Institute of High Performance Computing

IHPC

HARNESSING POWER OF SUPERCOMPUTER TO ADVANCE MARINE, OFFSHORE AND RENEWABLES

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A*STAR

Oct 15, 2020

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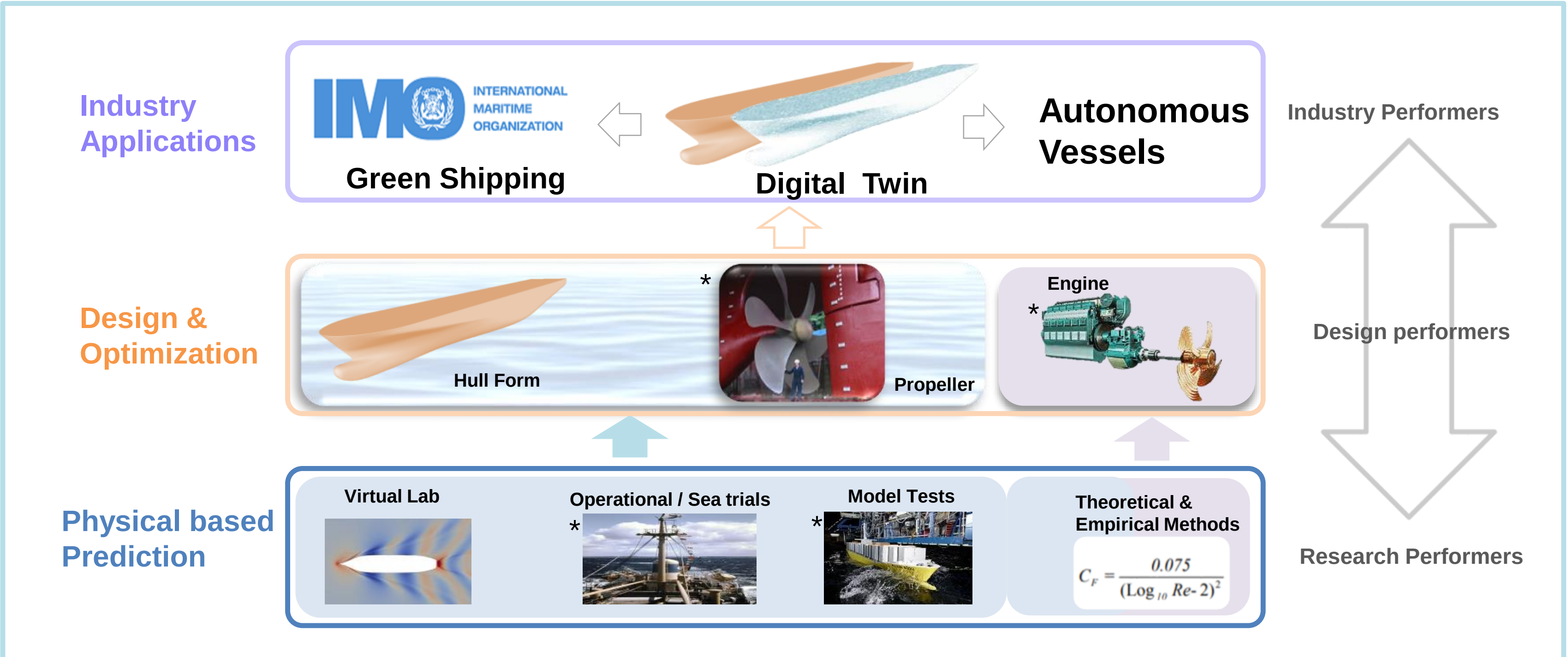
Towards Green Shipping and Digital Twins



* *Pictures from Wikipedia*

CREATING GROWTH, ENHANCING LIVES

Computational Fluid Dynamics (CFD)

01

Pre-processing

- Geometry and domain
- Boundary conditions
- Model defining
- Mesh

Solving Navier-Stokes Equations

02

Discretization methods

- Finite volume method
- Finite element method
- Finite difference method

$$\rho \frac{D\mathbf{u}}{Dt} = -\nabla p + \nabla \cdot \boldsymbol{\tau} + \rho \mathbf{g}, \quad \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

"Uses numerical analysis and data structures to analyze & solve problems that involve fluid flows"
__ *Wikipedia*

Validation and Verification

- Experimental data
- Analytical or empirical analysis
- Full-scale testing data, such as sea trials, flight tests

04

Post-processing

- Analysis and visualization of the results
- CFD advantage over model tests
  - Provide flow field details

03

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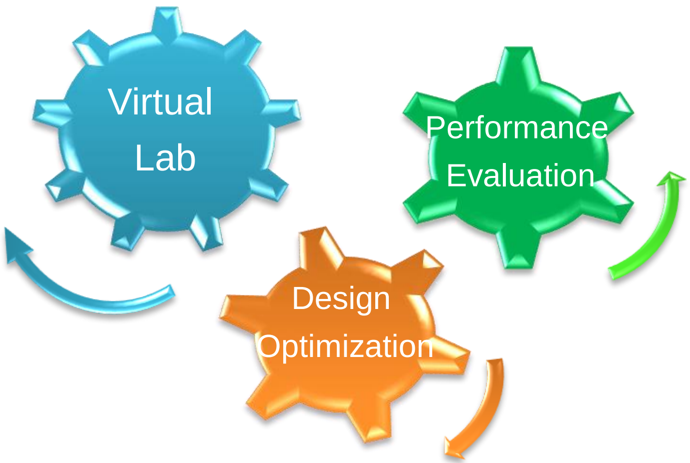
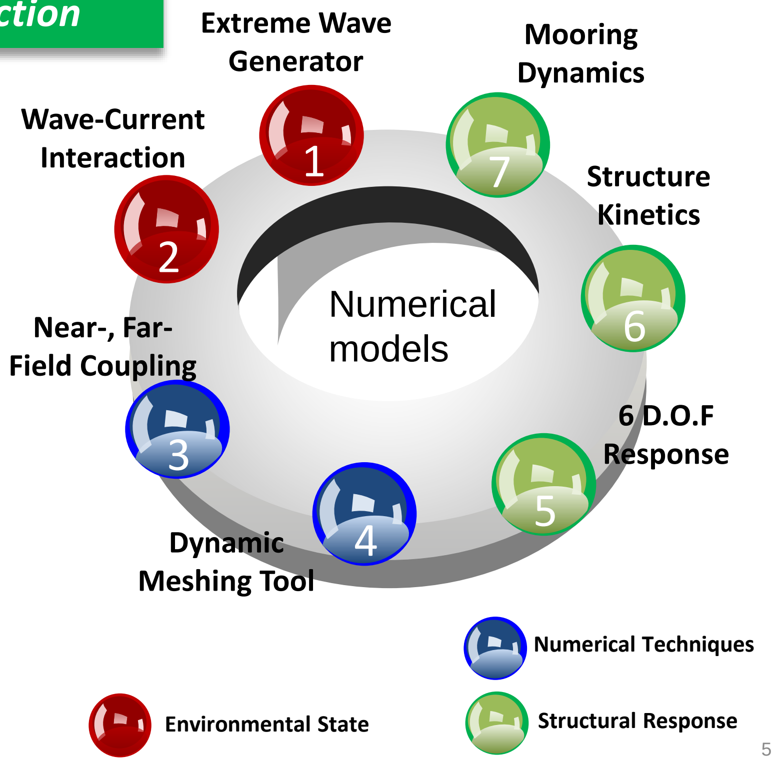
Towards Green Shipping and Digital Twins



CFD based Design Optimization

Geometry model → Mesher → DOE → Morphing → CFD based solver → Objective Function values → Optimization Algorithm → Optimized model

