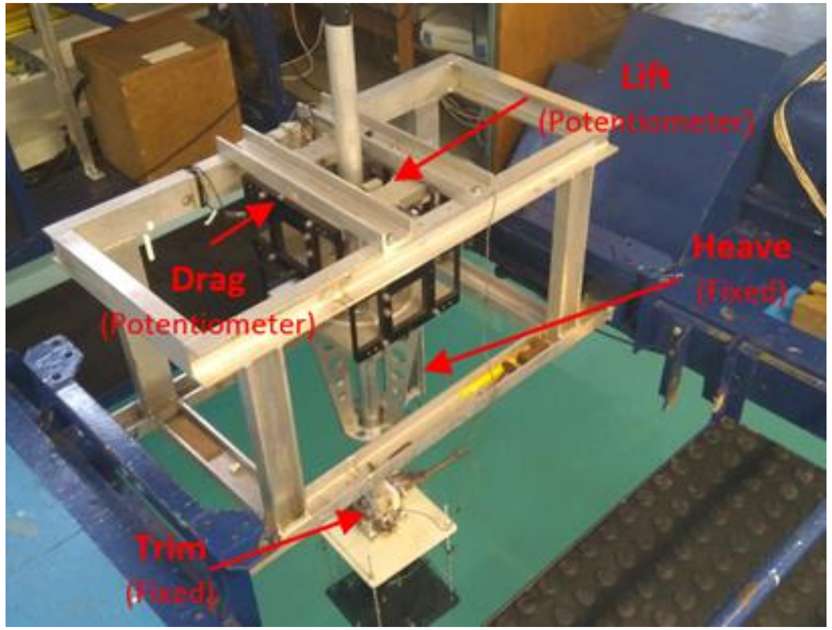


SOLENT UNIVERSITY

FORCE MEASUREMENTS

- 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)
  - Angle of attack of 11 degrees for 130k < Re < 160k

