TEXAS A&M UNIVERSITY

Advanced Hydrodynamic Analysis for Design and Verification

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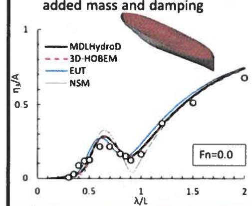
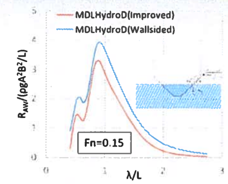
Frequency Domain Analysis Tool – MDL HydroD

First Order Analysis

- 3D Green function based potential flow program
- Asymmetric shape analysis
- Zero and forward speed modification
- Zero and infinite frequency added mass and damping

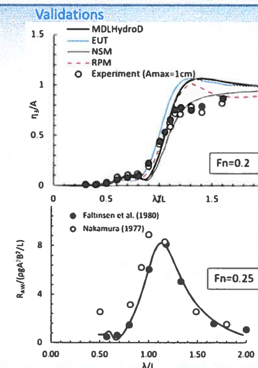


Second Order Analysis

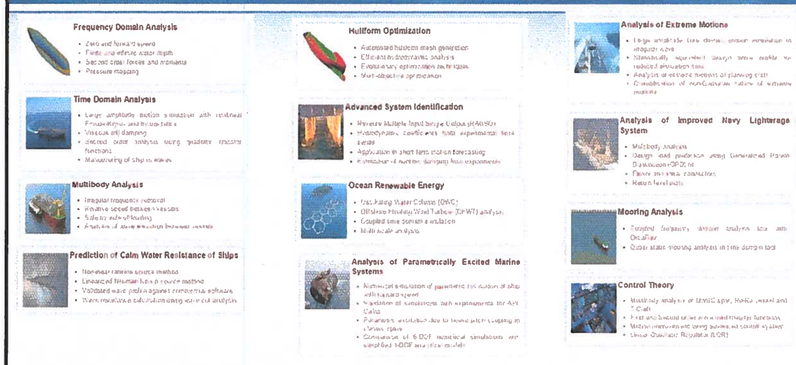


- Near field pressure integration method
- Added resistance with flare angle modification
- Mean drift force
- Standard input/output formats