Physical Based Prediction



Physical Based Performance Evaluation towards Green Shipping and Digital Twins

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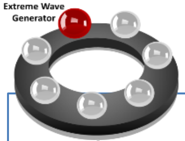
Wave Generator

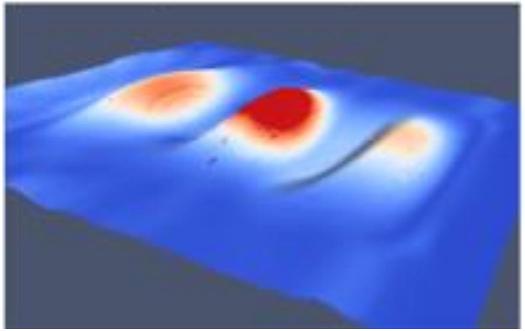


Motivation

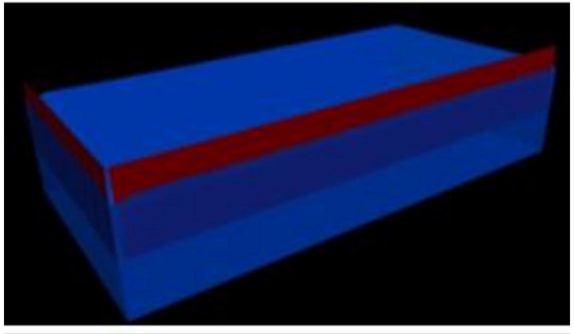
- Advantage of capturing relevant hydrodynamic non-linearities, such as free surface elevation including wave breaking, viscous drag, and turbulence effects.
- Offering access to all field variables and flexibility in tank layout and experimental design.

Approach

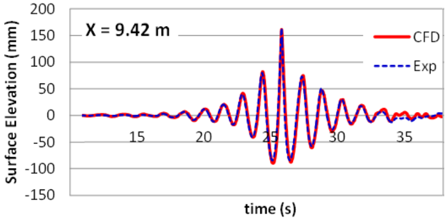
- Develop and integrate a set of CFD tools for offshore applications of complex hydrodynamic problems.
- Offshore Platforms and Cases: Floating Barge, Semi-Submersible, FPSO and so on.
- Studies: Hydrodynamic forces, Wave pattern, Rigid body motion, Vortex-induced motion of floaters.

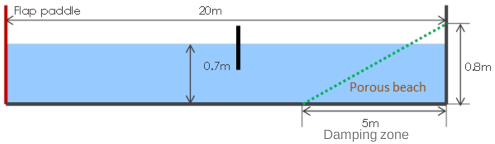


Generating waves using wave theories



Generating waves using moving paddles



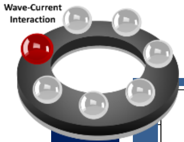


Wave generation using paddle movement signal from experiment

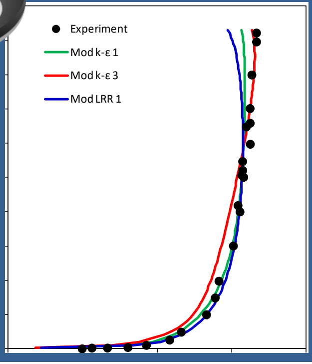
Model Validation

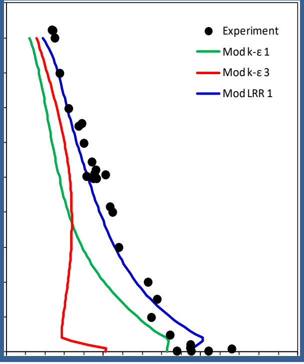
X. LV, et al., 2014, A CFD Study for Multi-Directional Focused Extreme Wave, ISOPE - I -14 - 509.

Wave Current Interaction



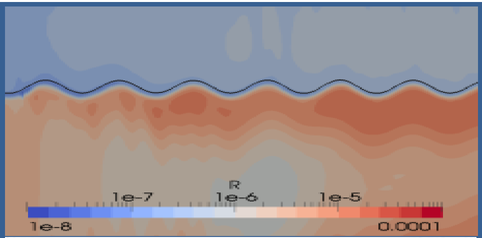
Current

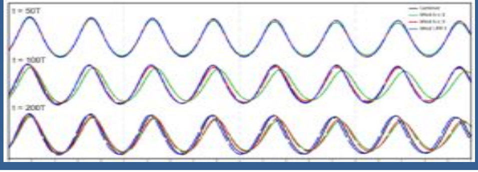




Predict correctly:
- Mean current.
- TKE profile.