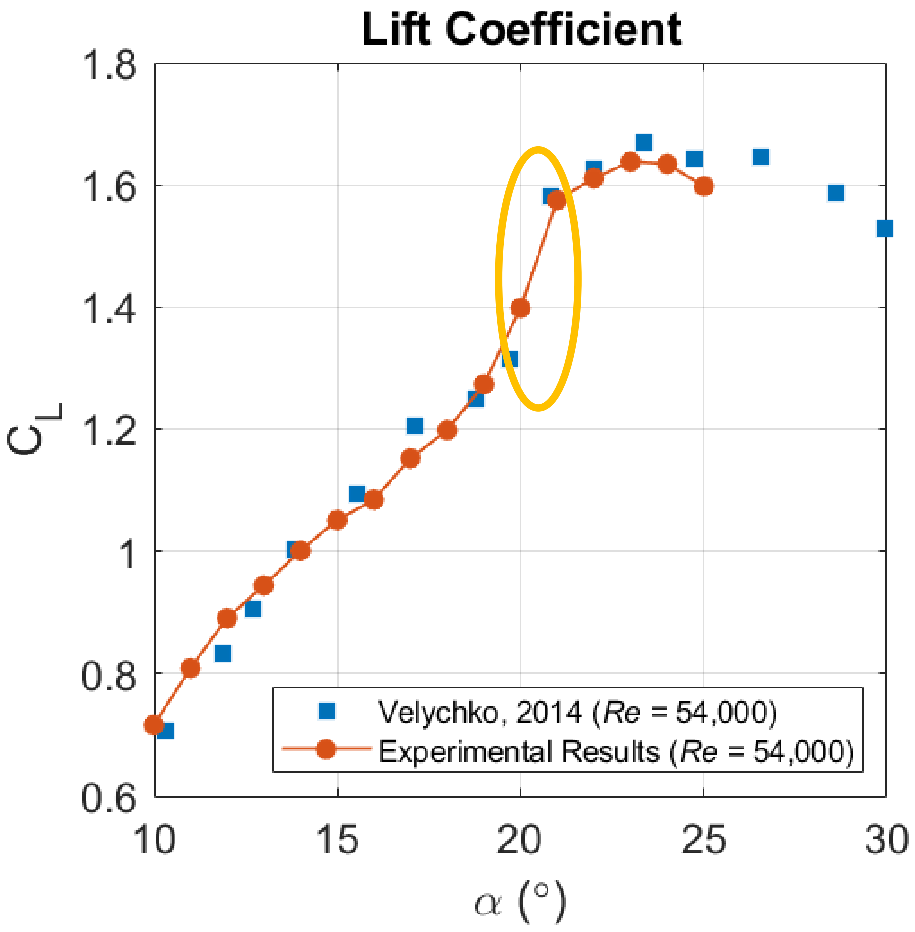


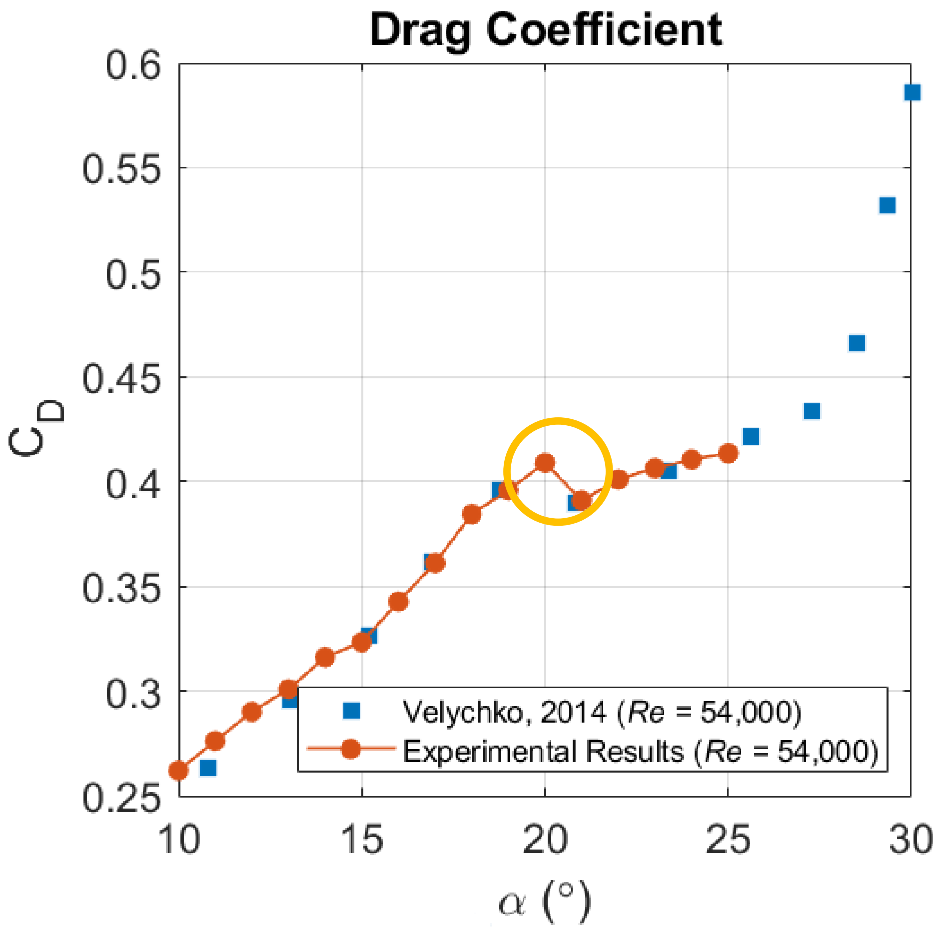


SOLENT UNIVERSITY

FORCE MEASUREMENTS VALIDATION

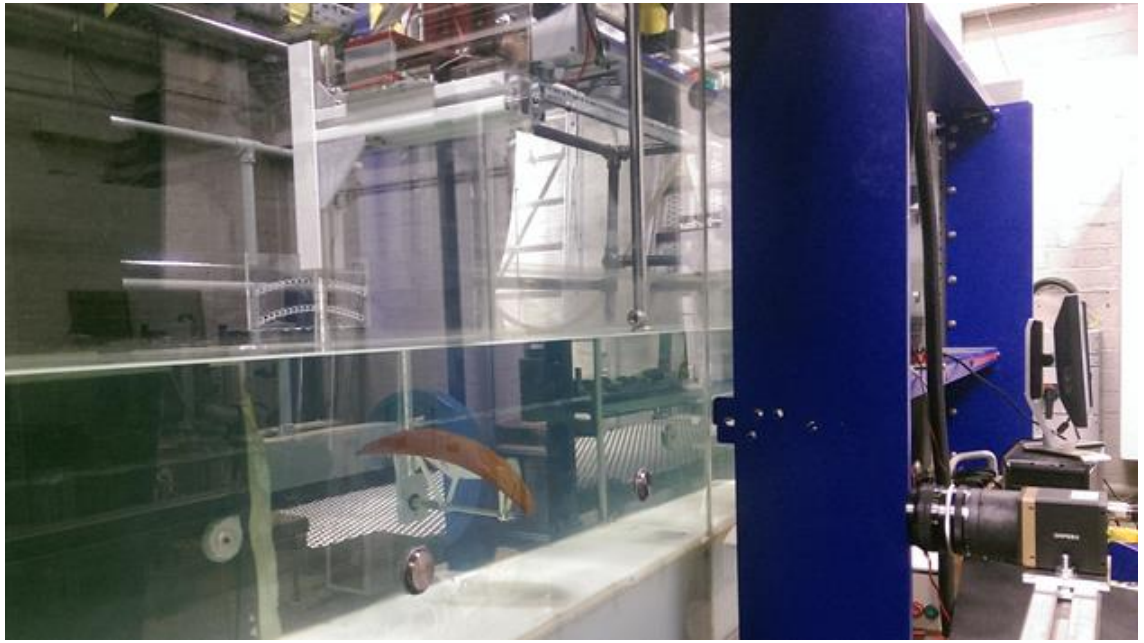
- Validated against Velychko's (2014) wind tunnel experiment.

