IMPLEMENTATION OF PRESSURE BASED SOLVER FOR SU2

3rd SU2 Developers Meet | Akshay.K.R, Huseyin Ozdemir, Edwin van der Weide

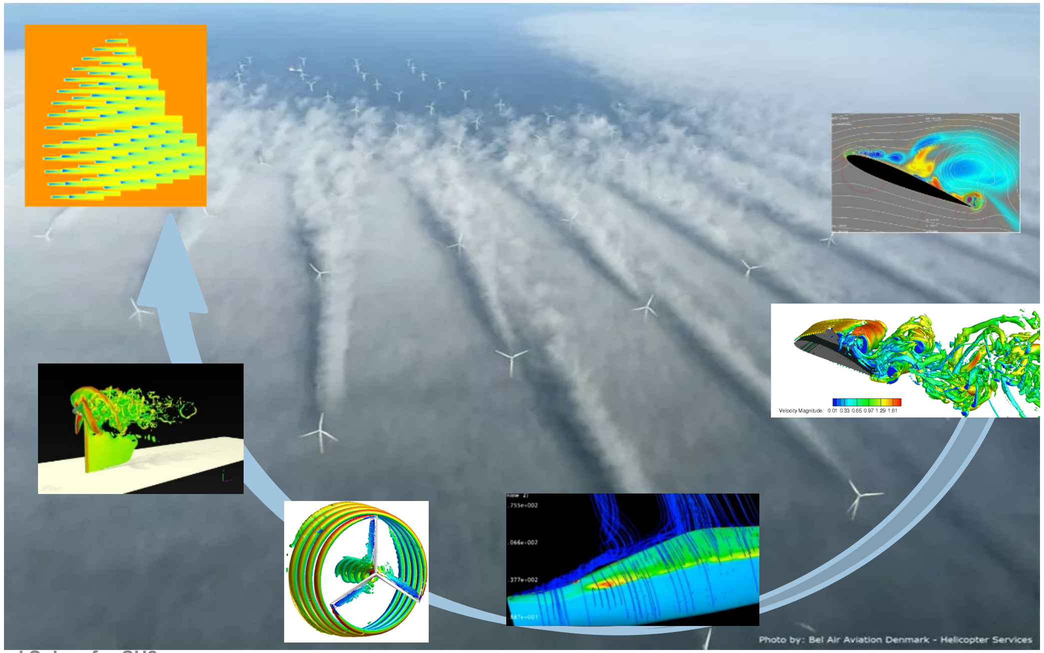
ECN TNO innovation for life

Content

- ECN part of TNO
- SU2 applications at ECN
- Incompressible flow solver
- Pressure-based solver
- Research plan
- SU2 in past and current projects

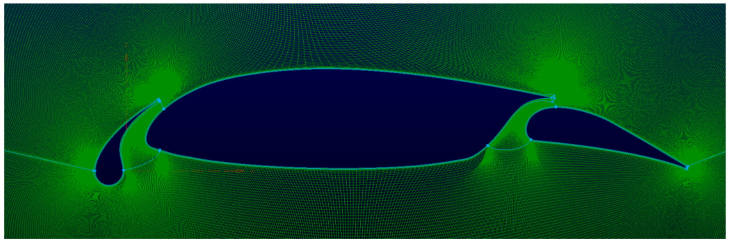
ECN part of TNO

- **ECN** - Energy Research Center of the Netherlands merged with **TNO** as of April 2018.
- Research on many topics of **renewable energy technologies**
  - Wind energy, Solar energy, Biomass, etc.
- Wind energy unit mainly focused on **low-fidelity tools** that are tailor made for wind energy applications (about 50 researchers on various topics)
- **SU2** is our first serious attempt to include **CFD** in our research/design tool chain