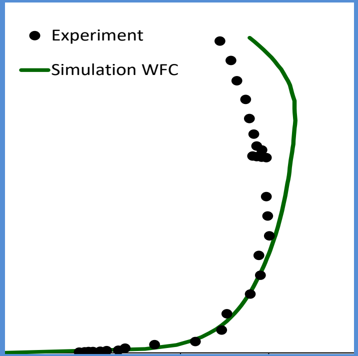
Wave

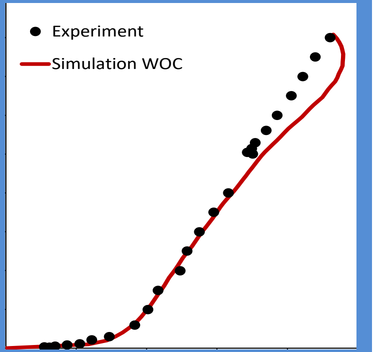


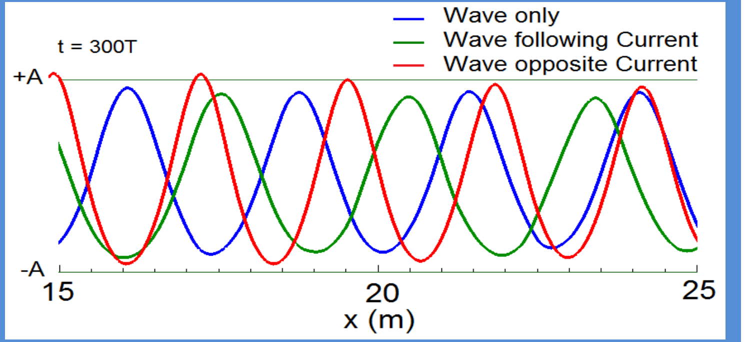


- Successfully model surface wave
- Minor decrease of the wave amplitude

Wave-current interaction







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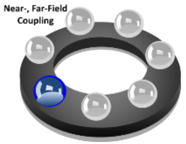
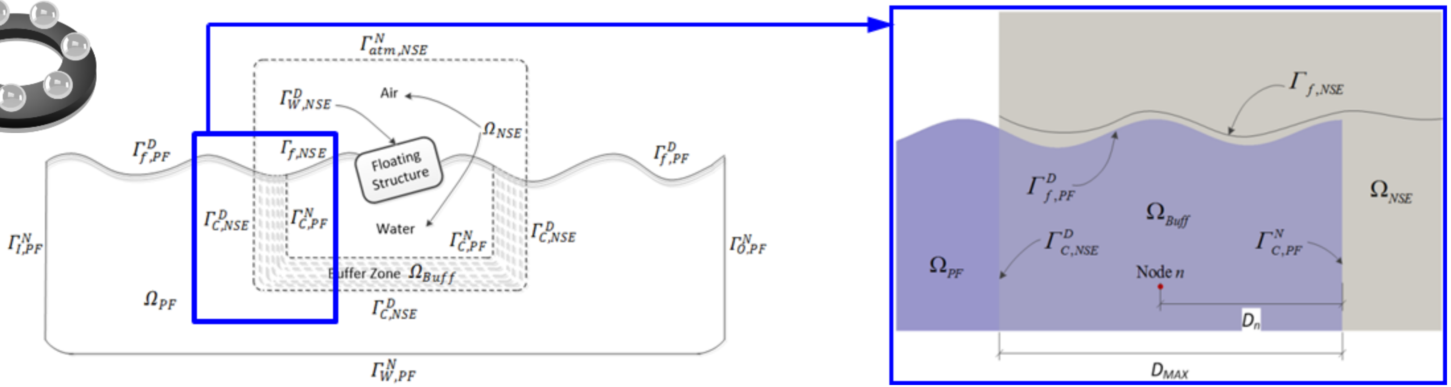
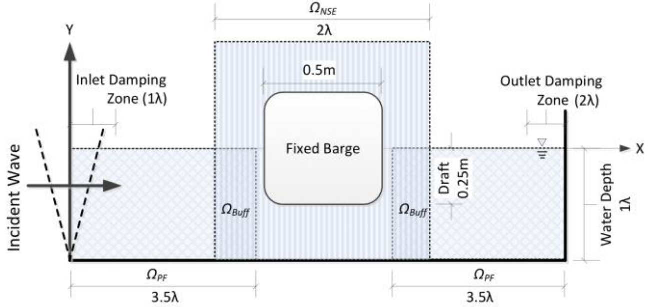
MH Dao, J Lou, 2016, Numerical simulation of wave-current interaction in laboratory basins, ISOPE-I-16-337.

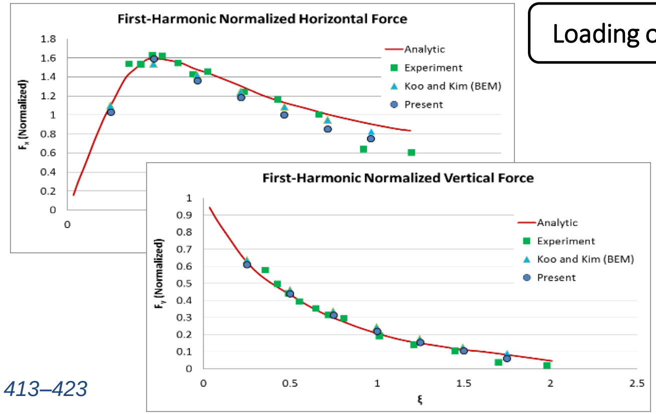
CFD-Potential Flow Coupling





Model Validation

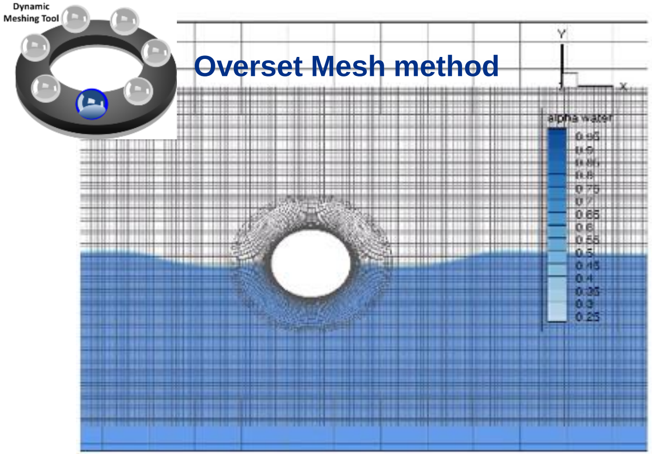


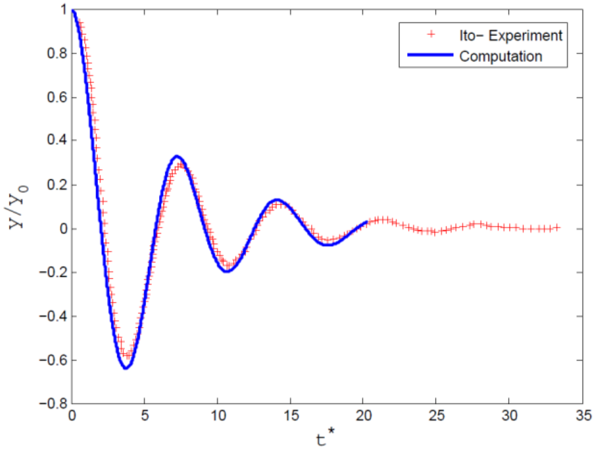


Loading on Barge

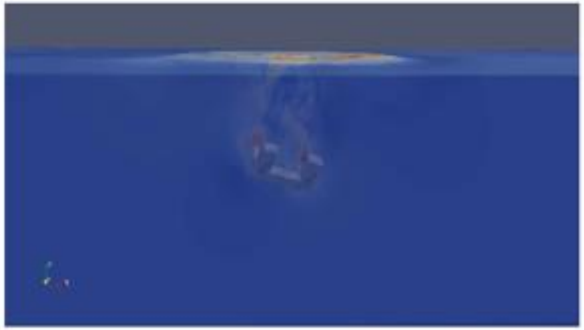
X. Lv, et al., Int. J. Comp. Meth. and Exp. Meas., Vol. 4, No. 4 (2016) 413–423

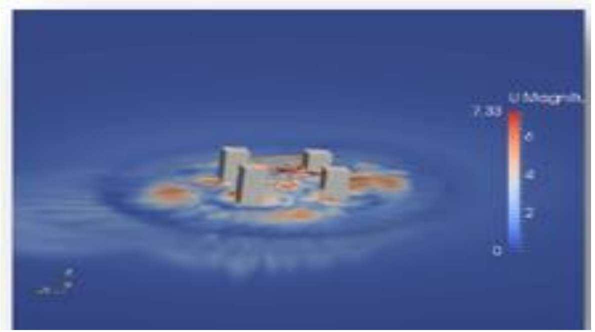
Dynamic Meshing





Technology Disclosure:
OPERA: Overset Mesh Parallel Engine for Engineering Applications (IHPC-TD-FD-2015-003, ETPL Ref: IHPC/Z/09187)





Chandar, D., 2015，Development of a Parallel Overset Grid Framework for Moving Body Simulations in OpenFOAM, Journal of Applied Science and Mathematics, 20.

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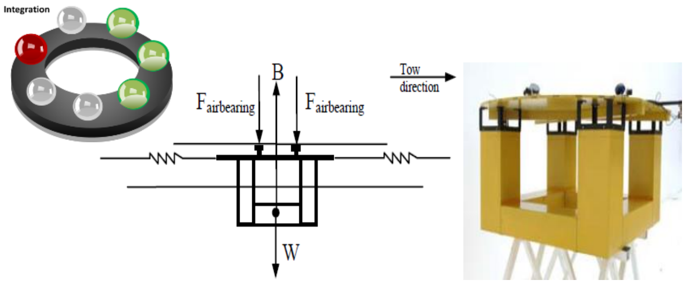
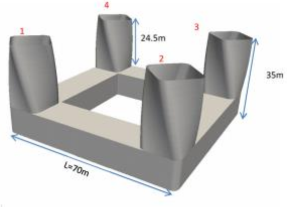
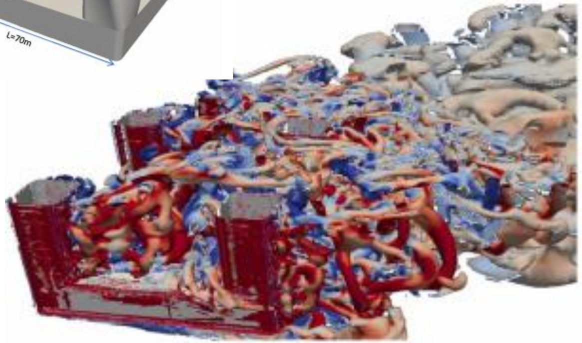
Vortex Induced Motion





Reduction of 90% VIM at the peak lock-in condition



Motivation

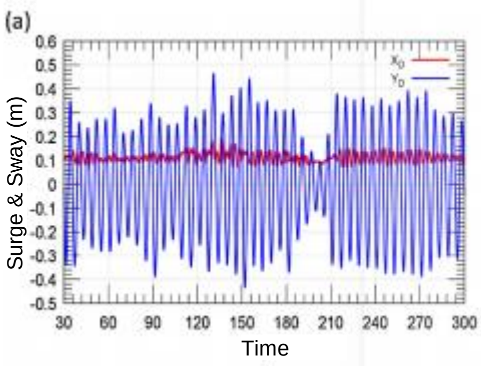
- Aims at the development of a passive control technique for the vortex synchronization of deep-draft semisubmersibles (DDS) via continuous cross-sectional twisting of the rounded square column along the span wise direction.

