Validation of CFD models to predict hydrodynamics of stirred tank flows in the transitional flow regime.

Georgina Wadsley[1,2]
David F. Fletcher[3]
Joelle Aubin[2]
Andy Ingram[1]
Waldo Rosales[4]
Mark J. Simmons[1]

IChemE Fluid Mixing Processes Meeting
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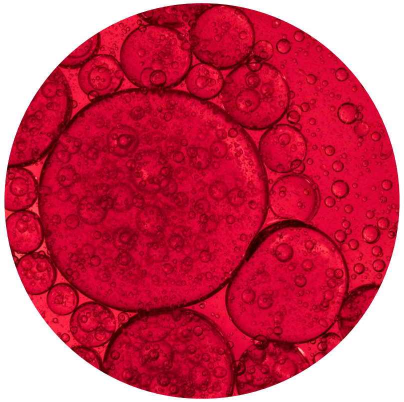
[1]School of Chemical Engineering, University of Birmingham, [2]Laboratoire de Génie Chimique, UMR CNRS 5503, [3]School of Chemical and Biomolecular Engineering, University of Sydney, [4]Unilever R&D, Port Sunlight Laboratory

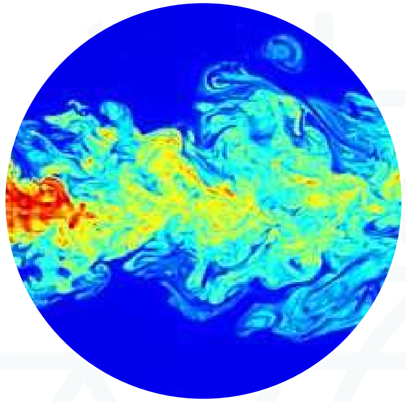
Project Context

Home & personal care products



Multiphase formulations

Complex rheology & microstructure



Transition between flow regimes

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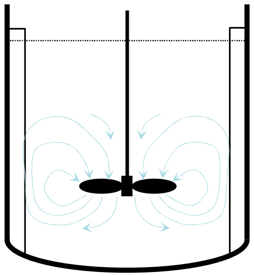
State of the Art - Modelling of Transitional Flows

Re < 2,000

Laminar

Navier Stokes

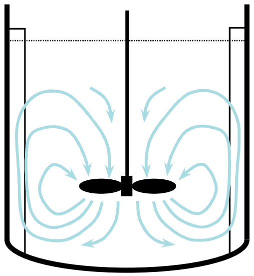


Re < 10

2,000 < Re < 4,000

Transitional

?

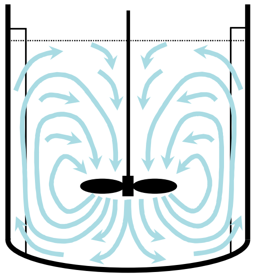


10 < Re < 20,000

Re < 4,000

Turbulent

Navier Stokes
+ turbulence model



Re < 20,000

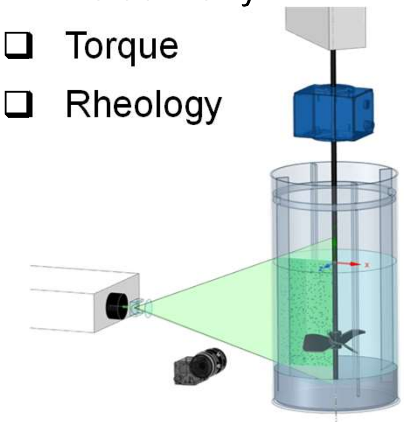
Aims - Investigative Approach

"Prediction of complex industrial flows in the transitional regime"

Flow Characterisation

Experiments:

- ❑ PIV - Particle Image Velocimetry
- ❑ Torque
- ❑ Rheology

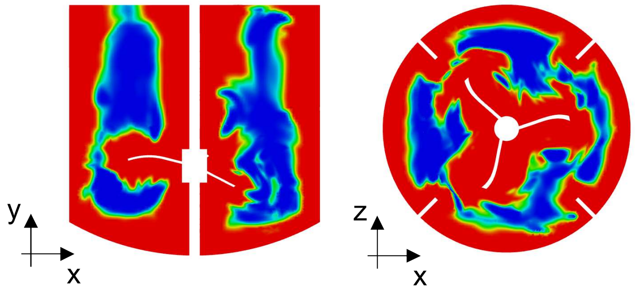


⇒ Regime limits

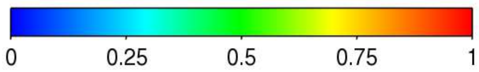
⇒ Reynolds number scaling & self-similarity