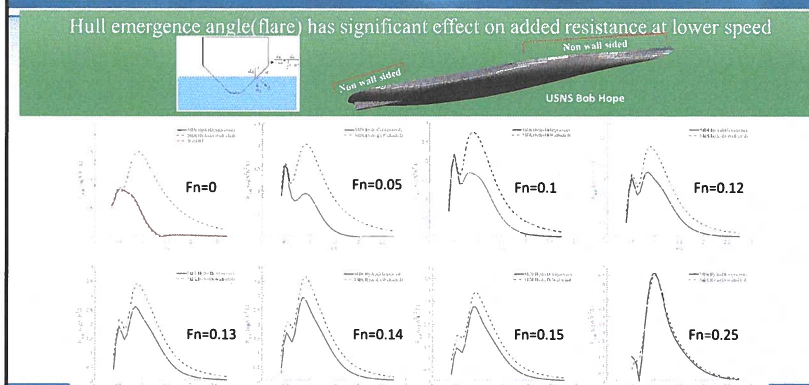
Validations



Current and Past Research Projects



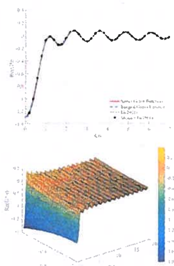
Effect of the Hull Emergence Angle



Finite Depth Analysis – MDL HydroD

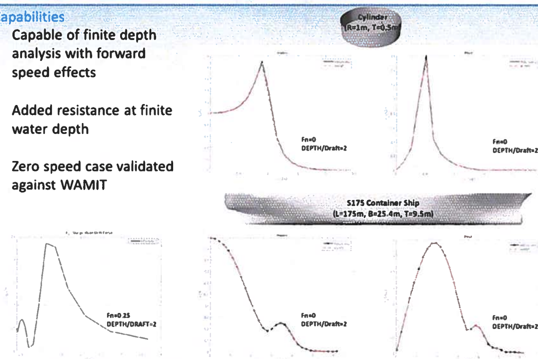
Green Function

- A new in-house finite depth Green function has been developed and implemented



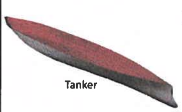
Capabilities

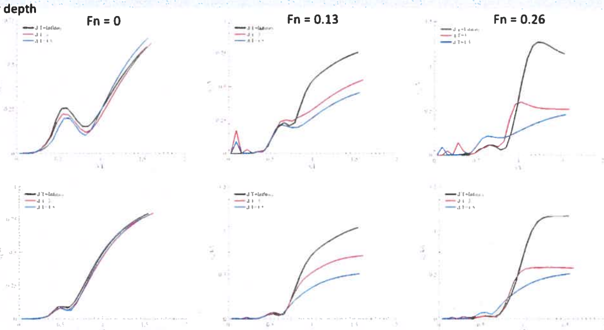
- Capable of finite depth analysis with forward speed effects
- Added resistance at finite water depth
- Zero speed case validated against WAMIT



Effect of water depth on vessel motion

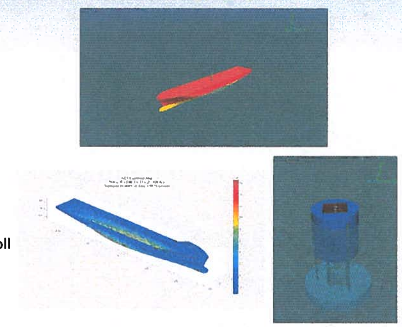
- Motion increase with speed
- Motion increase with water depth





Time Domain Simulation Tool - SIMDYN

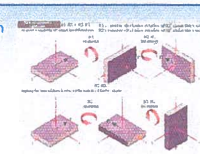
- Six degrees of freedom model
- Nonlinear equations of motion
  - Euler angles formulation to include large amplitudes of rotation
- Nonlinear Froude-Krylov forces and moments
  - Wheeler stretching
- Nonlinear hydrostatics
- Linear scattering and radiation forces and moments
  - Impulse response function formulation for radiation forces and moments
- Nonlinear viscous roll damping
  - Standard Ikeda/Himeno approach for empirical roll damping prediction
- Runge Kutta 4th order integration scheme



Time Domain Simulation - SIMDYN

Large Amplitudes of Rotation

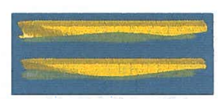
- Finite Rotations are NOT commutative
- Order of Euler Angle Rotations:
  Roll – Pitch – Yaw

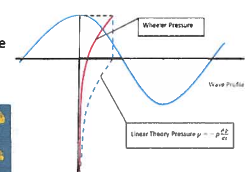


* Source: Universe Review

Nonlinear Froude Krylov Forces and Moments

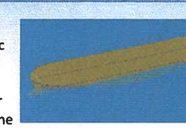
- Wheeler Stretching
- Integrate wheeler pressure over the area under the incident waterline





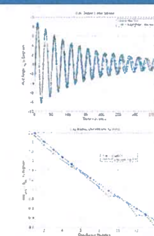
Nonlinear Hydrostatics

- Integrate hydrostatic pressure over the instantaneous displaced hull under the incident waterline

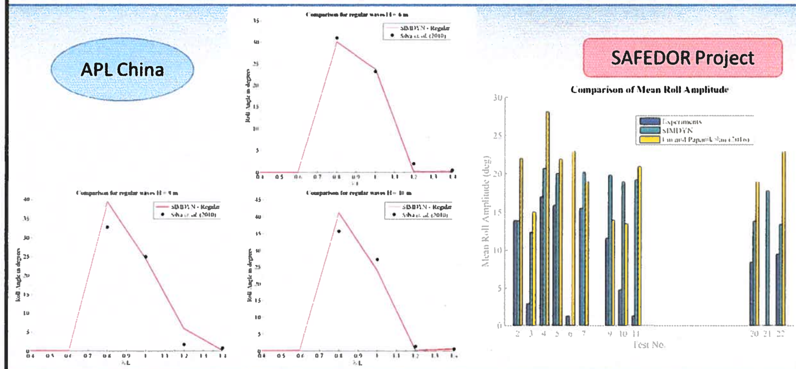


Nonlinear Viscous Roll Damping

- Ikeda's Empirical Formulation
  - Skin Friction Damping
  - Eddy Damping
  - Lift Damping
  - Bilge Keel Damping