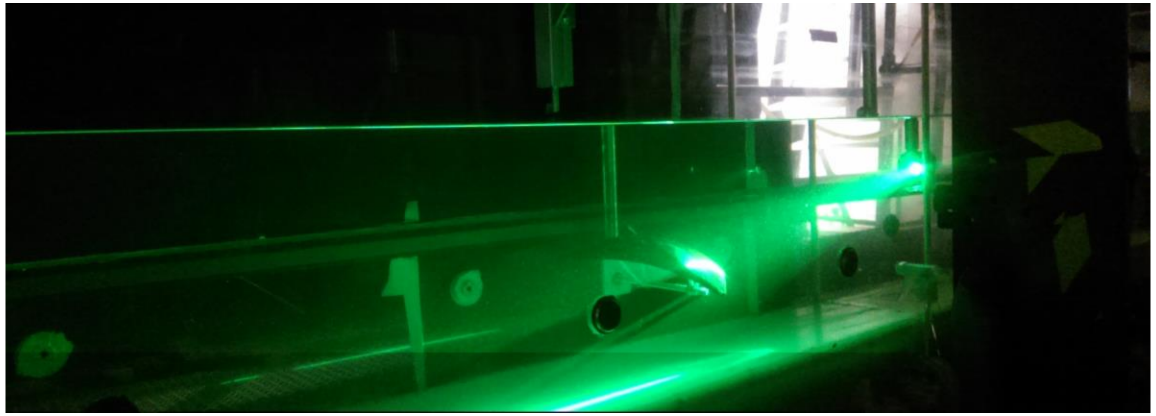


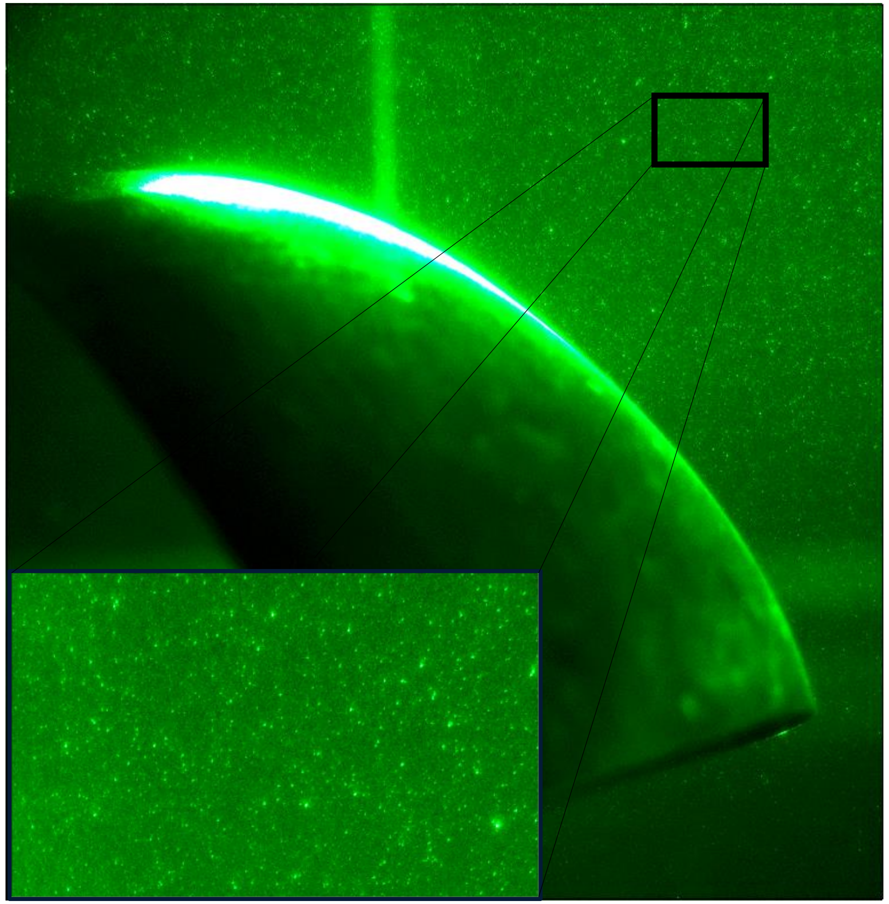


SOLENT UNIVERSITY

FLOW DIAGNOSTICS
PARTICLE IMAGE VELOCIMETRY (PIV)

