VAWT Aerodynamics

ALEXANDER GILES

PROFESSOR W.E. LEITHEAD, JAMES SEAN CARROLL

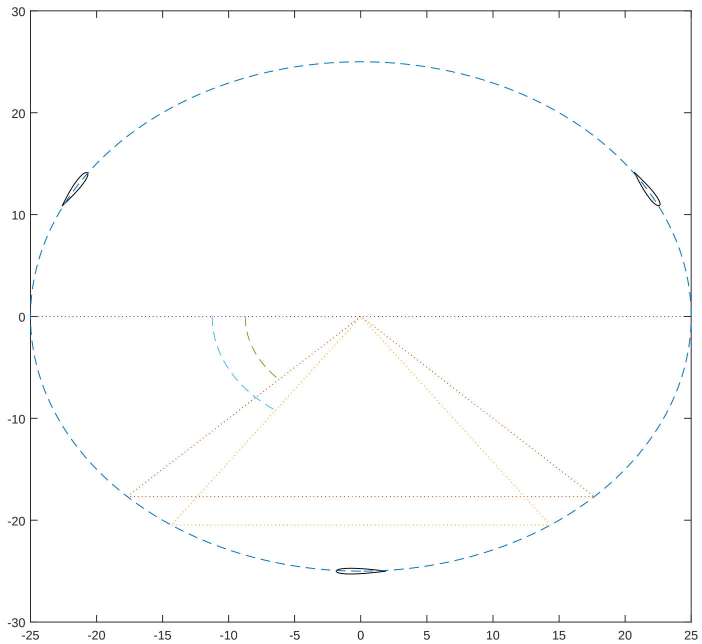
futurewind 2016
ACADEMIA-MEETS-INDUSTRY

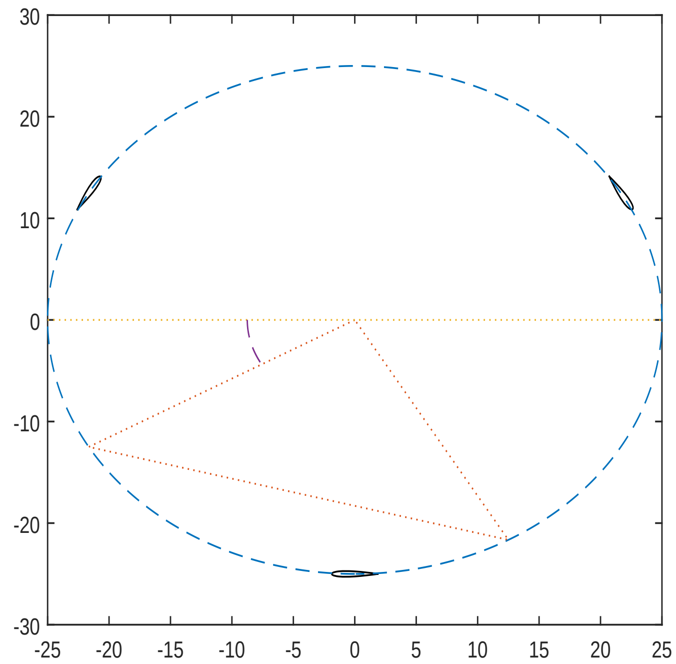
Objective

"Create a reasonably accurate aerodynamic code which can simulate the performance of a vertical axis wind turbine in the presence of a turbulent wind field and do so with sufficient speed such that control system analysis can be carried out."

BEM (DMST) for a VAWT

- Rotor's swept area is divided into a set of actuator discs.
- Although the swept area is divided into a number of surfaces, the BEM equations (slightly altered to handle VAWTs) are actually applied at the corner points of each surface, which is followed by linear interpolation to get the performance across the swept area.



