

Computational Study on the Hydrodynamic Effects of Interceptors Fitted to Transom of Planing Vessel



Suneela Jangam, V. Anantha Subramanian and P. Krishnankutty

Abstract The use of stern flaps, either fixed or controllable and interceptors in high-speed boats, has become an acceptable option to control the running trim of the vessel to enhance its speed and powering performance. The interceptor changes the pressure distribution underneath the hull over a certain distance forward of the transom. The stern interceptor effect on planing craft performance depends on its parameters and also on those of the craft. The aim to improve the performance on already built high-speed crafts has become an important issue for ecological and economic aspects. So, an in-depth study of the hydrodynamic behaviour of interceptor is essential, before it is adapted to a vessel, to get the best performance during the craft operation. Computational fluid dynamics (CFD) is being used for modelling ship flows due to the advances in computational methods. The aim of this paper is to predict the pressures and resistance characteristics of a high-speed planing craft equipped with an interceptor. The data regarding trim and resistance is generated for a planing hull with interceptor using CFD. In view of the above, an interceptor with 1 mm height is used to study the performance of a planing hull and compared with the experimental studies of Savitsky, Steen, and Srikanth. The numerical model predicts favourable trim and reduced drag for the planing hull with an interceptor.

Keywords Hydrodynamics · Stern interceptor · Planing hull · Resistance · Trim

Nomenclature

LCG	Longitudinal centre of gravity
C_f	Schoenherr turbulent friction coefficient
∇	Volume of displacement
ρ	Mass density of water
Δ	Displacement

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β	Deadrise angle
V_1	Average bottom velocity
V	Forward speed
h_i	Height of interceptor
$C_{D_{int_S}}$	Coefficient of drag by Steen
$C_{L\beta}$	Lift coefficient for a deadrise surface
A_D	Additional drag force due to interceptor
b	Maximum beam at chine
D_f	Viscous component of drag
c	Distance between N and CG
N	Resultant of pressure forces acting normal to bottom
τ	Trim angle of keel, deg
λ	Wetted length to beam ratio
ε	Turbulent energy dissipation rate
i	Interceptor height
L_w	Mean wetted length
D_{int_S}	Added drag due to interceptor

1 Introduction

The application of interceptor to high-speed planing crafts is a relatively recent innovation. The idea for interceptor design discussed herein originated from transom flaps research conducted in the 1900s. Interceptor is a stern appendage which consists of a thin plate fitted on or near the transom of a boat whose sharp tip follows the shape of the transom edge. Interceptors do not extend aft of the transom but go vertically downwards at the transom. Stern wedges, flaps are all been used commonly on many high-speed small crafts such as work boats, patrol crafts, and pleasure crafts. However, the principal reasons for the effectiveness of these devices on high-speed crafts are significantly different from that on large ships such as destroyers and frigates. The stern interceptors create a vertical lift force at the transom and modify the pressure distribution on the aft portion of the hull. The knowledge of the hydrodynamic action of the interceptor, which changes the surrounding flow, is important for selecting its size, form, and orientation. The practice shows that the blade always experiences a decelerated mean flow at the aft by Brizzolara [1]. On planing crafts which operate at high speed and derive a significant portion of the total hull lift from dynamic forces, the vertical forces from interceptor affect the hull trim angle by as much as 2° – 4° . The effect of interceptor on the drag and trim of prismatic hulls for different deadrise angles is presented by Luca and Pensa [5]. On these hulls, the key to minimizing resistance is to reduce the hull trim angle. The most effective planing surface that maximizes hull dynamic lift and minimizes wetted surface, friction drag, and wave resistance is derived at this reduced trim angle. John et al. [3] studied experimentally the effect of flaps, wedges, and interceptor on displacement vessel, catamaran, and a planing hull. They found that interceptor with

wedge gave good performance in planing hull compared to other vessels. Salas and Tampier [6] made a CFD study on a displacement hull with flaps and interceptor and used spray rail for semiplaning hull. They found the resistance reduction in all three devices is around 5–10% and evaluated them as energy-saving devices. Karimi and Abbaspoor [4] made an experimental study on a scaled-down model of a high-speed planing catamaran and tested with and without controllable stern interceptors in calm water and regular head waves, to investigate the effect of automatically controlled interceptors on vertical motion reduction of the model.

The interceptor powering benefit is attributable to the induced change in the field flow around the hull. This flow field changes cause a reduction in drag on the ships aft body and modify the wave resistance of the craft. The pressure changes are verified computationally by RANS solver using STAR CCM+ on high-speed craft for interceptor of 1 mm height. In this work, numerical modelling has been undertaken to simulate the flow past the bare hull and later with interceptor in the aft region.