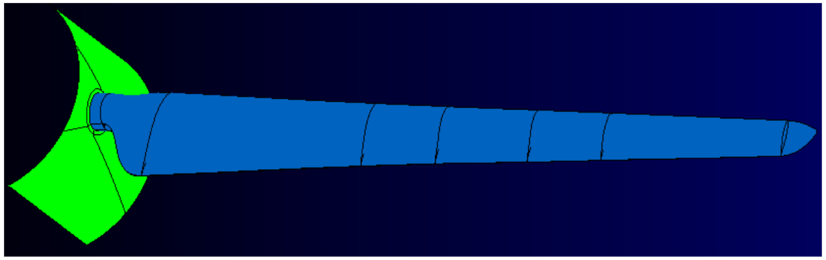


SU2 Applications at ECN

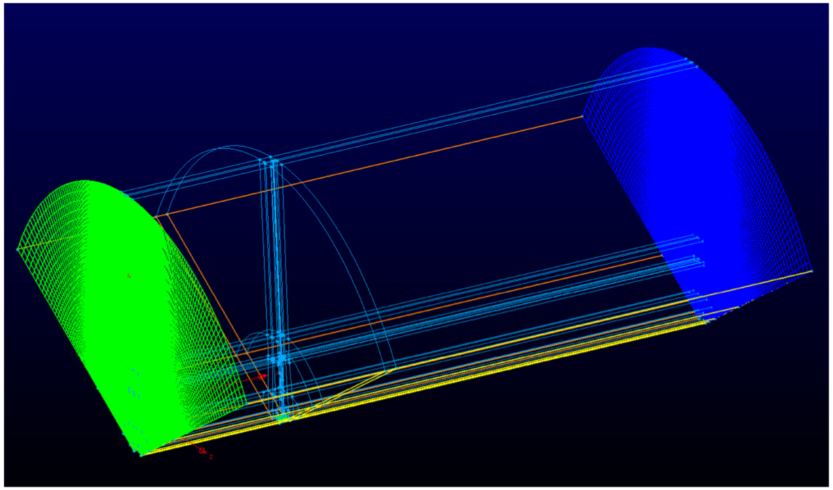
- Airfoil analysis:
  - Thick airfoils (30%-40% thickness)
  - Blade sections with add-ons like VGs



- Wind turbine rotor simulations
  - Rotating and periodic simulations
  - Load computations



- Wind farm simulations (planned)
  - Actuator disk models



Incompressible Flow Solver

- Wind energy applications have typical $\mathbf{Ma \sim 0}$ **and** $\mathbf{Re \sim 10^6}$.
- Artificial compressibility method not suitable in this regime – ***very high mesh requirements*** and accuracy issues.
- Need an ***accurate incompressible solver*** for wind energy applications.
- Segregated ***pressure-based*** solver – SIMPLE family of algorithms.

Pressure Based Solver: Governing Equations

Momentum Equation:

$$\partial_t U + \nabla \cdot \left(\overrightarrow{F^c} - \overrightarrow{F^v}\right) - Q = -\nabla P$$

Pressure correction equation:

$$\nabla \cdot \nabla k P' = \sum_f \dot{m}^* + RHS$$

SIMPLE

Start with u^n, v^n, ... as the initial guess

↓

Solve momentum equations to get u^*, v^*, w^*

↓

Update mass flux, $m_f{}^*$and other terms in the RHS

↓

Solve pressure correction equation

↓

Update pressure and velocities to get u^{**}, v^{**}, w^{**}

Repeat till convergence

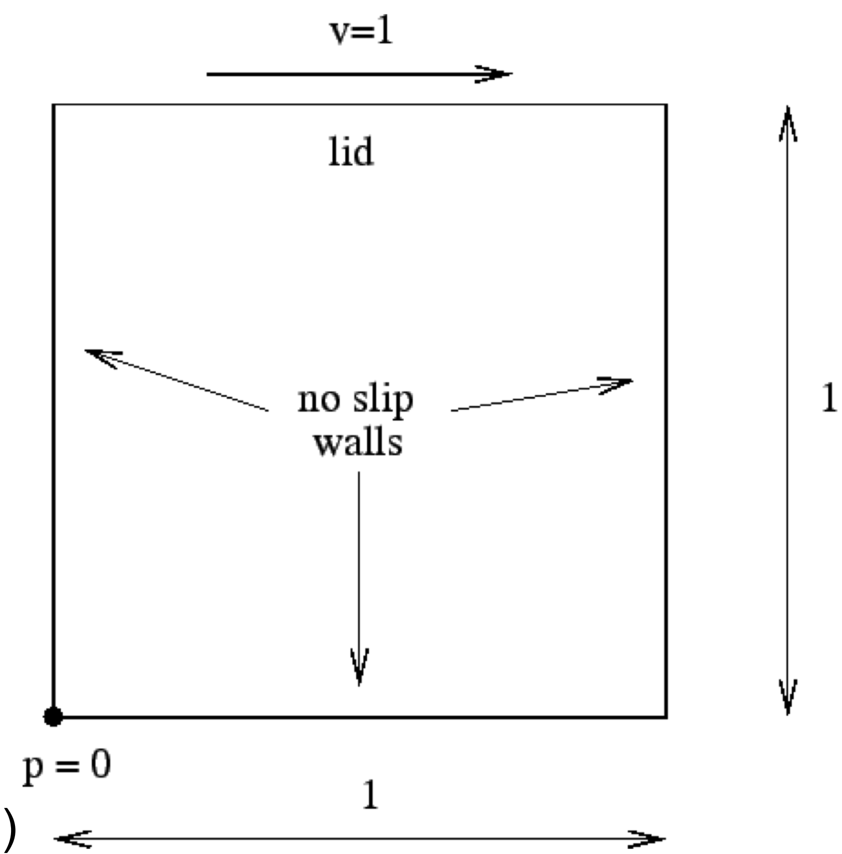
Research Plan

- *Research code*
  - Develop ***research code*** to test and analyze different features of the code
  - Implement an ***artificial compressibility*** version and a ***pressure-based*** version
- *SU2*
  - A finite volume discretization for the ***Poisson problem*** in SU2
  - ***Euler solver*** with the convective terms and ***N-S solver*** with the viscous terms following the code structure of SU2

Results: Research Code

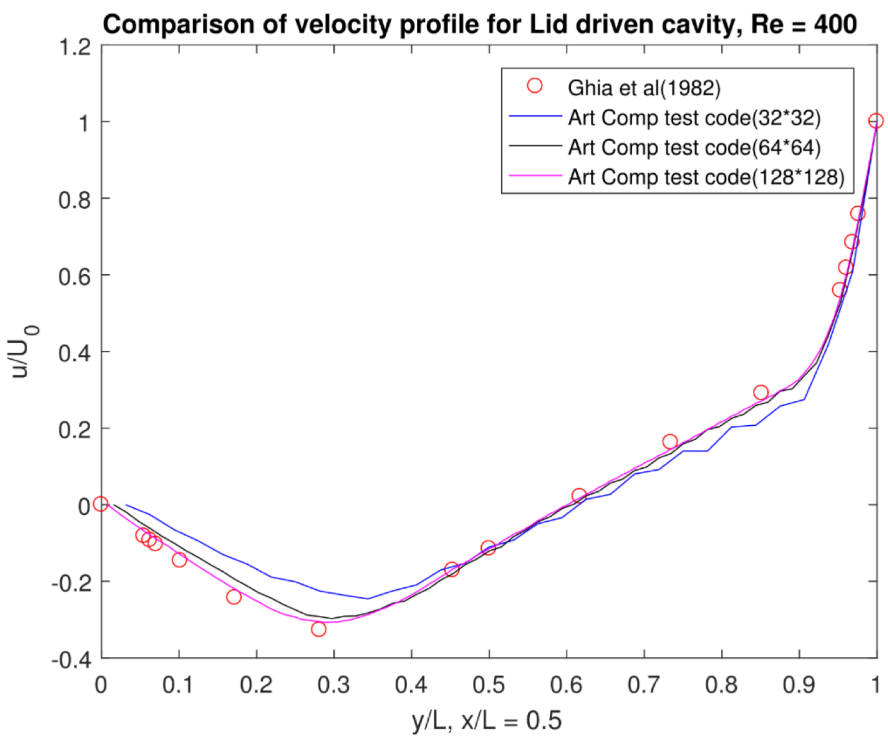
Lid driven cavity problem

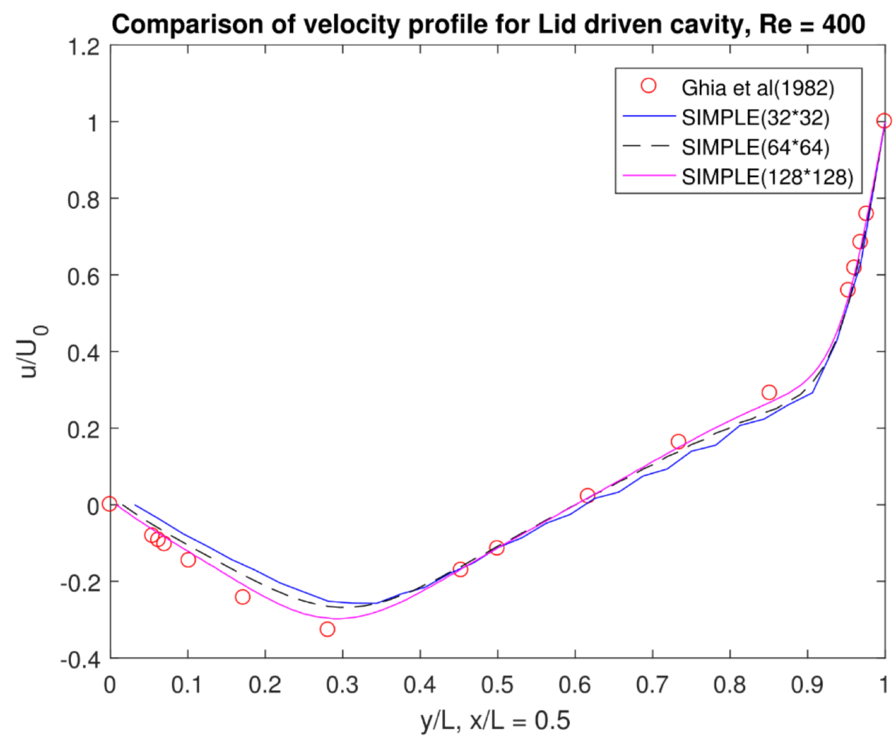
- Re = 400
- Vertex based FVM
- Uniform, cartesian grid
- Spatial discretization:
  - 1st order upwind
  - Central
- Time discretization:
  - Implicit Euler
  - Explicit Euler
- Linear solver:
  - Tri-Diagonal Matrix Algorithm (with ADI)
  - Gauss-Seidel
  - Plan to add MG