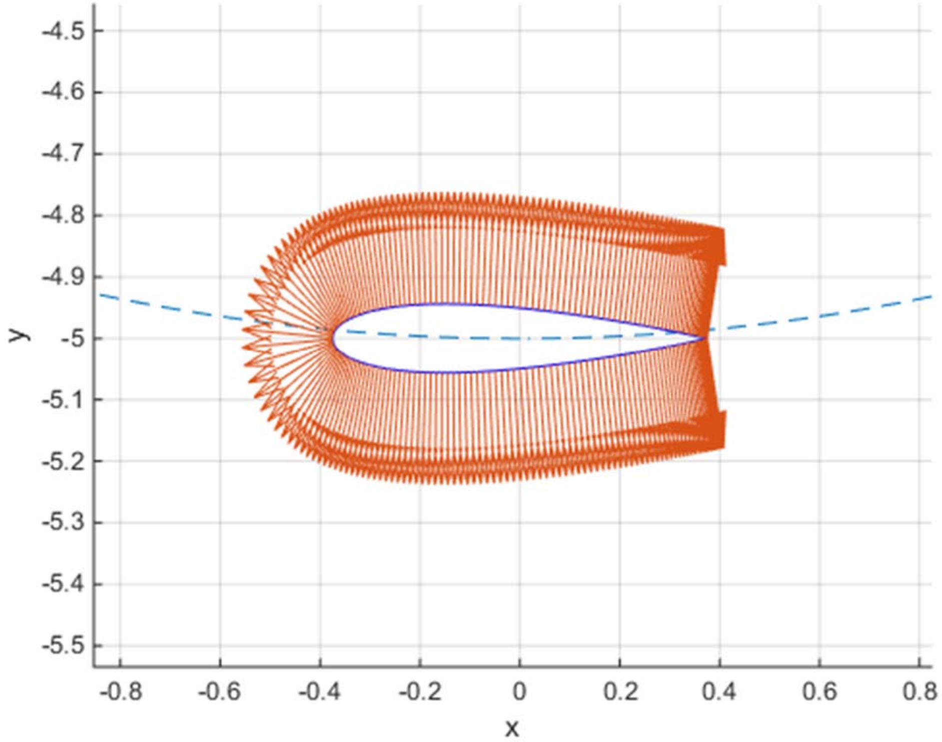


Critical opinion of BEM for VAWTs

- David Sharpe, Author of Wind Energy Handbook and creator of the DMST algorithm which features streamtube expansion:
  "*I completely agree with you that the DMS/momentum theory approach is wrong. A vortex method is required and, as you say, this requires a knowledge of the wake.*"
- Richard Brown, Professor at the University of Strathclyde who has worked extensively on helicopter aerodynamics and VAWT aerodynamics:
  "*I would advise that using stream-tube models for the wake of a VAWT can lead to misleading results for the aerodynamic forcing of the rotor that is at the heart of its structural response. I'd be very sceptical of any approach that accounts for turbulence without first accounting for the coherent vortex structures in the wake.*"
- Similar opinions were also voiced by Professor Helge Madsen (creator of the actuator cylinder concept), Professor Carlos Simao Ferreira (TU Delft), Dr Michael Borg (DTU) and James Strickland (creator of VDART3, a vortex model for VAWTs along with significant contributions to DMST development).
- All opinions came from independent researchers.
- MUST STRESS – THIS IS A PROBLEM SPECIFIC TO VAWT ANALYSIS USING BEM TECHNIQUES. NO OPINION IS MEANT AS A CRITICISM OF BEM APPLIED TO HAWTs.
- THE CRUX OF THE PROBLEM LIES IN REPRESENTATION OF THE WAKE.

Panel methods

- Laplace's equation plus boundary conditions (Neumann or Dirichlet)