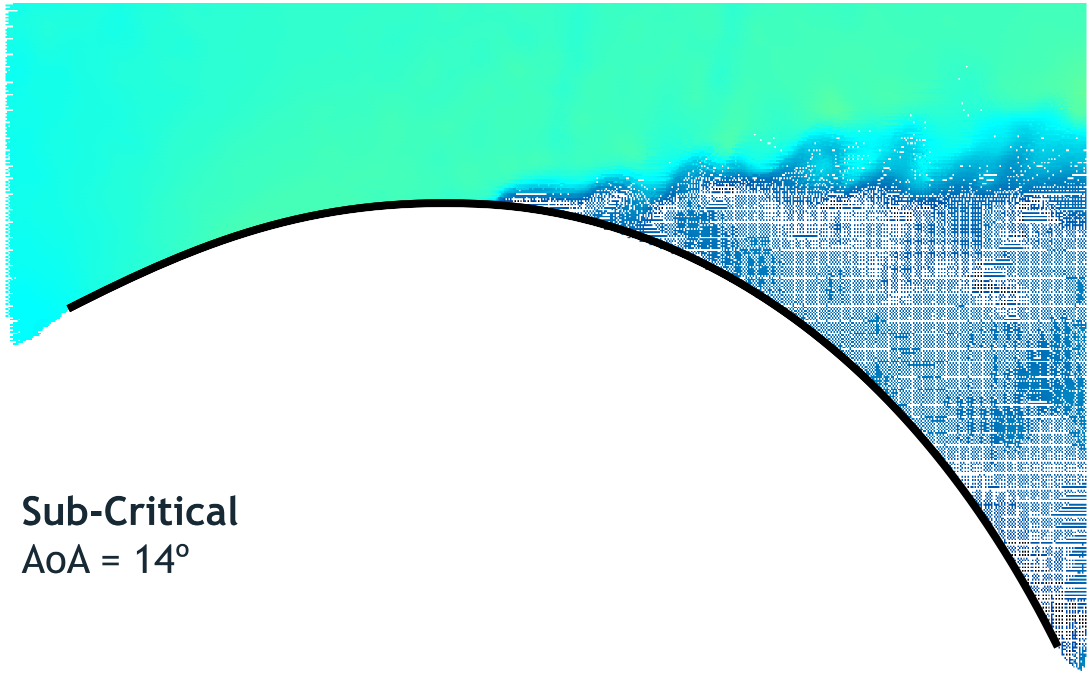




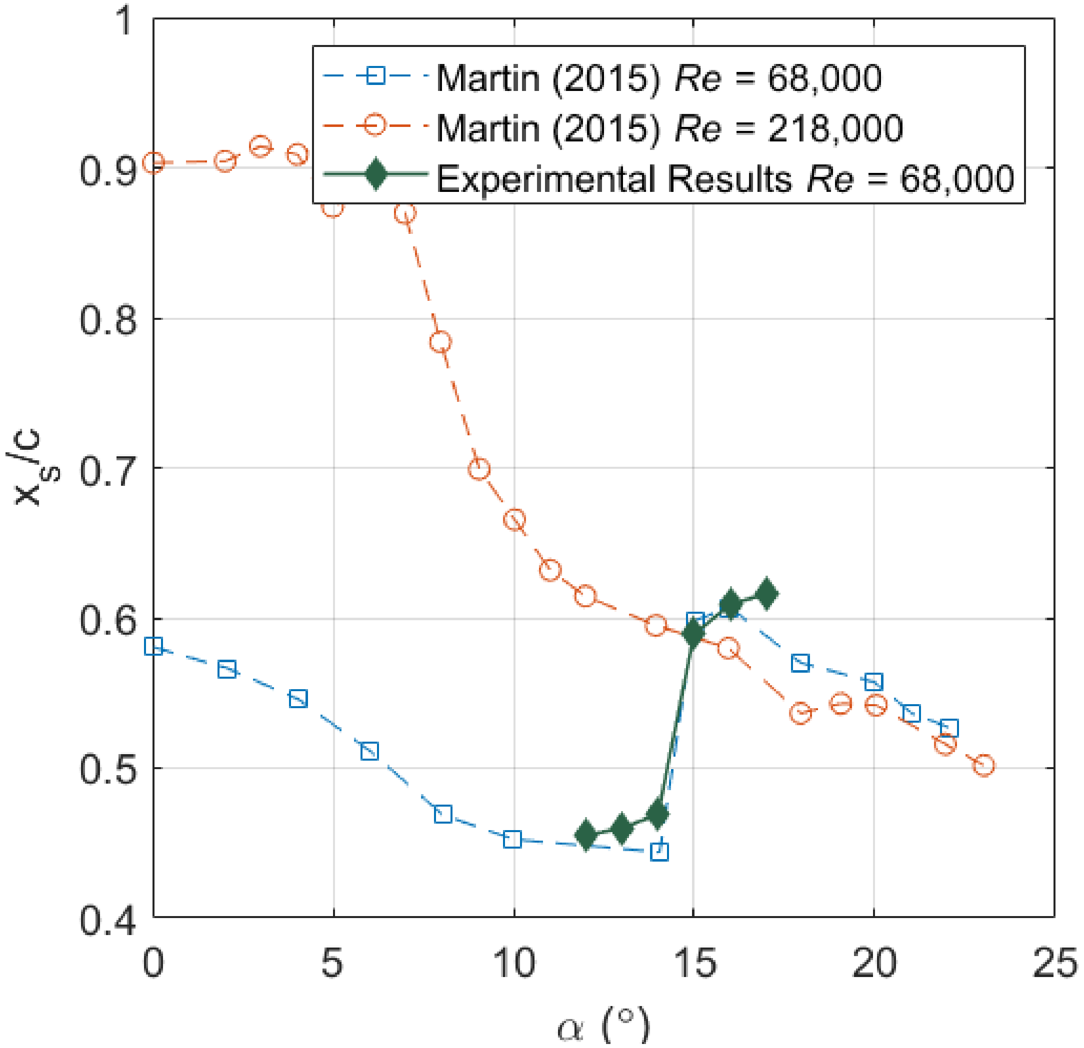


FLOW DIAGNOSTICS
SEPARATION POINT AND WAKE

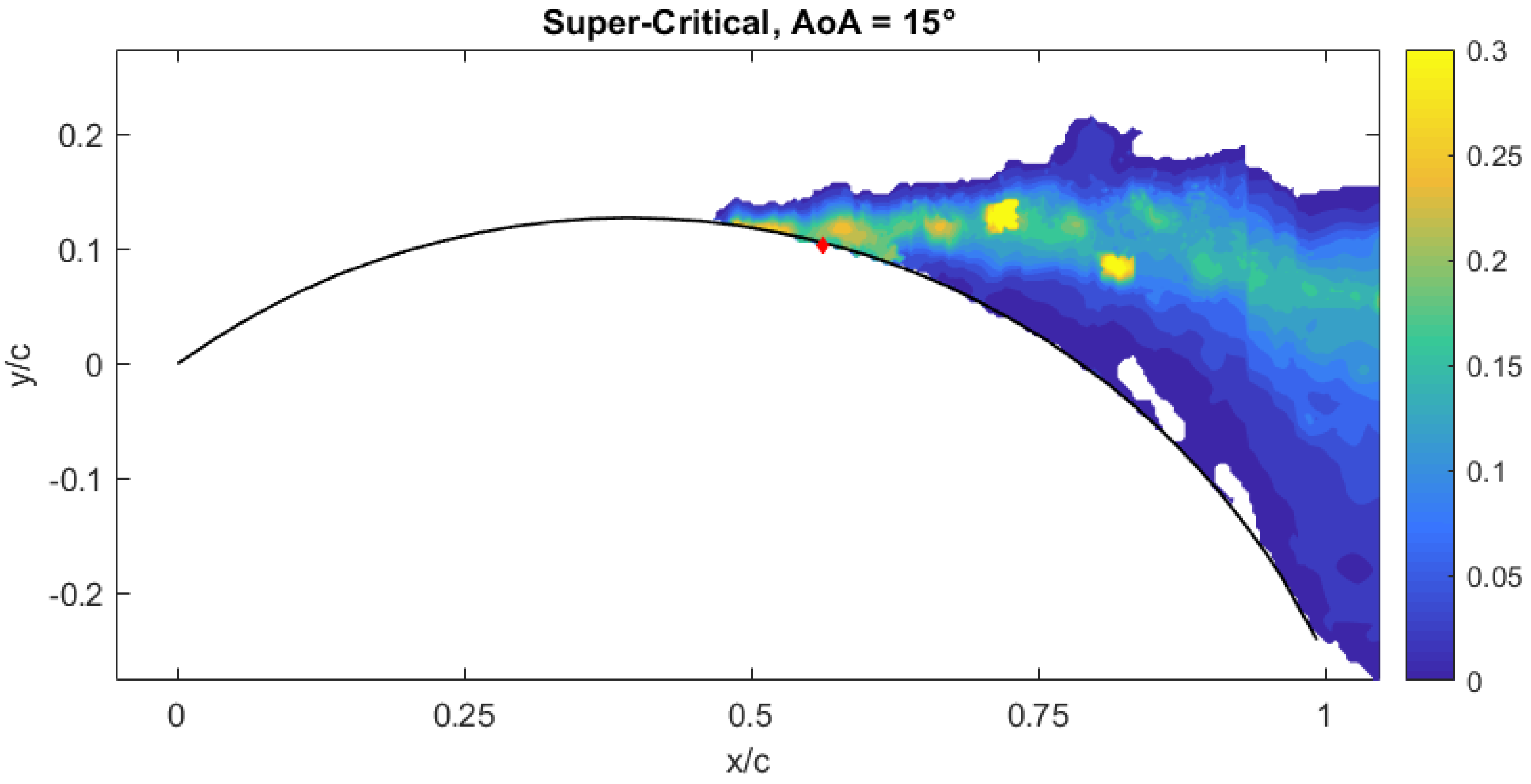
- Delayed separation consistent with the values of Martin (2015) and reduced wake, characteristic of laminar to turbulent transition.