Results: Research Code

Lid driven cavity problem



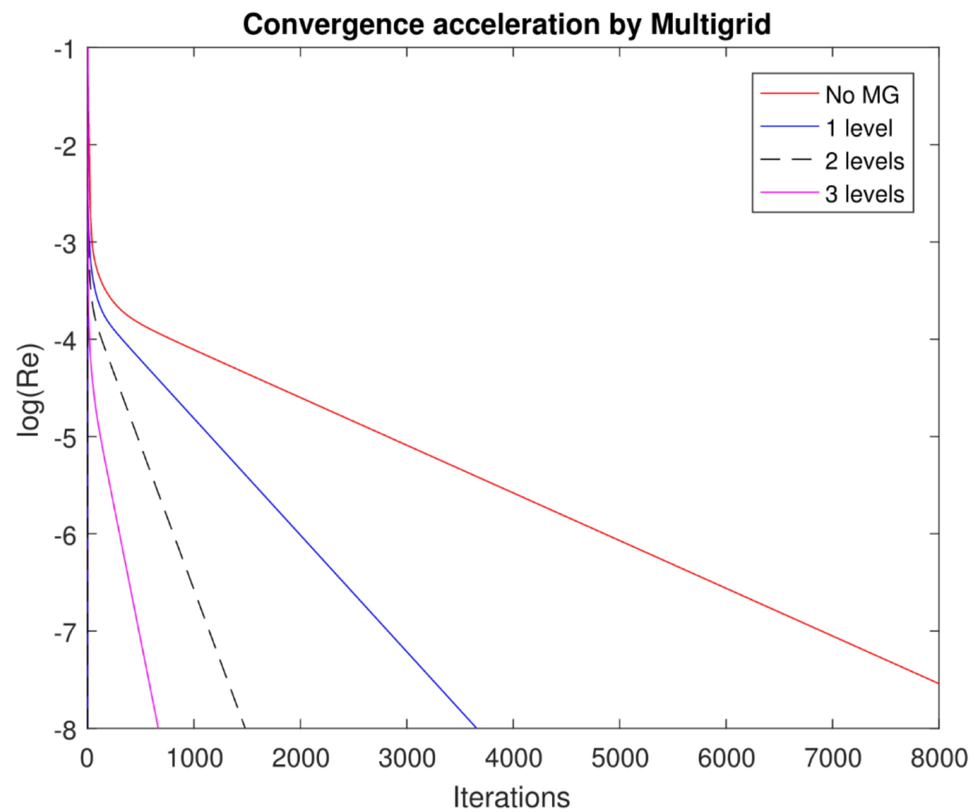


Centreline velocity

Results: SU2

Poisson Solver FVM

- Implement a FV discretization of Poisson equation.
- Solve an analytical test case to check solution.
- Needs to solved multiple times within every iteration.
- Enable multigrid to obtain a fast solution from the Poisson solver
- Algebraic multigrid might be necessary for unsteady problems to obtain acceptable computational times.