2 Interceptor Development

The study on interceptor by Brizzolara [1] is carried out by one of the first and most thorough published studies on interceptor hydrodynamics. He utilized a CFD approach to study the local flow around a 2D interceptor fitted to a flat boundary representing the bottom of the ship, at a Reynolds number of 1.4×10^9 . He used a standard boundary layer approach to specify the inflow and computed the free surface in the region behind the interceptor and the pressure distribution in the region upstream of the interceptor for several interceptor sizes. Interceptors are also installed on displacement and semi-displacement hulls as given by Deng et al. [2]. Figure 1 shows the shape of the interceptor at the transom.

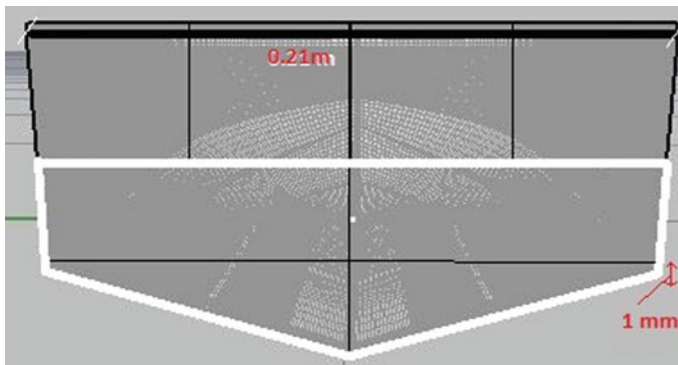


Fig. 1 Interceptor of 1 mm height at the transom

$$C_{L\beta} = \Delta / (1/2)\rho V^2 b^2 \tag{2}$$

$$D_f = C_f \rho V_1^2 (\lambda b^2) / 2 \cos \beta \tag{3}$$

These basic planing equations are used for predicting the performance of planing hull. The computational procedure involves the determination of running trim and resistance which provide for equilibrium conditions of the hull at a given running speed, load, and centre of gravity location. The above scheme is used iteratively, ensuring that first equation is satisfied by the iterative choice of values of trim angle. The hydrodynamic drag is obtained once the correct trim angle is obtained. The total hydrodynamic drag of planing surface is composed of pressure drag developed by pressure acting normal to the inclined bottom and viscous drag acting tangentially to the bottom in both the pressure area and spray area. It is assumed that the pressure acting normal to the bottom of the hull would be same as that acting on the interceptor. Along with the pressure at the transom, the interceptor also causes additional drag but is found to be very insignificant according to Srikanth and Datla [8]. Considering the formula to calculate additional drag produced due to the interceptor and the bare hull drag gives us the total drag acting on the high-speed craft.

Srikanth and Datla [8] mentioned interceptor as a surface imperfection which adds drag to the vessel where the boundary layer is forced to turn turbulent. The flow at the transom will not be laminar except for very low speeds. Depending on the size and shape, the drag is affected. In their experimental investigation on the performance of planing hull with interceptor found that there is exponential rise in drag with speed and substantial reduction of trim. They assumed that the added pressure at the bottom of hull at the transom will be same as that of the interceptor. The additional normal force they found is five times the additional drag force. The additional drag force is given by

$$A_D = 0.5\rho v^2 ib \tag{4}$$

Steen’s formulas for added drag due to interceptor for a planing hull is given below in Eq. 5. Since the drag is dependent on wetted length and height of interceptor the coefficient of drag, the added drag is given by

$$C_{D_{int_S}} = 292.18 \left(\frac{h_i}{L_w} \right)^2 + 7.183 \left(\frac{h_i}{L_w} \right) \tag{5}$$

$$D_{int_S} = C_{D_{int_S}} (0.5\rho V^2 b L_w \tau) \tag{6}$$

The wetted length is assumed to be the mean wetted length used by Savitsky.

3 Numerical Modelling

Numerical solution of any problem related to fluid dynamics is associated with a solution of conservation of equations, namely the mass and momentum conservation equations. The governing equations of fluid flow represent the mathematical statements for the conservation of mass and momentum. Numerical modelling is performed to simulate the high-speed free running condition of the vessel with consequent dynamic changes in trim, sinkage, and bottom pressure. The differential form of the Navier–Stokes equations combined with the Reynolds averaged form of the N–S equation (RANSE) gives the solution of governing equations for practical engineering applications. The determination of resistance and trim angle of a planing craft at speed involves simulation in calm water on the free surface, and for this purpose, the volume of fluid (VOF) method is used. This study is carried out using the commercial CFD software STAR CCM+.

3.1 Computational Domain and Boundary Conditions

A large domain was created in order to avoid effects from the domain boundaries to affect the flow near the hull. The vessel is enclosed by 3D rectangular parallelepiped computational domain over which the flow is solved. In Fig. 3, the computational domain is illustrated and its dimensions are expressed in terms of the overall hull length, LOA. These dimensions agree well with the minimum recommendations of ITTC.