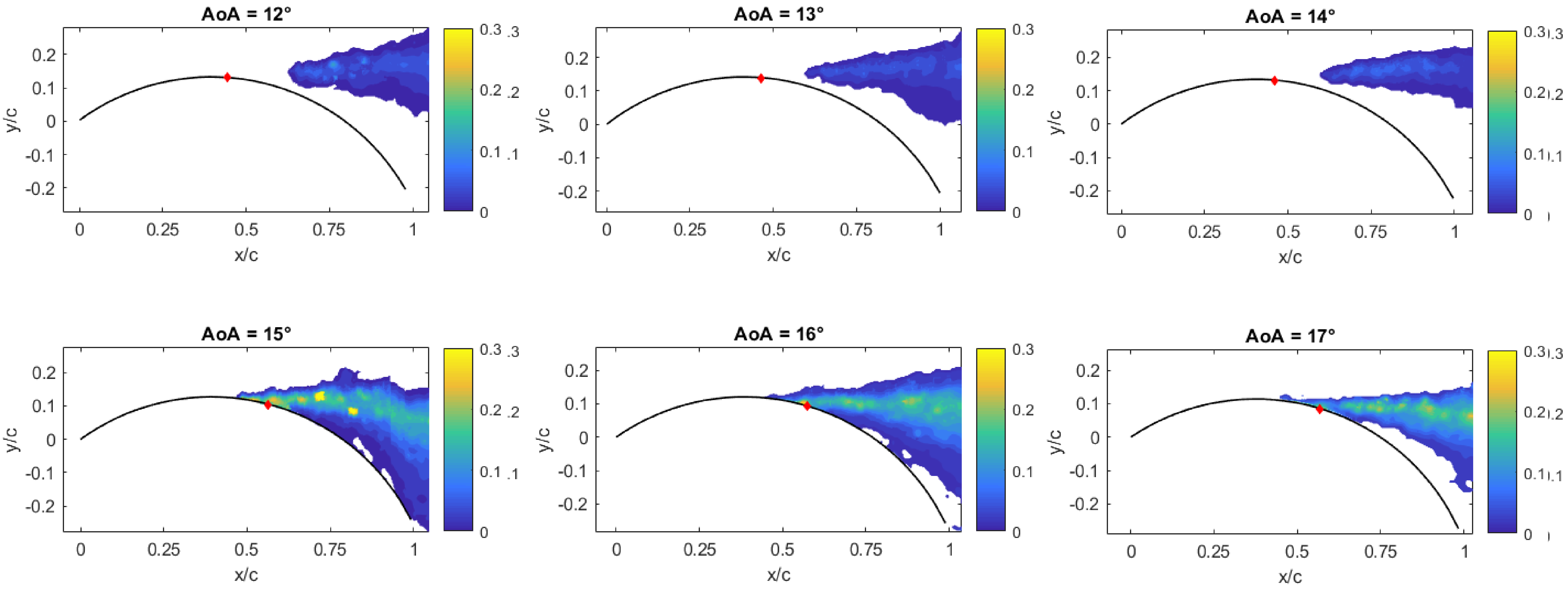
Sub-Critical
AoA = 14º



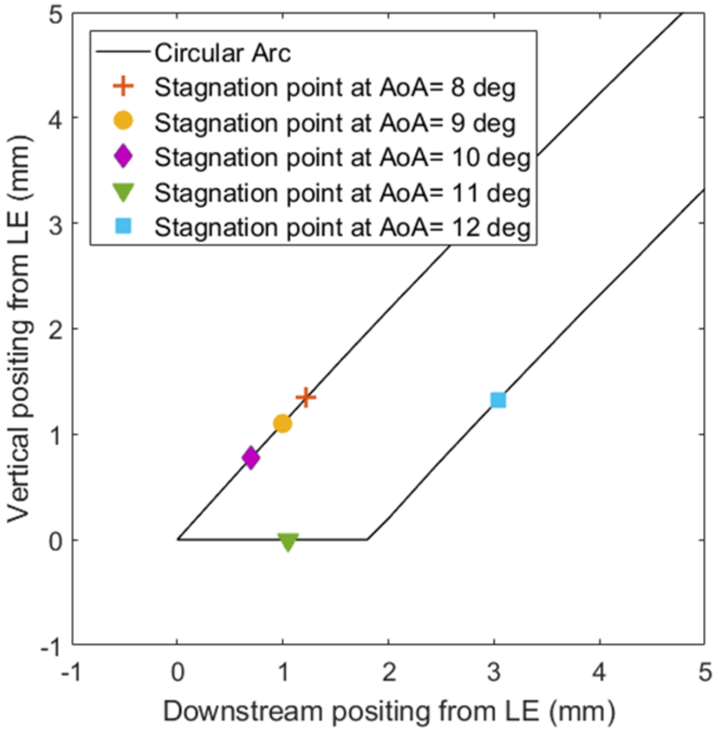
FLOW DIAGNOSTICS
TURBULENT KINETRIC ENERGY

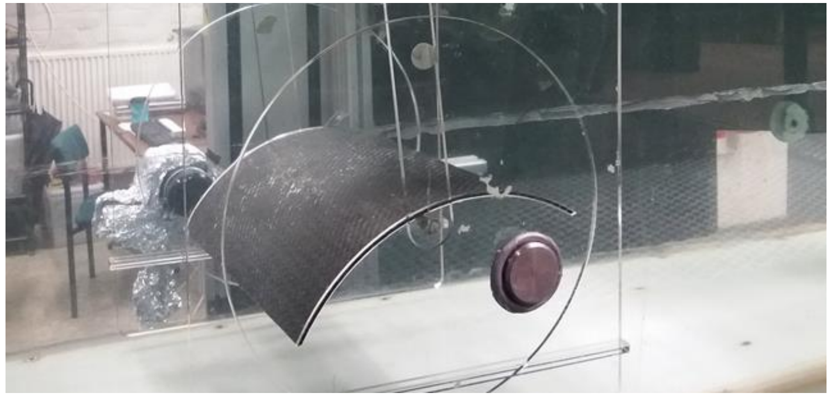


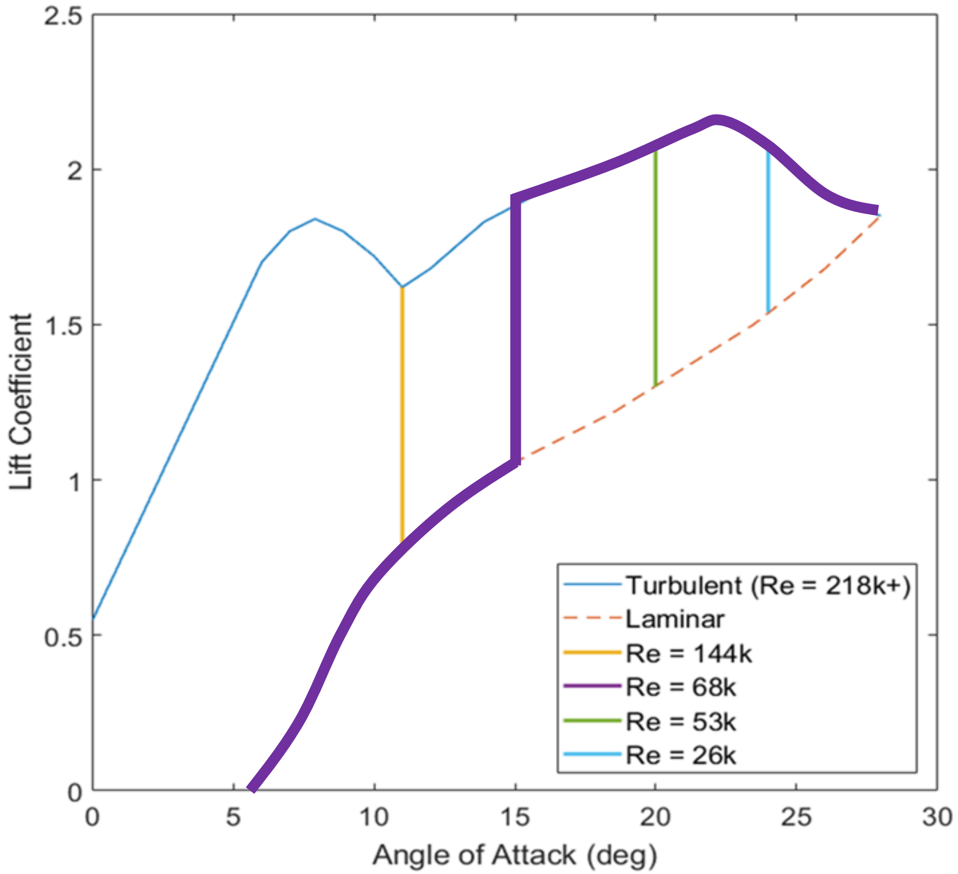
FLOW DIAGNOSTICS
TURBULENT KINETRIC ENERGY