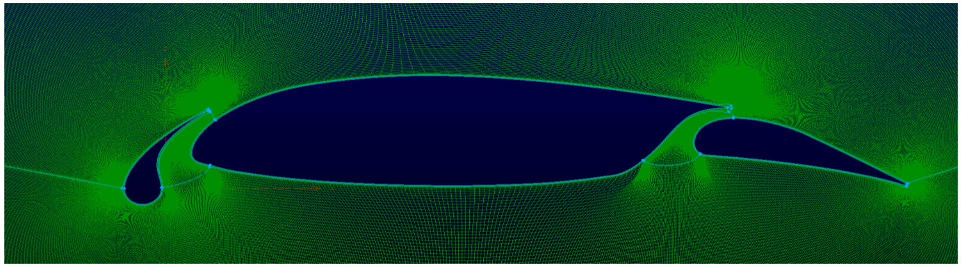
Current Status of Research

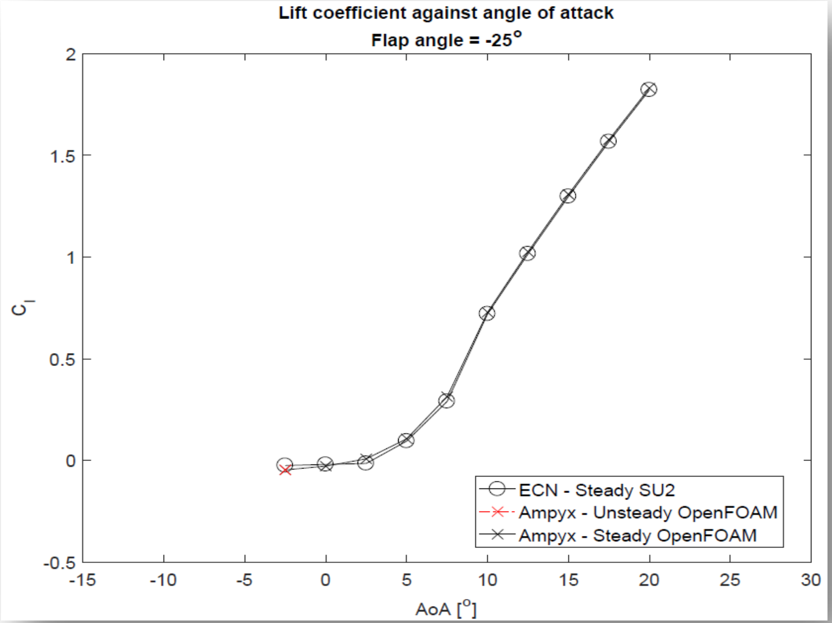
SUU2 Euler/NS solver

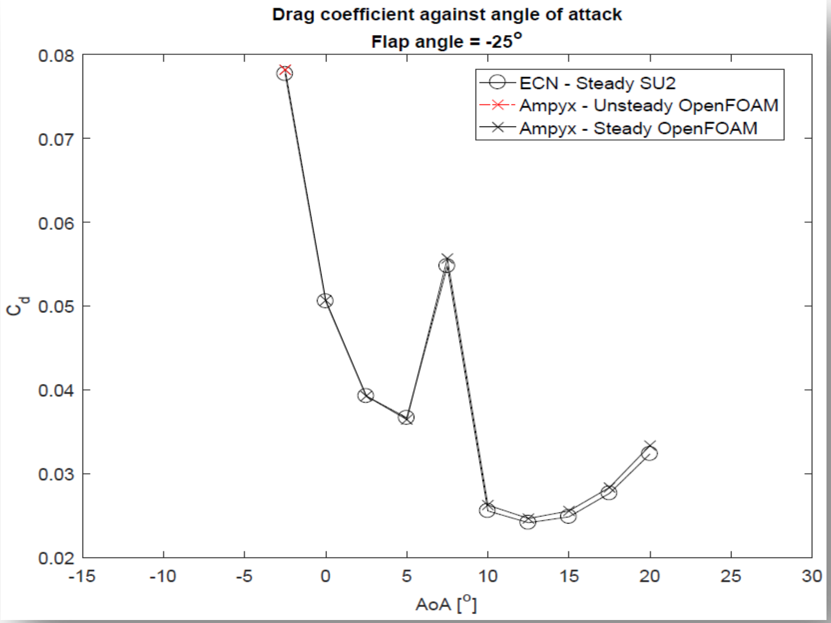
- Implementing the solver, numerical, variable and other associated routines for a pressure based system.
- Coupled the flow solver with the Poisson solver.
- Experimenting with different spatial discretization methods for the pressure-based solver.
  - Plan to implement first and second order upwind and central schemes initially.
  - Testing in the research code
- Extend the multigrid to not only Poisson but also to flow solver.
- Works only on single node so far.
- Add ALE, periodic options.

