Fluid-Structure Interaction of a Membrane Wing

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Purpose of high fidelity analysis

- Design optimization
- Understanding of the onset of aeroelastic instabilities
- Validation of lower fidelity models

→ Establish baseline for high Reynolds number analysis of a membrane wing

System characteristics

- Inertial terms small for canopy of membrane wing, however mass of other system components may not be negligible
- Structural damping small as compared to aerodynamic damping
- Large deformation and small strain loading of canopy of the wing
- Nonlinear aerodynamic forces with separation already at moderate angles of attack

Structural Model

- In-house Python code
- Finite Element Formulation (structural model computationally much cheaper than fluid model)
- Nonlinear 6 DOF shell element [1] for canopy of membrane wing

→ Mass lumping for inertial forces
→ Structural damping based on Rayleigh damping
→ Validation of quasi-steady & fully dynamic model on analytical solutions, benchmark cases from literature and coupling with unsteady inviscid method

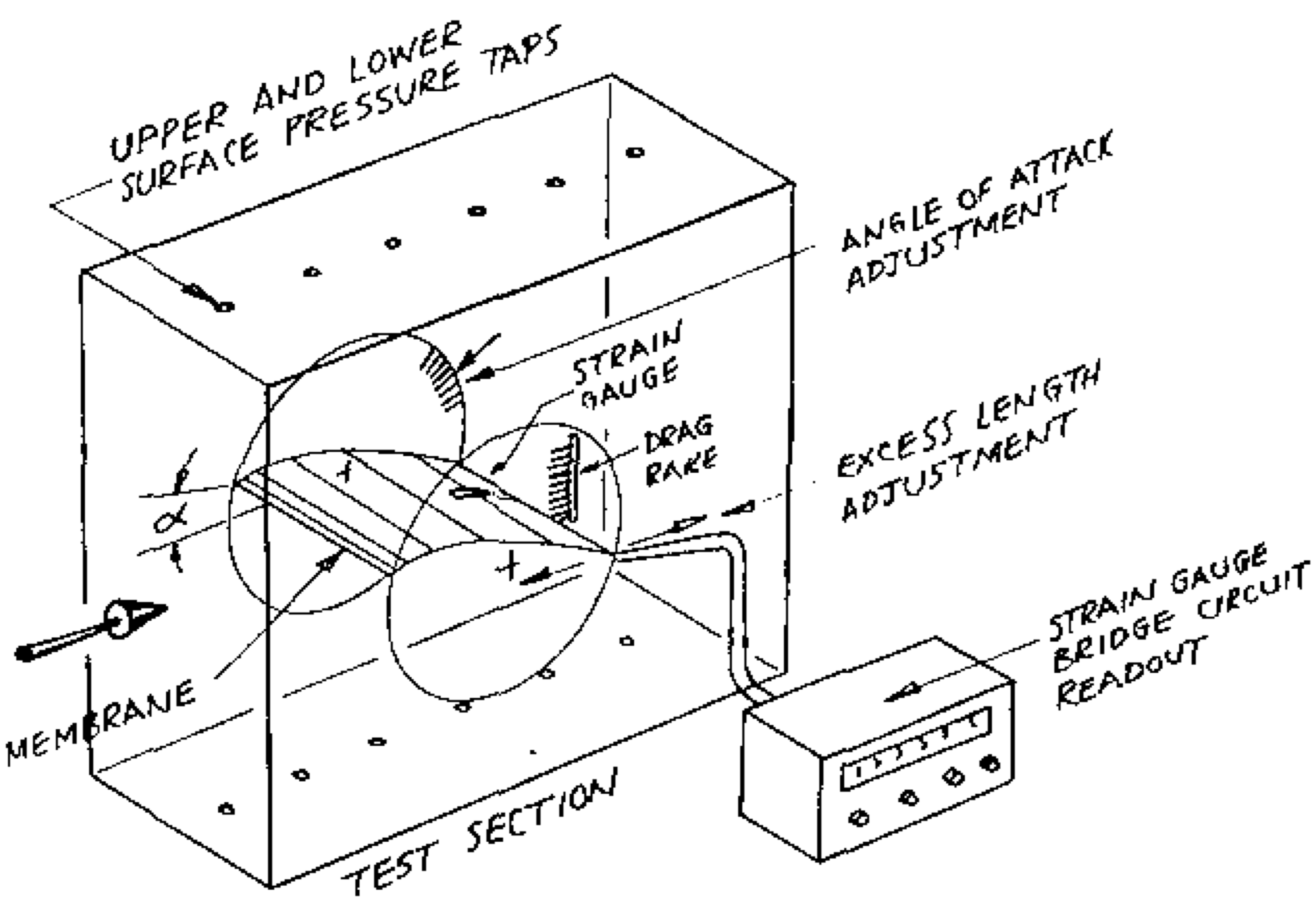

Fig: Experimental setup Greenhalgh [4]

