High block coefficient ship aft body shape optimization

Presented at the CAESES European Users’ Meeting 2017

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Content of presentation

- Background
- Optimization study
  - Shape variations
  - Objective function
  - Optimization
  - Case study
- Comments
- Conclusions
Scope and goals

• **Scope**
  • Shape optimization of the aft body
  • Full ships
    • High block coefficient
    • Low Froude numbers

• **Goals**
  • Minimize the delivered power
  • Show that it can be done in a short time with moderate computer resources.
Background
Resistance and propulsive efficiency

- Minimizing the power means the following
  - Minimize resistance, wave and viscous
  - Maximize hull efficiency, high wake fraction

- In most cases increasing wake fraction for efficiency will cause higher resistance – a trade-off is necessary to find best performance.
Background
Resistance and propulsive efficiency

• Optimum balance between Rt and w is very difficult to find based on resistance and wake results
• Self-propulsion is the best way to achieve optimum solution.
Case study based on Japan Bulk Carrier (JBC)

• JBC is a capesize bulk carrier designed jointly by National Maritime Research Institute (NMRI), Yokohama National University and Ship Building Research Centre of Japan (SRC).

• Towing tank experiments are available from NMRI, SRC and Osaka University, which include resistance tests, self-propulsion tests and PIV measurements of stern flow fields.

• Validation and Verification results using SHIPFLOW presented at Tokyo 2015 Workshop on CFD in Ship Hydrodynamics, Dec. 2-4, 2015
**Case study based on Japan Bulk Carrier (JBC)**

<table>
<thead>
<tr>
<th>Main particulars</th>
<th>Full scale</th>
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</thead>
<tbody>
<tr>
<td>Length between perpendiculares</td>
<td>L&lt;sub&gt;PP&lt;/sub&gt; (m)</td>
</tr>
<tr>
<td>Length of waterline</td>
<td>L&lt;sub&gt;WL&lt;/sub&gt; (m)</td>
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<tr>
<td>Maximum beam of waterline</td>
<td>B&lt;sub&gt;WL&lt;/sub&gt; (m)</td>
</tr>
<tr>
<td>Depth</td>
<td>D (m)</td>
</tr>
<tr>
<td>Draft</td>
<td>T (m)</td>
</tr>
<tr>
<td>Displacement volume</td>
<td>V (m&lt;sup&gt;3&lt;/sup&gt;)</td>
</tr>
<tr>
<td>Wetted surface area w/o ESD</td>
<td>S&lt;sub&gt;W&lt;/sub&gt; (m&lt;sup&gt;2&lt;/sup&gt;)</td>
</tr>
<tr>
<td>Wetted surface area of ESD</td>
<td>S&lt;sub&gt;E&lt;/sub&gt; (m&lt;sup&gt;2&lt;/sup&gt;)</td>
</tr>
<tr>
<td>Block coefficient (CB)</td>
<td>V / (L&lt;sub&gt;PP&lt;/sub&gt;B&lt;sub&gt;WL&lt;/sub&gt; T)</td>
</tr>
<tr>
<td>Midship section coefficient (CM)</td>
<td></td>
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<tr>
<td>LCB (%L&lt;sub&gt;PP&lt;/sub&gt;), fwd+</td>
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<table>
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<tr>
<th>Service speed</th>
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<tbody>
<tr>
<td>U (knots)</td>
<td>14.5</td>
</tr>
<tr>
<td>Fn</td>
<td>0.142</td>
</tr>
</tbody>
</table>
Shape variations
Resistance

• To minimize viscous resistance it is necessary to minimize wetted surface

• but without:
  • increasing wave resistance by e.g. too blunt bow
  • viscous pressure resistance by too full stern causing separation.
Shape variations

Wake

• To increase hull efficiency and avoid sudden changes of propeller loading, the wake should be more circular and concentrated in the propeller disc.