SU2 in Current Projects at ECN

Airfoil with add-ons

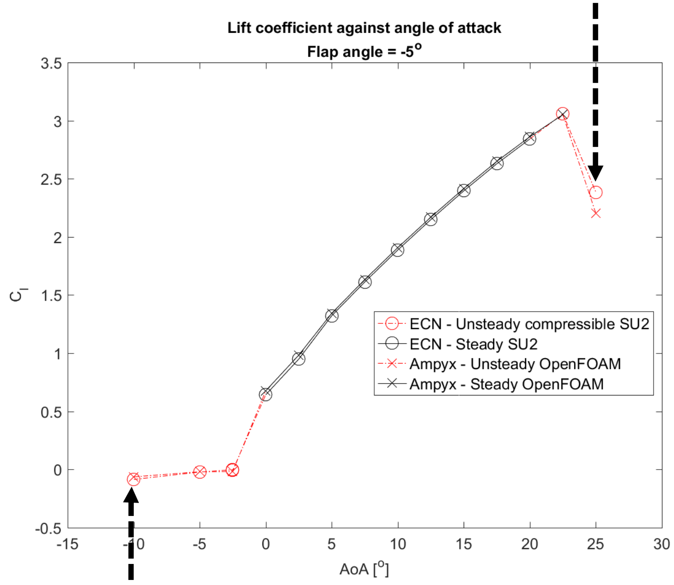


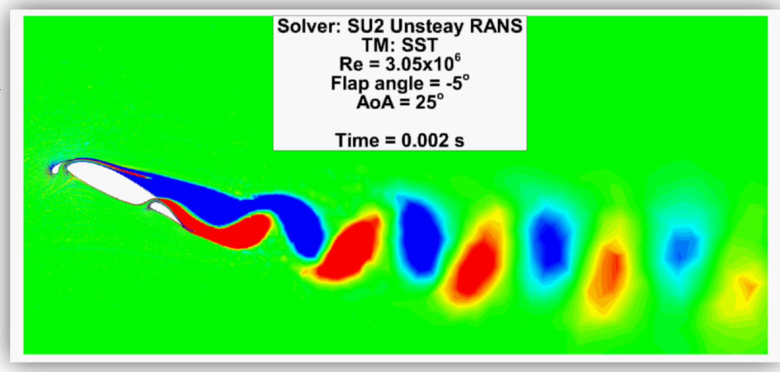


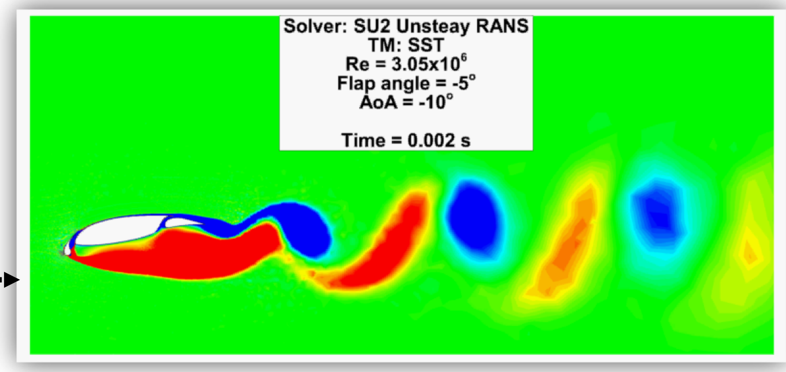


Aero polar for flap angle = -5deg

Airfoil with add-ons

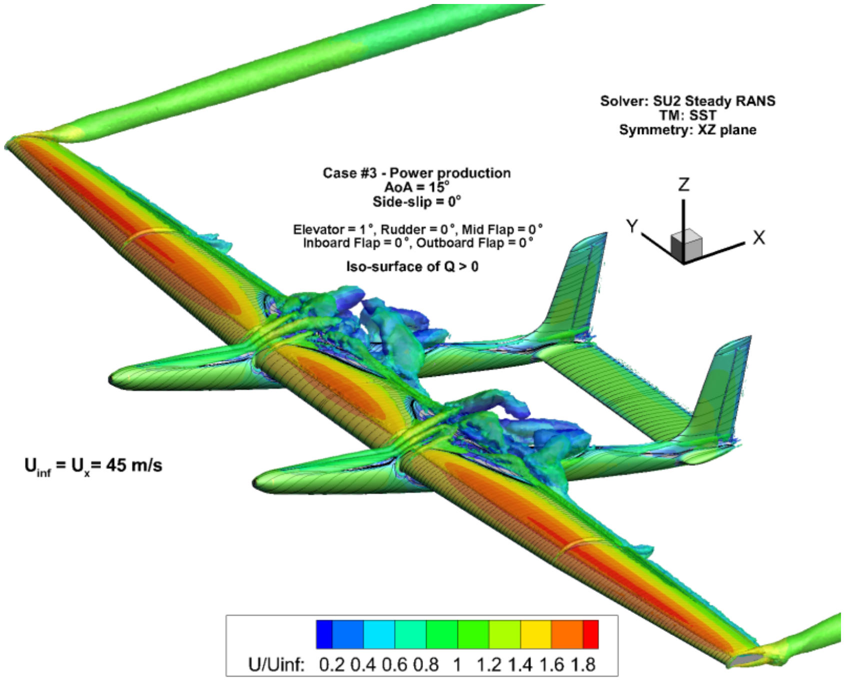


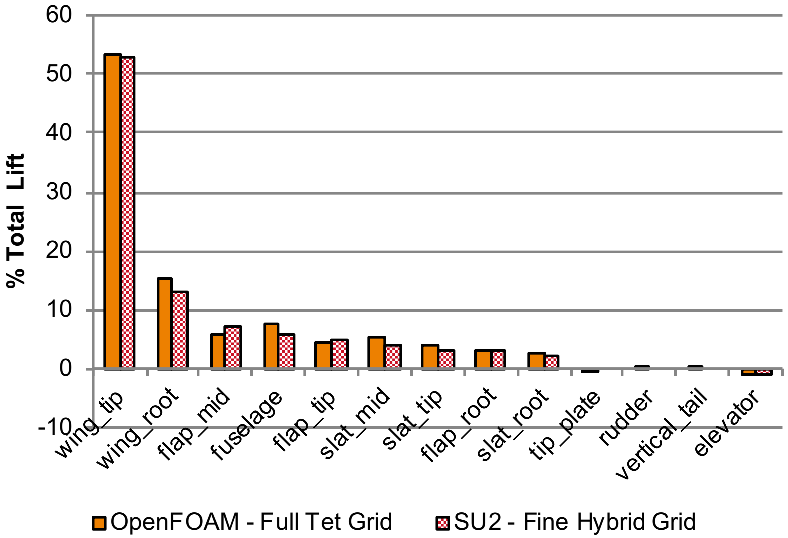




Load Computation

Power plane – Novel concepts for wind power generation.