IDEALISED MODEL



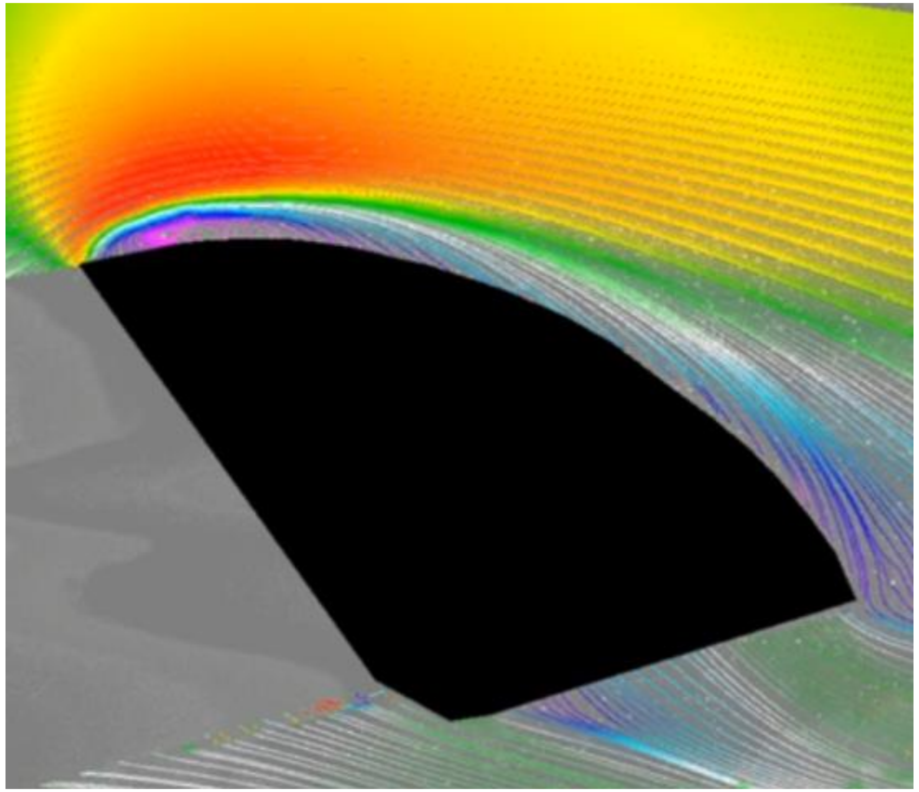


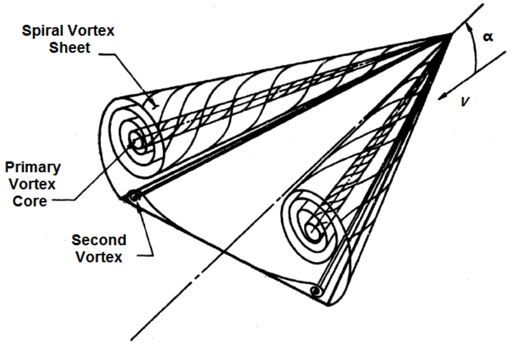


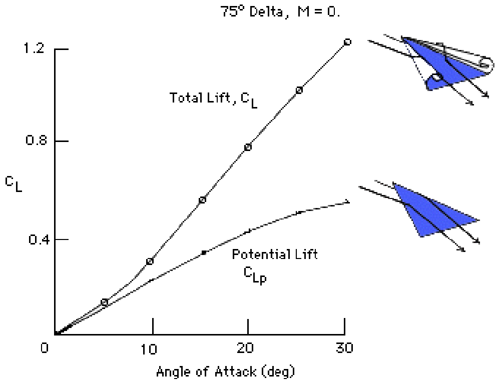
- What angle of attack is needed to inflate a soft spinnaker? **11°**
- And what is the associated critical Reynolds number? **144k +/-2**

