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Numerical Analysis of Stern Flap on Hydrodynamic Performance of Prototype Ship

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Abstract—*The effect of stern flap is numerically evaluated for a high speed slender vessel. The main parameters of the flap are chosen according to recommendations in relevant technical literature. The CFD analysis is performed using the SHIPFLOW modelling and analysis program. SHIPFLOW models the flow around the hull as nonlinear potential flow, calculating an equilibrium sinkage and trim from the integrated dynamic pressure. It computes wave resistance using either an integration of the pressures or a wave cut analysis, since the wave train produced by the ship is also a result of the calculations. The stern flap suppresses the wake behind the transom and alters the flow behind the stern. Comparison of SHIPFLOW CFD results for flap angles and their associated running trim and sinkage were made. Result of model tests conducted worldwide on optimum hydrodynamic design of stern flap suggests improved stern waves, increased propulsive efficiency and improved propeller cavitation performance.*

Keywords— Stern Flap, SHIPFLOW, Hydrodynamics, Sinkage, Trim.

I. INTRODUCTION

A stern flap is an appendage installed at the transom usually to improve the hydrodynamic properties of the vessel. The intention is to achieve the required speed and manoeuvring capabilities at lower fuel consumption. The stern flap is most effective modifying the trim rather than the sinkage, but since it also reduces resistance (somewhat related to the suction forces causing sinkage), sinkage is expected to be reduced by flap deployment. Sea trials and model tests suggest that stern flap is more advantageous at higher speeds. At high speeds, the flap helps the flow to detach cleanly so that it breaks away from the trailing edge.

II. NOMENCLATURE

CFD : Computational Fluid Dynamics
L_{BP}: Length between perpendiculars
B : Breadth moulded
D : Depth moulded
T : Draught
C_B : Block Coefficient
Fn : Froude Number
LWL : Length of waterline
C_W : Wave drag coefficient
C_T : Total resistance coefficient, $C_T=C_F+C_R$
C_R : Residuary resistance coefficient
C_F : Frictional resistance coefficient

III. METHODOLOGY

A slender ship hull form is chosen so as to achieve the required speed of 25 knots. The bare hull is analysed numerically with wedges of 6, 8, 10, 12 degrees. All the analysis are done for 16 knots and 25 knots. The results of the analysis are compared with bare hull resistance to highlight the extent of drag reduction.

Medium size Corvette ship type is chosen for the analysis. The shape of outer hull is obtained through methodological series with a modified stern to facilitate space for flap installation. Particulars of the ship are as follows:

L_{BP} = 104 m;
B = 12.6 m;
D= 8.9 m;
T = 4.8 m;
C_B = 0.5

SHIPFLOW runs were performed at the following conditions:

- Speeds: 16 and 25 knots ship scale, Fn = 0.27 and 0.42
- Bare Hull with wedges of 6, 8, 10 and 12 degrees

With a Froude number of only 0.27 at 16 knots, it is probable that the transom is wet or partially wet, resulting in less trim and higher form drag than predicted by SHIPFLOW CFD.

III.1: COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

The Hull CFD analysis was performed using the SHIPFLOW modelling and analysis program. The main intent of this calculation was to estimate the best angle for the stern flap and to establish an initial bilge keel trace. SHIPFLOW models the flow around the hull as nonlinear potential flow, calculating an equilibrium sinkage and trim from the integrated dynamic pressure.

It computes wave resistance using either an integration of the pressures or a wave cut analysis, since the wave train produced by the ship is also a result of the calculations. We used the results of these CFD calculations to estimate the stern flap angle for minimum resistance and streamline trace on the hull surface, the results applied as initial configurations for model testing. Comparison of SHIPFLOW CFD results for flap angles and their associated running trims were, showing good correlation and confirming realistic results.

A limitation of the CFD analysis is in prediction of the precise speed at which flow separation from the transom occurs (dry transom). The analysis assumed the transom was dry in all cases, meaning results at speeds above Fn = 0.3 are expected to match the actual flow well, but speeds below that may not. For hull, the Fn is 0.27 at speed of 16 knots and 0.42 for 25 knots.

