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Interceptor and trim tab combination to prevent interceptor's unfit effects

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ABSTRACT

Trim tabs, small surfaces connected to the end of the craft to control the trim by adjusting the angle of tab, relative to the larger surface, have been used to optimize the running trim of displacement, semi-planning, and planning vessels for many years. Interceptors are the same as trim tabs, but are vertically installed at the end of the craft to control the trim by changing the height. As demonstrated in this paper, the same size as the interceptor and trim tab (when span and chord of trim tab are respectively equal to span and height of interceptor), the interceptor shows better efficiency (better trim and resistance reduction). While efficiency of trim tab just depends on the trim tab angle, the effective factors on the interceptor effectiveness are little complicated. The interceptor efficiency highly depends on the interceptor height and boundary layer thickness at transom. Although the higher interceptor increases the amount of lift force, but that could create a very strong moment against trim moment and consequently negative trim angle. The results of this investigation prove that the combination of an interceptor with a trim tab shows better performance compared to an interceptor or a trim tab. Also instead of increasing the interceptor height to gain more lift, which could make intense negative trim, it is better to use integrated interceptor with trim tab. To do so, a comprehensive series of dynamic CFD simulations have been performed in the case of a simple planning boat model with three different trim control appendages. Unsteady Reynolds Average Navier-Stokes equations (URANS) are applied to model the flow around the considered model with interceptor, trim tab and combination of an interceptor and a trim tab at an equal span length. The model is analyzed based on finite volume method and SIMPLE algorithm using dynamic meshes in the Fluent computational code. For validation of the CFD results, the Savitsky planning boat calculations (only for model boat) and the grid convergence index (GCI) were used to estimate the uncertainties due to grid-spacing and time-step.

1. Introduction

At the direct motion of a vessel, a pressure distribution is created at the bottom of the vessel which causes the vessel trim and the vessel resistance. The hydrostatic pressure is generated at low speed (or Froude Number < 0.5) and hydrodynamic pressure is produced at high speed (Froude Number > 0.7), refer to Blountand and Codega (1992). The dynamic pressure distribution changes with the vessel motion, which causes the draft and trim variations. Trim variations may cause an increase in vessel resistance and create instabilities such as Porpoising instability in the fast vessels, see Ikeda et al. (2000). Therefore, it is necessary that the trim be controlled at the vessels and high speed crafts. The vertical blades, plates and wedge-shaped components, which are planted at the aft of the vessel, are the trim control appendages at the planning vessels. The most well-known trim control device of the high-speed planning crafts might be the trim tab. Trim tabs have been first generation of trim control device in fast vessel for many years. In recent years, interceptors have been successfully used on airplane wings, missiles, and boats to create lift forces for attitude control, refer to Xi and Sun (2006), Savitsky (1964), Ghadimi et al. (2012), Rostami et al. (2016) and Zeraatgar et al. (2012). Fig. 1 shows the outline of an interceptor, a trim tab and a combination of an interceptor and a trim tab implementation at the bottom of a planning craft.

For the first time, a series of model tests to compare and determine the roles of interceptor and Trim Tab, was suggested by MDI company (Maritime Dynamics, 2011) with interceptors of different heights, but the same span size. By means of tests, the hydrodynamic advantages of interceptors over trim tabs at different heights are clear. In the case of the controllable appendages, research efforts by Karafiath and Fisher (2009), Zeselezcky and Johnson (1984), and Zseleczky and Hays (1984) express that stern wedges have helped the surface combatant ships with their resistance and powering features. Molini and Brizolara (2005) introduced a very simple potential flow model for the prediction

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Nomenclature

d	interceptor height at the transom	$\overrightarrow{X}_j^m$	node position of neighbor node of $\overrightarrow{X}_i^m$ at iteration m
I	height (in -y direction) of interceptor	α	boundary node relaxation factor
h	boundary layer thickness at the transom	δ	trim tab angle
h_{min}	the minimum cell height of cell layer j	γ	layer collapse factor
h_{ideal}	the ideal cell height	μ	laminar viscosity
L	length of the boat	μ_t	turbulence viscosity
n_i	number nodes neighboring node i	U	velocity vector (u, v, w)
t	height (in -y direction) of trim tab	P	pressure
$\overrightarrow{\overline{X}}_i^m$	averaged node position of node I at iteration m	ρ	density
		S	momentum source
		β	the layer split factor