CFD Simulations

SBES - Stress Blended Eddy Simulation



LES
Large Eddy Simulation



RANS
Reynolds Averaged Navier Stokes

vs. Laminar & GEKO - Generalised k-ω SST

Building Complexity

Newtonian
▼
Non-Newtonian

Pipe Flow
▼
Stirred Tank

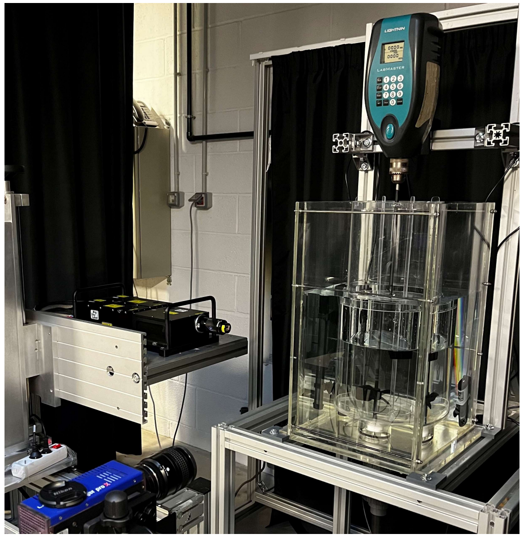
Case Studies

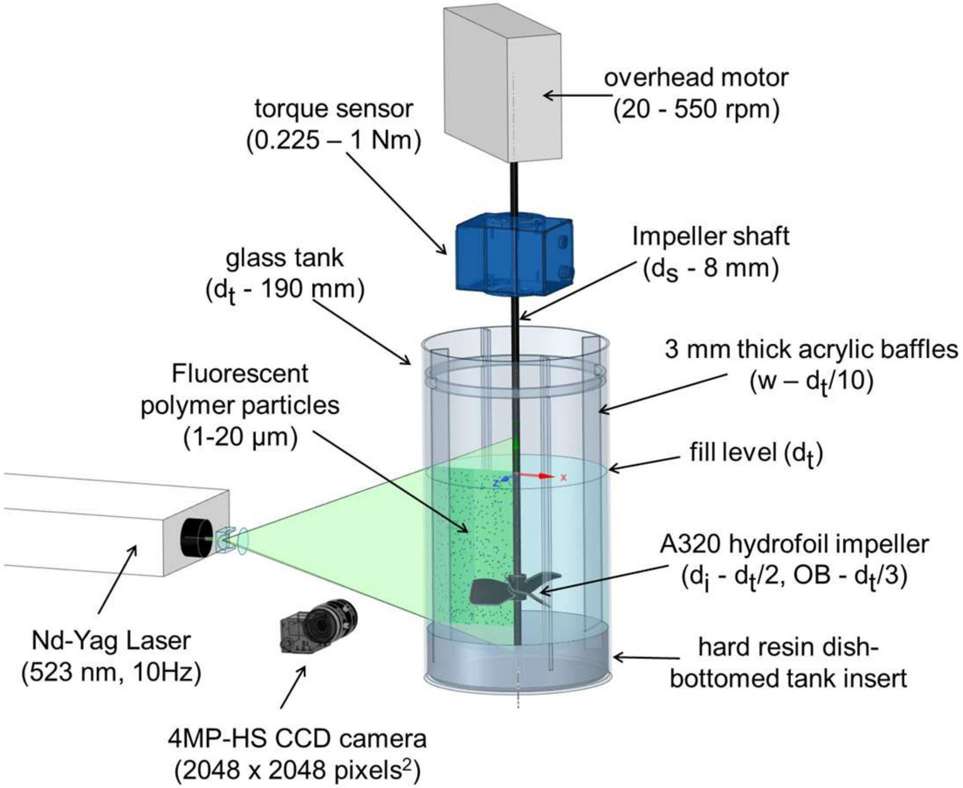
Industrial geometries & formulations

Machine Learning

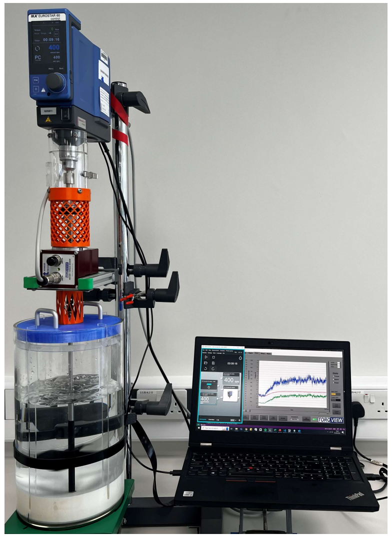
Experimental Set-Up

PIV 5 L





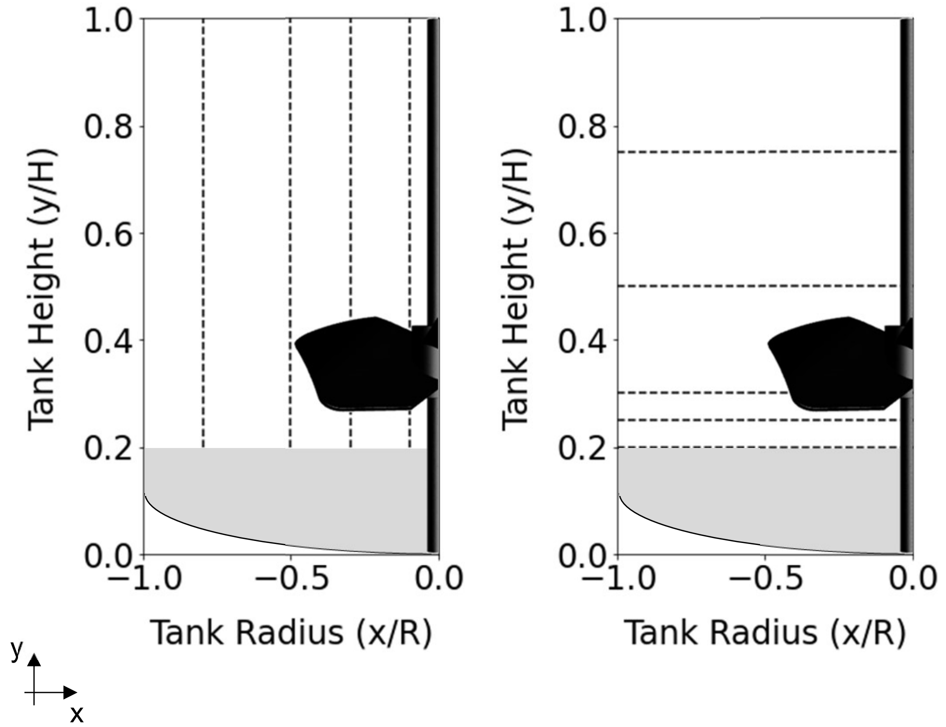
Torque 5 L



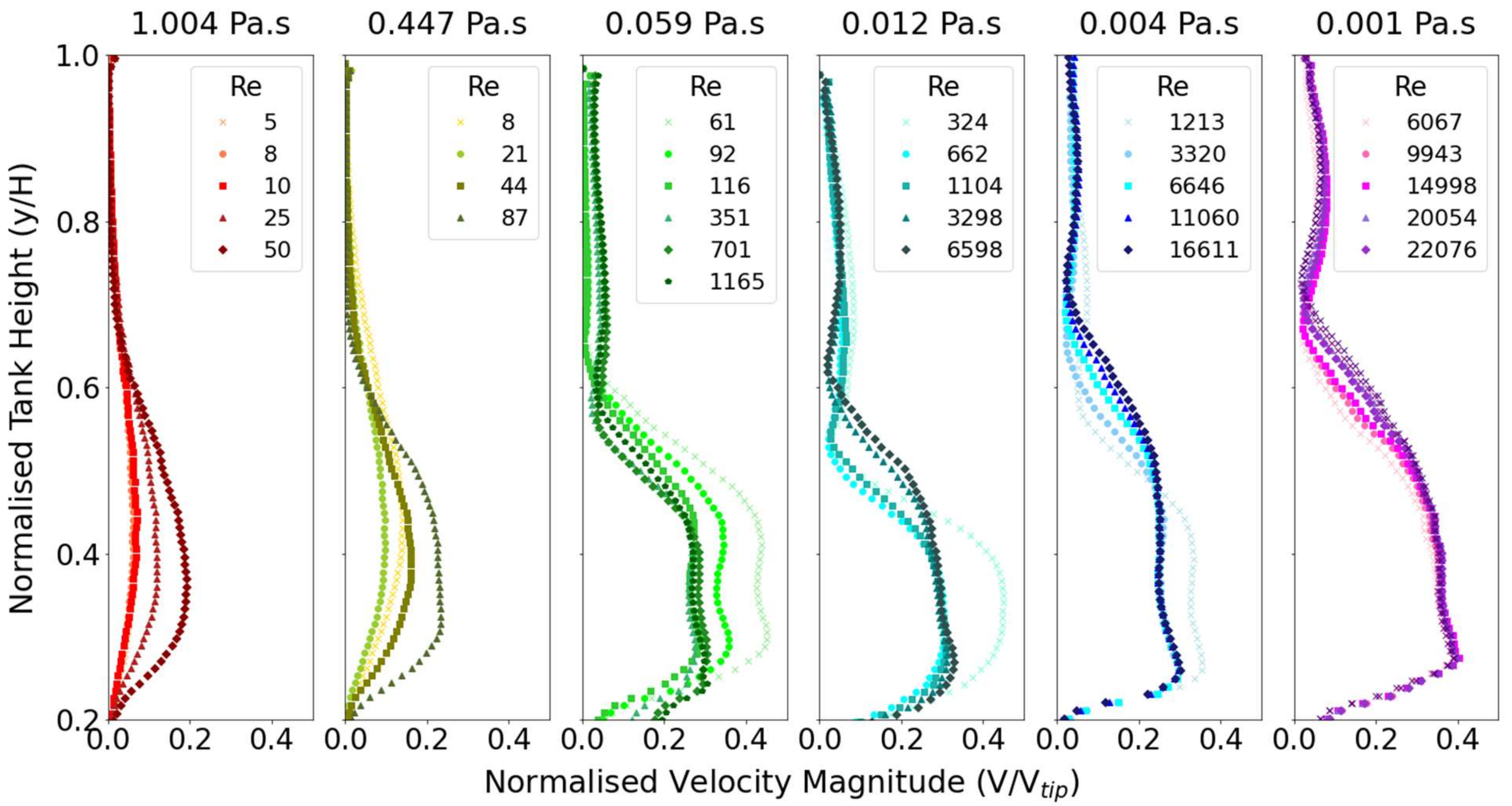