U- or V-shaped sections

Utilize the bilge vortices
Tools

- Shape variations
- Optimization methods
- Resource management

+ ShipFlow

- Grid Generation
- Flow simulations
- Result processing
Shape variations

- Hull shape modifications with Surface Delta Shift* 
  - Bilge radius 
  - Keel line profile of bossing 
  - Skeg (gondola) width 
  - Section fullness above skeg

* - partially parametric modelling
Shape variations

- Skeg width
- Section fullness
- Keel line profile
- Bilge radius
Shape variations

- Bilge radius
- Delta surface
Shape variations

- Keel line profile of bossing

- Delta surface
Shape variations

- Skeg (gondola) width
- Delta surface
Shape variations

- Section fullness above skeg

- Delta surface
Objective function / Optimization method

• Objective – Minimize the delivered power PD
  • Self-propulsion simulation
  • Scale effects
• Constraints
  • No loss of displacement
• Optimization method: Genetic Algorithm (NSGA-II)
Aft-body optimization of Japan Bulk Carrier (JBC)

- **Tools:**
  - SHIPFLOW and CAESES work environment
  - Direct self-propulsion optimization with SHIPFLOW
  - Partially parametric modelling with CAESES tools for good control and flexibility of hull modifications

- **Conditions:**
  - Self-propelled bare hull computations
  - Propeller pitch adjusted to find propulsion point
  - RPM fixed to desired engine
  - Design speed and design draught

- **Optimization:**
  - 4 independent variables
  - Delivered Power objective function
  - Displacement constraint (not less than baseline)
  - NSGA2 optimization algorithm
  - 12 generations, 24 individuals
CASE A – BASELINE hull

- Verification and Validation in:


- The resistance maximum comparison error of about 1.2%. The delivered power was underpredicted by 6% which was thought to be a result of a slight wake overestimation.
CASE B - Resistance optimization at model scale

- Reynolds number: 7.46e6
- Module: XCHAP using Krylov solver (SHIPFLOW 6.3)
- Fine grid, zonal approach, 1.2M cells (automatically generated from iges)
- 15 minutes per case (Intel i7 5960X)
- 288 designs investigated
- 1.2% decrease in RT at model scale (w.r.t. baseline)
CASE C - Self-propulsion optimization at model scale

- Reynolds number: 7.46e6
- Module: XCHAP using Krylov solver (SHIPFLOW 6.3)
- Medium grid with refinement, zonal approach, both sides, 3.0M cells (automatically generated from iges)
- Self-propulsion with integrated lifting line propeller model
- 4 cases per hour on a 4 node cluster (Intel Xeon X5675)
- 288 designs investigated
- 3.7% decrease in PD at model scale (w.r.t. baseline)
CASE D - Self-propulsion optimization at full scale

- Reynolds number: 2.10e9
- The same as the setup for “C” but with additional cells in normal direction (50% extra)
- 0.35% decrease in PD at full scale (w.r.t. baseline)
Cross-comparisons: model scale **RT** vs **PD**

- **Hull B** (optimized for min. RT at model scale):
  - has the lowest RT
  - But at the same time highest PD
  - Lower nominal wake than A (baseline)
  - Streamlined but not efficient
Cross-comparisons: model scale RT vs PD

• **Hull C** (optimized for min. PD at model scale):
  • Higher RT than hull B
  • But at the same time lower PD
Cross-comparisons: model scale RT vs PD

- **Hull D** (optimized for min. PD at full scale):
  - Higher RT than hull C
  - and Higher PD at model scale
Cross-comparisons: **model scale PD vs full scale PD**

- **Hull C** (optimized for min. PD at model scale):
  - Higher PD at full scale than hull D
Cross-comparisons: model scale PD vs full scale PD

- **Hull D** (optimized for min. PD at full scale):
  - Higher PD at model scale
  - But Lower PD at full scale
Some additional points

- Deformation techniques
  - Free box deformation can be better than delta surface shift in some cases e.g. for bulbs and skeg profile
Comments

• Constraints
  • Displacement
    • Appropriate penalty important
    • Design expected to be close to minimum displacement

• Optimization Approach
  • Wave resistance with XPAN:
    • TSearch or Sobol+TSearch if exploration is necessary
  • Viscous resistance and self-propulsion with XCHAP:
    • Genetic algorithm NSGA2
  • Note that the method selection will depend on the specific problem.
Comments

• CAESES and SHIPFLOW is an excellent environment for hydrodynamic optimizations
  • Partially parametric modelling delivered by CAESES gives very good control and flexibility of hull modifications, both global and local
  • SHIPFLOW is an efficient tool for self-propulsion simulations at model and full scale
• Aft body shape optimization of high block coefficient ship
  For best results:
  • optimize in self-propulsion condition
  • optimize directly at full scale.
Thank You

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