Numerical Simulations on Added Resistance and Ship Motions of KVLCC2 in Waves

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Motivations (1/2)

- Trend change of ship design and researches on ship performances

Before economic crises in 2008

Contract draft and speed in calm water

Design draft and speed in calm water (14.5m, 23 knots for C/C)

Operational profile in calm water

After economic crises in 2008

Operational draft and speed in calm water (12.5~14.5m, 17~21 knots for C/C)

Performance + Safety in seaway

Operational draft and speed in calm water and seaway taking into account realistic weather conditions
Motivations (2/2)

- **Benefits from studies on the ship added resistance**
  - Realistic S.M., accurate estimation of the speed loss, opt. for weather routine
  - Faster and safer ship in actual sea conditions, and reduced operation costs
  - Prediction of the ship motions for ship safety in a seaway and coastal areas

- **Regulations for global environmental protection from CO₂ Emissions**
  - **EEDI (Energy Efficiency Design Index):** Design specific
    \[
    EEDI \left[ \frac{g}{\text{ton} \cdot \text{NM}} \right] = \frac{CO_2 \text{ Emissions}}{DWT \times Speed \times f_W}
    \]
    - \( f_W \) (coefficient of ship speed reduction, IMO and 27th ITTC seakeeping committee)
      non-dimensional coefficient indicating the ship speed reduction in representative sea conditions (i.e. Beaufort scale 6 considering mean sea condition of north Atlantic and north Pacific) of wave height, wave frequency and wind speed
  - **EEOI (Energy Efficiency Operational Index):** Operational & Voyage specific
    \[
    EEOI \left[ \frac{g}{\text{ton} \cdot \text{NM}} \right] = \frac{CO_2 \text{ Emissions}}{\text{Cargo capacity} \times \text{Dist. of voyage}}
    \]
Safety in a Harbour

21 January 2012. 17:25.
Theofilos (NEL LINES) case.
Lemnos, Greece.
# Main Particulars for KVLCC2

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Unit</th>
<th>Full scale</th>
<th>Model scale (CFD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td></td>
<td>1</td>
<td>80</td>
</tr>
<tr>
<td>LBP</td>
<td>m</td>
<td>320.0</td>
<td>4.0000</td>
</tr>
<tr>
<td>LWL</td>
<td>m</td>
<td>325.5</td>
<td>4.0688</td>
</tr>
<tr>
<td>B</td>
<td>m</td>
<td>58.0</td>
<td>0.7250</td>
</tr>
<tr>
<td>D</td>
<td>M</td>
<td>30.0</td>
<td>0.3750</td>
</tr>
<tr>
<td>T</td>
<td>m</td>
<td>20.8</td>
<td>0.2600</td>
</tr>
<tr>
<td>Displacement</td>
<td>m³</td>
<td>312,622</td>
<td>0.6106</td>
</tr>
<tr>
<td>W.S.A.</td>
<td>m²</td>
<td>27,194</td>
<td>4.2491</td>
</tr>
<tr>
<td>CB</td>
<td></td>
<td>0.8098</td>
<td>0.8098</td>
</tr>
<tr>
<td>LCB, fwd+</td>
<td>%</td>
<td>+3.48</td>
<td>+3.48</td>
</tr>
<tr>
<td>LCG, fwd+</td>
<td>m</td>
<td>11.1</td>
<td>0.1388</td>
</tr>
<tr>
<td>KG (VCG)</td>
<td>m</td>
<td>18.56</td>
<td>0.2320</td>
</tr>
<tr>
<td>GM</td>
<td>m</td>
<td>5.71</td>
<td>0.0714</td>
</tr>
<tr>
<td>Moment of inertia</td>
<td>Kxx/B, Kyy,zz /LBP</td>
<td>0.40, 0.25, 0.25</td>
<td>0.40, 0.25, 0.25</td>
</tr>
</tbody>
</table>
Numerical Methods and Modelling

- Prediction of the added resistance due to waves
  - 3-D linear potential method
    - 3-D source-sink frequency domain with the zero-speed Greens functions
    - Near-field approach (direct pressure integration for the calculation of the added resistance)
    - Added resistance for regular waves in frequency domain
  - CFD method
    - Unsteady Reynolds-Averaged Navier-Stokes (URANS) approach
    - FVM and VOF methods
    - Dynamic Fluid Body Interaction (DFBI) for the ship vertical motions
    - Added resistance for regular waves in time domain
Grid Convergence Test for CFD

