Optimisation and CFD

High Performance Compution workshop – 24th June 2015

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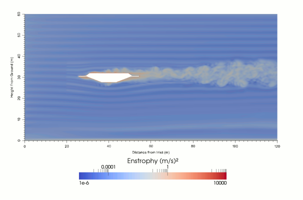
CFD and HPC

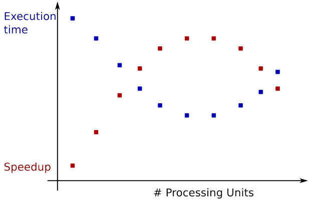
CFD is traditionally a HPC activity – requires significant computer resources for very long times (typically weeks).

Parallelisation usually via *domain decomposition* – split mesh into sub-meshes to run on individual processing units. Permits very large simulations for LES etc. Problems : mesh construction + setup, postprocessing, parallel slowdown

Alternative use of HPC for automated design optimisation – run large numbers of simulations simultaneously to optimise (directly) or construct surrogate model.

Examples : room comfort calculations, arterial blood flow, Ahmed body, rocket fin optimisation, tidal turbine arrays . . .



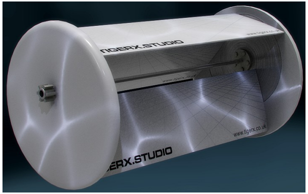


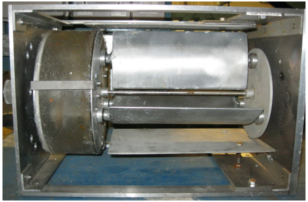
Tidal Turbines

Novel design for tidal turbine based on cycloidal turbine

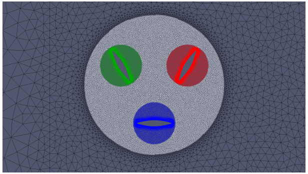
involving complex rotating airfoil blades

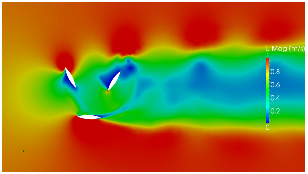
- Blades act in drag mode on one side; rotate (0.5Ω) to develop lift on other side
- Unit operates as cross-flow turbine
- Energy extracted through volume – high efficiency (measured efficiency of $\sim 50\%$)
- High blockage factor; suitable for near-surface (eg. esturine) sites.
- Likely deployment in very large arrays

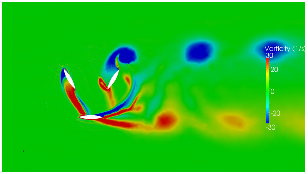




Blade motion



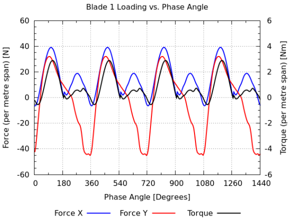


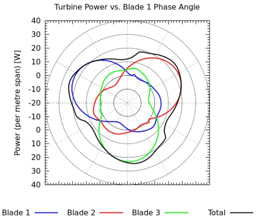


Very complex blade motion – GGI using 5 nested frames

Mesh generated with Pointwise – 2d simulations

- Swept turbine diameter = 0.14m
- $k - \omega$-SST model wall resolved ($y^+ \sim 1 - 2$)
- 100,000 cells; gradual mesh inflation
- Provides force and torque loadings





Full simulation very expensive to run – need something cheaper

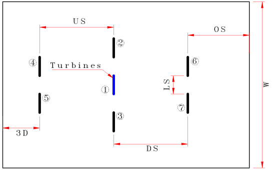
Immersed body force method :

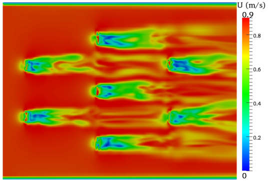
- Blades represented by stationary body forces

$$\overline{\mathbf{F}} = \overline{\mathbf{F}}_D + \overline{\mathbf{F}}_L$$

- Plus 'vortex ring' body forces
- Compromise between accuracy and efficiency
- Capable of representing large scale vortexes – 3d LES

Able to compute power, wake recovery for different turbine loadings within a farm.