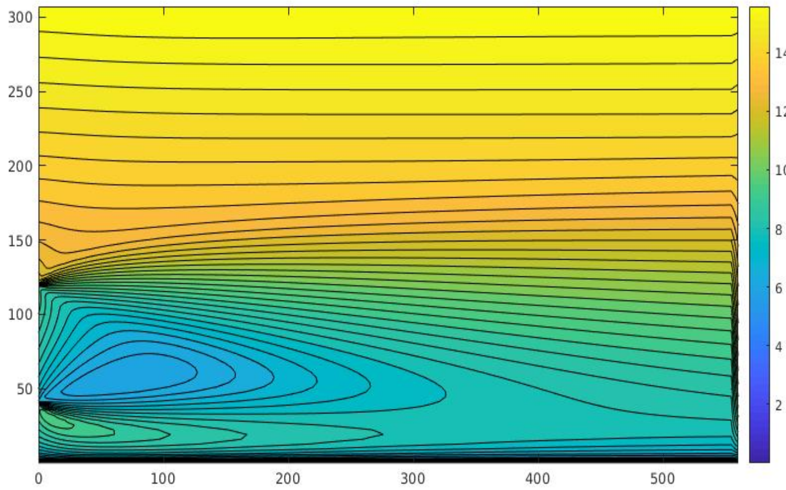


Comparison between OpenFOAM and SU2

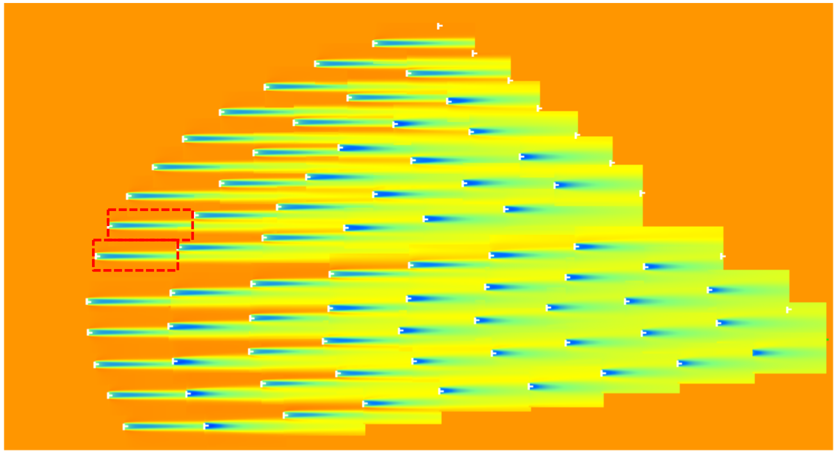
An alternative to traditional wind turbine designs.

Wind farm modelling

- Use actuator disk to approximate the turbine.
- Compute power output and optimize wind farm layouts.
- Currently use parabolized N-S solver, plan to use SU2.