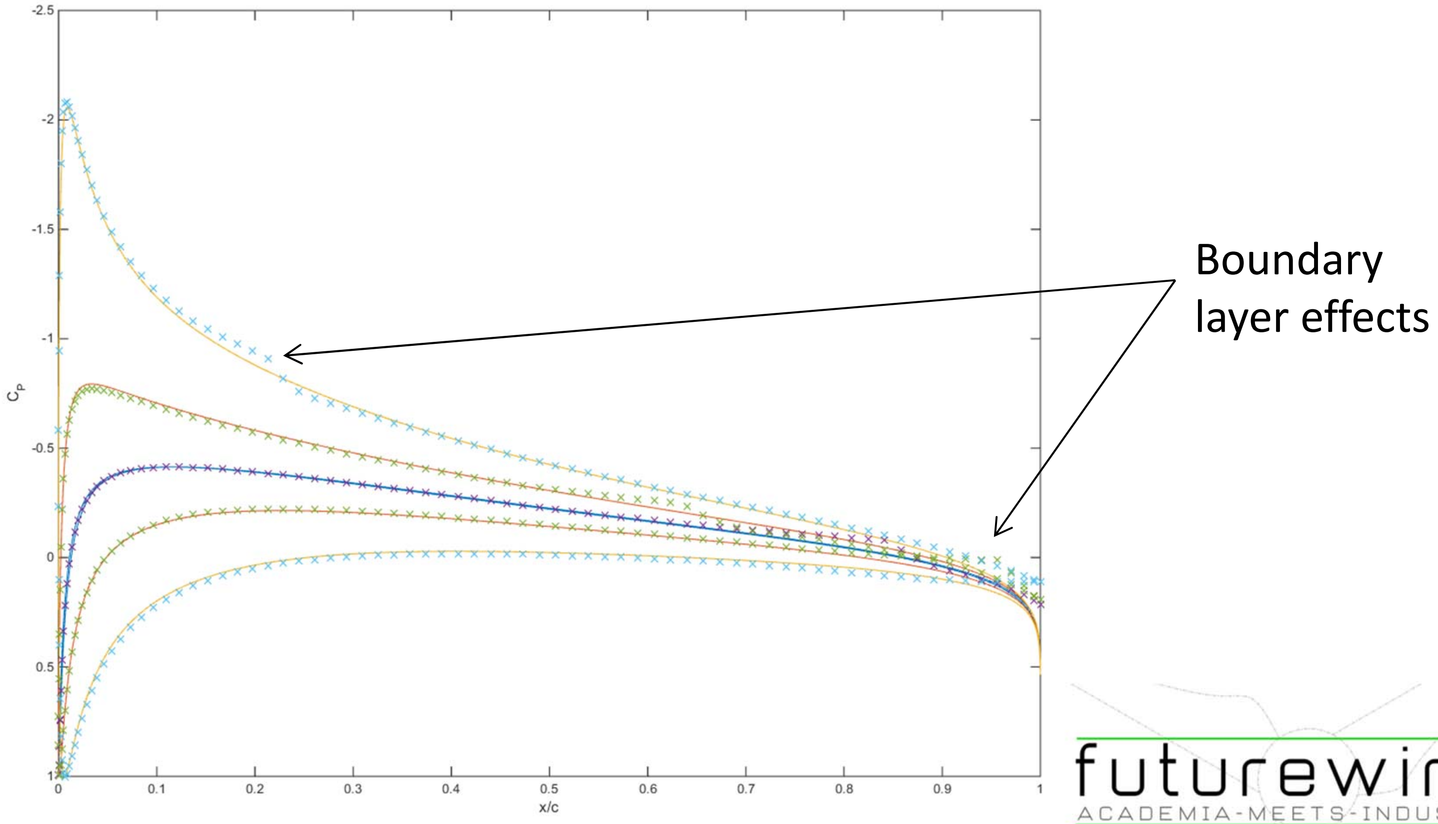


Implementation procedure

- Start simple, build up to more complex cases.
- First case – steady flow around a single lifting element in 2D (wake influence can be simplified significantly to a single panel). Easy to validate using Xfoil (yes I know it's ultimately a panel method too).
- Second case – heaving motion examples. Validate using wake analysis (following Katz and Plotkin methodology).
- Third case – VAWT flows

