# SEAKEEPING VALIDATION AND VERIFICATION USING DECOMPOSITION MODEL BASED ON EMBEDDED FREE SURFACE METHOD

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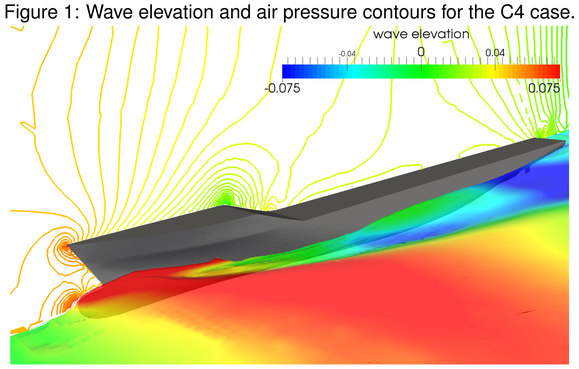
## SUBMISSION EXPLANATION

- *Test cases:* Case 2.10,
- *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: Wave elevation and air pressure contours for the C4 case.




## 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

- *Domain characteristics:*
  - $1L_{PP}$ in front of the ship, $2.5L_{PP}$ behind the ship,
  - $1.5L_{PP}$ from the portside, with longitudinal symmetry plane.
- Three unstructured grids are used with approximately 600 000, 950 000 and 1 600 000 cells. Average $y^+$ values on the hull: 37.6, 28.5 and 23.2.
- *Boundary conditions*:
  - Far–field (inlet, outlet, portside boundary): potential flow solution–damping diffracted fields with relaxation zones.
  - Top boundary: atmospheric pressure.
  - Ship hull: moving velocity boundary condition.
- *Ship motion:* Forward speed of the ship is modelled via implicit current in stream function wave theory, while heave and pitch are solved for.

## VALIDATION

Results of added resistance, heave and pitch for the fine grid (1 600 000 cells) for each case (C1 to C5) are presented with dimensionless transfer functions. Results show good agreement, with relative errors for the mean component of added resistance ranging from 16% (lowest $\lambda/L_{PP}$ case, coarsest grid resolution per wave height/length) to 5% (higher $\lambda/L_{PP}$, finest grid resolution per wave height/length). First order added resistance coefficients have relative errors between 11% and 17%, with exception of C2 case with relative error of 36%.

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

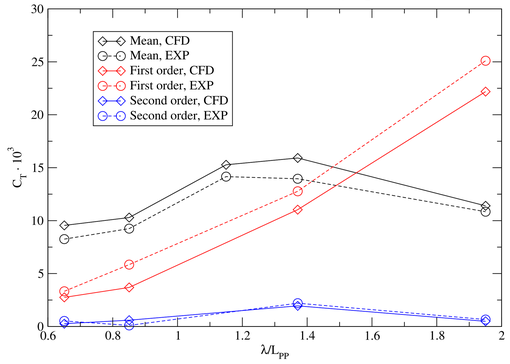



Figure 3: Dimensionless heave harmonics, $z/\zeta$ for all wave conditions.

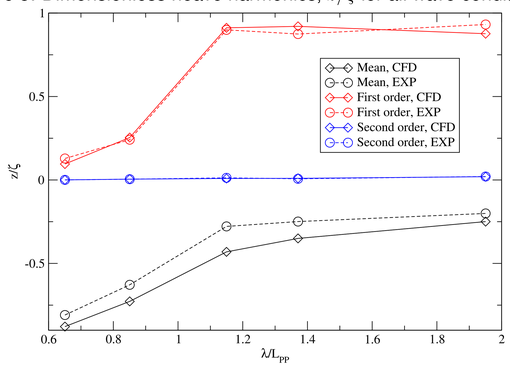
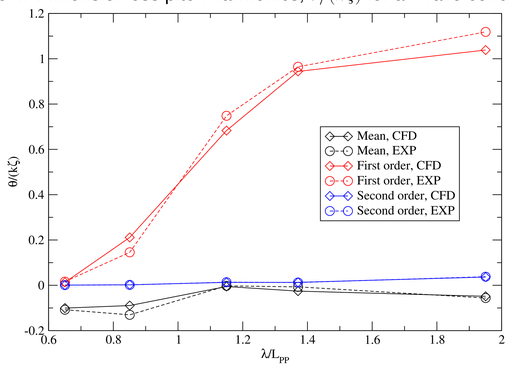


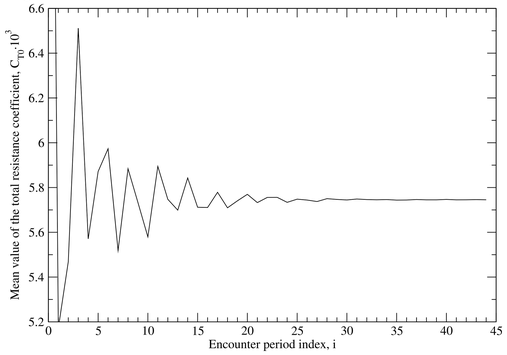

Figure 4: Dimensionless pitch harmonics, $\theta/(k\zeta)$ for all wave conditions.




## VERIFICATION

- *Periodic uncertainties:* evaluated via moving window FFT, where each simulation has been run for large number of encounter periods (up to 60). Periodic uncertainties for mean and first order of resistance, heave and pitch are below 2% of the fine grid solution. Higher order effects have higher periodic uncertainties.

Figure 5: Moving window FFT plot for the mean total resistance coefficient, case C5.




- *Grid uncertainties:* 3 (non–systematically) refined grids. Out of 75 harmonic amplitudes (resistance, heave, pitch for 5 test cases), 64 exhibit monotone or oscillatory convergence. Grid uncertainties for the added resistance are 3.3% on average for mean value, and less than 2% for the first order, except for the resonant C3 case with grid uncertainty of 12.5%. First order harmonic of heave and pitch have grid uncertainties smaller than 2% for most cases.
- 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 (1.6 million cells) simulation of the resonant C3 case has been performed using 40 cores. 7 motion correctors were used with a fixed time step of 0.004 s corresponding to approximately 330 time steps per encounter period. Maximum Courant–Friedrichs-Lewy number varied from 25 to 45 during the simulation. Simulation lasted 23.5 hours for 27.5 encounter periods, leading to 50 minutes of clock time per encounter period.

## ACKNOWLEDGEMENT

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