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Master Thesis

Development Of Flap Rudder Systems For Large Container Vessels

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Why Flap Rudder For Containership Operation?

• Higher safety and higher side force compared to conventional rudders
• Better maneuvering ability
• Compared to conventional rudder lesser rudder area required to provide same side force
• Improved course keeping with reduced rudder angle.
• Reduced tug assistance for small feeder vessels
Objectives of the Study

• Feedback from large containership owners regarding the low maneuvering problem in shallow water
• Previous CFD analyses indicates that flow separation starts from the flap rather than the leading edge
• Existing linkage mechanism means relatively aggressive flap operation at small rudder angles
• Initial project aim to develop new flap actuation ratios
Becker Flap Rudder CFD Analysis

• **Two dimensional analysis**
  1. New flap ratios find out by changing the value of a/b ratios.
  2. a/b values from 1.5 to 1.7 incremented by 0.05
  3. Flow analysis conducted at slow speed (8 knot) and cruise speed (23 knot) conditions.
  4. Wake values are derived from the model test result at 14.5 m draft ($V_A$).
Details of 2D CFD Plan

• Flow analysis conducted at +0.7R & -0.7R of the rudder horizontal section
• Domain size fixed based on chord length of rudder
• 50000 to 80000 cells used (polyhedral)
• Base size fixed at 0.9m with 1.05 times surface growth
• Prism layer count fixed at 7 with steady case & full scale rudder
• 5 to 10 minutes for meshing & analysis using 383 processor server
Results of Two Dimensional Analysis

![Graph showing Lift vs Flap Ratios](image-url)
Flow Separation at 12° for Existing Flap Rudder
Result of Two Dimensional CFD Study

• Analysis result recommend that Flap Ratios D (a/b=1.7) has reduced aggressiveness in flap operation
• Stall angle delayed 6 to 8 degree for each case of Ratio D
• Further increase of a/b ratio not possible due to space limitations caused by trunk/stock dimensions
• Flow separation appears to start from the forward part of flap / end point of suction side of rudder
Three Dimensional Analysis

• Flow analysis done with the ship hull and virtual propeller.
• Wake calculated independently, file as table in STAR-CCM+.
• Comparison of existing ratios and optimum ratios
• Impact of water depth in rudder side force.
• Hull force in different water depth.
Details of Three Dimensional CFD Plan

- Base size fixed 30.3 m
- 1/3 of the ship hull considered for the analysis
- Analysis done at full scale
- Steady-state
- 5 to 6 million cells used per case
- k-omega SST turbulence model used
- 383 processors
- Run time – about 2 hours per case
Details of Three Dimensional CFD Plan
Result of Three Dimensional Analysis

Rudder Lift vs Rudder Angle

Port

Starboard

EMSHIP 2016-18
Result of Three Dimensional Analysis

• Result from the 3D analysis are different from the 2D analysis

• From the flow analysis realized that flow separation starts from the leading edge

• Rudder Bulb appears to trigger flow separation
Result Of Three Dimensional Analysis

Rudder Lift vs Rudder Angle

-40 -30 -20 -10 0 10 20 30 40
Port
Starboard

LIFT FORCE (N)

-8.00E+00 -6.00E+00 -4.00E+00 -2.00E+00 0.00E+00 2.00E+00 4.00E+00 6.00E+00

Rudder Angle

-40 -30 -20 -10 0 10 20 30 40

Ratio D, slow speed
existing ratios, slow speed
without bulb, slow speed
Shear Stress Distribution At 18° Rudder Angle

Rudder with normal condition

Rudder with the absence of bulb
Leading Edge Flow Separation & Rudder Bulb Interaction

• Present flow analysis for the twisted flap rudder with bulb shows that flow separation starts from the leading edge of intersection of bulb and rudder geometry.

• Bulb is present to reduce fuel consumption – elimination of propeller hub vortex.

• Bulb optimized for power-saving.

Investigate effect of removing bulb
Symmetrical rudder with bulb
Symmetrical rudder without bulb
Twisted rudder with blended LE
Twisted Rudder with horizontal transition plate
New Geometries Vs Existing Twisted Flap Rudder

Rudder vs performance

- Port
- Starboard

Lift Force (N)

Rudder Angle (Deg)

Millions

- symmetric rudder
- symmetric rudder without bulb
- blended Leading Edge
- twisted rudder with transition plate
- existing rudder
Shear Force Comparison - Existing & Symmetrical Rudder Geometry (Rudder and Flap rotate 25° towards port side)

Existing rudder with new ratio D

Symmetric rudder with new ratio D
Impact of Ship Hull at Different Water Depths (8 knots)

- In this section we compare the ship hull forces and moments with approximate rudder turning moment.
- Ship hull force & turning moment are calculated with different turning radii to ship length ratio (R/L) and drift angle $\beta$. 
Rudder Side Force In Different Water Depths

![Graph showing Lift vs Depth with three different depth categories: shallow, intermediate, and deep water. The graph indicates a decrease in lift as the rudder angle increases, with the shallow depth showing the least change and the deep water showing the most change.](image-url)
Hull Moment & Rudder Moment – Suez Canal & Deep Depth

Hull Moment

Drift Angle (Deg)

Hull Moment in million (N.m)

-200 -100 0 100 200 300 400 500 600 700 800 900 1000

- shallow depth R/L=100
- shallow depth R/L=10
- shallow depth R/L=5
- Deep water R/L=100
- Deep water R/L=10
- Deep water R/L=5
Hull Moment & Rudder Moment – Suez Canal & Deep Depth

Hull Moment & Rudder Moment comparison

- Shallow depth R/L = 100
- Shallow depth R/L = 10
- Shallow depth R/L = 5
- Deep water R/L = 100
- Deep water R/L = 10
- Deep water R/L = 5
- Flap rudder - Max. rudder moment
How to Overcome the Existing Problem of High Hull Force & Turning Moment

• Hull forces dominate in shallow water condition compared to deep water.

<table>
<thead>
<tr>
<th>Solutions</th>
<th>Benefits</th>
<th>Penalties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing rudder Area</td>
<td>Increasing the side force</td>
<td>operation difficulties, production cost</td>
</tr>
<tr>
<td>Improving the rudder section</td>
<td>Improving the flow characteristics, Increasing the side force</td>
<td>Unlikely to provide sufficient improvement</td>
</tr>
<tr>
<td>Twin-screw propulsion</td>
<td>Increasing the side force in large magnitude</td>
<td>gain in side force vs production expense?</td>
</tr>
</tbody>
</table>
Conclusions

• 2D & 3D analysis results are different
• Flap ratio D has better performance
• Rudder bulb appears to start the flow separation at leading edge
• Numerical analysis of flow around rudder recommend that symmetrical rudder without bulb have improved flow separation & side forces than existing one
• Large container ships in shallow water – hull forces dominate.
• Vessel operated in shallow water require a specific recommendation of maneuvering operation
Future Works & Recommendations

- Transient analysis with explicit propeller (rotating mesh)
- Full 3D restrictions (include banking)
- Bulb details
- Model tests

Thank you