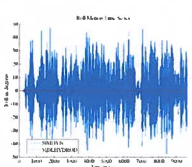


Validation with Experiments

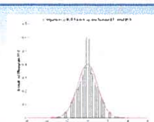


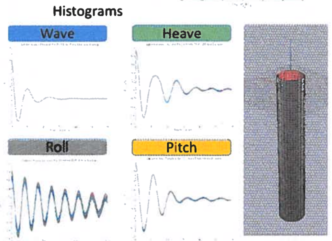
SIMDYN – Simulating Nonlinear Phenomena

Parametric Roll of Container Ship in Irregular Seas
- Bretschneider Spectrum
  - Hs = 10 m
  - Tz = 13 s
- 30 simulations
- Comparison with Normal Distribution

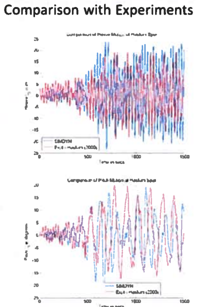


Statistical Analysis
- Roll Non-Ergodicity
  - Auto-covariance
- Probability Density Function
  - Normalized Histograms





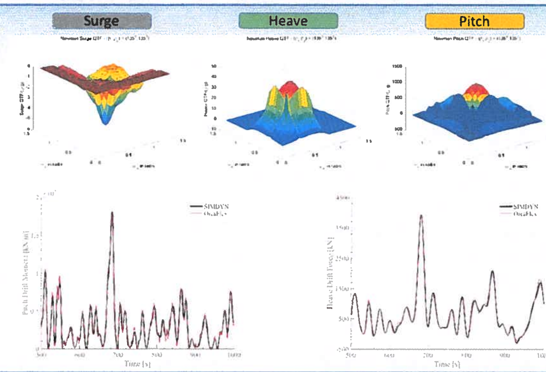
Spar Platform – Instability
- Haslum Classic Spar
- Comparison with Experiments



SIMDYN – Second Order Analysis

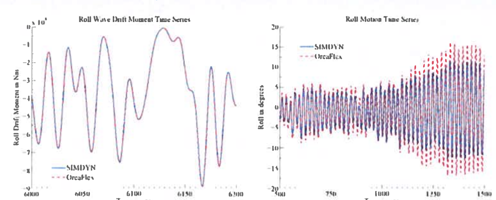
SIMDYN Options

- Consistent second order formulation
  - Linear wave forces
  - Linear equations of motion
  - QTF calculation – Newman approximation
  - Validations with commercial software OrcaFlex
- Approximate nonlinear formulation
  - Nonlinear wave forces
  - Nonlinear equations of motion
  - Use of Wheeler stretched wave kinematics

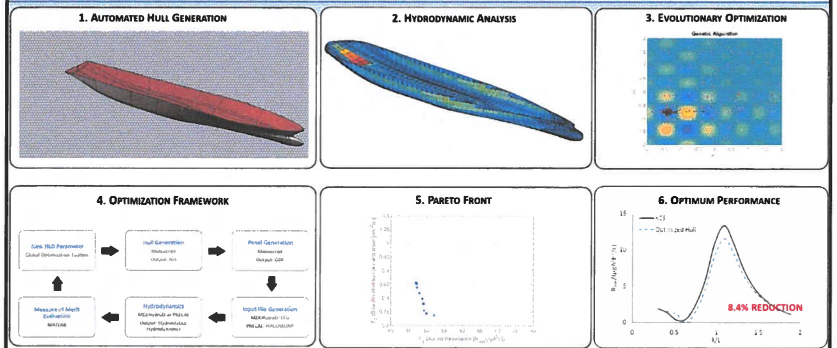


SIMDYN – Second Order Roll Motion

- Second Order Roll Motion
  - KVLCC2 hull form
- Comparisons with OrcaFlex in Irregular Sea State
  - Drift Moment
  - Impulse Response Function
    - Infinite Frequency Added Mass
    - Tail Extension
  - Roll Motion Response

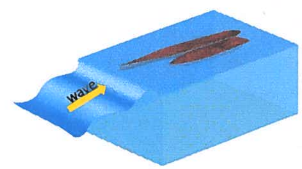


Automated Hull Form Optimization



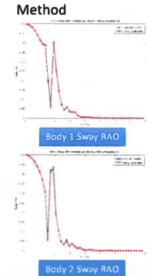
Multibody Analysis: Irregular Frequency & Gap

- Extension to MDL HydroDyn for multibody analysis
- The gap between two vessel causes non physical wave elevation due to resonance effect
- Free surface damping has been added to realize physically observed wave elevation