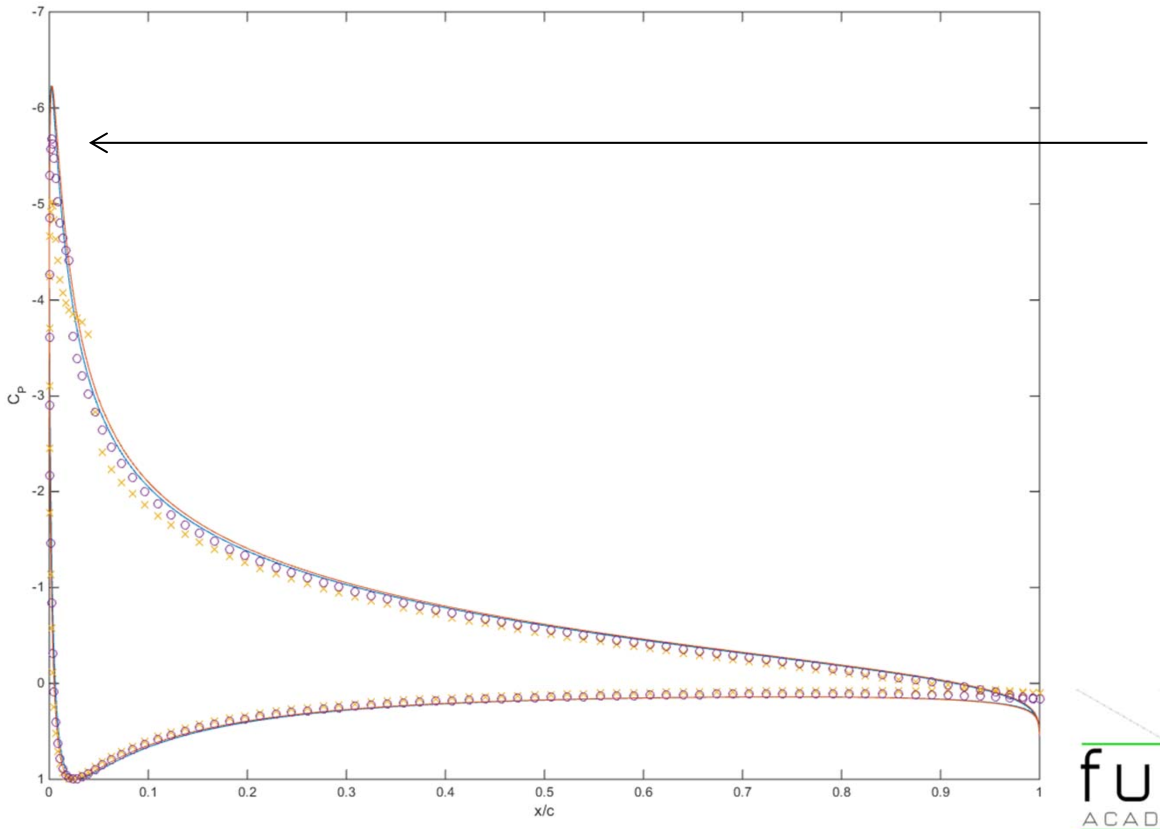
2D steady state flows

- Pressure distributions over NACA 0012 aerofoils (used in Musgrove 850) at low angles of attack: 0, 2 and 5 degrees. Xfoil simulations run at relatively low Reynolds number of 350,000. Small discrepancies begin to occur at 5 degrees (these have little effect on Cl curve).



2D steady state flows

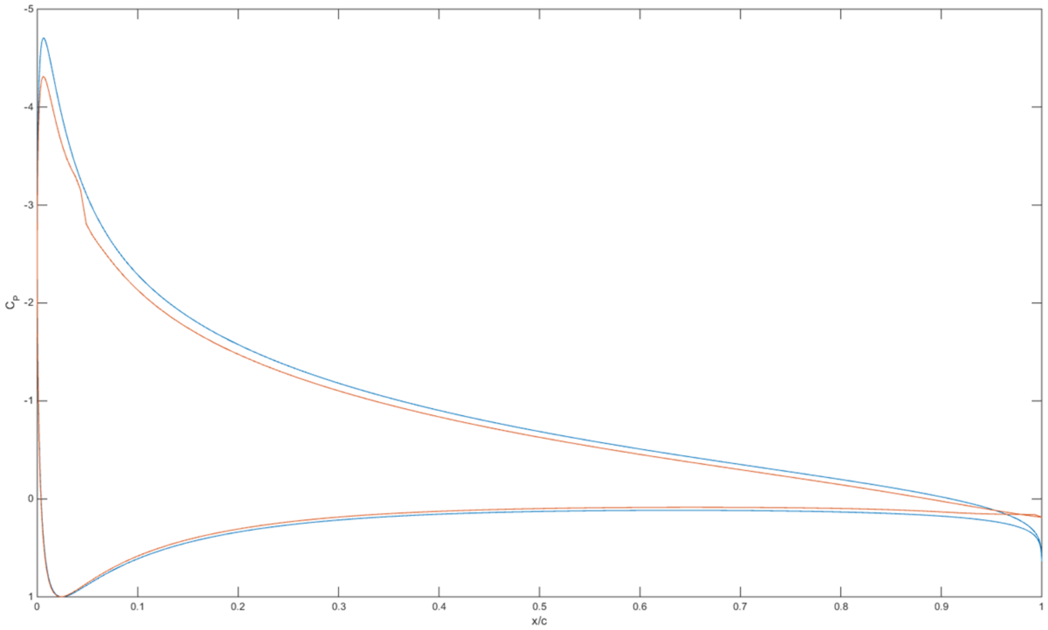
- Pressure distribution over NACA 0012 at α = 10 degrees at Reynolds numbers of 350,000 (crosses) and 2,000,000 (circles) and ∞ (blue line).



