

Computation of Vessel Motions in Waves using Forward-Speed Free-Surface Green Function

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7th MASHCON – 21 May 2025

Wave Response of a Vessel with Forward Speed

- Ship sailing with constant forward speed
- Irregular incident waves
- Response characterised using RAOs
- Added resistance and drift forces
- Squat
- Required for:
 - Channel design
 - UKC forecast systems
 - Navigation simulations



History of Computational Methods

Ship Design

- Physical modelling
- BEM with forward-speed Green functions
- BEM based on time-domain Green functions
- Rankine panel models
- RANS
- CFD

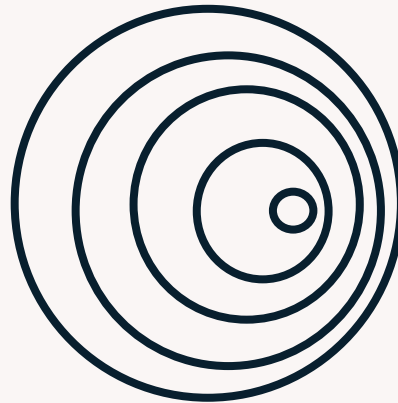
Channel Design, UKC Forecast Systems and Nav. Sims

- Empirical relations
- Strip theory
- BEM based on zero-speed Green functions
- *BEM with forward-speed Green functions*

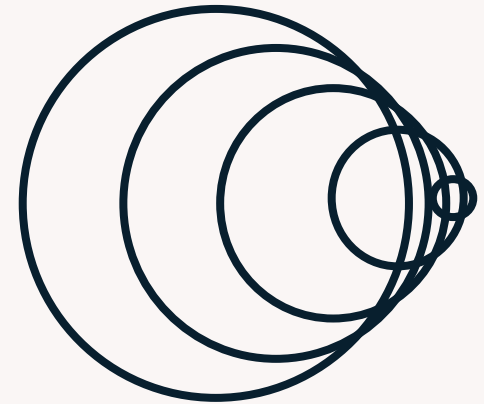
Waves Formed by an Oscillating Source



Zero-speed



**Source moving
slower than the
waves**

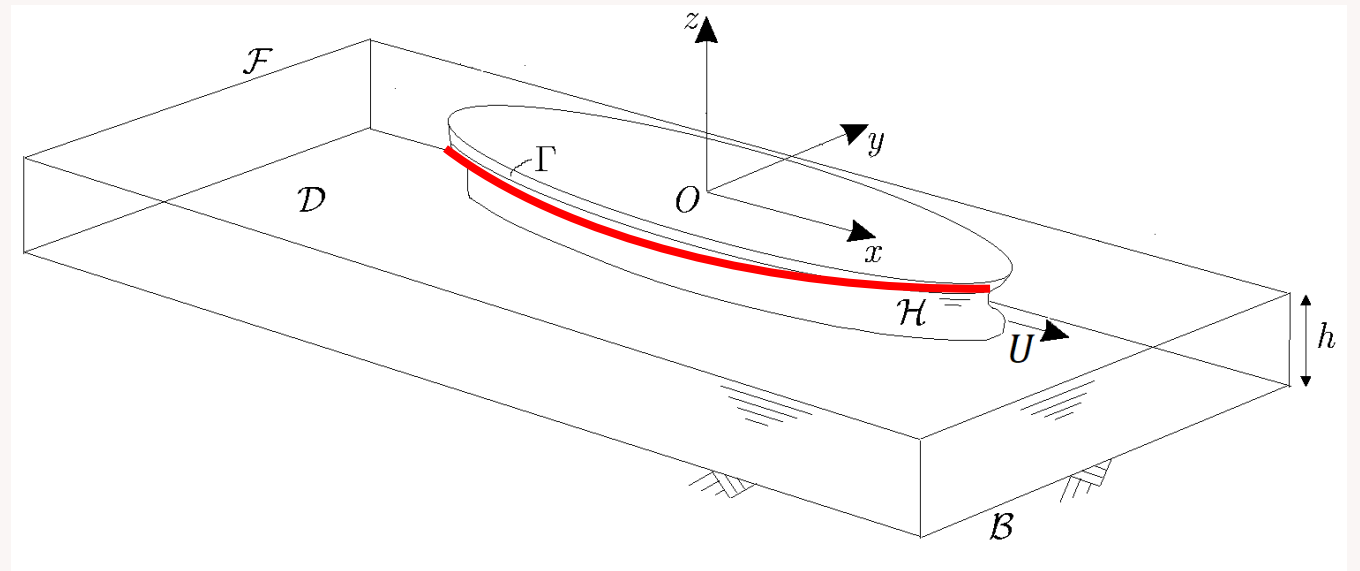


**Source moving
faster than the
waves**

Model Formulation

- Implemented in 3D-BEM “Wavescat”
- Option based on zero-speed Green function available
- Forward-speed Green functions added

$$\phi^S = \iint_{\mathcal{H}} \sigma G^f dS + \frac{U^2}{g} \int_{\Gamma} G^f n'_x dl$$