Torque 170 L

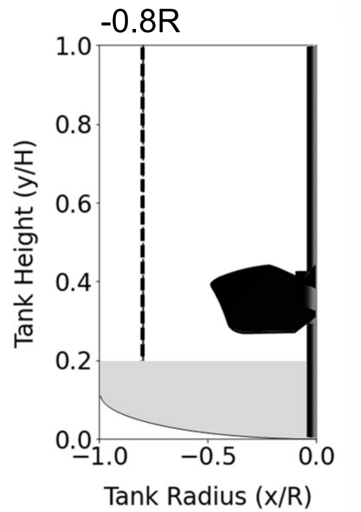
Stirred Tank Investigation – PIV & Torque

- **Re** = 5 – 35,000
  - $\mathbf{V_{tip}}$ 0.1 – 2.7 m/s
  - **μ** (apparent) 1.5 – 0.001 Pa.s
    - Glycerol (40 – 100 wt%)
    - CMC (0.1 – 0.2 wt%)
- Observe trends of normalised velocity magnitude & fluctuations
  - ∆ Re, constant μ
  - ∆ μ, constant Re
  - Newtonian vs non-Newtonian



PIV Results - ∆ Re, constant µ

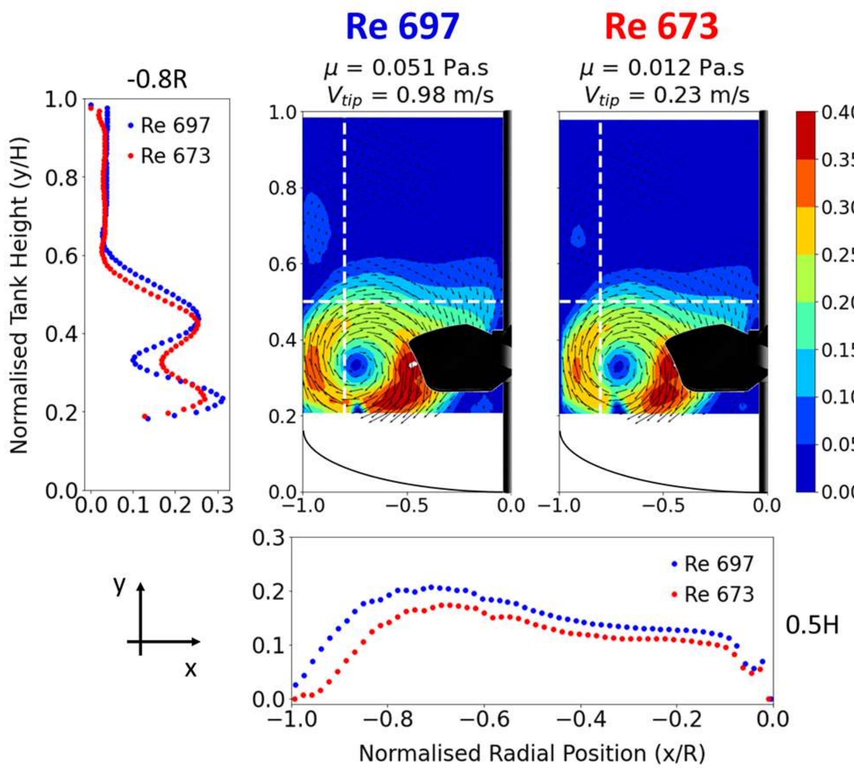




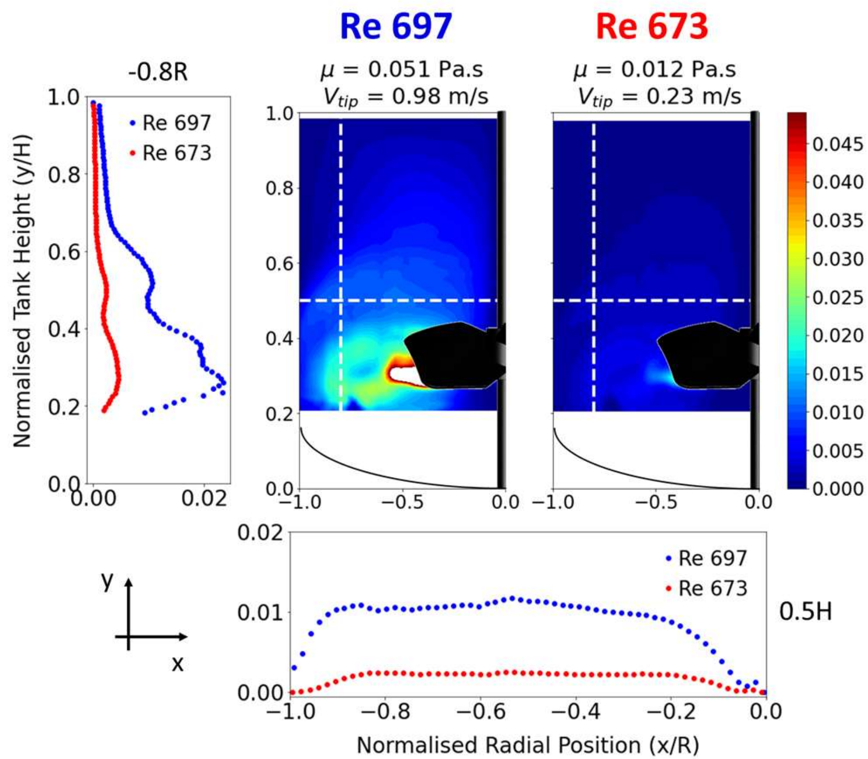
$$V_{fluc} = {}^{3}/_{4}\sqrt{\tilde{u}^2 + \tilde{v}^2}$$