III.2: INPUT DATA

SHIPFLOW runs were performed at the following conditions:

Speeds: 16 and 25 knots ship scale,
Fn=0.27 and 0.42
Bare Hull, and with wedges of 6, 8, 10 and 12 degrees

With a Froude number of only 0.27 at 16 knots, it is probable that the transom is wet or partially wet, resulting in less trim and higher form drag than predicted by SHIPFLOW CFD.

IV.RESULT OF NUMERICAL ANALYSIS

The CFD runs provided two estimates of wave drag, surface pressure integration and wave cuts. Resistances presented in this report are results from surface pressure integration. Comparisons of CFD-generated resistances with model tests have been much less successful historically than CFD-generated wave patterns, streamlines, or sinkage and trim. CR is obtained by adding a 15% form factor to the CFD calculated wave drag coefficient (CW). All of these were for bare hull (no stern flap).

IV.1. VISUAL REPRESENTATIONS

The stern flap suppresses the wake behind the transom and alters the flow behind the stern. This can be clearly seen from Figure 1 and Figure 2 , which show the comparison, with flap and without, of the wave surface elevation at 16 knots. Wave height is non-dimensionalized by the waterline length. Figure 3 and 4 show similar results at 25 knots. At top speed, the surface elevation is much higher and the disturbance area is much larger. Note, due to the image scale, the contrast of the stern wave suppression of the stern flap is visually less obvious at top speed than that at cruise speed. The flap effect on the stern flow is also obvious from the contour plots of the hull surface dynamic pressure, as shown in Figures below.

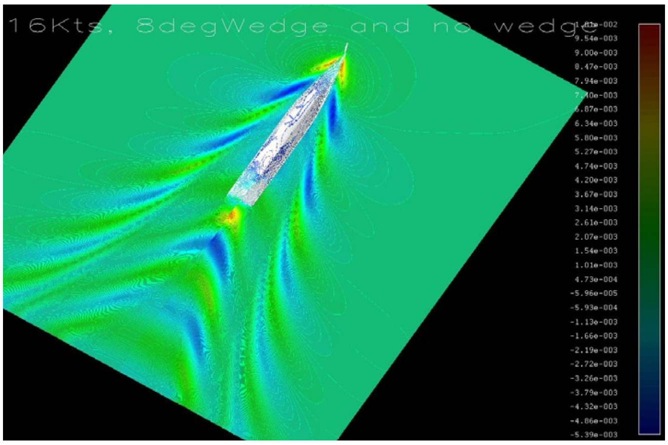

FIG 1 :Free Surface Comparison at 16 knots, 8 deg wedge (port) vs. no wedge (stbd)
(wave height non-dimensionalized by LWL)

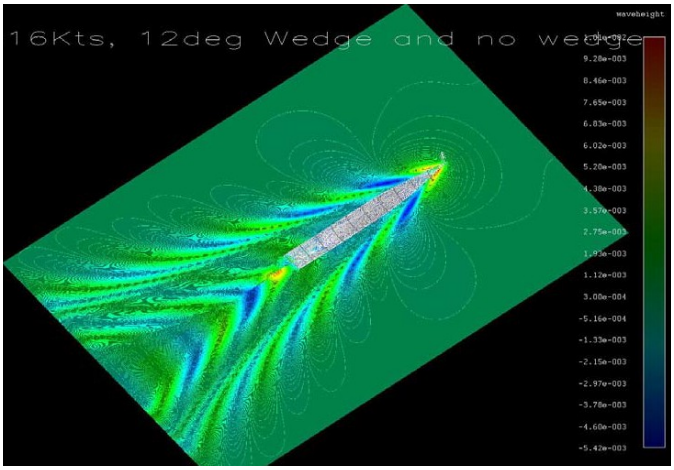

FIG 2 : Free Surface Comparison at 16 knots, 12 deg wedge (port) vs. no wedge (stbd)
(wave height non-dimensionalized by LWL)