Irregular Frequency Removal

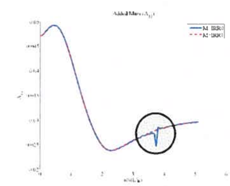
- Modified Green Function Method
- Extended Boundary Condition Method



- Perturbation Methods

$\vec{F}^{(1)}, \vec{M}^{(1)} \sim f[o(\varepsilon)]$

$\vec{F}^{(2)}, \vec{M}^{(2)} \sim f[o(\varepsilon^2), o(\varepsilon)\cdot o(\varepsilon)]$

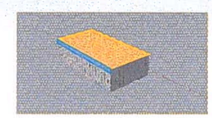


Multibody Analysis: Irregular Frequency & Gap

- Multiple Floaters in Waves:
- Irregular Frequency Removal
- Drift Force and Improvement
- Multibody with Current

Irregular Frequency Removal

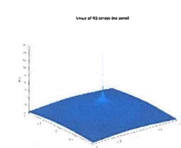
- Concept of the Formula



- Evaluate the Singularity

Gaussian quadrature method

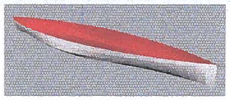
Proposed 4 methods

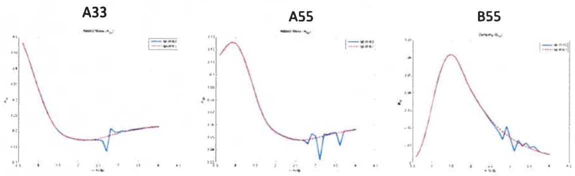


Singular Integral

Irregular Frequency Removal

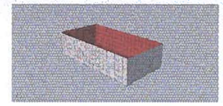
- Wigley Hull

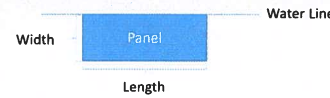




Drift force & Improvement

- Mean Drift Force





- Two approaches in Multi DYN
  - Approach I --- Same with Industry Standard.
  - Approach II --- Improved method, theoretically more accurate

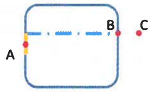
- Case Set-Up of Mini-boxbarge
  - Multi DYN Waterline Panel Size = 1x1 (Length x Width)
  - Industry Std. Waterline Panel Size = 1x1, 1x0.4, 1x0.3, 1x0.2, 1x0.1 (Length x Width)

Drift force & Improvement

True Background Story:

- In developing the module of mean drift force, we used a theoretically more reasonable method.
- However, the results were not consistent with Industry Standard Program.
- Thus, we investigated the reason and found that we had discovered an improved method.

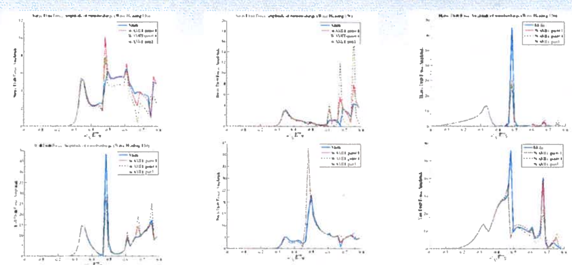
$$\zeta_r = \zeta - \left(\vec{X} - \vec{X}_0 - \vec{X}'\right)_z$$



Approach I:	At A	At B
Approach II:	At C	At B

Industry Std: Approach I only
Multi DYN: Approach I & II

Drift force & Improvement



NOTE: When using the smaller panels, the spikes in higher frequencies will disappear. WAMIT results converge to results from Multi DYN.

20

Multibody with Current

- **Formula of the nonzero speed case:**

$\nabla^2 \bar{\Phi}^{(1)}_{rel} = 0$ *in fluid domain*

$-\frac{1}{g}\left(\frac{\partial}{\partial \bar{t}} - U\frac{\partial}{\partial \bar{x}}\right)^2 \bar{\Phi}^{(1)}_{rel} = \frac{\partial \bar{\Phi}^{(1)}_{rel}}{\partial \bar{z}}$ *on* $\bar{z} = 0$

$\vec{n}' \cdot \vec{\nabla} \bar{\Phi}^{(1)}_{rel} = \vec{n}' \cdot \left[\dot{\bar{\vec{\eta}}}^{(1)} + \dot{\bar{\vec{\alpha}}}^{(1)} \times \vec{X}' - U\left(\bar{\vec{\alpha}}^{(1)} \times \vec{i}\right)\right]$ *at body surface*