- Meshes & boundary conditions including mesh convergence test

<table>
<thead>
<tr>
<th>Mesh</th>
<th>λ/Δx</th>
<th>H/Δz</th>
<th>Te/Δt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>70</td>
<td>14</td>
<td>181</td>
</tr>
<tr>
<td>Base</td>
<td>100</td>
<td>20</td>
<td>256 (2^8)</td>
</tr>
<tr>
<td>Fine</td>
<td>140</td>
<td>28</td>
<td>362</td>
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</tbody>
</table>
Test Cases for CFD Methods

- Simulations at 15.5kts as the ship design speed to be conducted to be compared with existing experimental results for validation.

<table>
<thead>
<tr>
<th>Cond. No.</th>
<th>Vs [knots]</th>
<th>Wave length ($\lambda/L$)</th>
<th>Wave height (H) [m]</th>
<th>Steepness ($H/\lambda$)</th>
<th>$fe$ [Hz]</th>
<th>$Te$ [sec.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C00</td>
<td>Calm water</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C10</td>
<td>0.30</td>
<td>1.60</td>
<td>-</td>
<td>-</td>
<td>1.8835</td>
<td>0.5309</td>
</tr>
<tr>
<td>C11</td>
<td>0.50</td>
<td>2.67</td>
<td>-</td>
<td>-</td>
<td>1.3293</td>
<td>0.7523</td>
</tr>
<tr>
<td>C12</td>
<td>0.75</td>
<td>4.00</td>
<td>-</td>
<td>-</td>
<td>1.0186</td>
<td>0.9818</td>
</tr>
<tr>
<td>C13</td>
<td>1.00</td>
<td>5.33</td>
<td>1/60</td>
<td>-</td>
<td>0.8476</td>
<td>1.1798</td>
</tr>
<tr>
<td>C14</td>
<td>1.20</td>
<td>6.40</td>
<td>-</td>
<td>-</td>
<td>0.7560</td>
<td>1.3227</td>
</tr>
<tr>
<td>C15</td>
<td>1.40</td>
<td>7.47</td>
<td>-</td>
<td>-</td>
<td>0.6872</td>
<td>1.4552</td>
</tr>
<tr>
<td>C16</td>
<td>1.60</td>
<td>8.53</td>
<td>-</td>
<td>-</td>
<td>0.6332</td>
<td>1.5793</td>
</tr>
</tbody>
</table>
Time History Data (CFD)

- Total resistance in short and long waves (15.5kts)

(\lambda/L=0.5, Te=0.7523 \text{ sec.})

(\lambda/L=1.2, Te=1.3227 \text{ sec.})
Ship Vertical Motions

- Heave and pitch responses in head waves ($V_s=15.5\text{kts}$)
  Verification for ship motions is required because added resistance due to waves is proportional to the relative motions (typically, heave and pitch motions) and inaccuracies in the predicted motions will be amplified in resistance errors.
Added Resistance in Waves

- Added resistance coefficients in short and long waves (Vs=15.5kts)
- Investigation on the added resistance has been done in not only long wave but also short wave (\(\lambda/L=0.3\sim0.75\)) conditions.
Numerical Results (CFD, Vs=15.5kts)

- Periodic wave patterns over a period of encounter (15.5 knots, λ/LBP=1.2)

(a) \( t/T_e = 0.00 \)  
(b) \( t/T_e = 0.25 \)  
(c) \( t/T_e = 0.50 \)  
(d) \( t/T_e = 0.75 \)
Numerical Results (CFD, Vs=0.0kts)

Vs=0.0kts, t/Te=0.5, $\lambda/L=1.2$

Ensemble Period ($t/T_e$)

$R_w$ (N)

Heave (m)

Pitch (Deg.)
Conclusions

- Wide range of studies have been performed for the prediction of the added resistance and the ship vertical motions in waves using the 3-D potential flow and the CFD methods.
- The optimal mesh system has been investigated and established from the grid convergence test.
- Unsteady wave patterns and the added resistance with ship motions in time domain are simulated and analysed using CFD.
- It is observed that the total resistance force in the time domain at the stationary speed ($Vs=0.0$kts) could be larger than that at the design (15.5kts) and operating speeds (12.0kts).