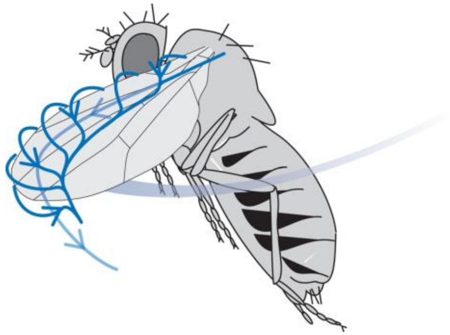
LEADING EDGE VORTEX

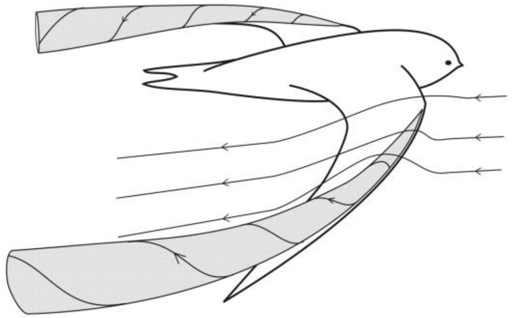
- Evidence of LEV on:
  - Delta Wings (1950s)
  - Insects (1996)
  - Birds (2004)
  - Spinnakers (2014) – Numerically
  - Spinnakers (2017) - Experimentally



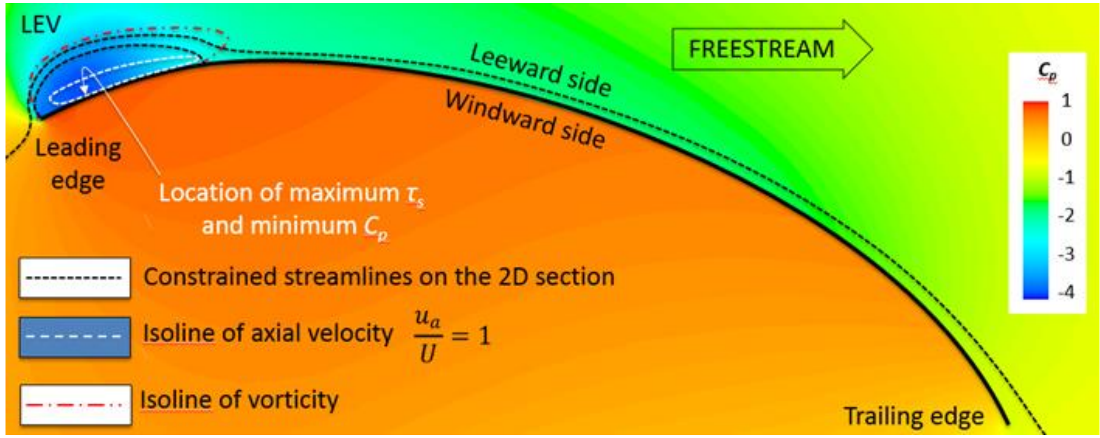






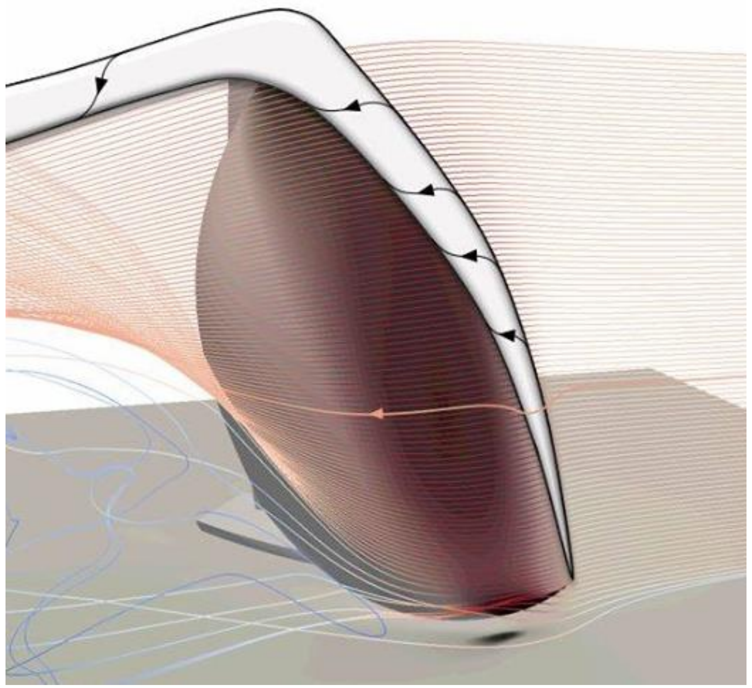


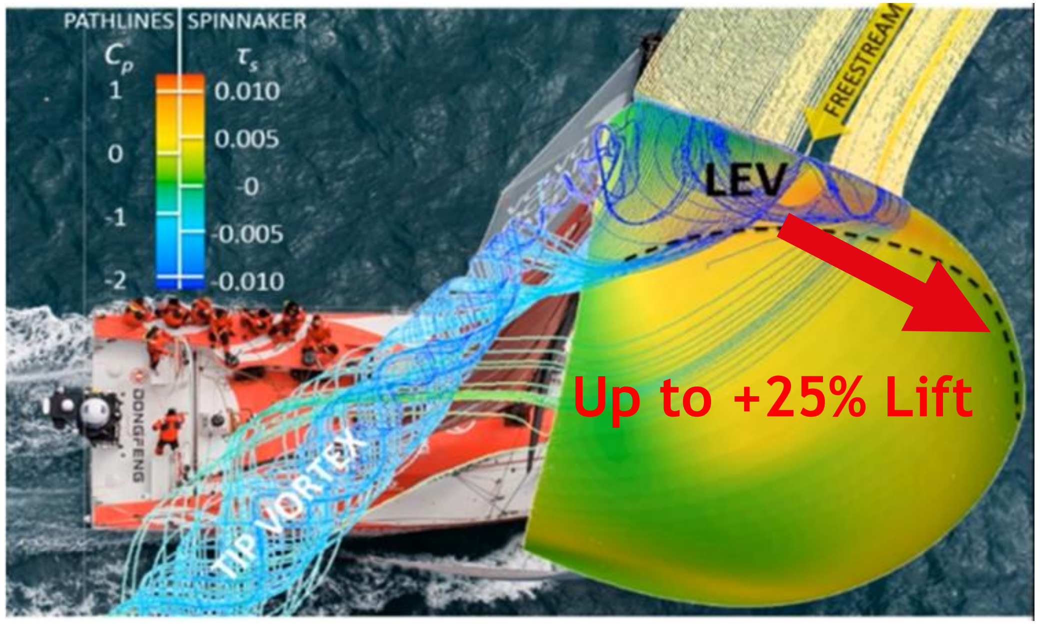
"Birds can't fly"

