VALIDATION AND VERIFICATION OF DECOMPOSITION MODEL BASED ON EMBEDDED FREE SURFACE METHOD FOR OBLIQUE WAVE SEAKEEPING SIMULATIONS

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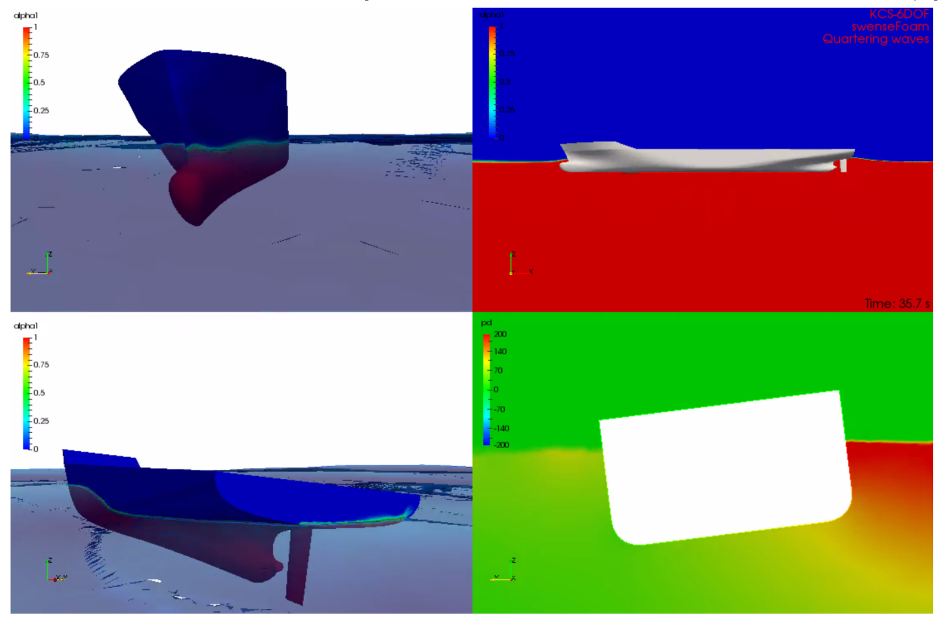
SUBMISSION EXPLANATION

- *Test cases:* Case 2.11,
- *Name of the code:* `swenseFoam` in the Naval Hydro pack based on `foam-extend 3.1`, a community driven fork of the OpenFOAM software.
- *Institution:* FMENA, University of Zagreb, Croatia.

Figure 1: Perspective, side and midship section views for the C4 case (quartering waves).



MODELLING

- *Governing equations:* Two–phase, incompressible and turbulent decomposition model with arbitrary potential model flow coupling and embedded free surface approach.
- *Embedded free surface model:* Interface corrected discretisation schemes derived from free surface jump conditions.
- *Interface capturing:* Implicitly redistanced Level Set method.
- *Turbulence modelling:* Two–equation $k - \omega$ SST turbulence model.
- *6DOF:* Rigid body motion with quaternion based rotations.
- *Grid motion:* Whole grid moves as a rigid body.
- *Numerics:* Second–order accurate polyhedral Finite Volume Method with PIMPLE pressure–velocity coupling.

GRIDS AND BOUNDARY CONDITIONS

- Three grids used for the head waves simulations (KCS case 2.10) are mirrored and used here for oblique wave simulations, leading to 1 200 000, 1 900 000 and 3 200 000 cells.
- Same boundary conditions are applied as in head waves cases.

VALIDATION

Results of added resistance, heave and pitch for the fine grid (3 200 000 cells) for each case (C1 to C5) are presented with dimensionless transfer functions. Mean value of added resistance for head and beam waves deviates 2% and 4%, respectively, while the error is larger for beam, quartering and following waves. Note that the measured mean value of resistance is smaller for beam waves compared to calm water condition, which authors consider peculiar. The first order of added resistance does not compare well with experimental results, where significantly smaller values are obtained in the experiment.

Figure 2: Total resistance coefficient harmonics, C_T for all wave headings.