Green Function

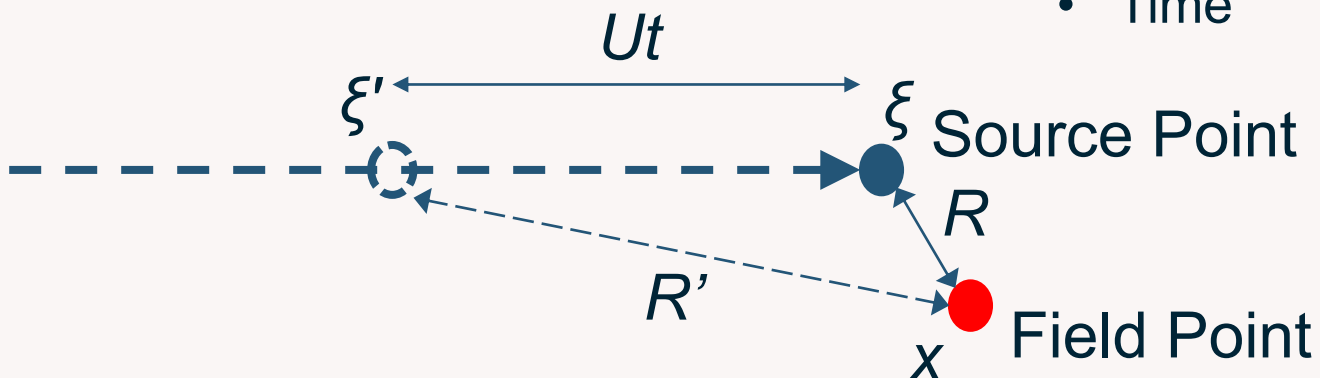
- Zero-speed: $G^f(R, z_x, z_\xi, h, \omega)$
- Forward-speed: $G^f(\vec{x}, \vec{\xi}, h, U, \omega) = \int_0^\infty G^t(\vec{x}, \vec{\xi}', h, t) e^{-i\omega t} dt$

$$G^f(\Delta x, \Delta y, z_x, z_\xi, h, U, \omega)$$