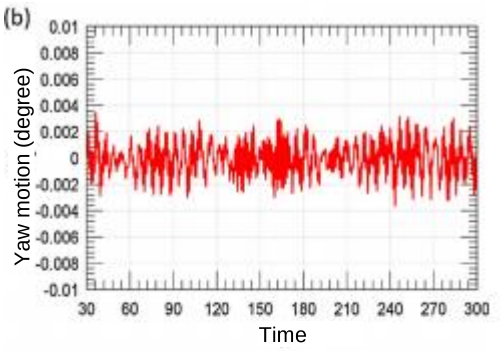
Methods

- The computations are performed using a hybrid URAN-LES turbulence model based on the finite volume method.

Results

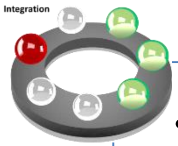
- The semisubmersible with twisted columns is a very efficient design to reduce the VIM response





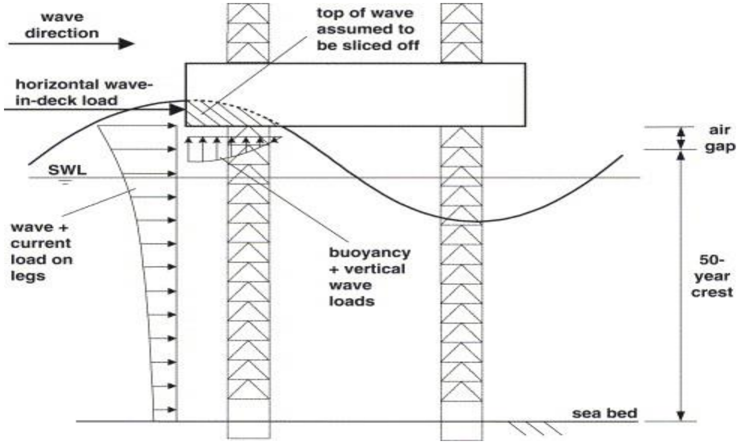
CH Wu, et al., 2018, A new passive control technique for the suppression of vortex-induced motion in deep-draft semisubmersibles, Applied Ocean Research.

Wave Impact



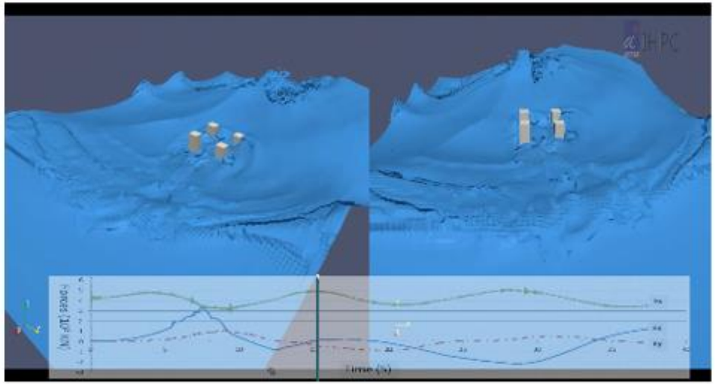
Objective

- To develop advanced CFD tools to predict various environmental loads (i.e. current, wave-in-deck, steep and breaking waves) for fixed offshore structures under extreme weather conditions.



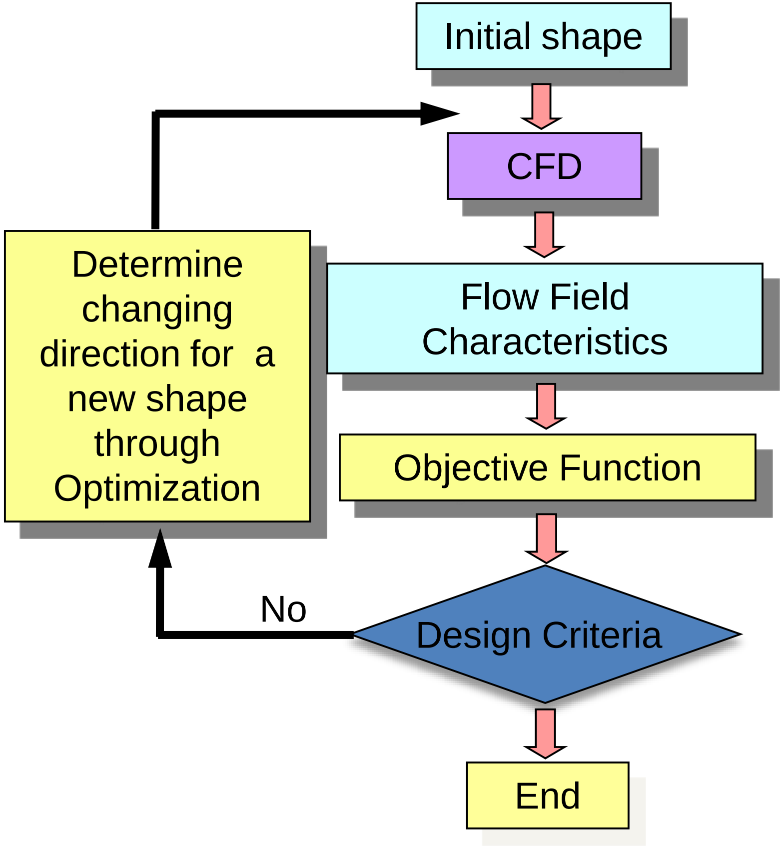
Extreme Wave Impact

OpenFOAM testing: Extreme “ROGUE” Waves Impact Simulation in a Basin



CFD based Design Optimization towards Green Shipping and Digital Twins

CFD based Design Optimization



- **Gradient-based algorithms**
  - High efficiency
  - Applied to all size, shape and topological design
  - Not for discontinuous functions
- **Stochastic algorithms**
  - Genetic Algorithms (GA)
  - Simulated Annealing (SA)
  - Simultaneous Perturbation Stochastic Approximation(SPSA)
- **Neural network methods**
- **Surrogate based algorithms (Metamodeling)**

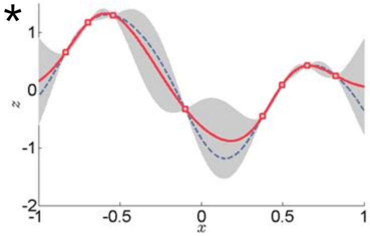
Surrogate Models for Design Optimization

Initial & B.C. → Full order models → Objective functions

Initial & B.C. → Surrogate models → Objective functions

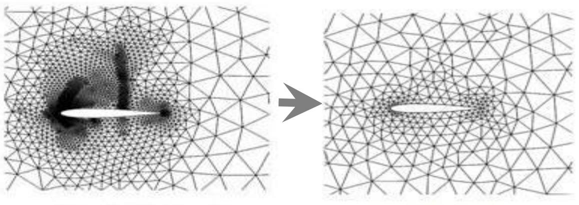
- **Data fit surrogates**

*



+ High speedups
+ Must balance local consistency with global accuracy
+ Examples: response surface methods, machine learning…

