CeSOS/AMOS 2013 Conference

A TWO-TIME SCALE FOR SHIP MANEUVERING IN A SEAWAY WITH APPLICATION TO JOINT MANEUVERS OF TWO SHIPS

MARINTEK

Renato Skejic
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CONTENT

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- Unified seakeeping and maneuvering model
  - Particulars
  - Modular concept
  - Summary
- Numerical studies
- Conclusions
INTRODUCTION

The ship maneuvering characteristics:
- calm water (traditional approach, early design stages)
- seaway (the environmental loads: wind/waves/current/ice)

Combined seakeeping and maneuvering analysis is important for:
- maneuvers and close proximity marine operations carried out in complex environmental conditions (waves, wind, current; ice)

in order to satisfy requirements for: safety, efficiency, operability, feasibility
Close proximity marine operations:

- **Carried out:** under specific conditions and requirements (low, moderate speeds) in order to accomplish given tasks in different regional and environmental zones
- **Involve:** the floating/stationary objects of different size with/without the forward speed(s) and with/without the propulsive, maneuvering and control capabilities
  (Examples: passing, meeting, overtaking, replenishment, lightering, inspection maneuver)

- **Performed in:** coastal or open and deep waters
  - presence of combined effects of the weather conditions (waves, wind, current, ice), constrained waters with limited water depth and speed of the objects
UNIFIED SEAKEEPING AND MANEUVERING MODEL

- **Formulation: Two-Time Scale approach; Skejic and Faltinsen (2008, 2013)**
  - slowly varying (nonlinear maneuvering)
  - rapidly varying (seakeeping; regular and irregular waves)

- **Model assumption:**
  - Froude number $Fn < 0.25$

- **Communication between the scales:**
  - slowly varying parameters through modular maneuvering concept (physical decomposition of the interacting ship(s)/propeller(s)/rudder(s)/flow effects)
  - based on the rational approach (real time)

- **Model particulars:**
  - forward speed drop
  - maneuvers with moderate/high rudder angles
• **Modules are:**

  • **Resistance and propulsion**
    - ‘Holtrop – Mennen’ (1982) method
      (total calm water resistance with/without the finite water depth/channel effects)

  • **Maneuvering module**
    - 6 DOF slender body theory and 3D model with the finite water depth/channel effects
      – Skejic (2012, 2013)

  • **Rudder module**
    (Selected type of rudders - Ankudinov et al., 1993; Kijima et al., 1993)

  • **Nonlinear viscous cross-flow drag module**
    (based on the Cross-flow principle - Faltinsen, 1990; 2005)
• **Hydrodynamic interaction loads module (2 ships) – calm water**
  - Newman and Tuck (1974) slender body theory (infinite fluid)
  - Xiang and Faltinsen (2010) 3D model (infinite fluid)
    Work in progress: inclusion - free surface and/or the finite water depth/channel effects

• **Uniform current module**
  - Horizontal and/or vertical plane(s) – Artyszuk (2004)

• **Wind load module (work in progress)**
• **Motion control modules (‘autopilots’)***
  Fossen and Breivik (2009, 2011)

**Type I**
- overtaking, meeting maneuvers
- maneuvers for abeam, tandem configurations

**Type II**
- specific type of maneuvers with the constrains
• Mean 2\textsuperscript{nd} order wave loads module; Single ship (Regular waves – deep water)
  - slender body theories
  - 3D theory, Xiang and Faltinsen (2011)

• Slow - drift 2\textsuperscript{nd} order wave loads module; Single ship (Irregular waves – deep water)
  - 2D spectral formulation of a seaway $S(\omega)$ (long-crested wave field)
• **Hydrodynamic interaction loads module; Two ships (Regular waves – deep water)**
  - 3D theory, Xiang and Faltinsen (2011)
  
  Work in progress: 3D spectral formulation of a seaway $S(\omega,\beta)$
  
  Short-crested irregular wave field
  
  The finite water depth/channel effects in waves
  
  Hydrodynamic interaction loads module; Two ships (Irregular waves)

**Note:** In two (or multiple) ships configuration the hydrodynamic interaction (calm water/waves) can be neglected or taken into account depending on the relative forward speed and position between two ships.
Unified Seakeeping and Maneuvering Model – **Summary**