Wake behind a turbine



Wind farm layout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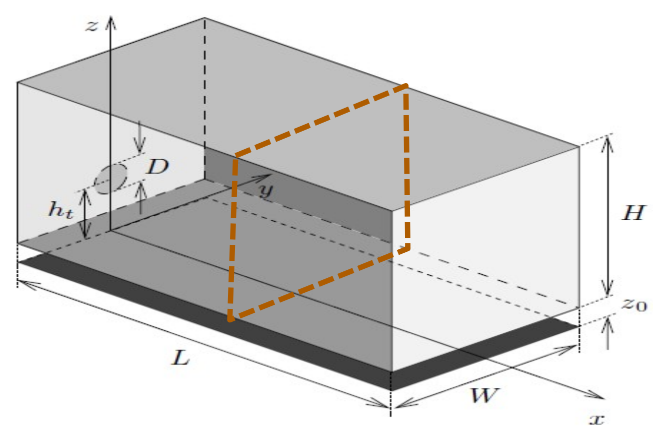
FarmFlow simulation time

- A typical case consists of
  - 10x10 = 100 wind turbines
  - 25 wind speed levels
  - 72 wind directions
  - 1 turbulence intensity level
- In total
  - (10x9)x25x72x1 = 162000 cases to simulate
  - 162000 x 3 seconds / 3600

~ 135 hours

FarmFlow simulation time for a single case

- Simulation time (CPU time) for a single:
  - Wind turbine (single wake)
  - Wind speed
  - Wind direction
  - Turbulence intensity level
- On a:
  - Intel® Xeon® CPU E5620 @2.40 GHz
  - 8 GB ram
  - Windows 64 bit operating system
- **~ 3.0 seconds**



ABL stability model

Stable conditions:

$$u = \frac{u_{*0}}{\kappa}\left[\ln\left(\frac{z}{z_0}\right) - \psi_m(z/L)\left(1-\frac{z}{2z_i}\right) + \frac{z}{L_{MBL}} - \frac{z}{z_i}\left(\frac{z}{2L_{MBL}}\right)\right]$$

Unstable conditions:

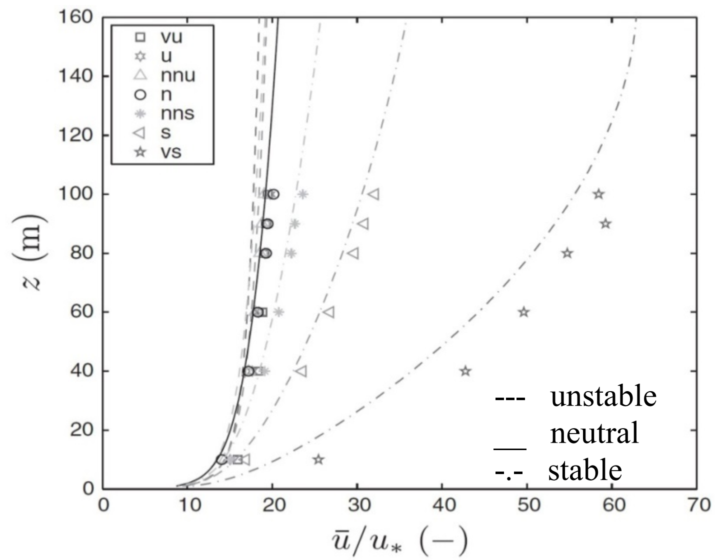
$$u = \frac{u_{*0}}{\kappa}\left[\ln\left(\frac{z}{z_0}\right) - \psi_m(z/L) + \frac{z}{L_{MBL}} - \frac{z}{z_i}\left(\frac{z}{2L_{MBL}}\right)\right]$$

Neutral conditions:

$$u = \frac{u_{*0}}{\kappa}\left[\ln\left(\frac{z}{z_0}\right) + \frac{z}{L_{MBL}} - \frac{z}{z_i}\left(\frac{z}{2L_{MBL}}\right)\right]$$

Empirical fit for scaling parameter, L_{MBL} :

$$\frac{u_{*0}}{fL_{MBL}} = \left(-2\ln\left(\frac{u_{*0}}{fz_0}\right) + 55\right)e^{\left(-\frac{(u_{*0}/fL)^2}{400}\right)}$$



	Unstable	Neutral	Stable
L	-128 m	321 m	41 m
z_i	117 m	205 m	49 m
L_{MBL}	283 m	866 m	69 m

$$z_i = c\frac{u_{*0}}{|f|}$$

Gryning et.al. “On the extension of the wind profile over homogeneous terrain beyond the surface boundary layer,” Boundary-Layer Meteorology, Vol. 124, No. 2, 2007, pp. 251–268.