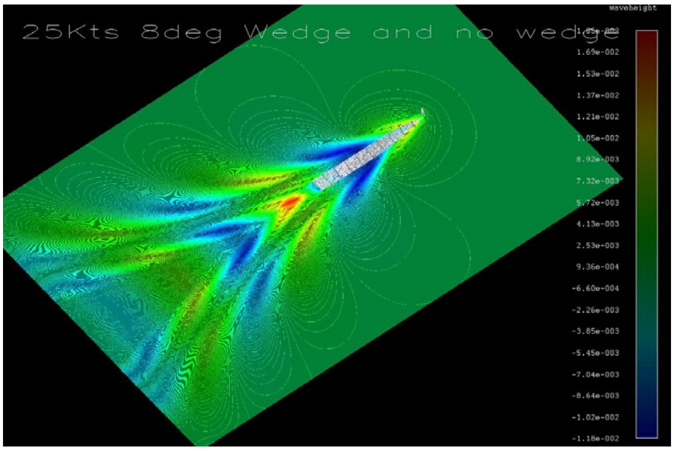

FIG 3 :Free Surface Comparison at 25 knots, 8 deg wedge (port) vs. no wedge (stbd)
(wave height non-dimensionalized by LWL)

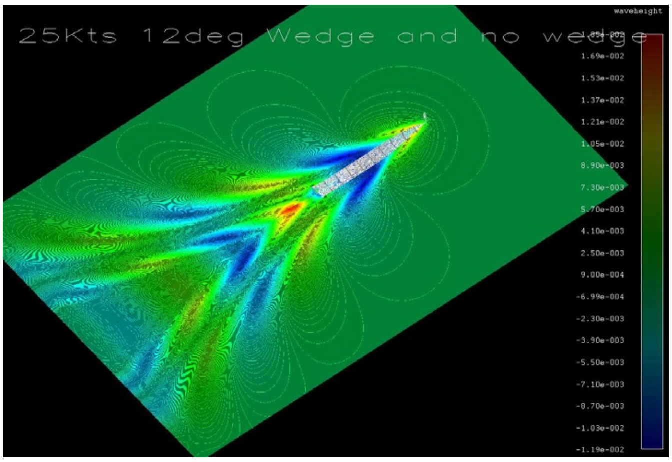

FIG 4 : Free Surface Comparison at 25 knots, 12 deg wedge (port) vs. no wedge (stbd)
(wave height non-dimensionalized by LWL)

IV.2 : OUTPUT DATA FROM SIMULATIONS:

Sinkage and Trim

The stern flap is most effective modifying the trim rather than the sinkage, but since it also reduces resistance (somewhat related to the suction forces causing sinkage), sinkage is expected to be reduced by flap deployment. The CFD runs gave predictions for sinkage and trim. These predictions are based on computations of the flow around the hull, modified by changes to sinkage and trim from the resulting dynamic pressures around the hull. The software continues computing corrections until convergence is achieved (no further change in sinkage or trim from the most recent computation of the flow pressures). The trim in degrees is plotted against Froude number for bare hulls in Figure below.