Coupling

Strong added mass effect of problem necessitates the use of an an efficient implicit coupling scheme for stability and accuracy of model)

→ Industry standard IQN-ILS

Fluid Model

Computational Fluid Dynamics model with RANS turbulence model and preCICE coupling interface [2]

Benchmark FSI

- Low Reynolds benchmark case [3]
- Channel flow around rigid cylinder with flexible flag attached where vortex shedding on cylinder induces periodic motion of flag

→ Good agreement with reference results

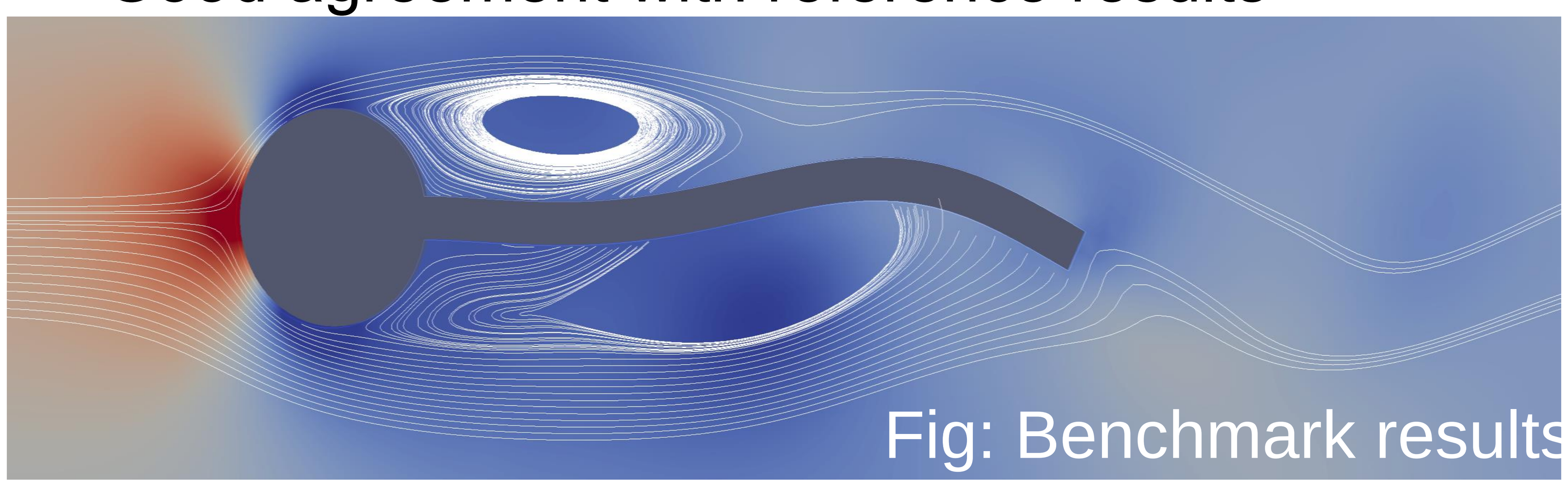

Fig: Benchmark results

Goal Application

- 2D membrane wing case with experimental validation data from literature [4]

→ Membrane rigidly clamped at leading and trailing edge (see left column)
→ Reynolds number 1.3 million
→ Variation in angle of attack and membrane excess length