of pressure and lift force in front of the interceptors. Tsai and Hawing (2004) examined the effect of trim mechanisms on resistance decrease. The outcomes of the experiment verify that the resistance of the planning craft and the running trim can be reduced by a well-designed trim mechanism. Peláez et al. (2010) performed a preliminary CFD simulation with Fluent to find the best angle for stern flap at every speed of boat. The outcomes refer to a great increase of efficiency (vertical force to drag force). Syamsundar and Datla (2008) presented a tank-test study of interceptors fitted to a prismatic 3.75-feet-long planning hull, with the goal of extending the well-known semi-empirical method for prediction of planning hull performance by Savitsky (1964) to incorporate the use of interceptors. By their investigations, a simplified approximation for the pressure generated by the interceptor has been proposed, based on a drag coefficient obtained by treating the interceptor as a surface imperfection, and integrated into the Savitsky methodology. Their method developed qualitatively, predicting the general trends of the test results, but the quantitative accuracy was less satisfactory.

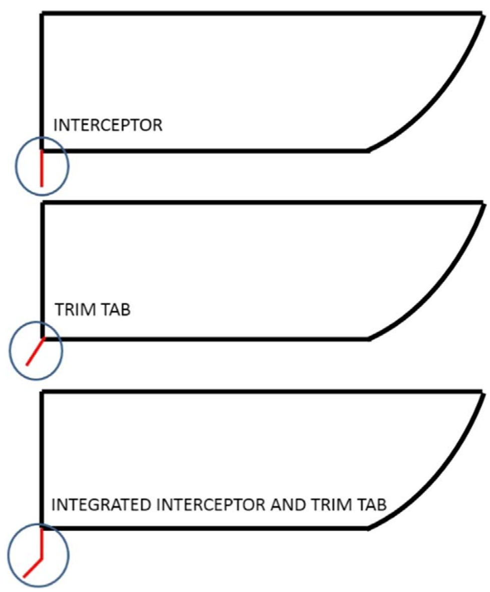

Fig. 1. The implementation of interceptor, trim tab and combination of interceptor and trim tab.

The effect of hydrodynamic interceptors on fast crafts are investigated by Ghassemi and Mansoori (2011) to find their optimum geometrical characteristic based on numerical method. Their results show that the interceptor causes an intense pressure rate on its contact point. It also decreases the wet surface of the craft and drag force coefficient. At last, they lead to a better control of trim. For first time, the effects of boundary layer thickness on interceptor efficiency have been investigated by Mansoori and Fernandes (2015, 2016a). Their finding proved that, for good interceptor efficiency, except the interceptor height, many parameters should be taken into consideration, but the most important factors, which are from boundary layer, could be summarized as d/h ratio. Also they showed that, the interceptor could control porpoising instability (Mansoori and Fernandes, 2016b).

In this paper (which is in continuation of previous investigations of the authors, refer to Mansoori and Fernandes (2015) and Mansoori and Fernandes (2016a and 2016b)), a planning model boat is simulated with dynamic mesh which involves 2 degrees of freedom. The URANS equations, Versteeg and Malalasekera (1995), are applied to study a planning boat model which has separately an interceptor, a trim tab and the combination of them at two different sizes. At first, the effect of the trim tab, interceptor and integrated of them on pressure changes at the stern are studied. in the continue, the paper investigate the effect of the trim tab angle on trim tab efficiency, the effects of the interceptor height and boundary layer thickness at the stern on weak and unfit interceptor. At the end, this investigation introduces a good way by combining interceptor with trim tab to solve unfit effects of the interceptor height increment and consequently more safety.

Table 1
General details of Simulations.

Multiphase model	Volume of Fluid
Solver	Pressure Based
Velocity Formulation	Absolute
Unsteady Formulation	1st-order Implicit
Gradient Model	Green-Gauss Cell based
VOF Scheme	Implicit
Body Force Formulation	Implicit Body Force
Operating Conditions	Reference Pressure Location
Direction Vector	Direction Specification Method
Backflow Direction Specification Method	Normal to Boundary
Under-Relaxation Factors	Pressure=0.5 Momentum=0.1
Discretization (pressure)	PRESTO
Discretization (Pressure-Velocity Coupling)	SIMPLE
Volume Fraction	QUICK Scheme
Discretization (Momentum)	Second Order Upwind
convergence criteria	continuity to 1e−08
The Temporal and Spatial Approximations	Second Order Accuracy
CFL Number	2

Table 2
The independence of the grid to the elements number.

Trim (deg)	R_t/Disp.	The element numbers in grid
1.3	0.064	1000000 elements
1.93	0.091	5000000 elements
2.19	0.096	9000000 elements
2.4	0.103	Savitsky