The top, side, and bottom of the domain were prescribed with symmetry boundary conditions, and the hull was set to a wall with no slip. At the inlet, located in front of the hull, the velocity of the incident air and water was set to the hull speed that was simulated. The outlet located behind the hull was set to a pressure outlet. The inlet boundary conditions were used to initialize the flow field (Table 1).

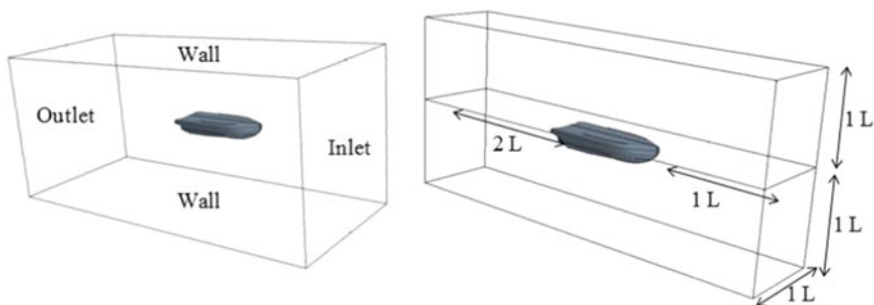


Fig. 3 Computational domain

Table 1 Boundary conditions for 20 m medium craft in calm water simulation

Inlet	Velocity inlet
Outlet	Pressure outlet
Walls	Slip
Body	No slip

3.2 Solver Parameters

The flow equations are solved sequentially in segregated solver where the pressure and velocity change with time. This means an appropriate pressure–velocity coupling procedure is to be adopted. The procedure adopted in this study for coupling the pressure and velocity is semi-implicit method for pressure-linked equations (SIMPLE). The turbulence model used is realizable $k-\epsilon$ which gives better results compared to standard $k-\epsilon$ because of the new equation used for dissipation rate. VOF is a free-surface modelling technique for tracking and locating free surface. This means an appropriate pressure–velocity coupling procedure is to be adopted. The procedure adopted in this study for coupling the pressure and velocity is SIMPLE (Semi-Implicit Method for Pressure-Linked Equations). A summary of the solver settings is given in Table 2 and the principal particulars of the vessel is shown in Table 3.

4 Results

High-speed planing craft of 20 m length with a design speed of 25 knots is considered for the study. To validate the current solution, the resistance of the craft in calm water is obtained and compared against experiments for the bare hull. The obtained CFD results of resistance and trim are shown in Fig. 4.

The present numerical model is used to analyze:

1. The effect of trim and drag on the hull in calm water for bare hull and interceptor.
2. The longitudinal distribution of pressure on the hull for bare hull and interceptor.

Table 2 Solver parameters used for 20 m craft in calm water simulation

Parameter	Setting
Solver	3S segregated, unsteady, implicit
Viscous model	Realizable $k-\epsilon$
Pressure–velocity coupling	SIMPLE
Free-surface scheme	VOF
Discretization of convective acceleration for transport equations	Second-order upwind scheme

3. The effect of the stern wave for the craft with and without interceptor.

4.1 Effect of Trim and Drag

Figure 5 shows the resistance and trim for the bare hull and interceptor of the model. To study the effect of trim angle, the planing hull with deadrise angle 20° is evaluated and compared with bare hull. The increase in speed will result in an overall decrease in drag and trim compared with bare hull and hull with an interceptor. For the 1-mm-height interceptor, the resistance is increasing as speed is increasing and

Table 3 Principal particulars of the high-speed planing hull taken for study

Particulars	Prototype	Model
Length, L (m)	20.5	0.873
Breadth, B (m)	5.3	0.212
Draft, T (m)	1.062	0.046
Depth, D (m)	1.03	0.412
Displacement, Δ (kg)	46,000	2.94
Block coefficient, C_b	0.41	
Design speed, V	25 knots	2.57 m/s
Scale	1:25.011	