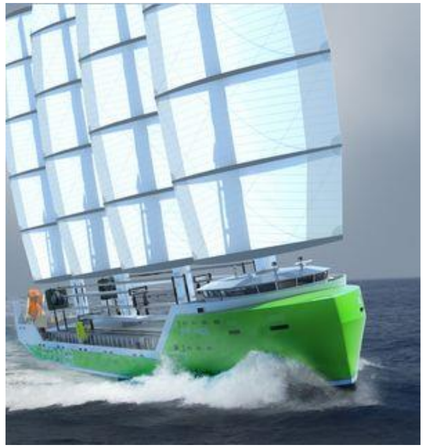


SOLENT UNIVERSITY

LEADING EDGE VORTEX & APPLICATIONS



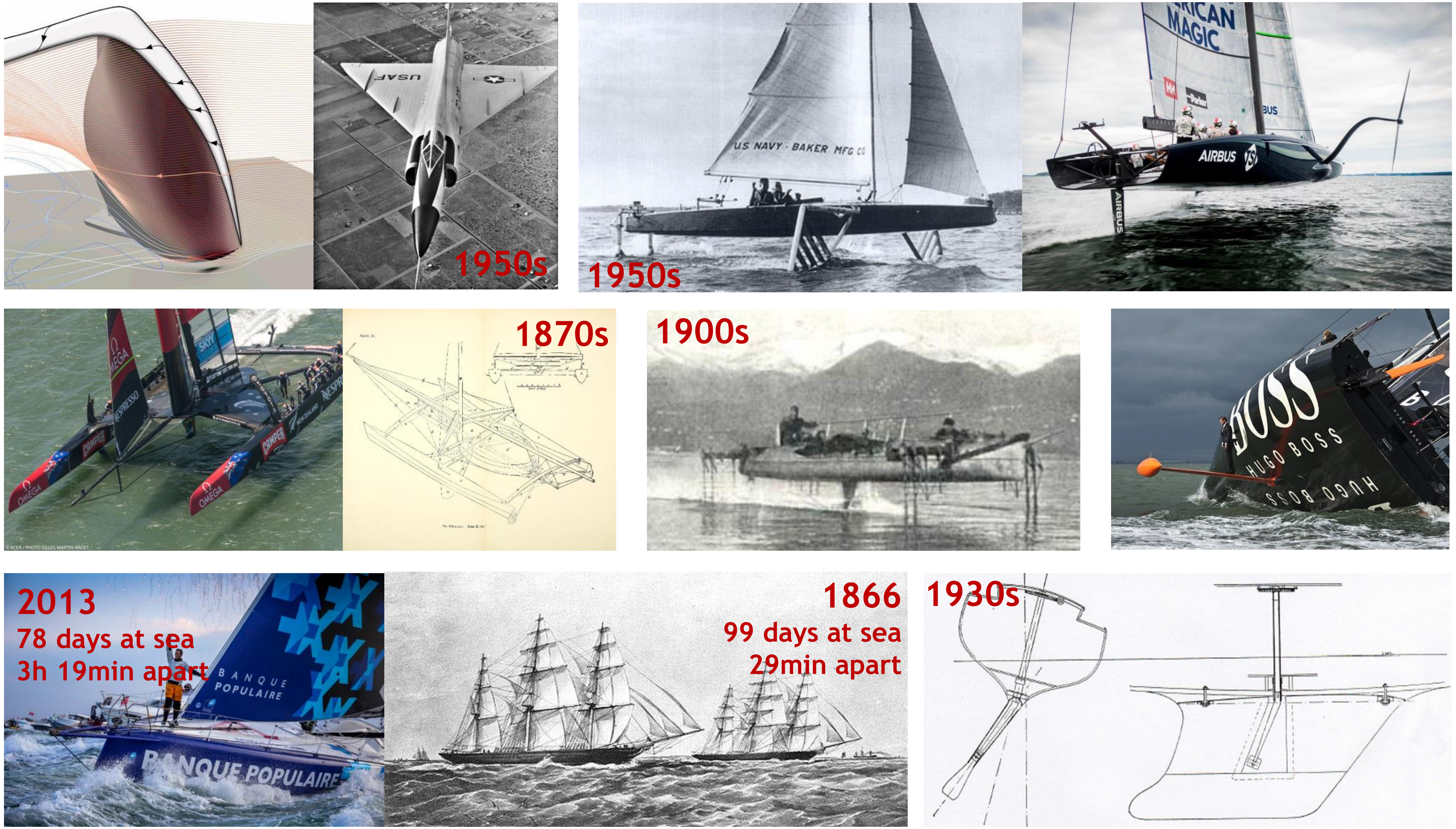




This project was recognized the 2018 ***Research, Innovation and Knowledge Exchange Award*** (Maritime Trust Fund) & the 2019 ***Stanley Gray Fellowship*** (IMarEST).

SOLENT UNIVERSITY

WHERE TO NEXT?



REVOLUTION

SOLENT UNIVERSITY

ONE LAST THOUGHT…

“Engineering is the art of modelling materials we do not wholly understand, into shapes we cannot precisely analyse so as to withstand forces we cannot properly assess, in such a way that the public has no reason to suspect the extent of our ignorance”

Dr A. R. Dykes

ONE LAST THOUGHT…

*“Engineering is the art of modelling materials we do not wholly understand, into shapes we cannot precisely analyse so as to withstand forces we cannot properly assess, in such a way that the public **and the environment** have no reason to suspect the extent of our ignorance”*

SOLENT
UNIVERSITY

THANK YOU

Jean-Baptiste R. G. Souppez

Senior Lecturer in Yacht Design and Composite Engineering

UK Principal Expert in Small Craft Structures | British Standards Institution
Visiting Professor and Research Supervisor | University of Liege, EMship +
Deputy Editor-in-Chief | SNAME Journal of Sailing Technology
Research Supervisor | University of Plymouth, MLA
Stanley Gray Research Fellow | IMarEST

jean-baptiste.souppez@solent.ac.uk