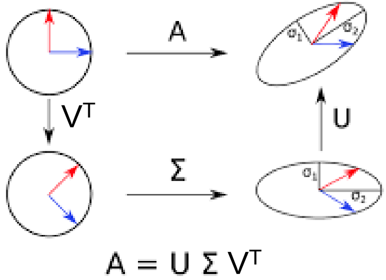
- **Multi-fidelity surrogates**



+ Finer/Coarser discretization
+ May require mapping

- **Reduced-order surrogates**

*



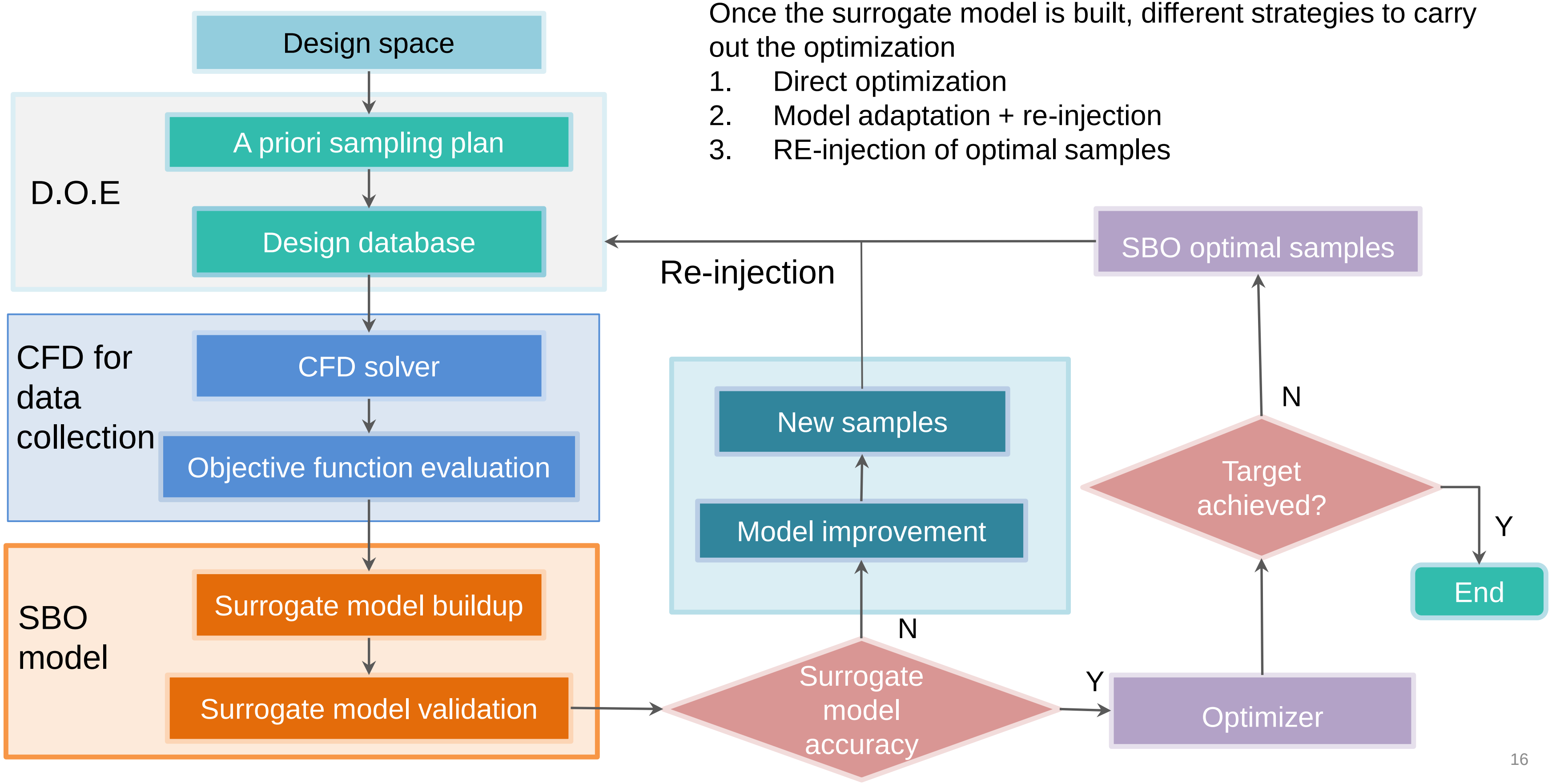
+ Emerging area
+ High speedups
+ Rigorous error analysis
+ Unproven for nonlinear dynamic systems

** Pictures from Wikipedia*

Surrogate Models for Design Optimization

Once the surrogate model is built, different strategies to carry out the optimization

1. Direct optimization
2. Model adaptation + re-injection
3. RE-injection of optimal samples



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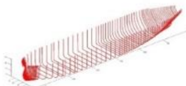
Platform Development with the Simulation and Optimization Tools

Platform: Intelligent Hull Operation, Processing & Evaluation (iHOPE)

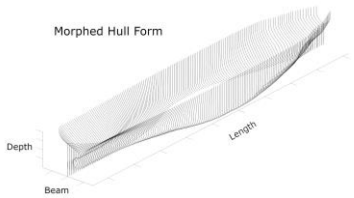


Hull Design

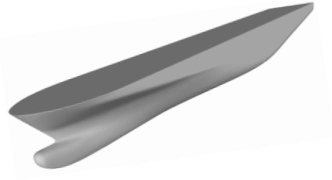
Design Model → Automatic Analyses → Design Optimization

- Innovative design
- Improve efficiency
- Reduce dependency on designer’s experience

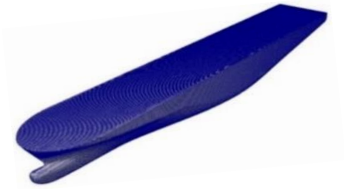
Hull Design DATA → **GEOMETRY** MODEL → **CFD** Pre-Processing → **Evaluation** Results



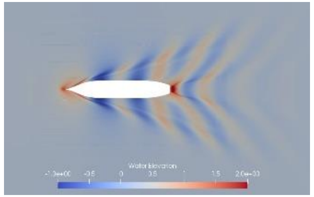
offset-table format.



The final reconstructed model.



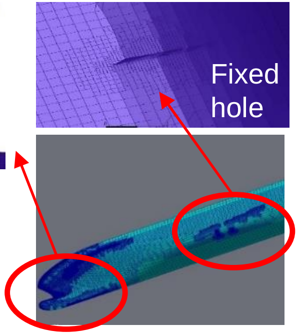
SnappyHex method is adopted to generate 3D mesh.