Boundary layer effects. Discrepancy decays with increasing Reynolds number.

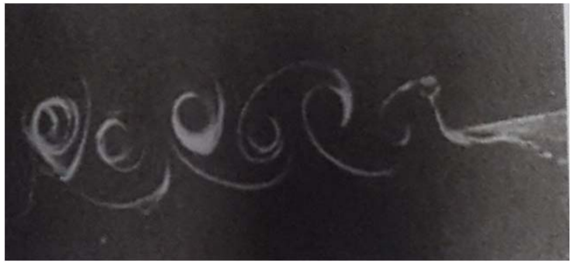
2D steady state flows

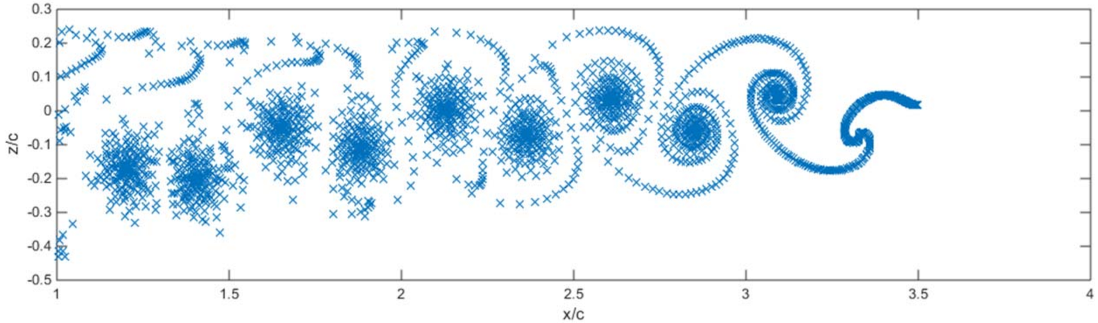
- Pressure distributions over NACA 0015 (used in Musgrove 450) at 10 degrees (towards the top end of angle of attack experienced at lambda = 4). Xfoil simulations run at Reynolds number of 2,000,000 (appropriate for large scale VAWTs).
- Beginning of separation at the trailing edge.



Unsteady flows

- An assumption must be made at the location of the most recently shed wake panel. Typically placed 0.3 times the distance travelled during previous time step. This is a way of correcting the fact that the model is discrete but reality is continuous.
- A simple model can be constructed using lumped vortices on the chord line for a thin aerofoil. This is preferred since its simplicity allows quick testing of the wake calculations, which would be used in a more accurate model (source-doublet formulation).
- Test scenario – heaving motion of a thin aerofoil:

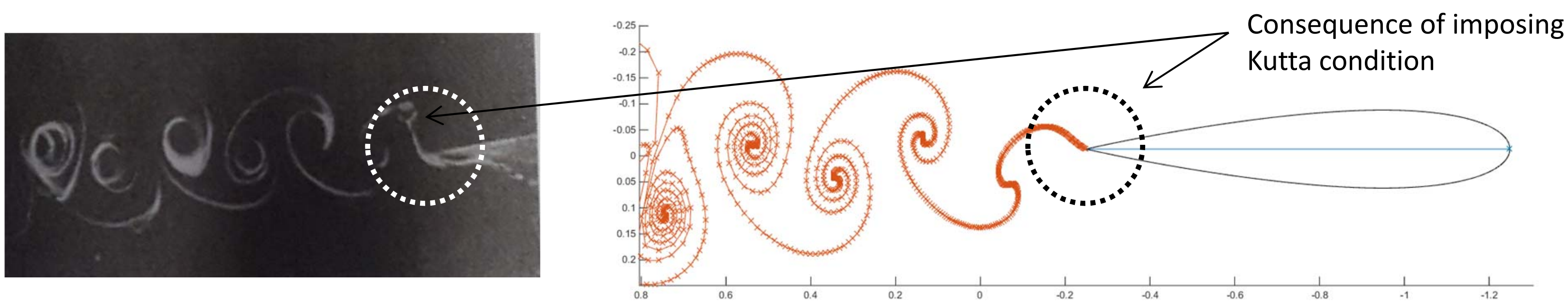




- It takes about 1 minute to simulate 2000 time steps starting from a scenario where there are no wake elements at t = 0.

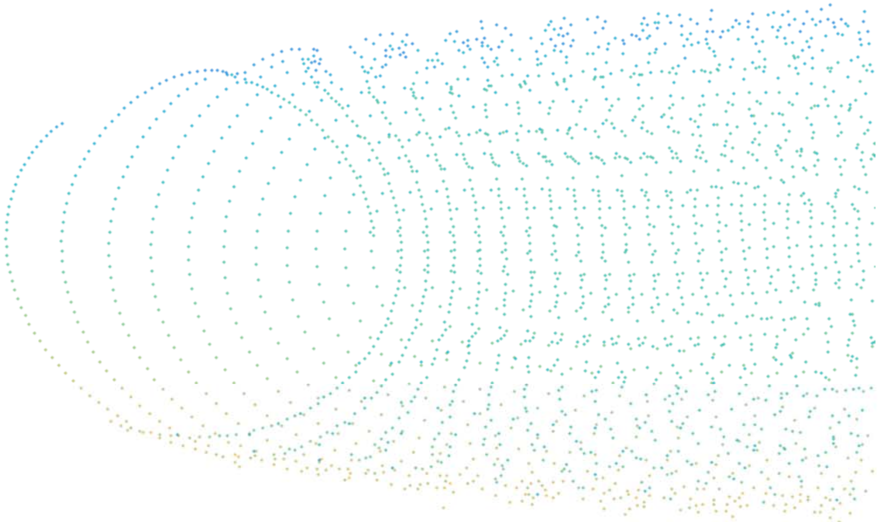
Source-doublet representation

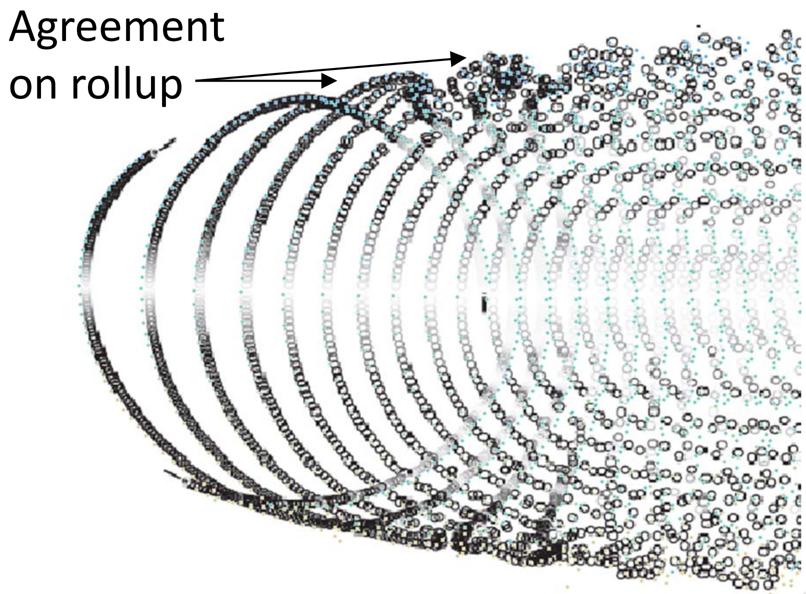
- A more proper representation of the aerofoil is achieved by using the panel method approach described earlier.
- Main source of computational cost is still in the influence calculations of the wake elements.
- Improved wake shape can be obtained by proper settings of vortex core sizes and with an appropriate time step.