$\frac{\partial \bar{\Phi}^{(1)}_{rel}}{\partial \bar{z}} = 0$ *on* $\bar{z} = -h$

proper radiation condition *at control surface*

Zero Speed Case:

$-\frac{1}{g}\frac{\partial^2 \Phi^{(1)}}{\partial t^2} = \frac{\partial \Phi^{(1)}}{\partial z}$ *on* $z = 0$

$\vec{n}' \cdot \vec{\nabla} \Phi^{(1)} = \vec{n}' \cdot \left[\dot{\vec{\eta}}^{(1)} + (\dot{\vec{\alpha}}^{(1)} \times \vec{X}')\right]$

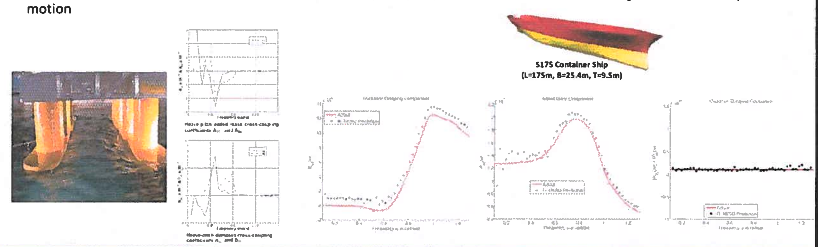
- **More assumptions:**
  - Assume $U\frac{\partial}{\partial \bar{x}} << \frac{\partial}{\partial \bar{t}}$ (one order smaller)

$$-\frac{1}{g}\left(\frac{\partial}{\partial \bar{t}} - U\frac{\partial}{\partial \bar{x}}\right)^2 \bar{\Phi}^{(1)}_{rel} = \frac{\partial \bar{\Phi}^{(1)}_{rel}}{\partial \bar{z}} \Rightarrow -\frac{1}{g}\frac{\partial^2 \bar{\Phi}^{(1)}_{rel}}{\partial \bar{t}^2} = \frac{\partial \bar{\Phi}^{(1)}_{rel}}{\partial \bar{z}} \quad on\ \bar{z} = 0$$

Conclusion: F.S.B.C. becomes identical with the zero speed case.

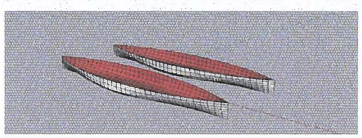
Advanced Nonlinear System Identification

- A nonlinear system modeling and optimization tool to validate hydrodynamic forces and moments from experiments
- This statistical signal processing method can be used to improve hydrodynamic force and moment prediction in a multi degree of freedom system
- Linear and nonlinear memory effects due to wave structure interactions are identified
- The method can quantify the linear and non-linear frequency dependent coefficients of an integro-differential equation of motion



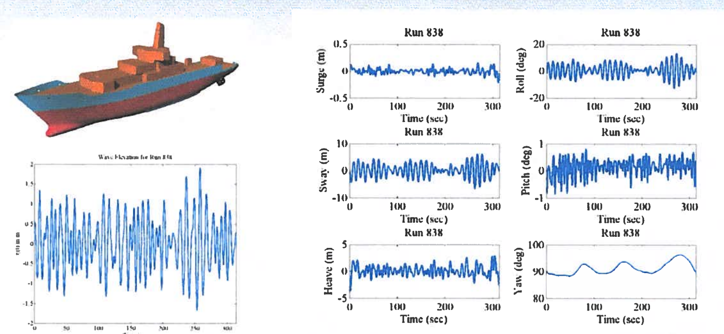
Multibody with Current

- **Wigley Hull**



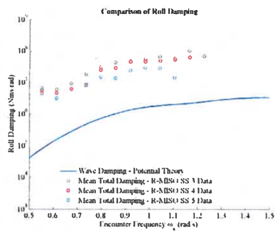
- **Results:**
  - Zero Speed Cases (Compared against industry standard)
  - Nonzero Speed Cases Separation + Speed