$$G^t(R', z_x, z_\xi, h, t)$$

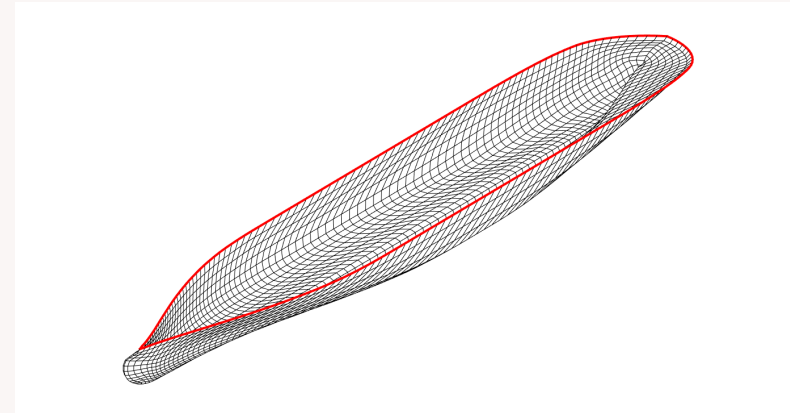
Chebyshev expansion (rel. to water depth):

- Horizontal distance
- Vertical distance
- Time



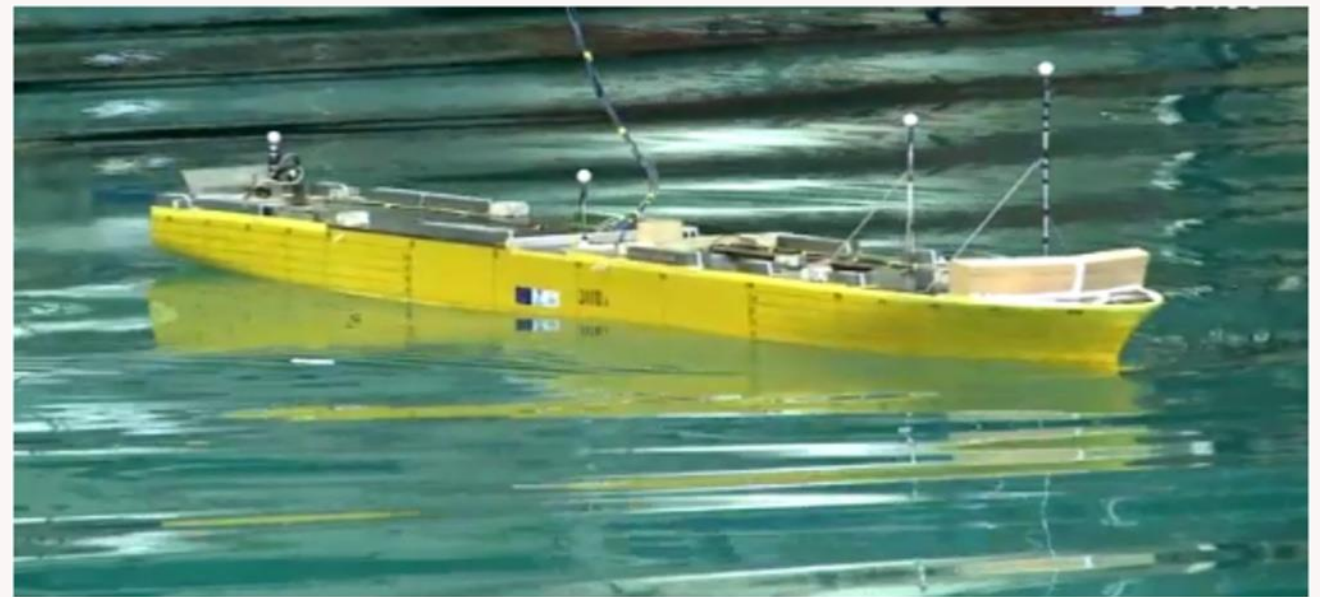
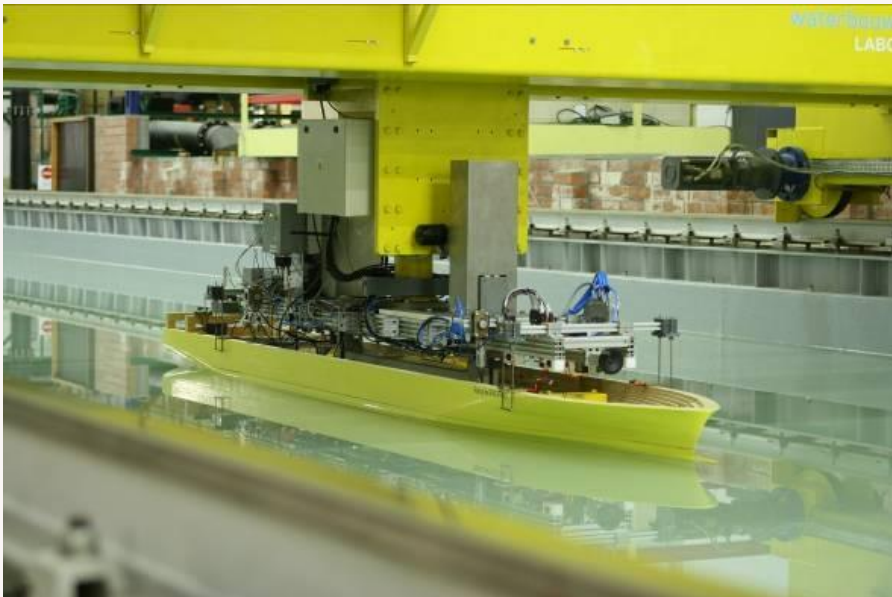
Numerical Implementation