PIV Results - Δ μ, constant Re

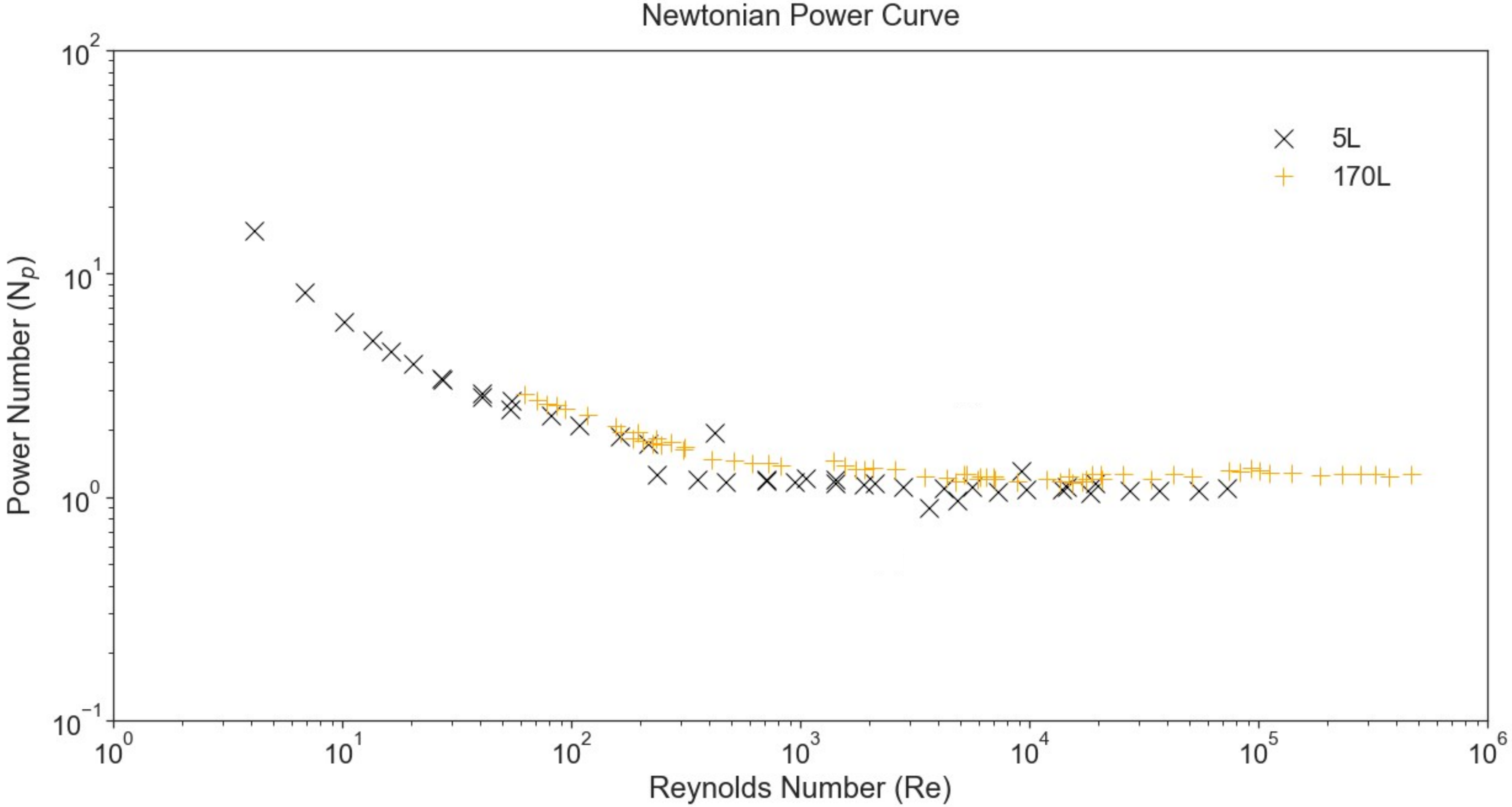
Normalised Velocity Magnitude (V/V_{tip})



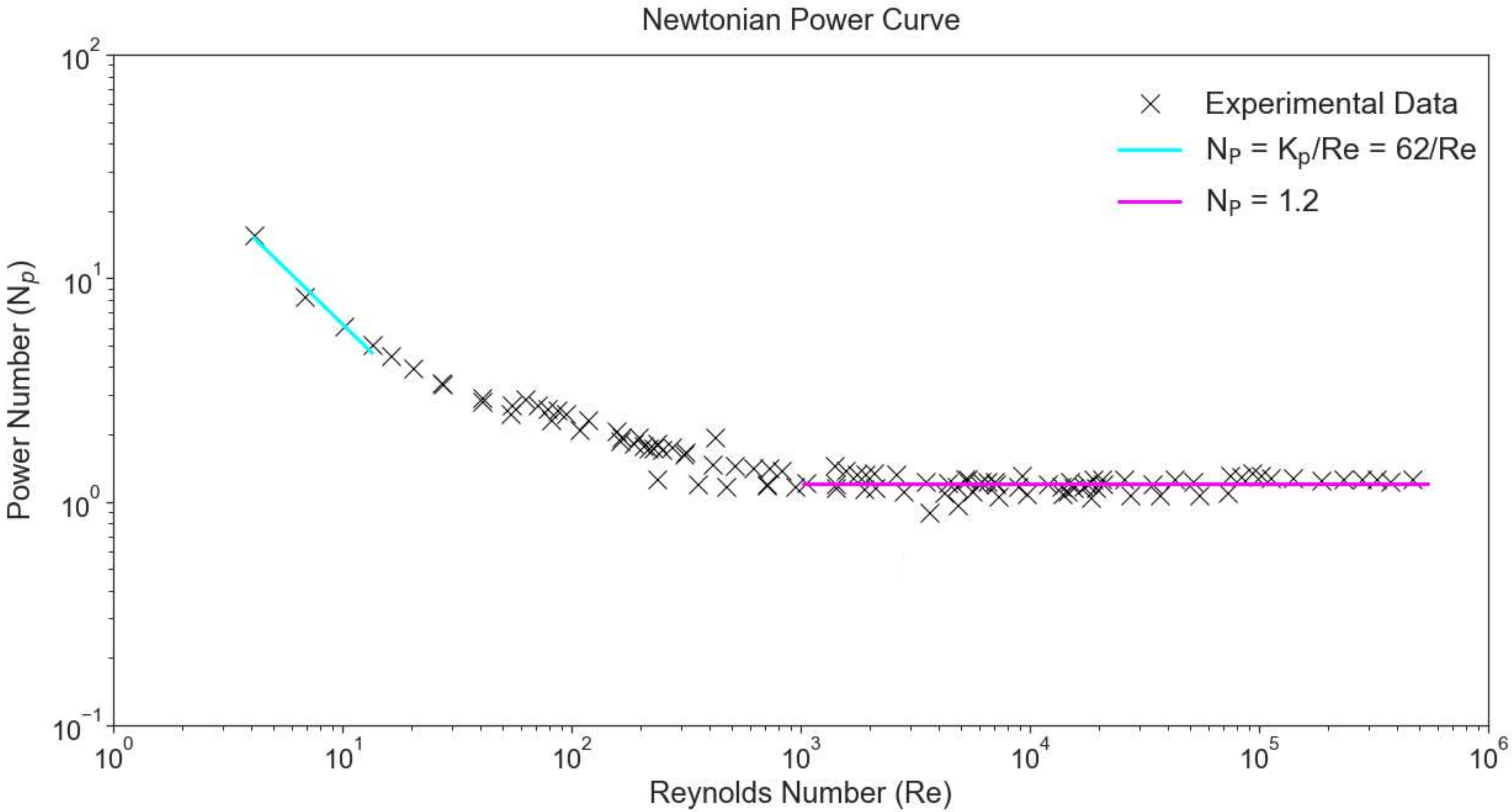
Normalised Velocity Fluctuations ($V_{fluc}/V_{tip}{}^2$)