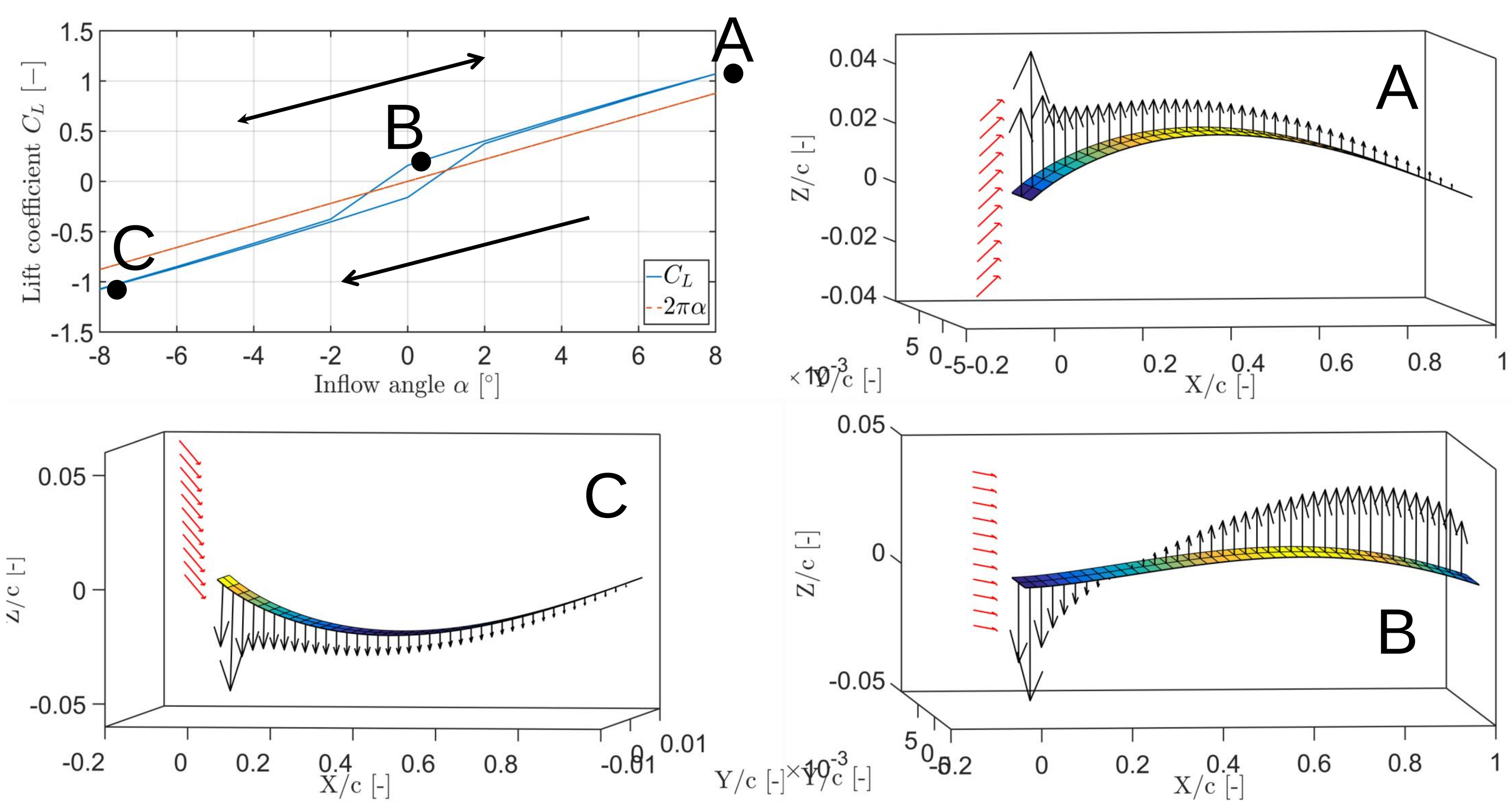

Fig: Unsteady lift, drag and membrane displacement results for Greenhalgh's setup with a Vortex Particle Method including flow hysteresis effects around zero degrees inflow angle

[1] Bosch, A. et al: Dynamic Nonlinear Aeroelastic Model of a Kite for Power Generation. Journal of guidance, control and dynamic **37(5),** 1426-1436 (2014)
[2] Turek, S. et al: Numerical Benchmarking of Fluid-Structure Interaction: A comparison of different discretisation and solution approaches.
[3] Blom, D., FOAM-FSI, (2016), GitHub repository, https://github.com/davidsblom/FOAM-FSI
[4] Greenhalgh, S. et al: Aerodynamic Properties of a Two-Dimensional Inextensible Flexible Airfoil. AIAA Journal **22(7), 865-** 870, (1984)

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