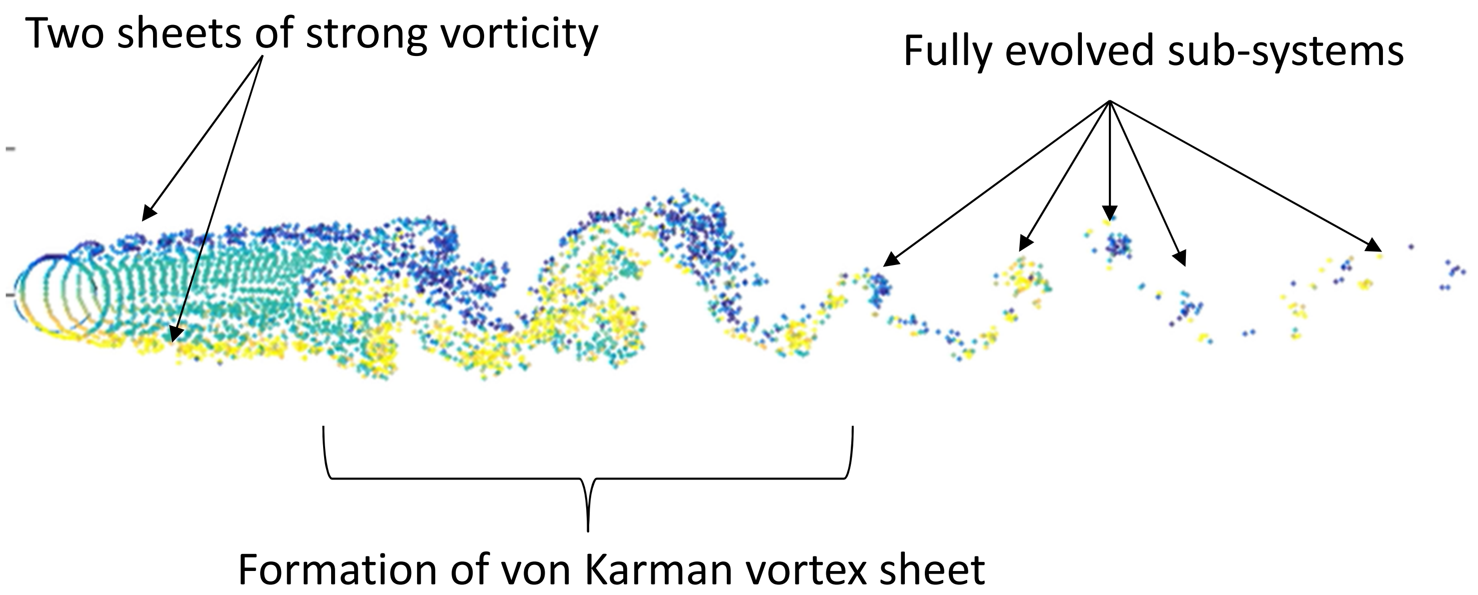
Wake visualisation

- Comparison with another vortex model (apologies for poor clarity of far-wake)
- Discrepancies can be due to wake calculations. This panel method currently models wake vortices as contributors to source term rather than being handled as part part source term/part potential term (see Katz and Plotkin ch. 13 pg 437).
- Choice of time-step may also have an influence, along with setting of vortex cores.





Possible wake simplification



Conclusions & future work

- A free-wake panel method has been developed to allow fine-tuning of BEM models or to use for VAWT studies on its own.
- The model can be simplified to a LLT model and coupled to look-up data, bypassing the requirement for a boundary layer model.
- If the user opts to stay with the source-doublet approach and integrates a boundary layer, investigations can be done into the effects of having two vortex emission points.
- Studies into variable pitch can be carried out, along with evaluations of the effect of turbulence.

Questions

futurewind
ACADEMIA-MEETS-INDUSTRY 2016

University of Strathclyde Glasgow

futurewind 2016
ACADEMIA-MEETS-INDUSTRY