CFD Simulation results

XQ Xing, et al., 2019, Development of an Automatic Analysis Methodology by Integration of Digital Hull Design, Model, Processing, and Evaluation, Journal of Physics: Conference Series 1357 (1), 012003

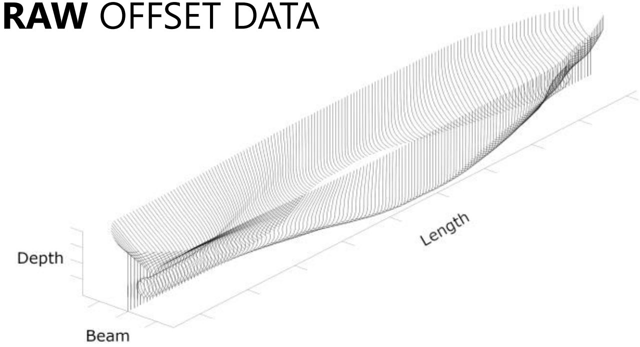
Platform: Intelligent Hull Operation, Processing & Evaluation (iHOPE)



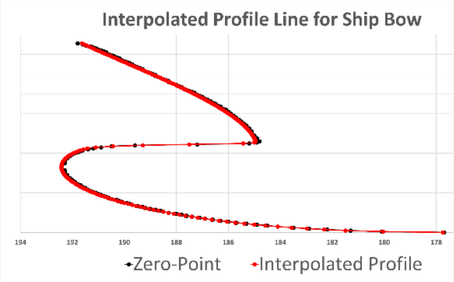
Geometry fix

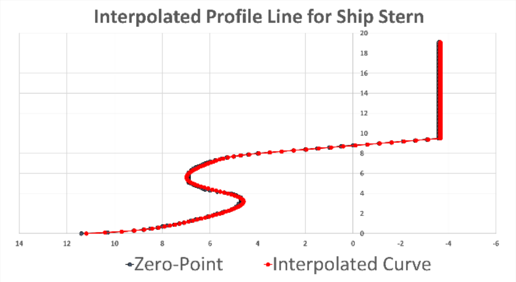
- Folded surfaces
- Gaps
- Holes
- Overlap surfaces
- Leakages
- Sharp joints

RAW OFFSET DATA

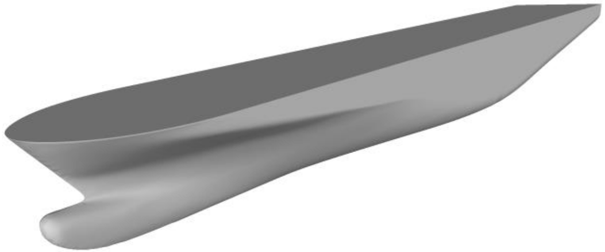


SURFACE RECONSTRUCTION





FINAL GEOMETRY MODEL



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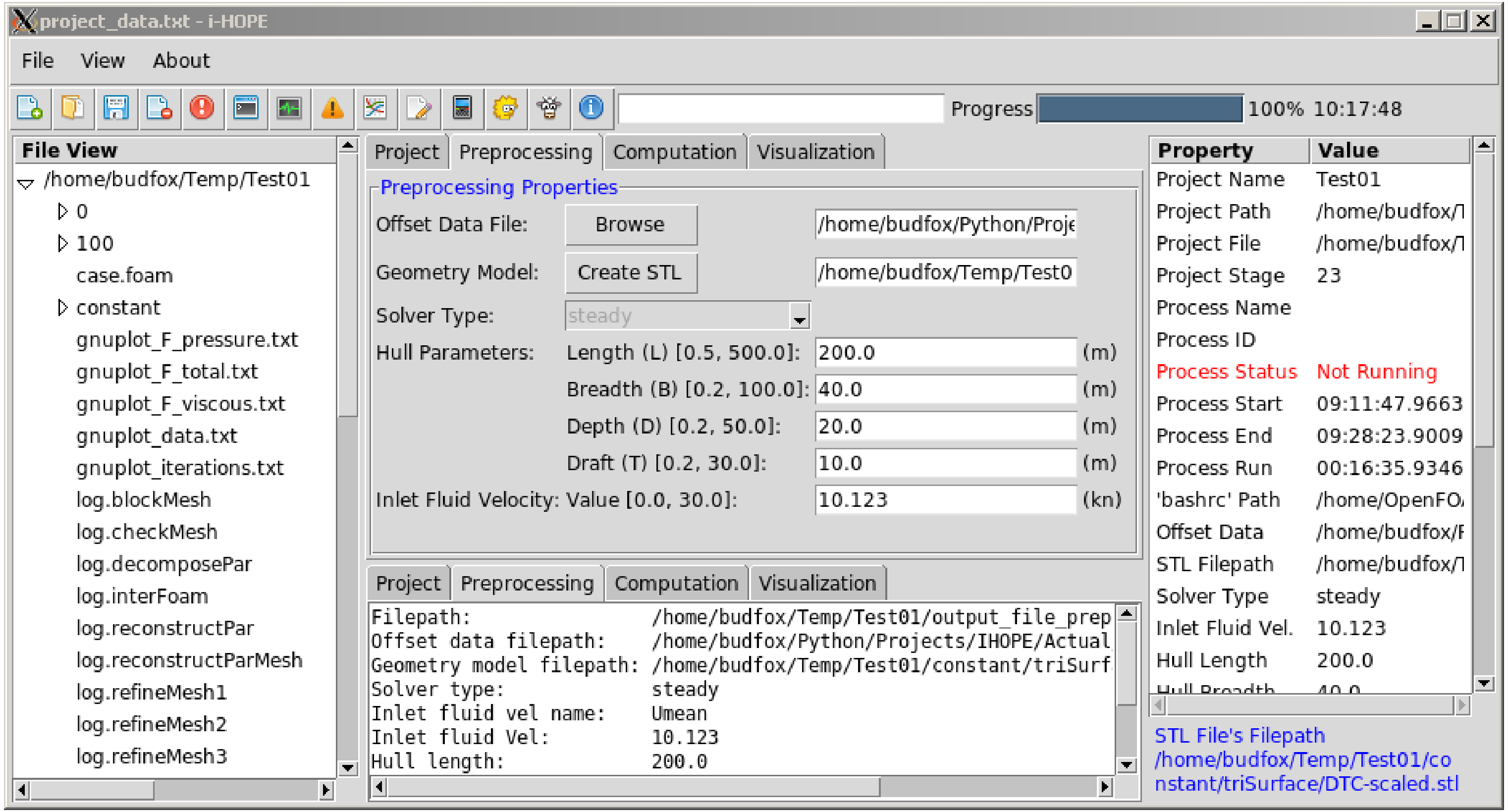
Platform: Intelligent Hull Operation, Processing & Evaluation (iHOPE)