- **Capabilities**
  - Safety analysis
  - Efficiency analysis
  - Operability analysis
  - Environmental analysis
  - Feasibility analysis

- **Applications**
  - Short time duration
    - Weather routing
    - Collision risk (avoidance) evaluation
    - Human response versus complexity of marine operation(s) and/or environmental conditions
  - Long time duration
    - Operational evaluation concerning the environmental conditions and/or complexity of marine operation(s)
    - Pollution aspects
    - Economic aspects related to fuel consumptions and associated costs

**Unified Model – Structure, Capabilities and Applications**
# NUMERICAL STUDIES

<table>
<thead>
<tr>
<th>Main particulars</th>
<th>‘MARINER’</th>
<th>‘S7-175’</th>
<th>‘KVLCC2’</th>
<th>‘Aframax’</th>
<th>‘Storage facility’</th>
<th>‘MARINER-(1:4)’</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{pp}$ ($\equiv L$)</td>
<td>160.934 m</td>
<td>175.0 m</td>
<td>320.0 m</td>
<td>230.0 m</td>
<td>50.0 m</td>
<td>40.23 m</td>
</tr>
<tr>
<td>$B$</td>
<td>23.165 m</td>
<td>25.4 m</td>
<td>58.0 m</td>
<td>42.0 m</td>
<td>43.3 m</td>
<td>5.78 m</td>
</tr>
<tr>
<td>$T$ (even keel)</td>
<td>7.468 m</td>
<td>9.50 m</td>
<td>20.8 m (full load)</td>
<td>7.5 m (ballast)</td>
<td>5.0 m</td>
<td>1.867 m</td>
</tr>
<tr>
<td>$C_g$</td>
<td>0.61</td>
<td>0.5716</td>
<td>0.8097</td>
<td>0.78</td>
<td>0.75</td>
<td>0.61</td>
</tr>
<tr>
<td>COG</td>
<td>(0.0, 0.0, -2.45) m</td>
<td>(0.0, 0.0, 8.06) m</td>
<td>(0.0, 0.0, -2.88) m</td>
<td>(0.0, 0.0, 0.0) m</td>
<td>(0.0, 0.0, -0.696) m</td>
<td></td>
</tr>
<tr>
<td>COB</td>
<td>(0.0, 0.0, -3.48) m</td>
<td>(0.0, 0.0, -4.27) m</td>
<td>(0.0, 0.0, -10.87) m</td>
<td>(0.0, 0.0, -3.6) m</td>
<td>(0.0, 0.0, -0.87) m</td>
<td></td>
</tr>
<tr>
<td>Propellers</td>
<td>1 (6.7 m) 4 blades WAGENINGEN – B SER.</td>
<td>Custom Yasukawa (2006, 2009)</td>
<td>1 (9.86 m) 5 blades WAGENINGEN – B SER</td>
<td>1 (6.8 m) 5 blades WAGENINGEN – B SER</td>
<td>N/A</td>
<td>1 (1.198 m) 5 blades WAGENINGEN – B SER</td>
</tr>
<tr>
<td>Rudders</td>
<td>1 (25.25 m$^2$)</td>
<td>1 (32.46 m$^2$)</td>
<td>1 (174.74 m$^2$)</td>
<td>N/A</td>
<td>N/A</td>
<td>1 (2.84 m$^2$)</td>
</tr>
<tr>
<td>Thrusters</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Main characteristics of the floating objects

‘MARINER’
‘Aframax’
‘S7-175’ (‘SR 180’)
‘KVLCC2’
‘Storage facility’
‘MARINER-(1:4)’
SINGLE SHIP (mono-, multihulls)

- Calm and deep water

‘S7-175’ (‘SR 180’) hull: – 35.0° Port Turn maneuver with approach forward speed 12.079 knots in calm and deep water

‘MARINER’ hull: 20.9° Starboard Turn maneuver with approach forward speed 15.4 knots in calm and deep water
**Regular waves (deep water)**