- Vessel hull panel mesh – no panels needed on free surface or seabed
- Calculate steady flow upfront $\rightarrow$ squat
- Time-domain Green functions determined upfront:
 - Rankine part $G^{(0)}$ ($1/r$ terms) $\rightarrow$ contributes to $\Re(G^f)$
 - Wave part $G^w \rightarrow$ input to FFT
- For each encounter frequency: apply FFT to get frequency-domain Green functions
- For each wave direction: calculate response and drift forces using the same Green functions
- Include interaction between wave flow and steady flow in wave forces



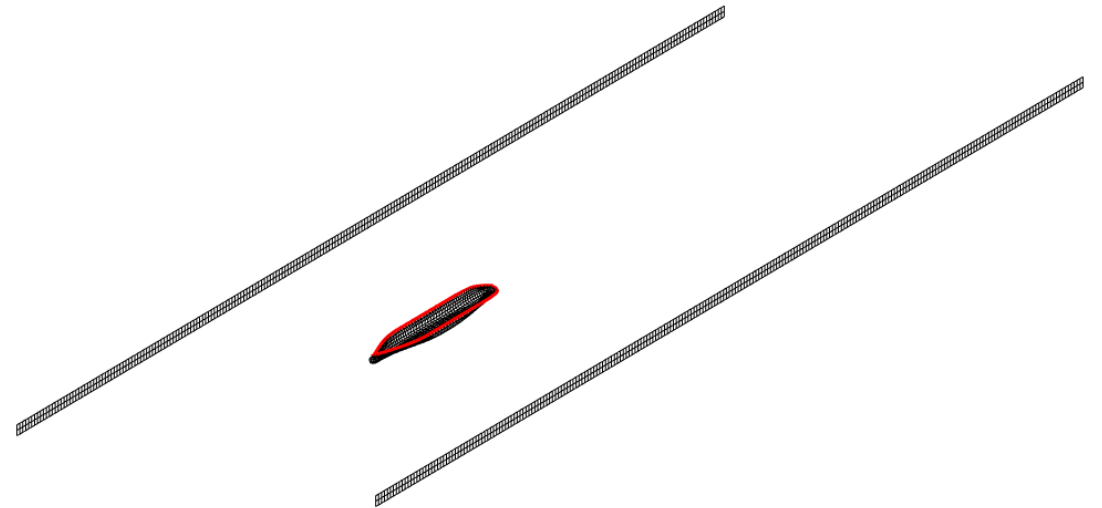
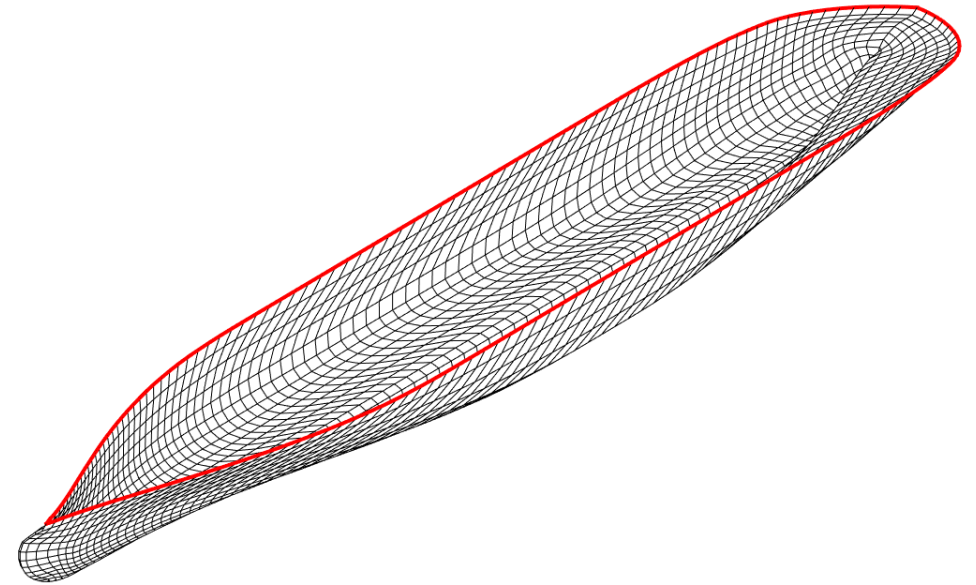
Model Tests for Validation

- DTC container ship (LxBxT = 355 x 51 x 14.5 m)
- Towing tank tests with captive model ship in shallow water at Flanders Hydraulics in head waves for RAOs. Data part of open benchmark data for MASHCON 2019
- Basin tests with free-running model ship in deep water at MARINTEK in all wave directions for drift forces. Data used for benchmark study as part of SHOPERA project