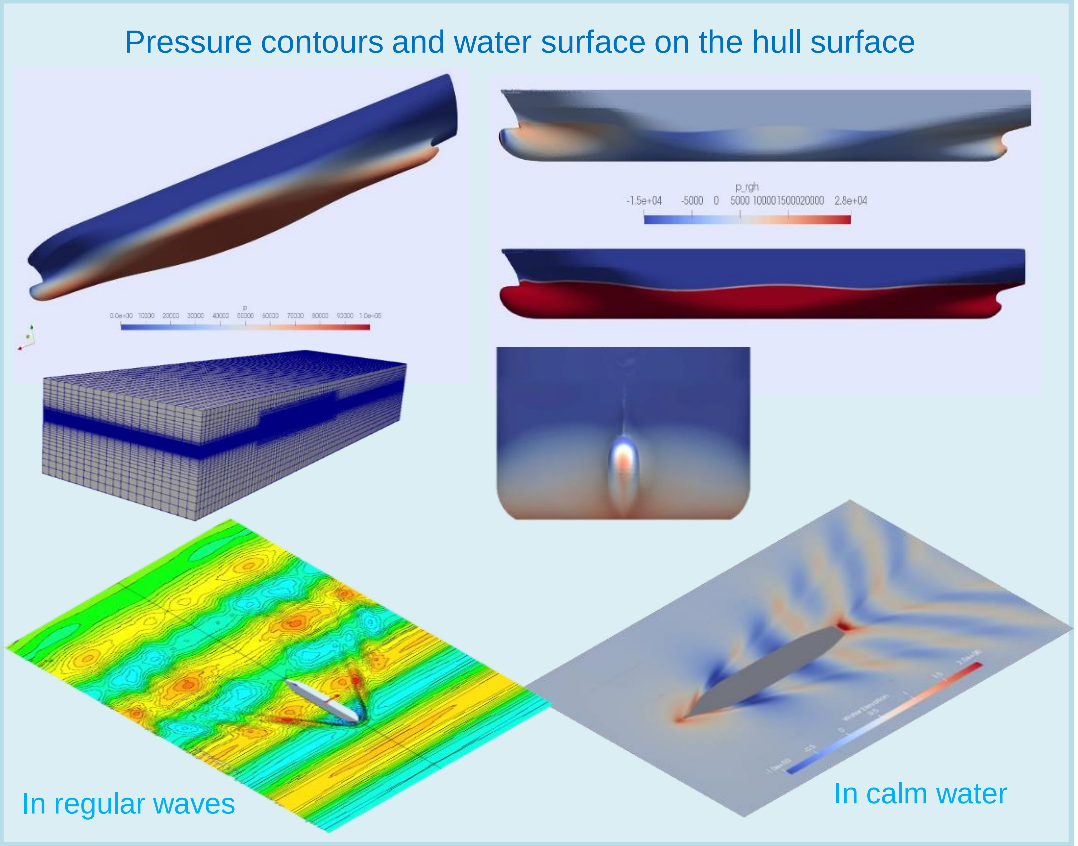
CREATING GROWTH, ENHANCING LIVES

Applications in Green Shipping and Digital Twins

CREATING GROWTH, ENHANCING LIVES

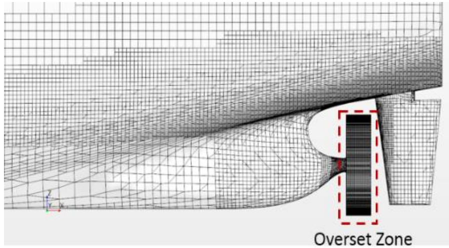
Hull Resistance Evaluation

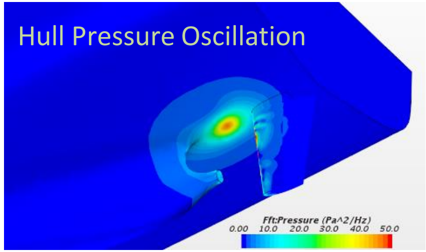
- ❑ Calm water resistance
- ❑ Wave induced added resistance
- ❑ Water elevation
  - ➢ Green water risk assessment
- ❑ Wave structure interactions
  - ➢ global structure analysis
    - Hogging and sagging
  - ➢ local structure analysis
    - Wave impact load
- ❑ Model scale and full scale results with access to all field variables and flexibility in operational conditions.

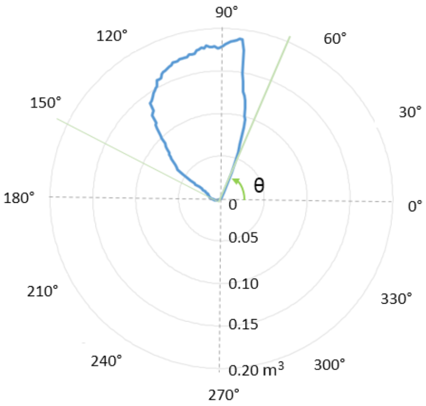


Propeller Cavitation

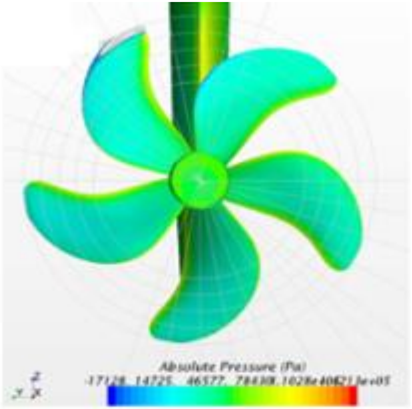
- **Motivation**
  - Surface ships cannot avoid cavitation in their normal operations.
  - Produce vibration that can make the sailing experience uncomfortable
  - Accelerate the wear of the components involved in the propulsion system
  - Causes blade surface erosion and consequently corrosion damage
  - Cavitation induced noise
  - Lower propeller efficiency and thrust







Cavitation Volume



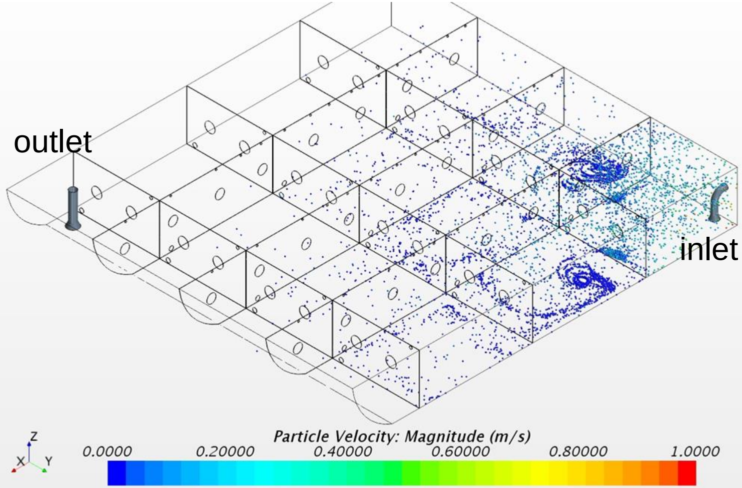
Cavitation on Blade Surface

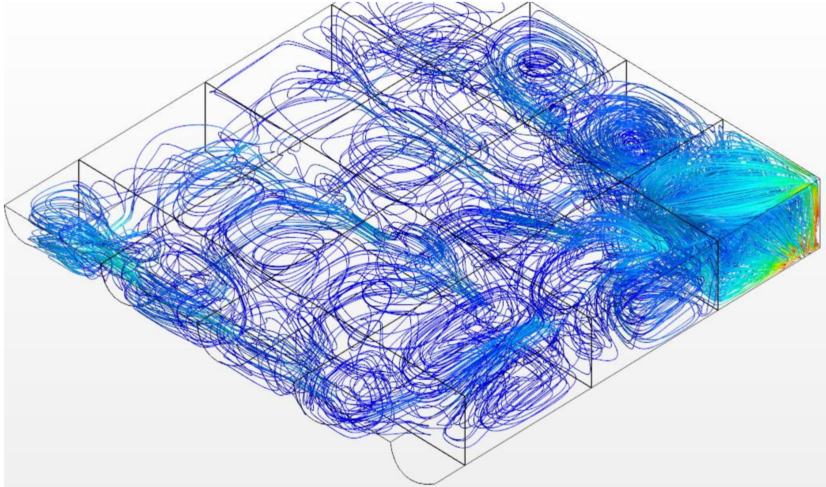
CW Kang, XQ Xing, 2019, CFD Study of Propeller Cavitation with Hull-propeller Interaction, ASME 38th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2019-95892

Ballast Water Sediment

- To understand:
  - Movement of the sediment
  - Distributions of the sediment
- To help with ballast tank cleaning
  - Ballast tank cleaning plan
  - Feasible and practical ballast tank cleaning methods

- Ballast tank design and modifications for better ballast water management
  - De-ballast suck pipe position
  - Lightening hole size, position, and numbers
  - Tank slope
  - Bellmouth location
  - Particle size
  - Water jet pressure/temperature





