Energy Efficient Safe SHip OPERAtion

2nd Order Wave Forces

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WP2 / WP4 meeting, Duisburg, 16.03.2015
1. **Overview**
   Tasks, Performed work

2. **Prediction Methods**
   Numerical, Empirical

3. **Numerical Investigation**
   Test Cases, Setup

4. **Results**
   Numerical, Experimental, Empirical

5. **Conclusion/Outlook/Discussion**
Overview

Tasks in the scope of SHOPERA regarding wave forces

• Development and validation of a field method (OpenFOAM) to calculate wave drift forces (Task 2.5+Task 4.2)
• Development of a database for second order wave forces (Task 2.4)

Performed work

• Investigation of the waves added resistance in short and long waves for different ship types related to:
  Discretization, viscous effects, surge motion, radiation and diffraction problems
• Comparison of the results with Level 1 methods
• Initial investigation regarding side force and yaw moment in oblique waves
Field methods OpenFOAM and Comet

- Discretization: Finite Volume Method
- Free Surface: Volume of Fluid + HARIC, MULES implicit
- Pressure/Velocity: SIMPLE, PIMPLE
- Ship Motion: Implicit coupling with 6-DOF rigid body motion eq. + mesh-morphing algorithm
- Waves: Regular and irregular waves. Velocity field and wave elevation imposed at inlet boundary.

Empirical methods Stawave1 and Stawave2
Numerical Investigation

Test cases/conditions

- Duisburg Test Case: Head waves, $\lambda/L=0.5-2$, $F_n=0.218$, $h_W=7m$
- Cruise Vessel: Head and oblique waves, $\lambda/L=0.2-2$, $F_n=0.159,0.223$, $h_W/\lambda=1/60$, $\mu=90°,120°,150°,180°$
- KVLCC2: Head waves, $\lambda/L=0.7-2$, $F_n=0.142$, $h_W=6m$
- Wigley Hull: Head waves, $\lambda/L=0.5-2$, $F_n=0.2,0.3,0.4$, $h_W/\lambda=1.5$

Grids

- Unstructured hexahedron grid (boundary layer)
- Grids suitable for the shortest wave (e.g. $\lambda/L=0.2$)
- Half domain $\approx 1.5 \times 10^6$ cells
**Computational Procedure**

Step 1: Computation of calm water resistance (RT)
Step 2: Computation of longitudinal force in waves (FX)
Step 3: Calculation of added resistance (average FX – RT)

**NOTE**

- Grid study in calm water and waves for every ship
- Same grid for calm water and waves
- Mean values over at least 5 wave periods
- Wave amplitude monitored
- Modell free to heave and pitch
Added Resistance: Discretization errors
DTC in head waves

Influence of spatial Discretization

Gitterstudie DTC, $v_M=1,668$ m/s

Added Resistance Coeff [-]

$\tilde{\omega}=(L/\lambda_W)^{(1/2)}$ [-]
Added Resistance: Friction part
DTC and cruise vessel in head waves

Cruiser: Head waves, \( F_n=0.23 \)

DTC: Head waves

\[ \omega = \left( \frac{L}{\lambda_W} \right)^{1/2} \]
Added Resistance: Influence of \( F_n \)
Wigley in head waves

Influence of Surge Motion

Wigley: Head waves, \( F_n = 0.2 \)

Wigley: Head waves, \( F_n = 0.3 \)

Wigley: Head waves, \( F_n = 0.4 \)
Added Resistance: Radiation and Diffraction
Cruise ship and KVLCC2 in head waves

Radiation and Diffraction

Cruiser: Head waves, $F_n=0.23$

KVLCC2: Head waves

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Added Resistance
Cruise ship in oblique waves

Encounter Angle

Cruiser: Oblique waves, $F_n=0.23$

Added Resistance Coeff. [-]

$\tilde{\omega}=(L/\lambda)^{1/2}$ [-]

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Added Resistance: CFD vs. EFD vs. empirical formula
Cruise ship in head waves

Comparison of Methods

Cruiser: Head waves, $F_n=0.23$

Cruiser: Head waves, $F_n=0.159$
Comparison of Methods

KVLCC2: Head waves

DTC: Head waves

Added Resistance: CFD vs. EFD vs. empirical formula

KVLCC2 and DTC in head waves
Drift Forces
Cruise ship in oblique waves

Side Force and Yaw Moment with fixed and free hull

Cruiser: Oblique waves, $F_n=0.2$, $\lambda/L=0.89$
Conclusion/Outlook/Discussion

1. The influence of the spatial discretization on the added resistance may be large especially for short waves
2. The frictional part of the added resistance is larger for short waves and negligible for long waves
3. The surge motion may have an influence on the added resistance at high Froude numbers
4. The sum of the diffraction force and a radiation force is not equal to the total added resistance especially for long waves
5. Used Level1 methods provide good results in their range of validity

Thank you!