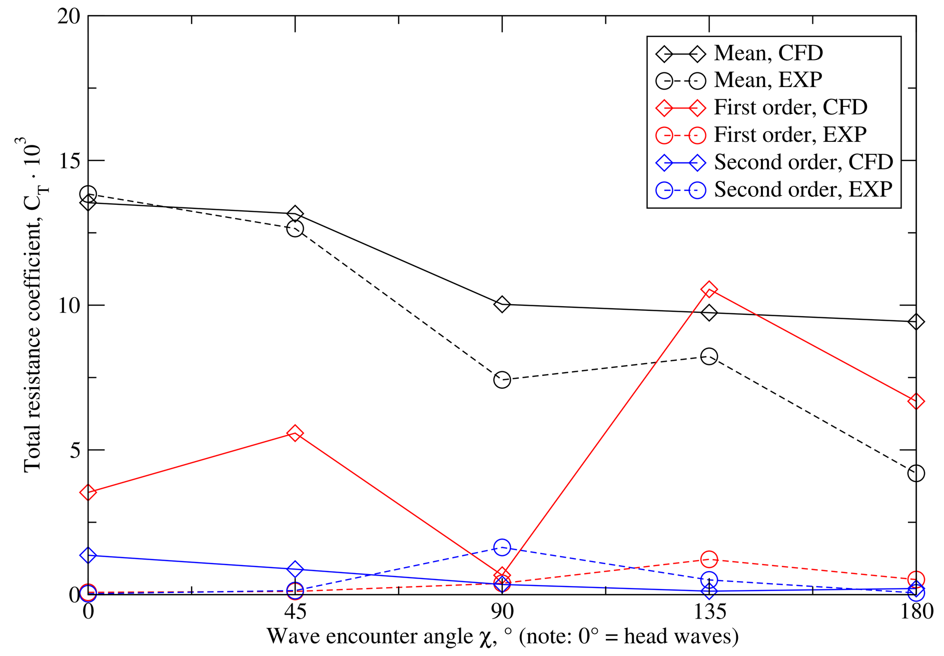


Figure 3: Dimensionless heave harmonics, z/ζ for all wave headings.

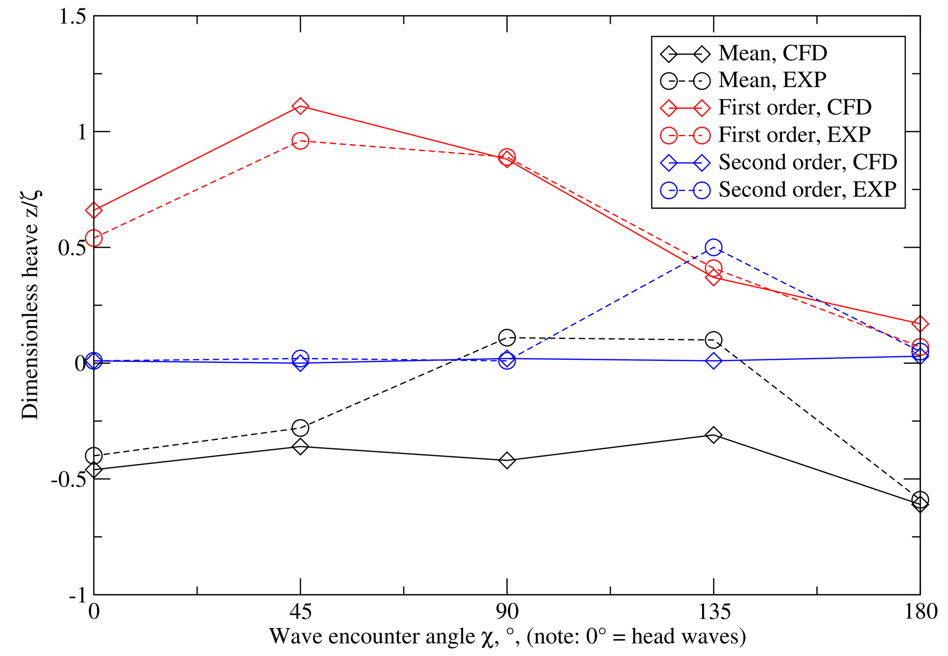


Figure 4: Dimensionless roll harmonics, $\phi/(k\zeta)$ for all wave headings.