Torque Results – 5L vs 170 L



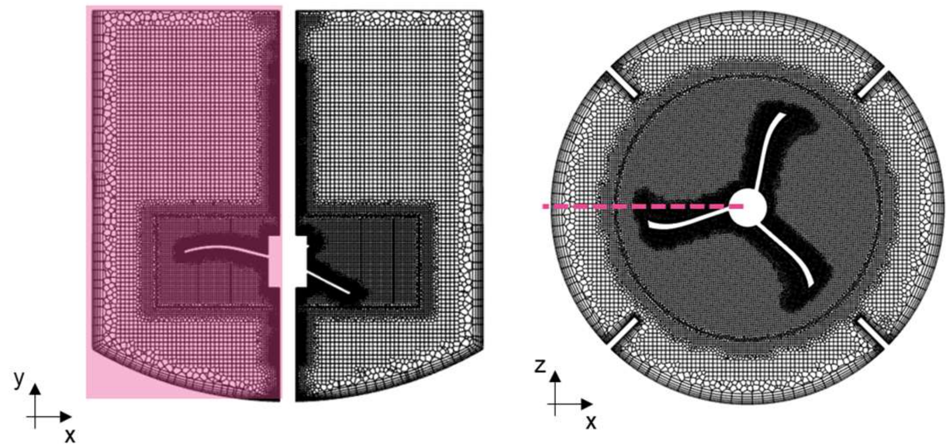
Torque Results – Laminar & Turbulent Regime Fitting



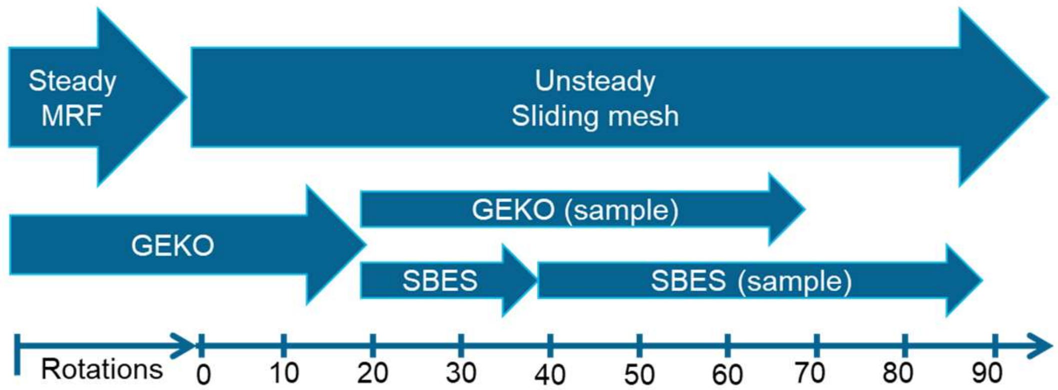
Simulation Set-up

- ❑ Convergence monitors
  - ❑ Residual values < 10^{-6}
  - ❑ Torque (impeller & walls)
  - ❑ Mass integral of ε
- ❑ Data sampling on a fixed plane
  - ❑ All blade positions
  - ❑ Periodic (every full rotation) - estimate pseudo turbulence due to blade contributions.

Polyhexcore mesh - 2.14M cells



Numerical Methods



Scale Resolving Simulations – Why SBES?

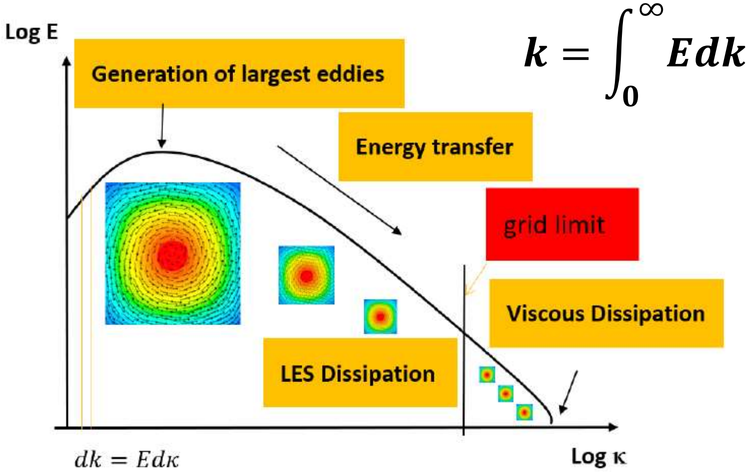
LES

- ❑ spatial filtering of NS
- ❑ resolves large scale turbulence
- ❑ models small scale structures