Farm Modelling

Case	Details	Spec	Time
GGI	160k cells, 30 revolutions	16 cores	5 days
IBF	1 turbine, 148k cells	12 cores	17 hrs
IBF	7 turbines, 1M cells	12 cores	44 hrs

Ultimate aim to optimise farm of 10's or 100's of devices, optimise based on position, loading factor etc. Targets; power output, cost

Most suitable technique – *Genetic Algorithm*. Capable of exploring complex N-d parameter space and reliably identifying optimum (Pareto front).

Develop *surrogate model* – run 10's of simulations and use *Kriging* to mine results and create correlation.

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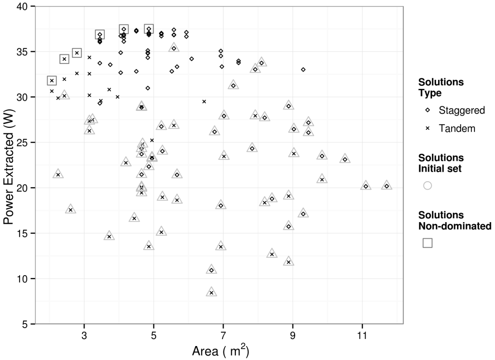
Optimisation

Results :

- 3 row farms – 2 alignments (staggered/tandem)
- 6 parameters (592704 layouts in total)
- Surrogate model based on initial sample of 30 solutions (per alignment) – create using Latin Hypercube sample
- Optimisation – GA evaluation using surrogate – evaluate new solutions using farm model



Conclusions

University HPC facilities valuable for CFD and optimisation research :

- CFD challenges in using massively parallel resources – case setup, parallelisation, post-processing, (license costs)
- Automated optimisation becoming a realistic proposition

Need to remain competitive with peers/competitors, eg :

- CFMS – 3,500 cores/300 compute nodes (cloud computing service)
- HPC Midlands – 3,008 cores, 48 teraFLOPS (U.Loughborough)
- U. Southampton – 12,320 cores, 250 teraFLOPS
- Virginia Tech – 6,500 cores, 398.7 teraFLOPS (fastest machine)
- TotalSim – 1500 CPUs

Acknowledgements

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"Optimal Design of Very Large Tidal Stream Farms for Shallow Estuarine Applications" (EPSRC) £1,126,664
M.R.Belmont, G.Tabor, I.Bryden, T.Bruce, D.Savic, S.Djordjevic

"Computational Modelling of Marine Turbines" (Laing Foundation Trust) £45,000, G.Tabor

Just starting :

"Data-Driven Surrogate-Assisted Evolutionary Fluid Dynamic Optimisation" (EPSRC) £687,882 R.M.Everson, G.Tabor, J.Fieldsend

Selected Papers

"Numerical modelling of a new class of cross flow tidal turbine using OpenFOAM I: calibration of energy extraction" M.G.Gebreslassie, M.R. Belmont, G.R.Tabor *Renewable Energy Journal* **50** pp. 994 – 1004 (2013)

"Numerical modelling of a new class of cross flow tidal turbine using OpenFOAM II: investigation of turbine to turbine interaction" M.G.Gebreslassie, M.R. Belmont, G.R.Tabor *Renewable Energy Journal* **50** pp. 1005 – 1013 (2013)

"Investigation of the Performance of a staggered Configuration of Tidal Turbines Using CFD", M.G.Gebreslassie, G.R.Tabor, M.R.Belmont, *Renewable Energy Journal* **80** pp. 690 698 (2015)

"Toward the optimal design of a tidal farm layout using a CFD model", M. Guidolin, M.G.Gebreslassie, D. Williamson, G.R.Tabor, M.R.Belmont, D.Savic. *In Preparation*