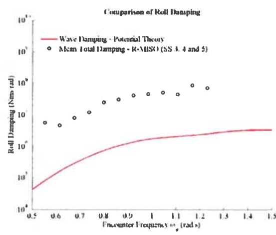
Environmental Ship Motion Forecasting



Effective Roll Damping Identification

- Effective Roll Damping from R-MISO Analysis of Model Tests in Realistic Seas
  - Beam Sea Case with 8 knots forward speed
  - Three sea states



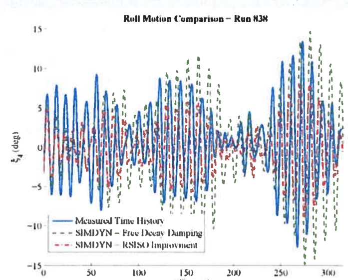


Significant Improvement of Roll Predictions

- Significantly improved motion prediction after improving numerical model
- Determine effective roll damping in realistic multi-directional waves in real time

Comparison of simulated and experimental roll time histories of Run 838 (SS 5).

Damping model	Normalized cross correlation coefficient (%)	RMS error (degrees)
No viscous damping model	70.51	13.32
Himeno damping model	77.69	10.07
Free decay damping model	86.70	7.60
R-SISO improved damping model	93.07	5.84



Calm Water Wave Resistance and Bulbous Bows

- Introduction & Motivation
- The Wave-making Resistance Problem
- Governing Equations
- The Neumann-Kelvin Method
- The Rankine Source Method
- ❑Wave cut analysis
- ❑Comparison of different methods
- ❑Calculation of bulbous bows

Motivation: Slow Steaming & Bulb Redesign

- A ship costs less fuel when it travels slower, which is called slow steaming. But the bulbous bows are designed for a particular speed.
- Multi-objective optimization: Coupling of the added resistance in waves and the calm water resistance.
- Bulbous bows are used to reduce the resistance force of a ship
- However, bulbs are designed for a particular design speed
- When the ship slow steams, bulb is operating off design and must be reconfigured

Governing Equations

- Governing equation, Φ is the total velocity potential:

  $\nabla^2\Phi = 0$

- Kinematic free surface condition:

  $\Phi_x\eta_x + \Phi_y\eta_y - \Phi_z = 0 \quad at \quad z = \eta(x,y)$

- Dynamic free surface condition

  $\frac{1}{2}(U^2 - |\nabla\Phi|^2) - g\eta = 0 \quad at \quad z = \eta(x,y)$

- Hull surface condition

  $\Phi_n = 0$

- Infinite depth condition:

  $\Phi = -U$

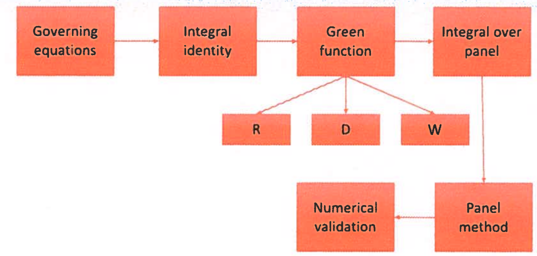
- Radiation condition condition(discuss later)

The Neumann-Kelvin Method

Main ideas of the Neumann-Kelvin method

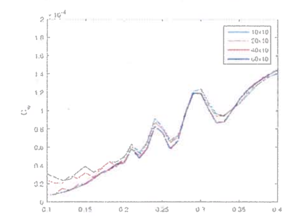
- Assume linear free surface boundary conditions. That means the free surface conditions only contain the linear terms and are satisfied on the calm water surface.
- The body surface condition is satisfied on an accurate hull surface. The body surface condition is nonlinear since the geometry of the hull surface is usually nonlinear.
- The surface panel method is used to discretize the velocity potential.

The Neumann-Kelvin Method

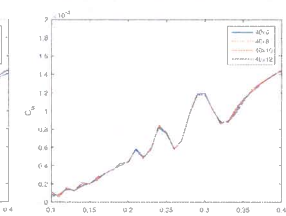


The Neumann-Kelvin Method

Convergence of panel layout



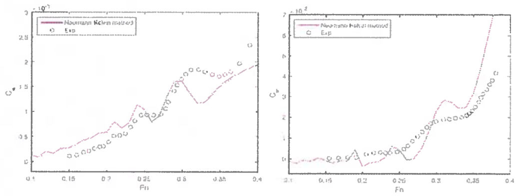
Wigley III



Wigley III

The Neumann-Kelvin Method

Comparison with experimental data

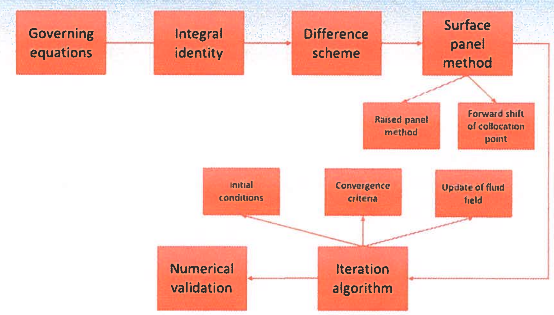


Wigley III   Series 60(Cb=0.6)