Model Set-up in Wavescat

- Mesh of submerged hull with 2160 panels
- Towing tank side walls included for squat calculation
- Open water assumed for wave response calculation
- Sensitivity run with side walls for wave response
- Time step 0.4 s
- Truncation T_G 120 s



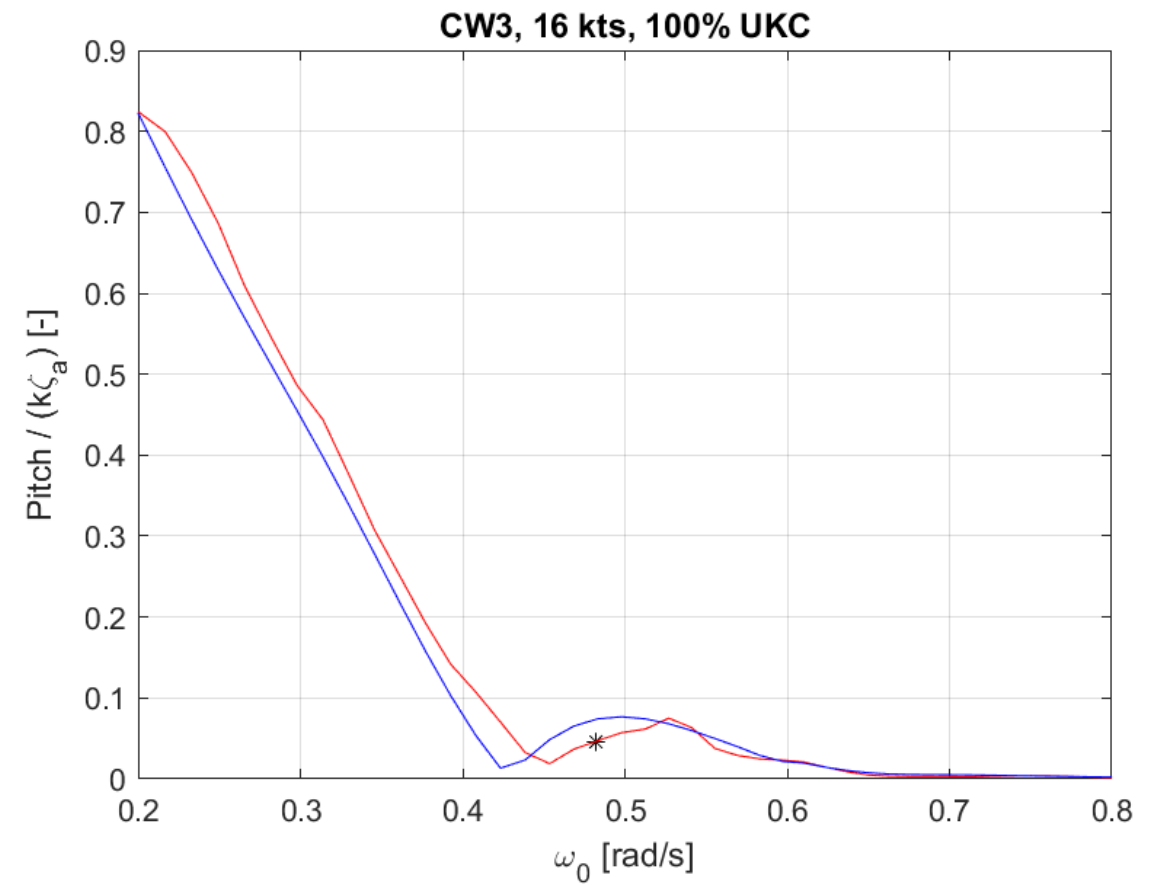
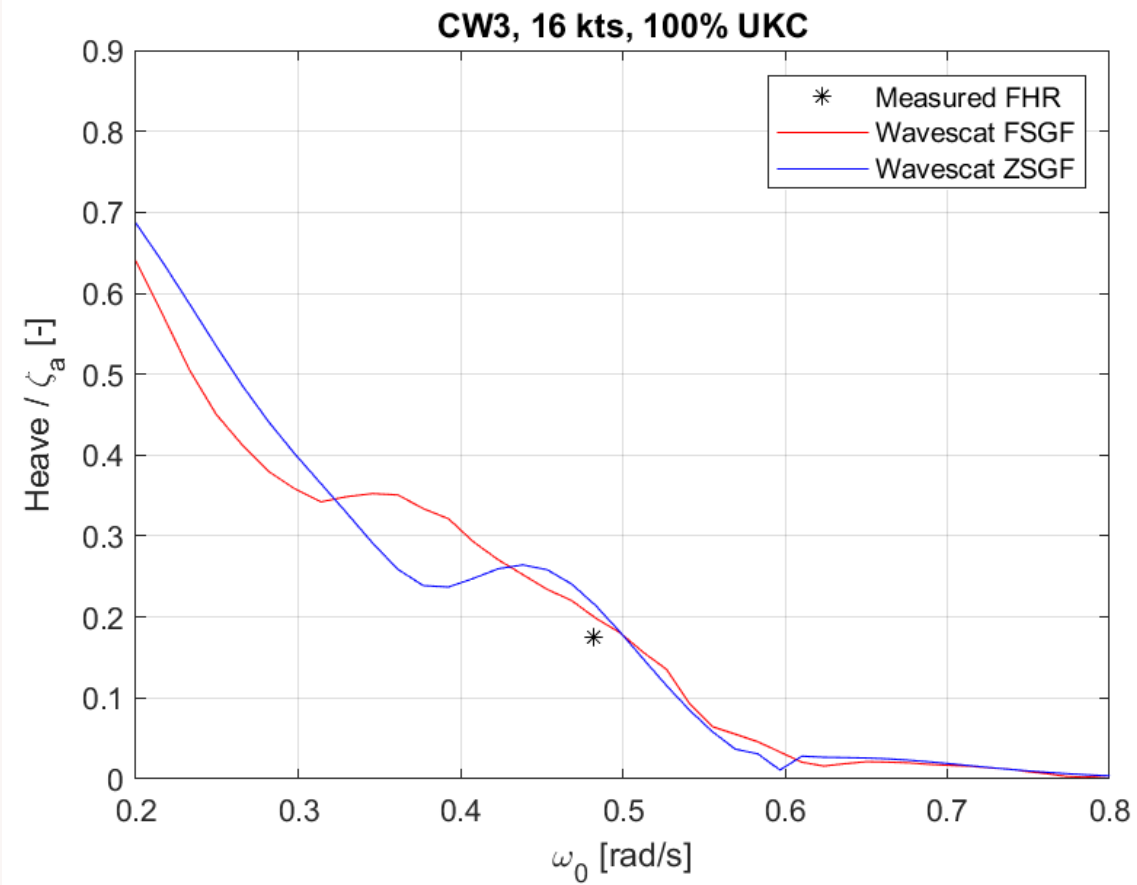
Squat