- **λ/L = 0.7, η = 270°**

  - ζ (m)
    - -1.75 -1.2 -0.8 0 0.6 1.2 1.75

  - **Transfer in meters**
    - **Advance in meters**
      - η = 270°

  - ζa (m)
    - -1.0 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1.0

  - **(deg.)**
    - 0 10 20 30 40

  - **(deg./s)**
    - 0 5 10 15

  - **(knots)**
    - 0 5 10

  - **RS/ρgζa^2B^2/L**
    - -10 -5 0 5 10

  - **RMS/ρgζa^2B^2/L**
    - -10 -5 0 5 10

  - **MZ/ρgζa^2BL**
    - -10 -5 0 5 10

  - **χ (deg.)**
    - 90 180 270 360

  - **Yasukawa (2006, 2009)**

- **‘S7-175’ (‘SR 180’) hull:** – 35.0° Port Turn maneuver with approach forward speed 12.079 knots in regular waves with wave amplitude ζa = 1.75 m
- Regular waves (deep water) - continue

**‘MARINER’ hull:** 20.9°  Starboard Turn maneuver with approach forward speed
15.4 knots in regular waves with wave amplitude $\zeta_a = 1.5$ m
**Irregular waves (deep water)**

**Uncertainty and mean value of ship(s) maneuvering simulations in seaway**

*‘MARINER’ hull: 20.9°* Starboard Turn maneuver with approach forward speed 15.4 knots in irregular waves (ISSC, 1978 spectrum: $H_{1/3} = 7.0$ m, $T_2 = 10.0$ s)
TWO SHIPS (mono-, multihulls)

- The close proximity maneuvers
  - **Particulars:** - short or long time duration
    - carried out in different environmental conditions
    - increased collision hazard due to the hydrodynamic interaction effects

- Calm and deep water
  - Overtaking maneuver

**Approach**

1. ‘Aframax’
2. ‘KVLCC2’

**Abeam**

3. High collision risk

**Departure**

4. 5.
Lightering maneuver - configuration
- lightering ship ‘Aframax’ - (RED SHIP), initial position (200.0, -200.0) m with the approach speed of 6.0 knots
- ship to be lightered ‘KVLCC2 – Moeri tanker’ - (BLUE SHIP), initial position (800.0, 400.0) m with the approach speed of 4.0 knots
- desired: transverse clearance 12.5 m, longitudinal distance 20.0 m

Inspection maneuver - configuration
- inspection ship scaled ‘MARINER - (1:4)’ - (RED), initial position (-100.0, 100.0) m with the approach speed of 6.0 knots
- floating object ‘Storage facility’ - (BLUE), initial position (10.07, -3.17) m
- desired: ship $|\text{steady turning radius}| = 60.0$ m
- calm water (the floating object is moored)
- uniform current: $|V_C| = 0.2916$ knots, $\psi_C = 315^\circ$ (the floating object is free to drift)
• **Regular waves (deep water)**
  
  - **Lightering maneuver** - configuration
    - lightering ship ‘Aframax’ - (RED SHIP), initial position (200.0, -200.0) m with the approach speed of 6.0 knots
    - ship to be lightered ‘KVLCC2 – Moeri tanker’ - (BLUE SHIP), initial position (800.0, 400.0) m with the approach speed of 4.0 knots
    - **desired**: transverse clearance 12.5 m, longitudinal distance 20.0 m, constant heading angle 22.5°
    - **incident waves**: \( \eta = 157.5° \) (port head beam sea), \( \lambda = 287.99 \) m, \( \zeta_a = 1.5 \) m
CONCLUSIONS

- **Maneuvering of a single ship in a seaway**
  - Unified seakeeping and maneuvering model based on slowly varying maneuvering time scale accounts for the wave field loads obtained on rational way from seakeeping analysis
  - Incident regular/irregular waves can have significant influence on ship maneuvering
  - Due to complexity of the ship maneuvering problem in a seaway further investigations in both; theoretical and experimental directions are needed

- **Close proximity maneuvers and complex marine operations in a seaway**
  - The hydrodynamic interaction loads alone or combined with other weather conditions (waves, wind, current, ice) have significant influence on the maneuvering behavior of objects involved in the close proximity maneuvers and complex marine operations
  - Without ‘autopilot’ motion control system (mimics qualified bridge and deck personnel) the close proximity maneuvers and complex marine operations in calm water/seaway with zero collision risk tolerance can not be accomplished
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