The Rankine Source Method

- **The main ideas of the Rankine source method**
- Assume the nonlinear free water surface boundary condition. That means the free surface conditions contain the nonlinear terms and are satisfied on the accurate free surface.
- The body surface condition is satisfied on accurate hull surface. So the body surface condition is nonlinear.
- The surface panel method is used to discretize the velocity potential.

The Rankine Source Method

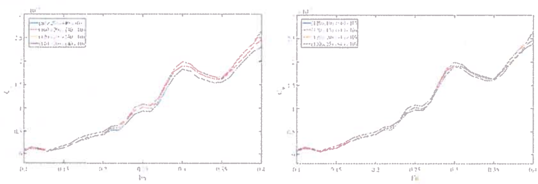


The Rankine Source Method

1. Convergence of panel layout

The Rankine Source Method

Convergence of panel layout on free surface

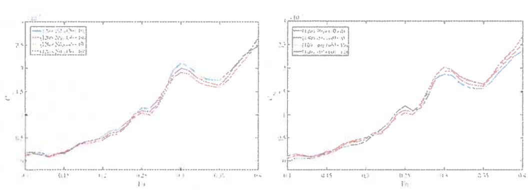


convergence of panel layout, free surface, x direction, Wigley III

convergence of panel layout, free surface, y direction, Wigley III

The Rankine Source Method

Convergence of panel layout on hull surface

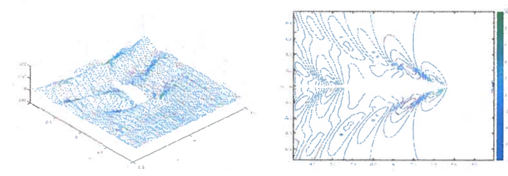


convergence of panel layout, hull surface, x direction, Wigley III

convergence of panel layout, hull surface, z direction, Wigley III

The Rankine Source Method

3. free surface elevation

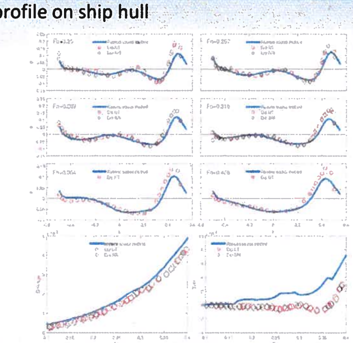


Wave elevation, Wigley III, $F_n = 0.3$

Wave-making resistance, Wigley III, $F_n = 0.3$

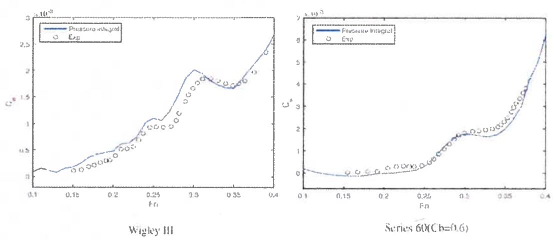
The Rankine Source Method

4. Wave profile on ship hull



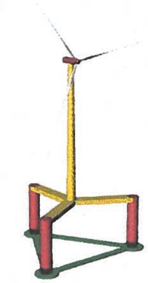
The Rankine Source Method

5. Wave-making resistance



Wind Turbine: Analysis and Safety

- Effect of nonlinear wave induced forces on floating offshore wind turbine
- Optimization of floater design for enhanced performance and safety
- Couple our time domain simulation tool SIMDYN with aerodynamic code FAST (aero-hydro simulation)
- Nonlinear control theory application to improve wind turbine efficiency
- Using Land Based Control Algorithms results in unstable platform motions



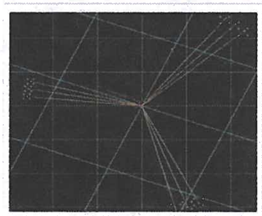
Mooring Design and Analysis

Coupled analysis of offshore platform with mooring The frequency domain program MDLHydroD has been coupled with the commercial program OrcaFlex. With this coupling, the complicated problem of simulating the motion of offshore structures with moorings and risers can be solved.