Speed (kts)	Water Depth (m)	Measured	Sim., Open Water	Sim., Canal, Raw	Sim., Canal, Adjusted
Sinkage at Aft Perpendicular (m)					
16	29	0.438	0.342	0.393	0.463
6	17.4	0.110	0.083	0.096	0.100
Sinkage at Forward Perpendicular (m)					
16	29	0.737	0.631	0.685	0.778
6	17.4	0.132	0.137	0.152	0.157

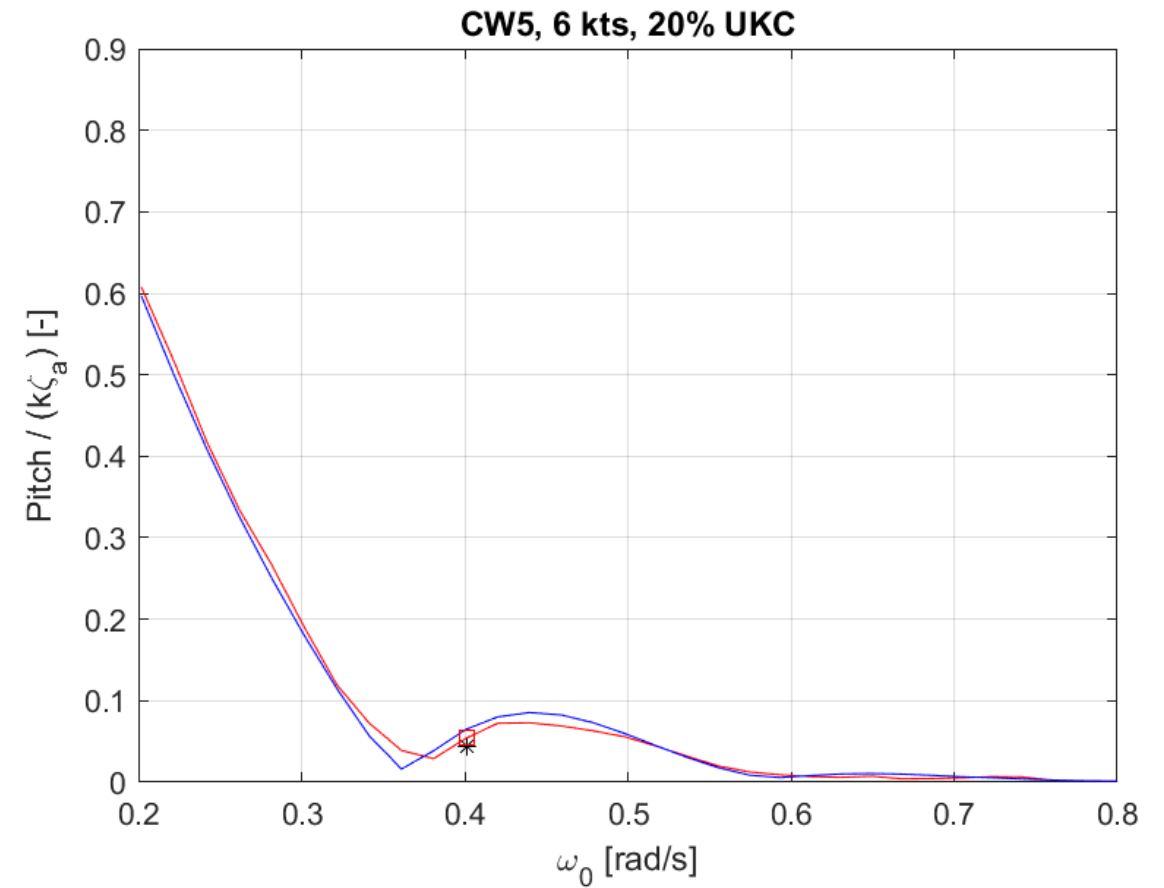
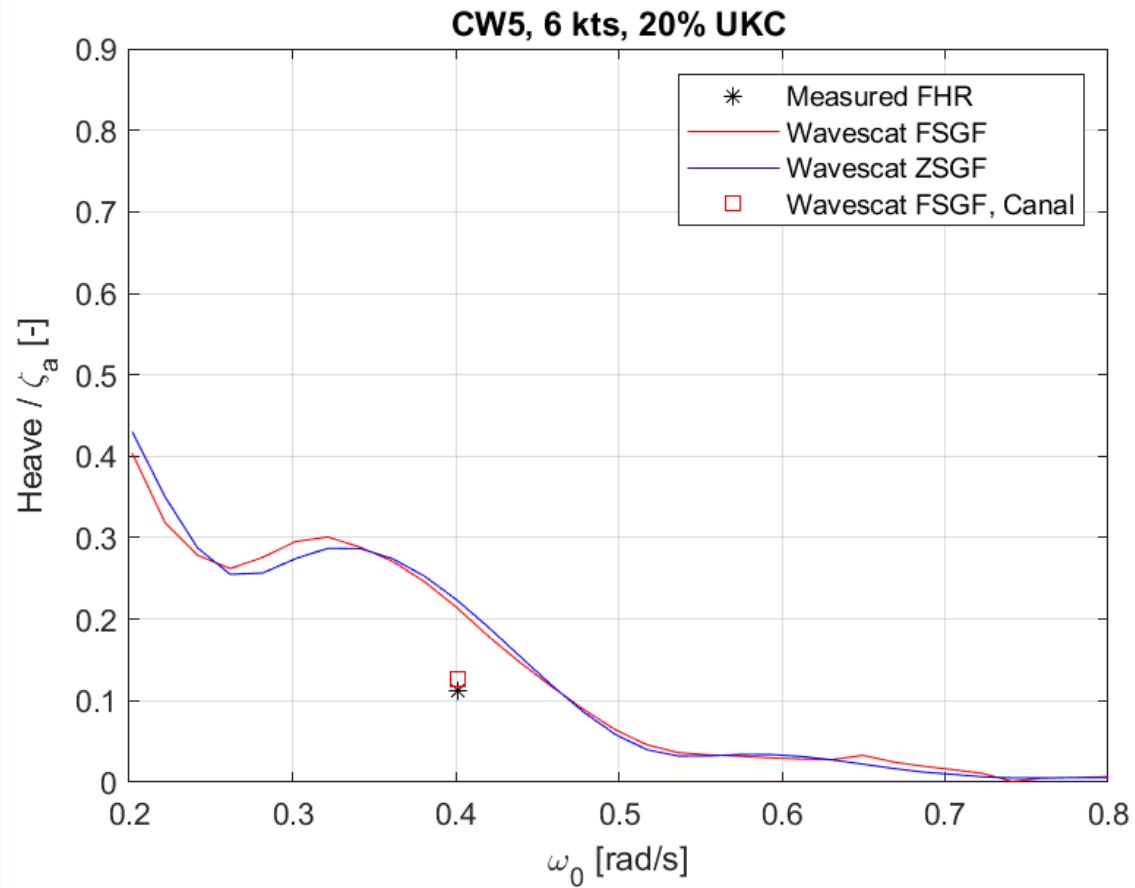
Squat effects:

- Linear, open water ($\sim U^2$)
- Tuck factor ($1/\sqrt{1-F_h^2}$)
- Canal effects, linear
- Canal effects due to water level drop – critical speed at $h = 29$ m is 25 knots

Wave Response RAOs



Wave Response RAOs



Wave Response RAOs

Speed (kts)	Water Depth (m)	Measured	Wavescat ZSGF	HydroStar	Wavescat FSGF	Fatima
Heave (-)						
16	29	0.175	0.214	0.214	0.199	0.194
6	17.4	0.113	0.224	0.220	0.215	0.214
Pitch / (ka) (-)						
16	29	0.045	0.075	0.079	0.048	0.053
6	17.4	0.043	0.065	0.063	0.054	0.043

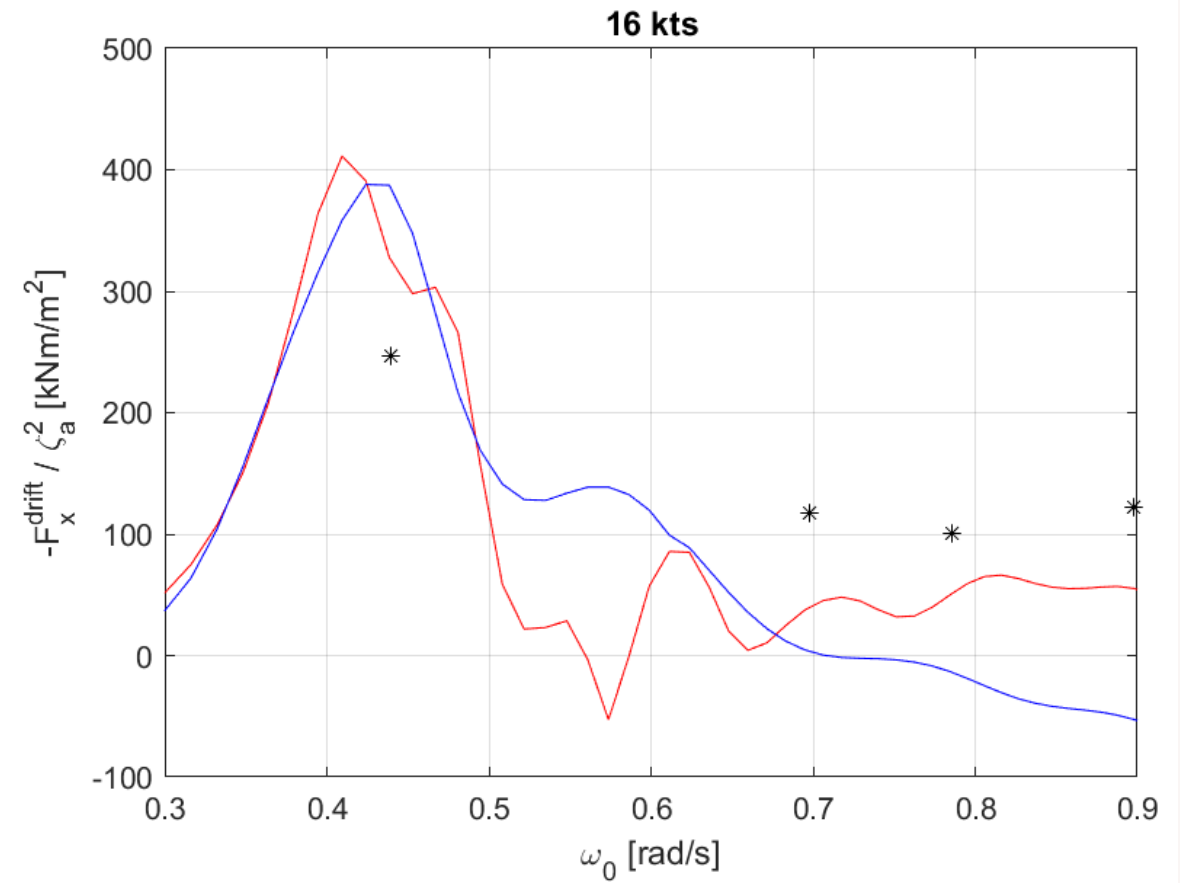
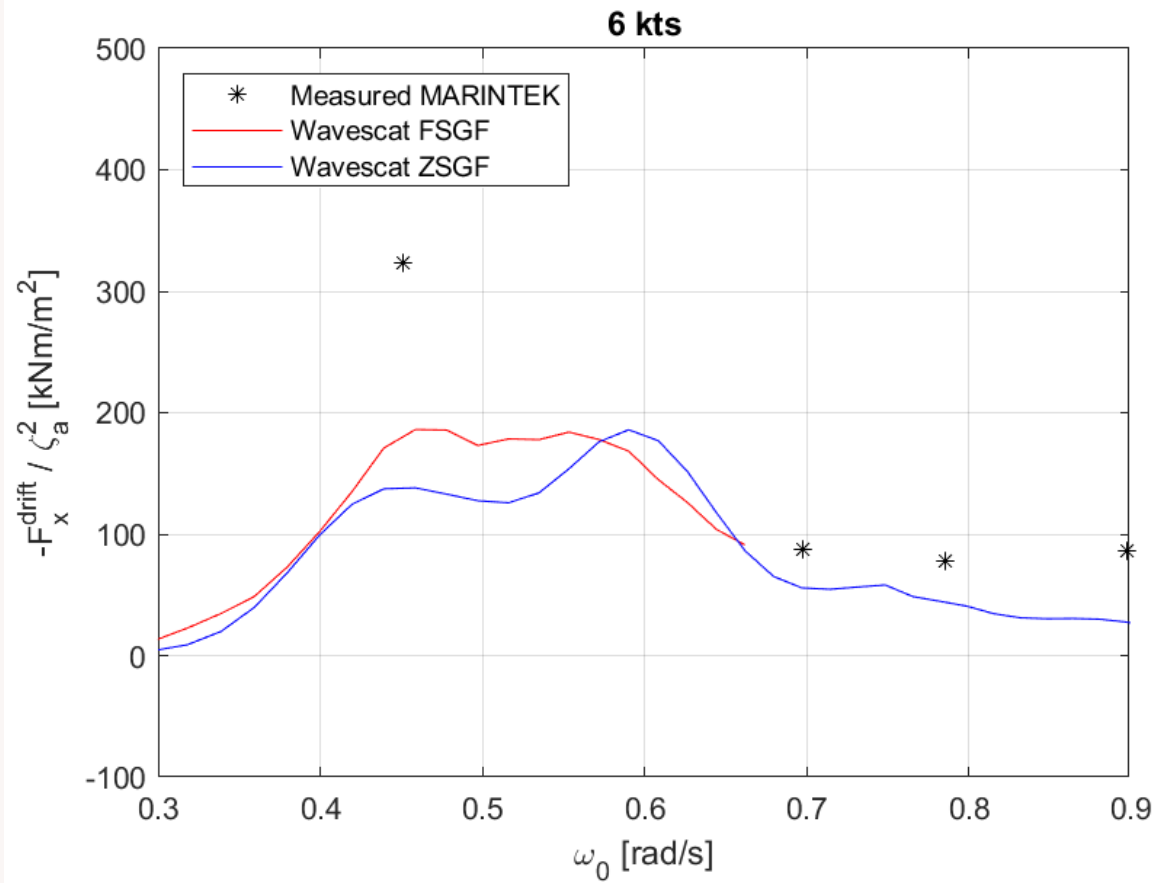
ZSGF: Zero-speed Green function