X.Q Xing, SIMENS PLM User Workshop, : Oct 17.2018

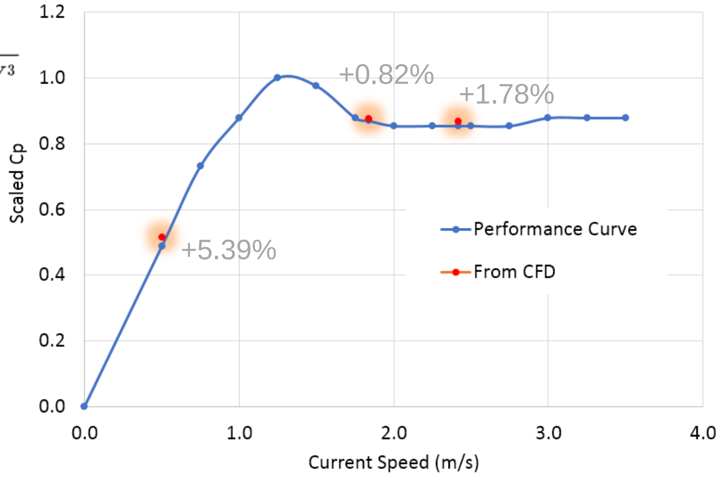
Applications in Offshore Renewable Energy

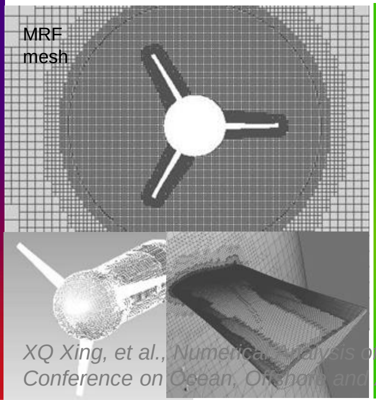
CREATING GROWTH, ENHANCING LIVES

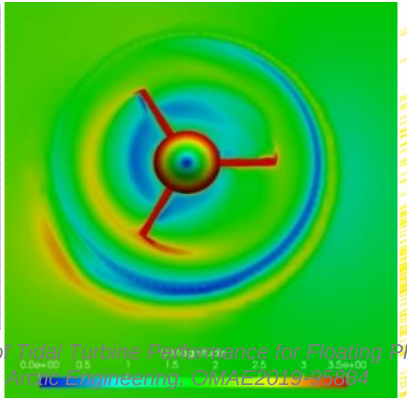
Tidal Turbine

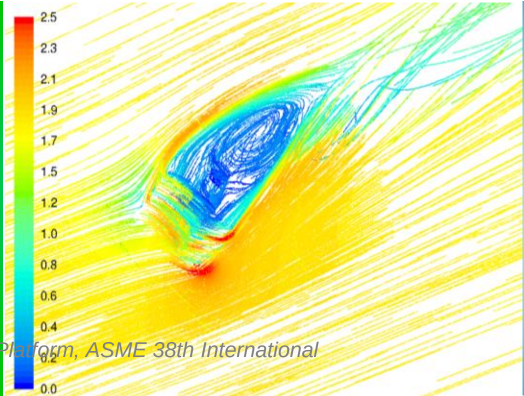
- Performance prediction
  - Understand the flow field details when the incoming current is misaligned with the tidal turbine.
- Wake flow information at different incoming flow velocity and incident angle for turbine array design
- Provide flow field detailed information for turbine design improvement

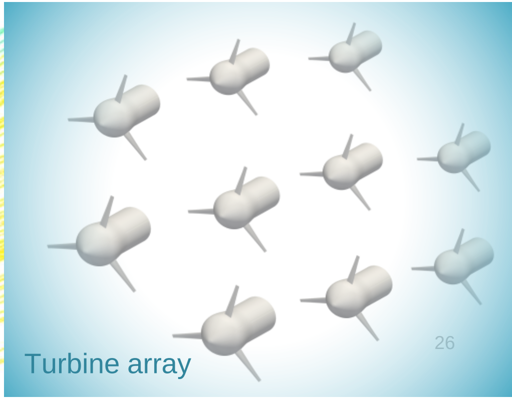
$$C_P = \frac{P}{\frac{1}{2}\rho A V^3}$$









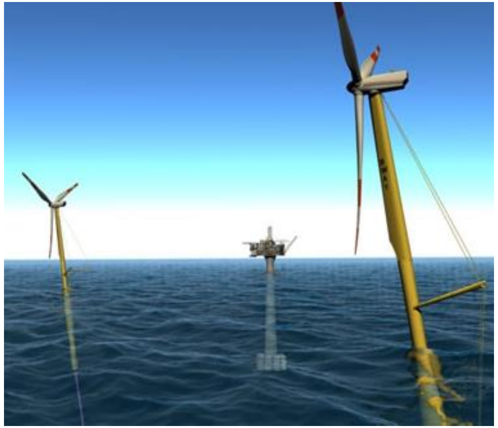


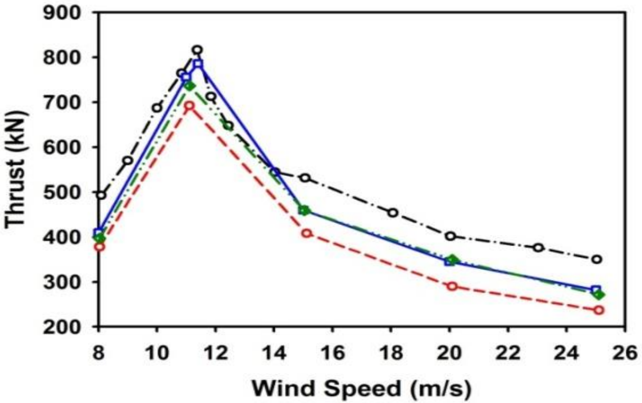
XQ Xing, et al., Numerical Analysis of Tidal Turbine Performance for Floating Platform, ASME 38th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2019-95884

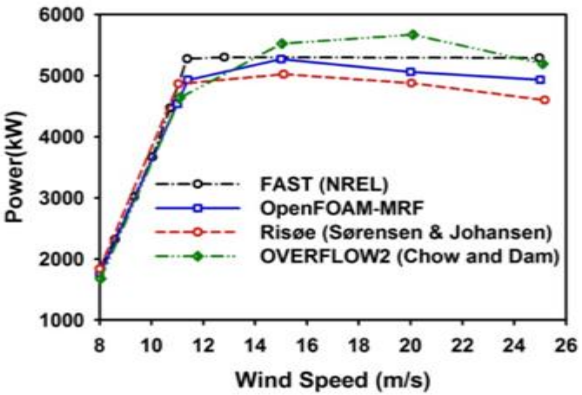
Floating Wind Turbine

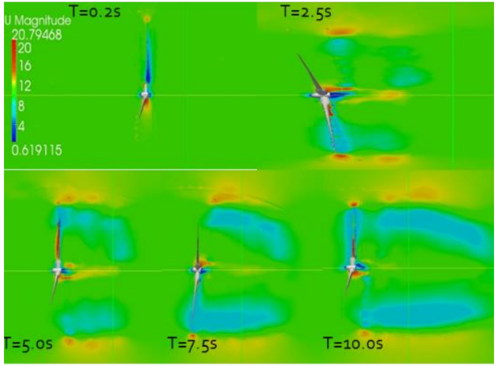
Challenges

- Aerodynamics of wind turbine
- Hydrodynamics of a floating platform
- Interactions between the floating platform and the wind turbine
- Mooring line effects on the motion and the power output of the wind turbine









CHK Wu, VT Nguyen, 2017, Aerodynamic simulations of offshore floating wind turbine in platform-induced pitching motion, Wind Energy 20 (5), 835-858

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Summary

- The new and innovative modeling and simulation technologies are being developed to utilize **High Performance Computing,** which benefits to marine offshore industry and offshore renewable energy sectors.
  - Make the performance prediction and design optimization **more efficient.**
  - Enable the industry move towards **Green shipping, Digital Twins,** and lead to **autonomous operations** eventually.

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THANK YOU

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