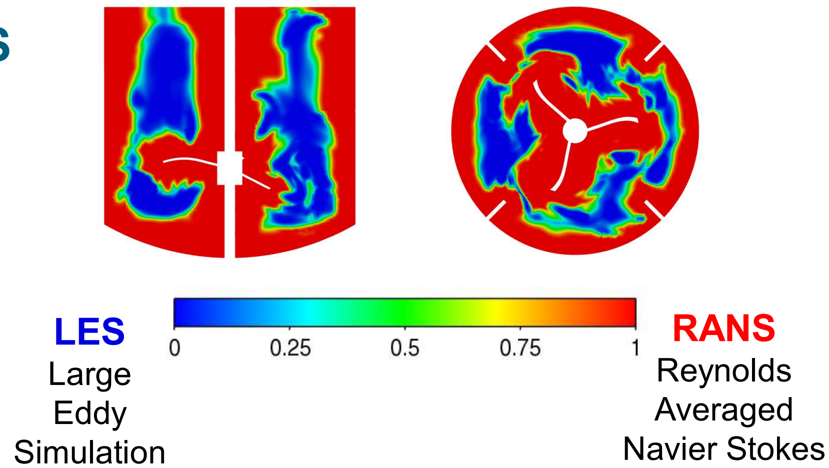
RANS

- ❑ averaging of NS
- ❑ must model Reynolds stresses
- ❑ GEKO (k-ω SST closure model)

$$k = \int_0^\infty E dk$$



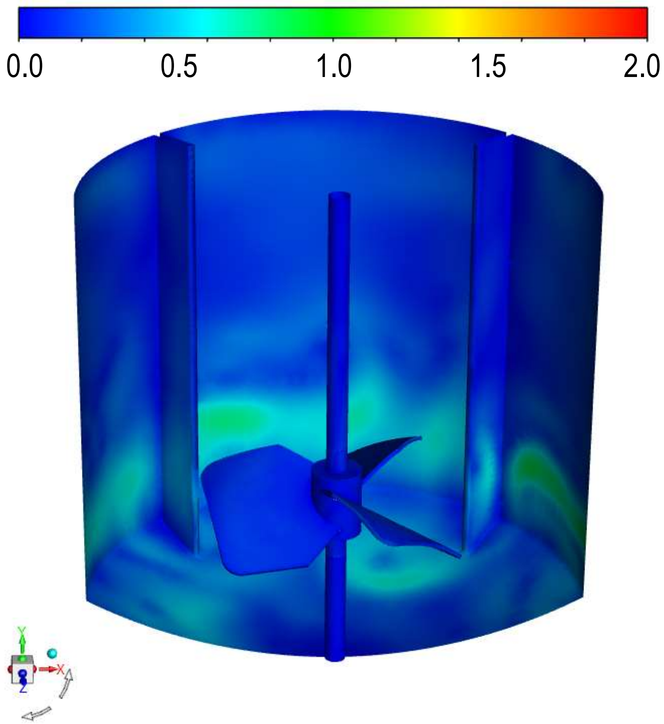
SBES



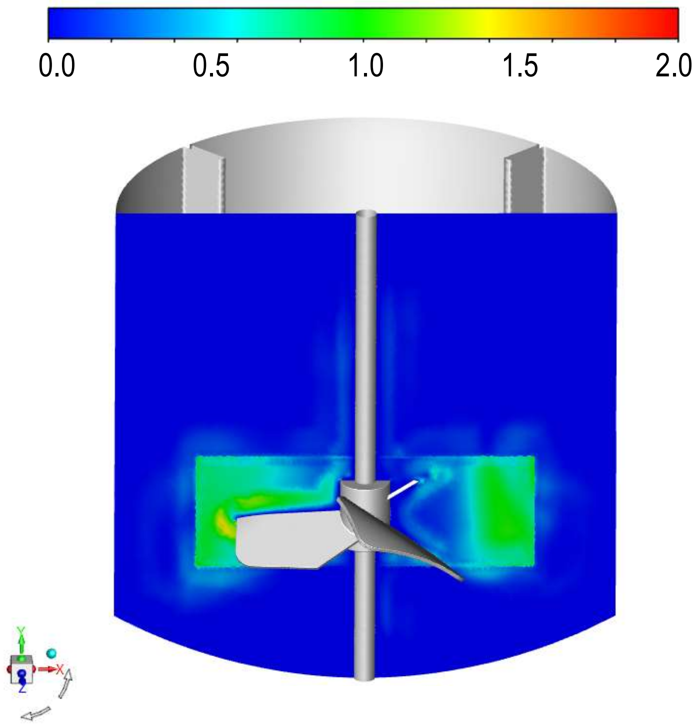
Menter, F., (ANSYS), Best Practice: Scale-Resolving Simulations in ANSYS CFD. 2015.