FSGF: Forward-speed Green function

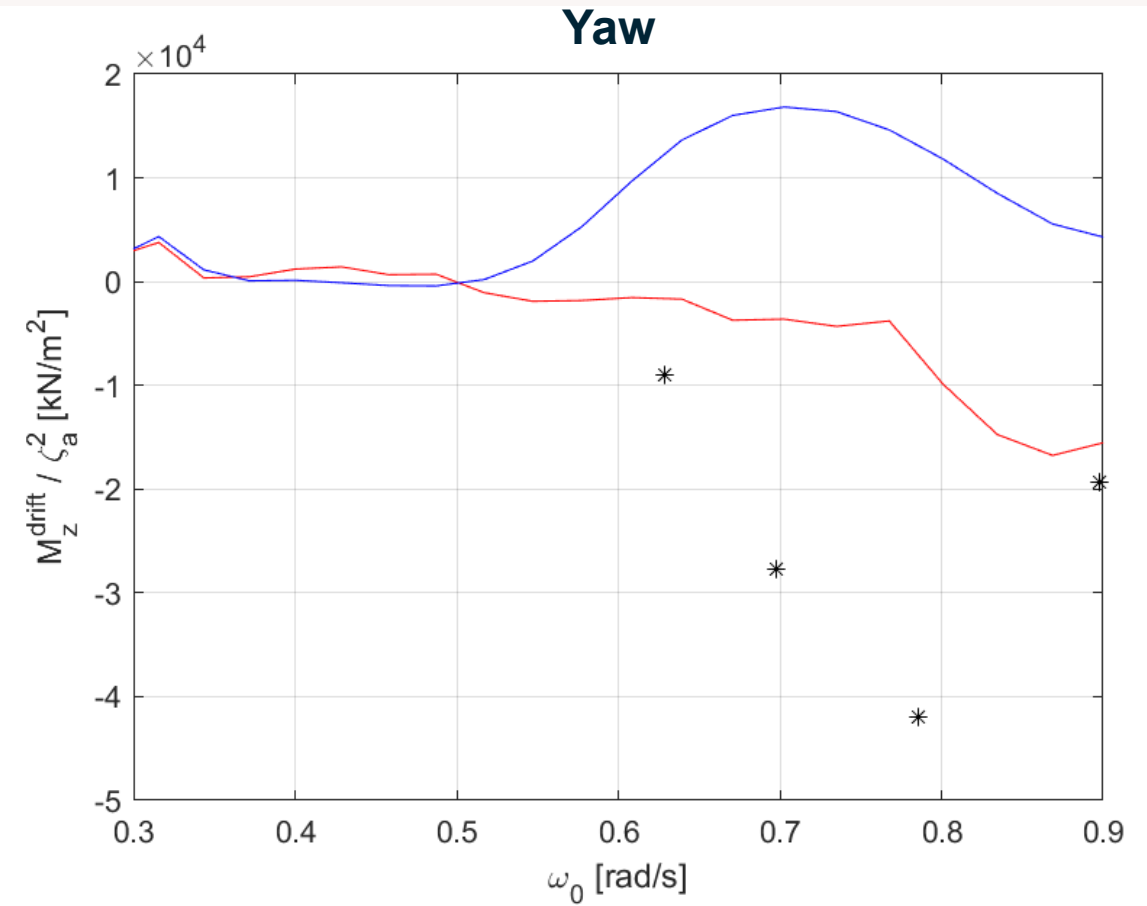
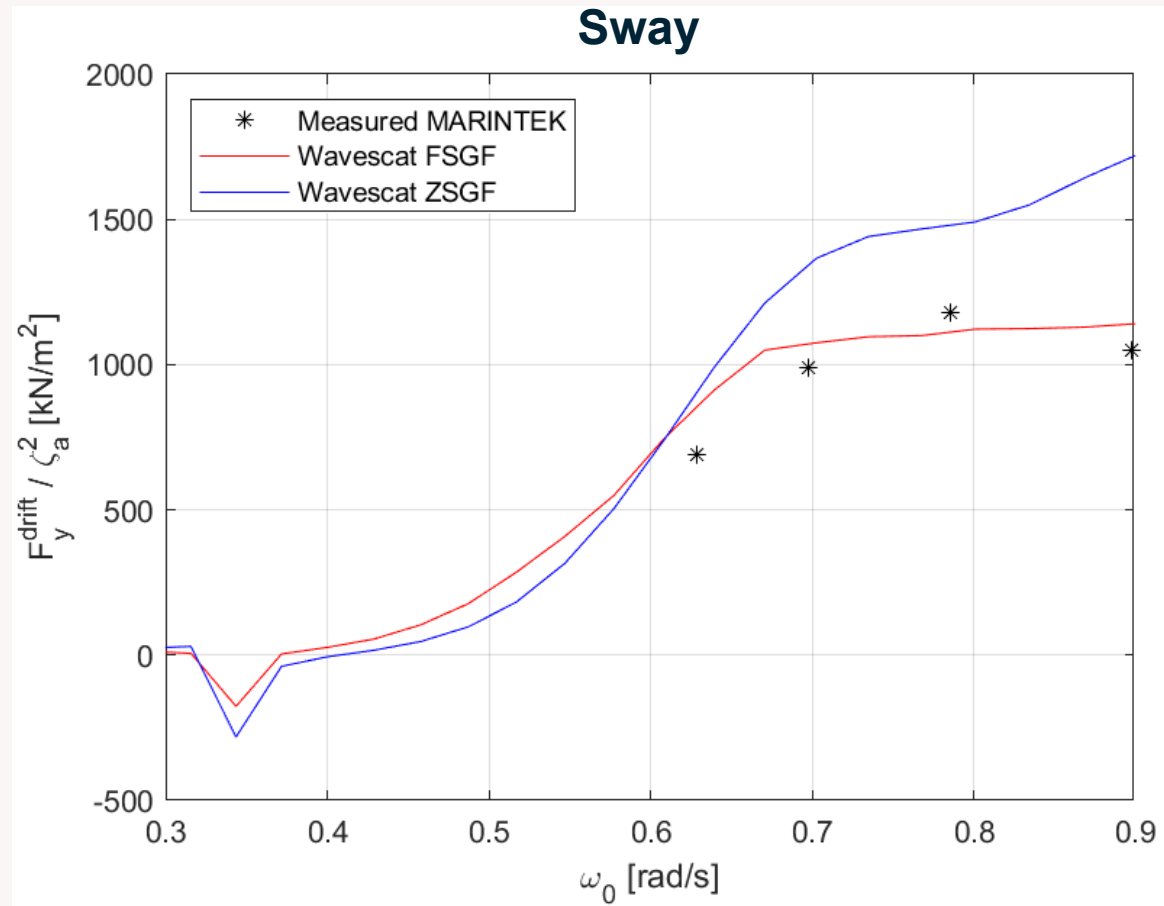
Fatima: Rankine panel model (Marin)

HydroStar: Panel model based on zero-speed Green function

Added Resistance



Sway Drift Force and Yaw Drift Moment



Summary and Conclusions

- Efficient new method using forward-speed Green functions. Time-domain Green function calculated upfront. Then efficient FFT possible for a large matrix of encounter frequencies and wave directions.
- Target application for UKC forecast systems and input to navigation simulations
- Model predicts RAOs, added resistance and drift forces
- Improved RAO results in long swells and at high speed compared to ZSGF
- More measured data desired for validation at different wave periods and vessel speeds
- Further assessment of the effect of the waterline integral recommended
- Added resistance and drift forces affected by irregular frequency effects. May be eliminated using a lowered lid inside the vessel. Topic for future work.

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THANK YOU!

Baird.

Innovation Engineered.