We have developed our own Simplified **quasi-static mooring module** included in SIMDYN (similar to the one used by NREL's FAST) based on a catenary equation.

Currently developing more sophisticated Mooring Model

- Finite Element Analysis
- Morison elements to include lift and drag forces
- Input instantaneous position and forces on hull to OrcaFlex from SIMDYN
- Iterative approach to ensure dynamic equilibrium is reached at each time step



Extreme Load Prediction

Improved Navy Lighterage System (INLS)

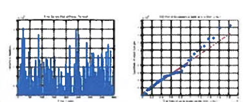
- Multiple bodies connected by flexors and hinge type joints
- Joint: Allows Free Relative Pitch Motion
- Flexor Analysis

Analysis of Flexor Tension

- Predict operational maximum tension in flexor
- Statistical Analysis
- Return Plots for Flexor Tension

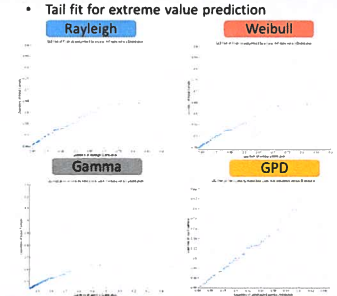
Peaks Over Threshold and Generalized Pareto Fit

- Threshold Selection
- Gather Peaks
- Log Likelihood Fit
- Probability of Exceedance



Planing Craft Motion

- Non-Gaussian motion due to lift forces and moments
- Tail fit for extreme value prediction



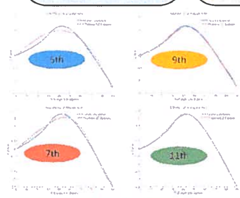
IMO Second Generation Ships Stability Criteria:

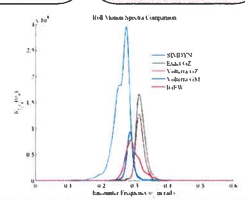
- IMO second generation of intact stability criteria
  - Dead ship condition
  - Pure loss of stability
  - Parametric roll
  - Surf riding or Broaching
- Simplified models capturing relevant nonlinearities
  - Volterra GZ model

- Prescriptive static stability
  - Calm water GM
  - Calm water GZ curve
- Current approach of IMO

- Discussion towards a 2nd generation of stability criteria
- Analytical model approach

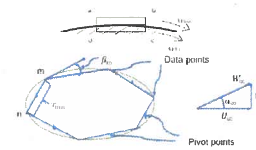
- Time domain simulations
  - Time consuming
  - Computationally Expensive



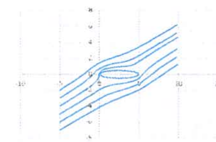


2-D Roll (Eddy) Damping Analysis of a Boxed Barge

- Instead of the Douglas-Neumann source panel method used to calculate hydrodynamics, a surface vorticity model (SVM) is used as the basis of this project; it has the advantage of obtaining the lift force without using high orders.
- This method models a real flow environment of high Reynolds number flow with arbitrary body shapes by using the boundary integral method.
- The purpose of this project is to develop an in-house application for calculating the pressure distribution, lift, drag coefficients, and eddy damping coefficient of a barge.



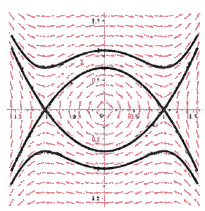
Surface velocity SVM comparison with exact solution (Cylinder)

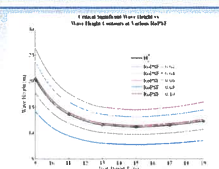


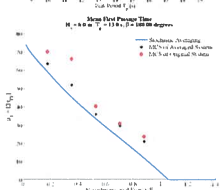
Streamline of uniform flow passes an ellipse programed by SVM

Analytical Techniques: Predict Rare Events

- Nonlinear Dynamical Systems
  - Melnikov Approach
  - Rate of Phase Space Flux
    - Rate at which safe basin is eroded
- Stochastic Dynamics
  - Mean First Passage Time
    - Average time for system to reach capsizing boundary







THANK YOU