Simulation Solution Checks

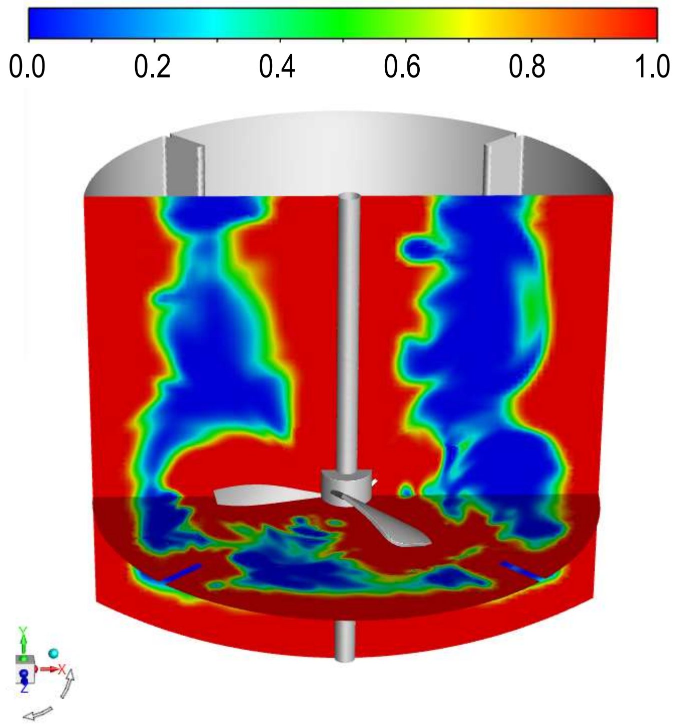
Wall Y+



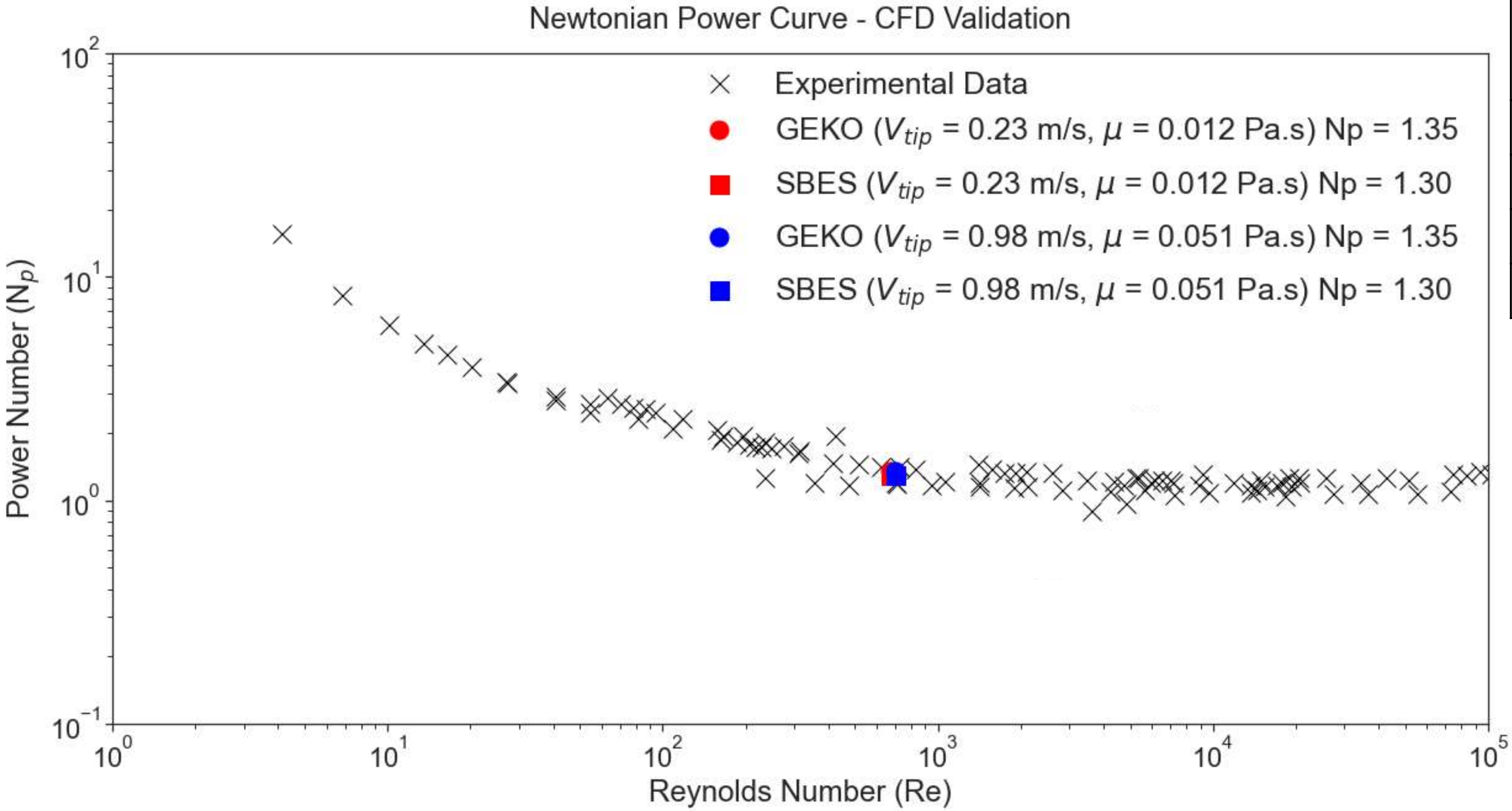
Cell Convective Courant



Blending function for SBES
(LES = 0, RANS = 1)



CFD Validation - Torque



Np from wall torque
1.07
1.33
1.07
1.30

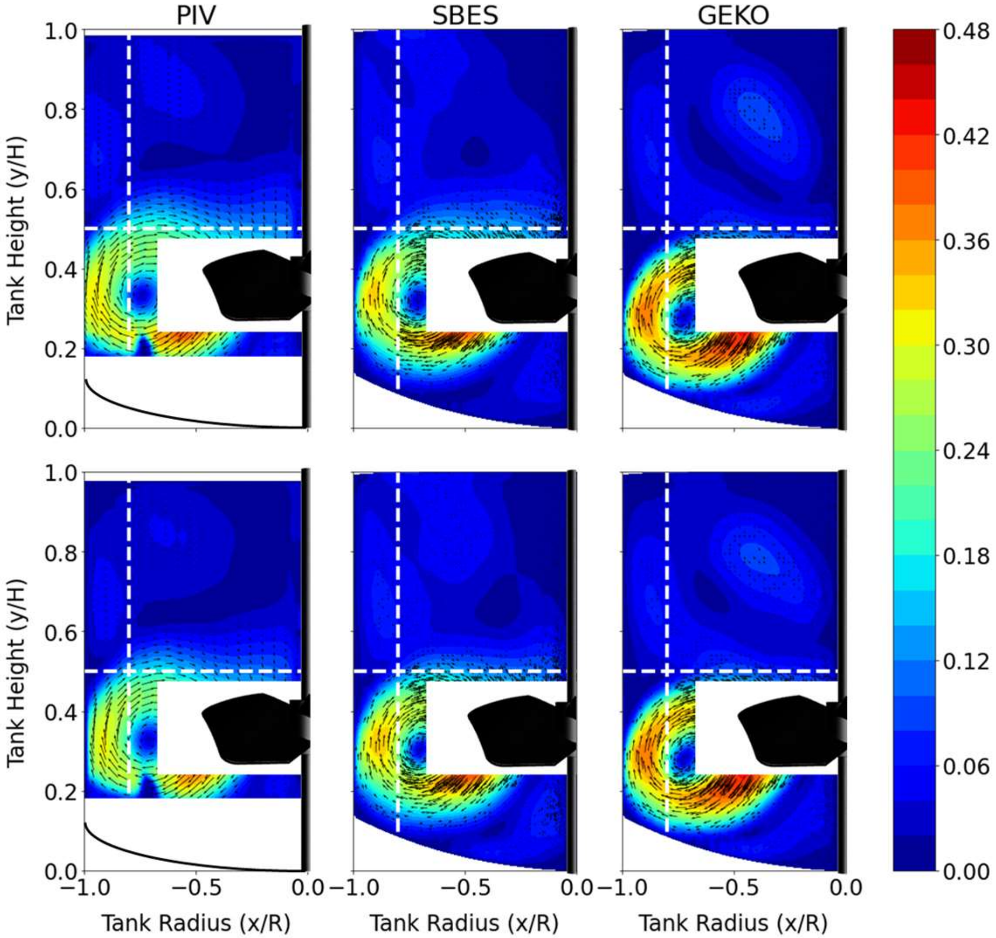
CFD Validation – Normalised Velocity Magnitude (V/V_{tip})