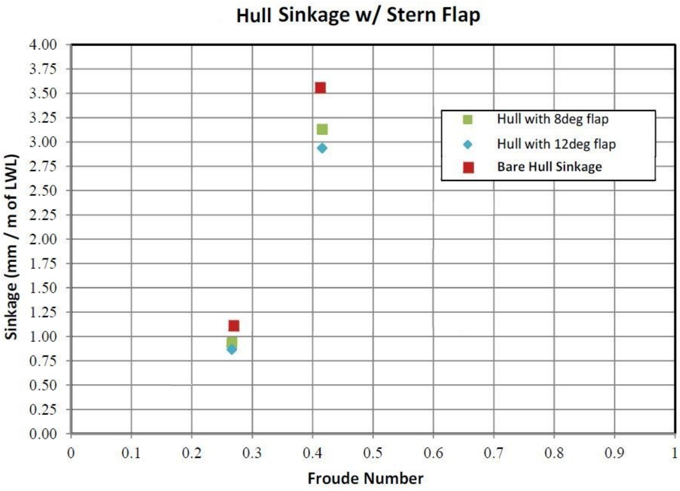

FIG 5 : Dimensionless Sinkage with Stern Flap Angles of 8 and 12 degrees

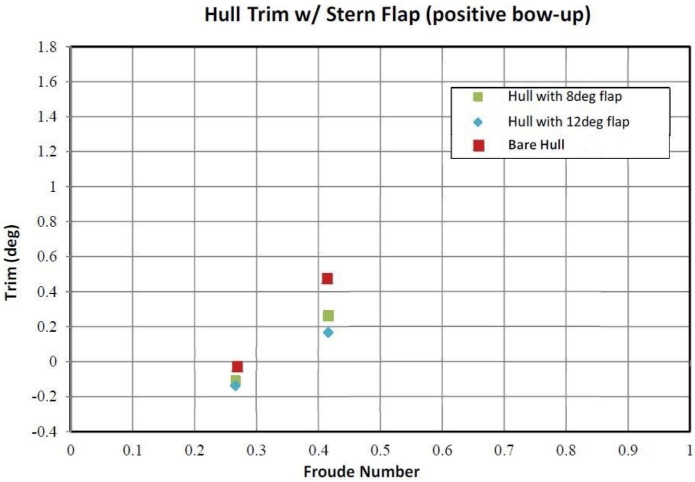

FIG 6 :Trim Angles with Stern Flaps of 8 and 12 Degrees

Resistance

The CFD runs provided two estimates of wave drag, surface pressure integration and wave cuts. Resistances presented in this report are results from surface pressure integration. Hull CR is obtained by adding a 15% form factor to the CFD calculated wave drag coefficient (CW). All of these were for bare hull (no stern flap).

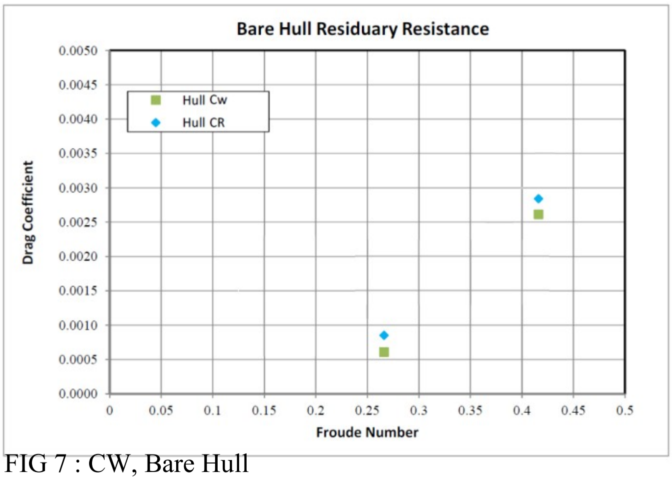

FIG 7 : CW, Bare Hull

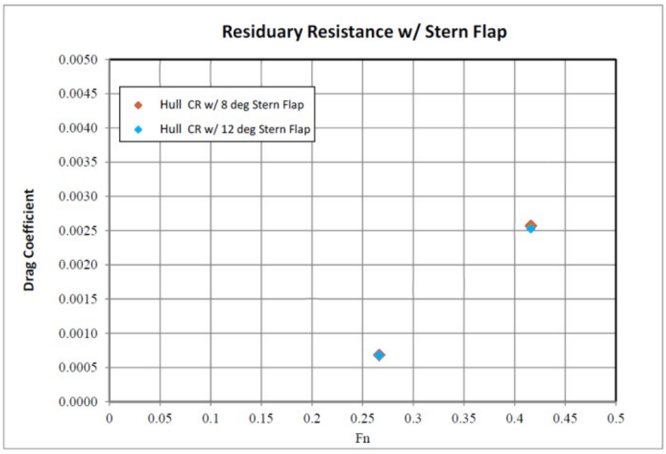

FIG 8 : CW for Stern Flap Angles of 8 and 12 degrees

V. RESULTS

For the prototype vessel, an 8 degree flap will yield about 10% residual drag reduction, which amounts to 6.3% total drag reduction at 25 knots. The 12 degree flap yields about 11% and 7.2%, respectively, based on CFD calculation. CFD shows the flap having even better reduction at cruise speed of 16 knots. However, the dry transom assumption may not be completely valid since the transom flow may not be totally separated at 16 knots.

VI. REFERENCES

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