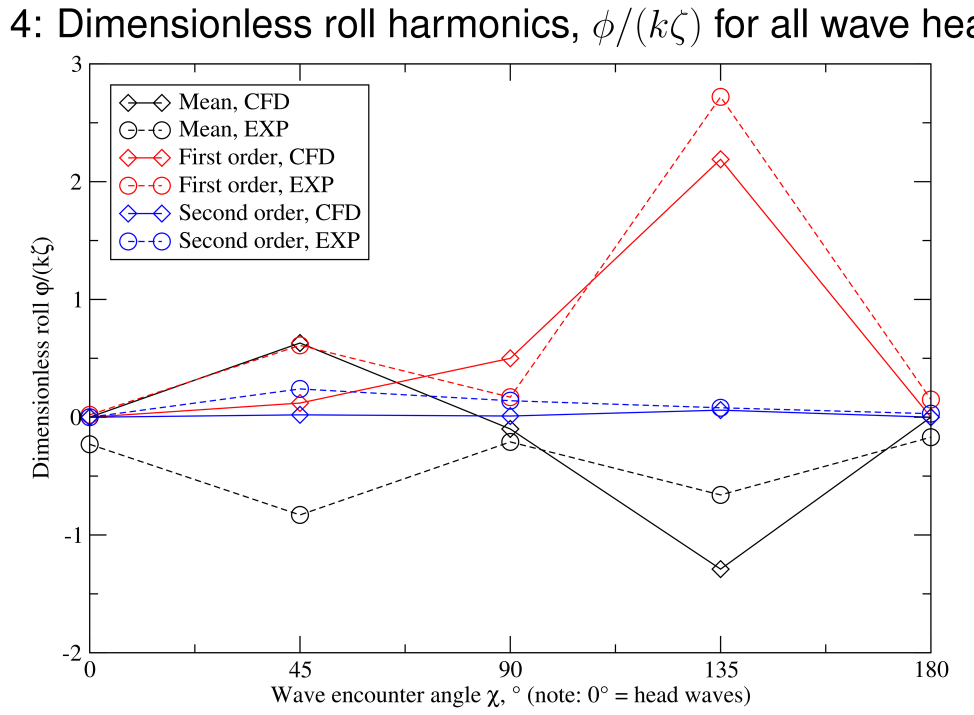
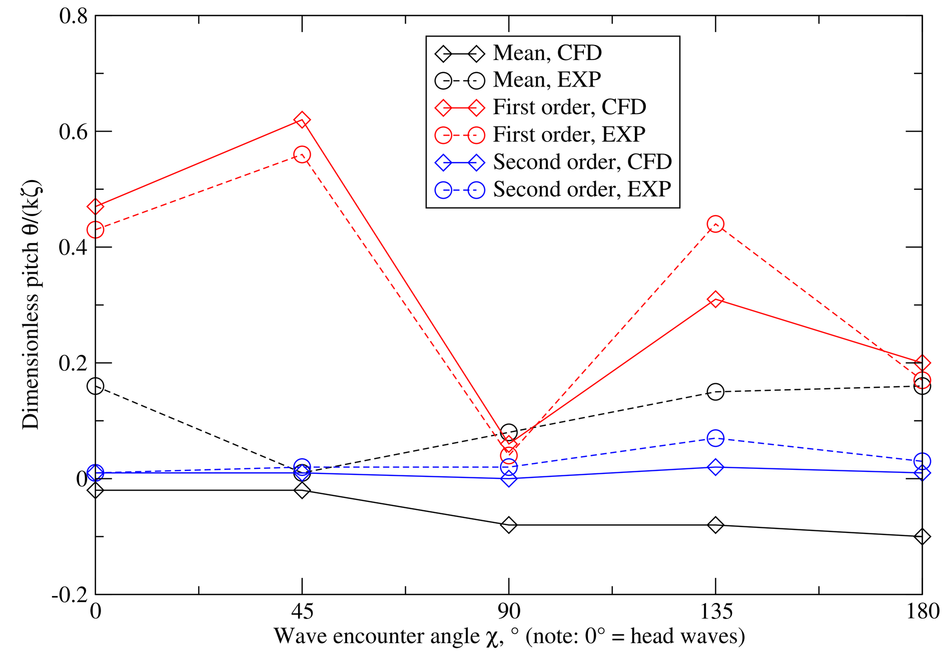


Figure 5: Dimensionless pitch harmonics, $\theta/(k\zeta)$ for all wave headings.



VERIFICATION

- *Periodic uncertainties:* evaluated via moving window FFT. Periodic uncertainties for mean and first order of resistance, heave, roll and pitch are below 1% of the fine grid solution, with exception of roll in head and following sea conditions, and pitch in beam sea condition, which are negligibly small in CFD. Higher order effects have higher periodic uncertainties.
- *Grid uncertainties:* 3 (non–systematically) refined grids, where a conservative estimate of uncertainty is calculated as $U_G = |S_U - S_L|$ because monotone, oscillatory and non–converging variables are obtained. Grid uncertainties for the added resistance are 10% on average for mean value, and less than 2% for the first order, except for the beam sea C3 case. First order harmonic of heave, roll and pitch have grid uncertainties smaller than 2% for most cases, with exceptions for very small motions obtained in some cases (e.g. roll response in head and following waves).
- Complete validation and verification results can be found in a spreadsheet document submitted to the Workshop.

HARDWARE AND SIMULATION TIMES

Simulations were performed on a cluster with 6 computational nodes: CPU–2x Intel Xeon E5–2637 v3 4–core, 3.5GHz. As an example, the fine grid (3.2 million cells) simulation of the bow waves C3 case has been performed using 56 cores. 7 motion correctors were used with a fixed time step of 0.004 s corresponding to approximately 225 time steps per encounter period. Maximum Courant–Friedrichs-Lewy number varied from 55 to 70 during the simulation. Simulation lasted 40.2 hours for 60 encounter periods, equalling 40 minutes of clock time per encounter period.

ACKNOWLEDGEMENT

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