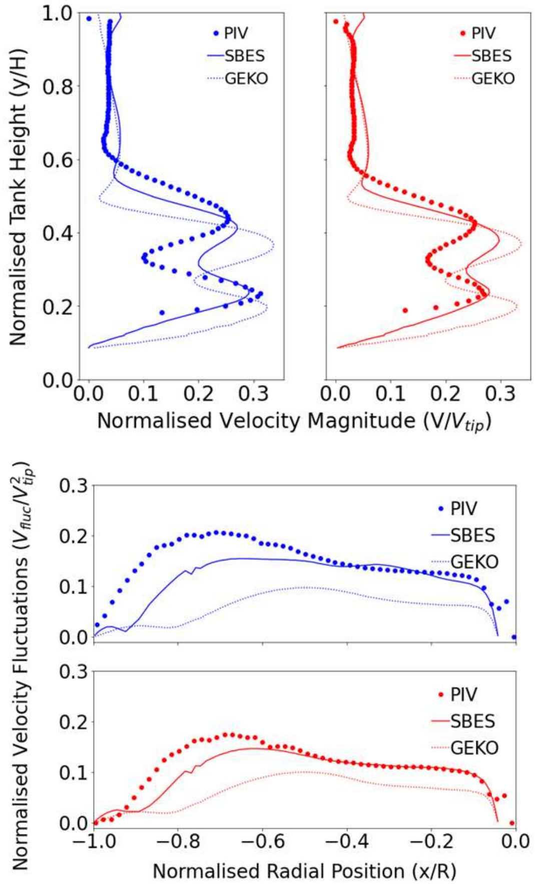
Re 697

μ = 0.051 Pa.s
V_{tip} = 0.98 m/s

Re 673

μ = 0.012 Pa.s
V_{tip} = 0.23 m/s





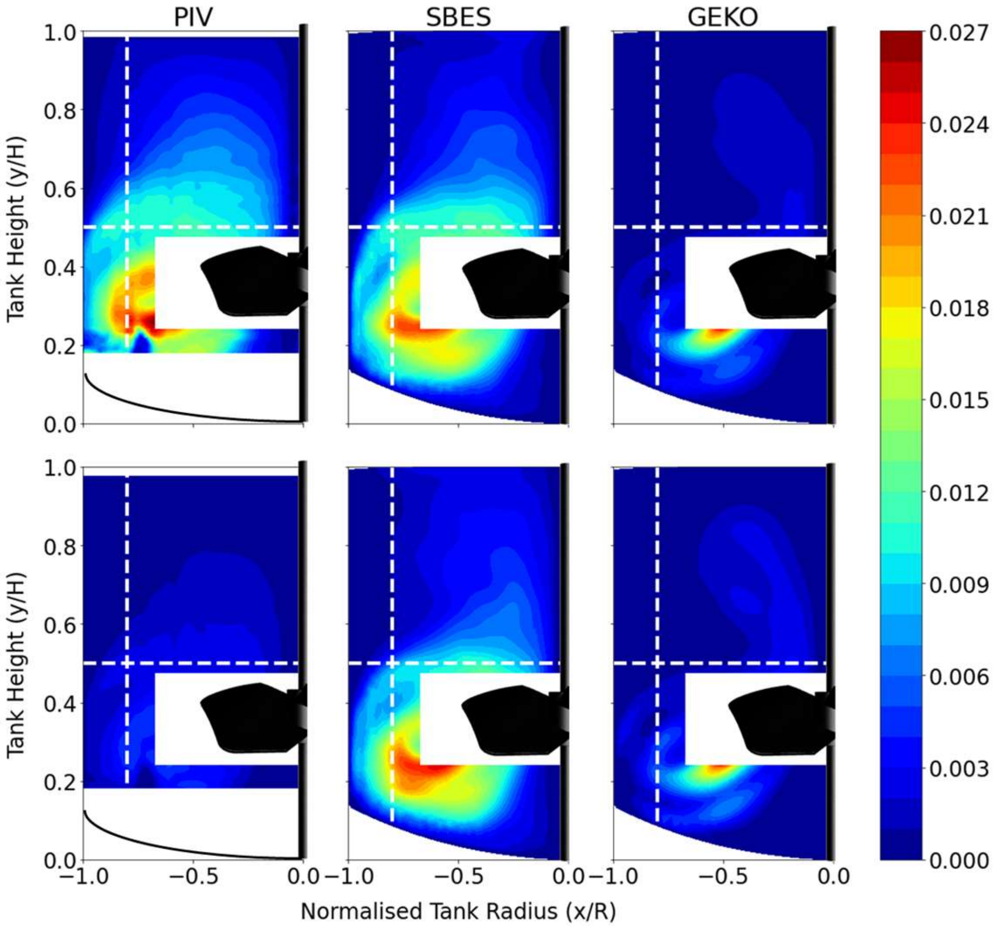
CFD Validation – Normalised Velocity Fluctuations (V_{fluc}/V_{tip}^2)

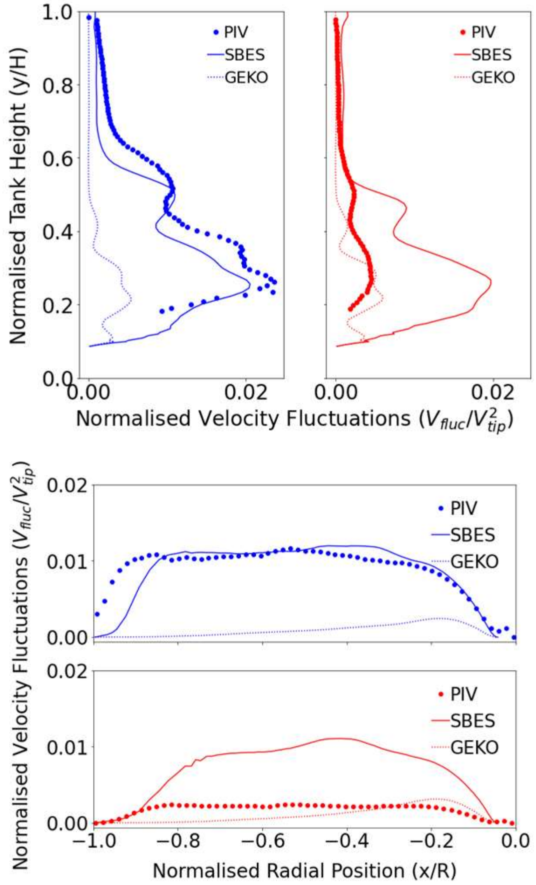
Re 697

$\mu = 0.051$ Pa.s
$V_{tip} = 0.98$ m/s

Re 673

$\mu = 0.012$ Pa.s
$V_{tip} = 0.23$ m/s





Conclusions

- ❑ Distinct flow behaviours identified for each flow regime.
- ❑ Transitional regime limits are not constant - vary with fluid viscosity (μ).
- ❑ Transitional regime flows scaled for same Re do not exhibit self-similar flow hydrodynamics.
- ❑ Both GEKO & SBES closure models validated for torque prediction.
- ❑ SBES performs better to predict torque balance & velocity magnitudes.
- ❑ Failure to predict difference in velocity fluctuations between two transitional regime cases with same Re.

Future Work

- ❑ Fix SBES blending function to run larger region of LES.
- ❑ Confirm both GEKO & SBES accurately predict high Re cases.
- ❑ Explore impeller blade and baffle periodicity using POD & periodic averaging.

Thank you

For more information, please get in touch…

Georgina Wadsley

gkw059@student.bham.ac.uk

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