Fig. 4 Comparison of total resistance and trim for the bare hull model

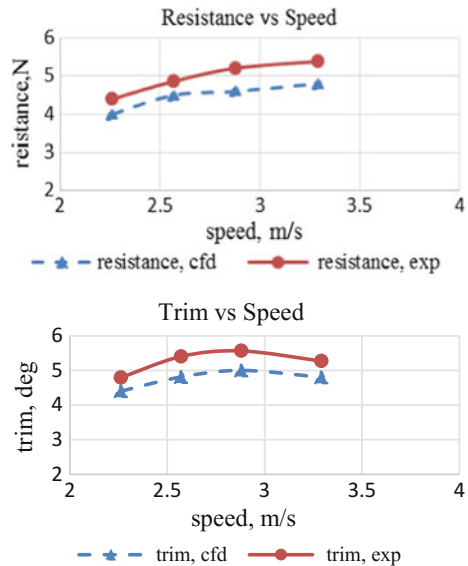
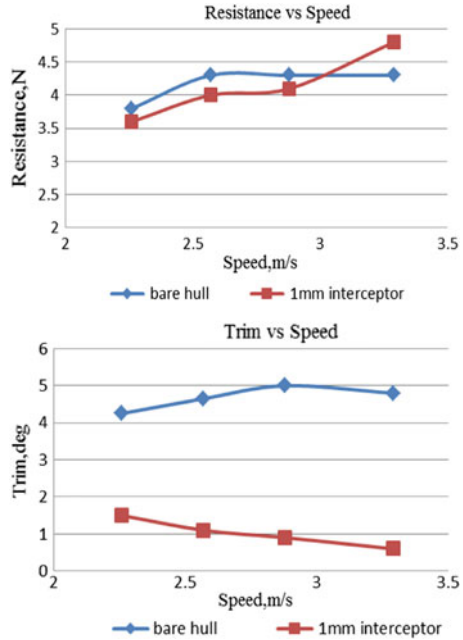


Fig. 5 Total resistance and trim of craft without and with interceptor of 1 mm height



trim is decreasing with increase in speed. When compared with bare hull, there is a reduction of 5–7% in resistance. There is better performance with interceptor at a design speed of 2.57 m/s.

4.2 Pressure Distribution on the Hull with and Without Interceptor

The longitudinal pressure distribution at the design speed is given in Figs. 6 and 7 for CFD simulations. To study the longitudinal pressure distribution, hull without interceptor and with interceptor is taken. The result for interceptors of 1 mm height is compared with the bare hull. As shown in Fig. 6, the pressure distribution on the bottom of bare hull is less at the stern when compared to the hull with an interceptor. Due to this high pressure at the stern, the hull experiences a lift force at the transom and rises up which gives trim on the vessel with less drag. Figure 7 describes well that there is no pressure at the transom of bare hull, whereas the pressure is acting at the transom where the interceptor is fitted.

Fig. 6 Pressure distribution at the bottom of hull without and with an interceptor at design speed (model)

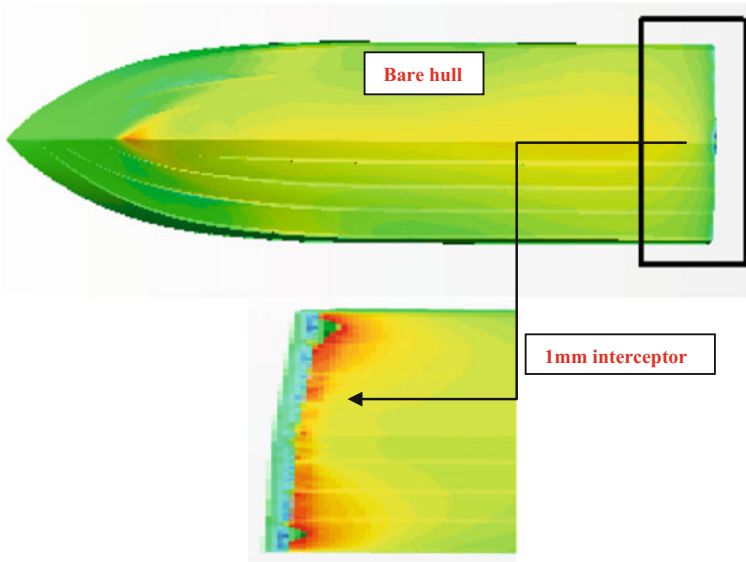
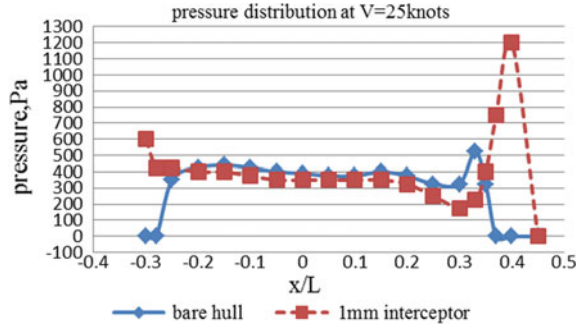


Fig. 7 Pressure distribution along the wetted surface of the model boat and at the stern interceptor of 1 mm height

4.3 Effect of Stern Wave

The free-surface wave pattern is shown in Fig. 8 which shows the wake at the stern is actually modified when compared with the bare hull. The energy transfer from hull to the water is more in the bare hull which increases the resistance of the craft. The effect of rooster tail is experienced in the stern region of planing hull and is not seen in the forward region. As a result, the effect of rooster tail is studied for 1-mm-height interceptor.

The results of stern wave height are presented in Fig. 9 in terms of height of stern wave over speed. The localized flow around the transom is greatly modified by the stern interceptor. Thus, the interceptor reduces the height of this peak traditionally

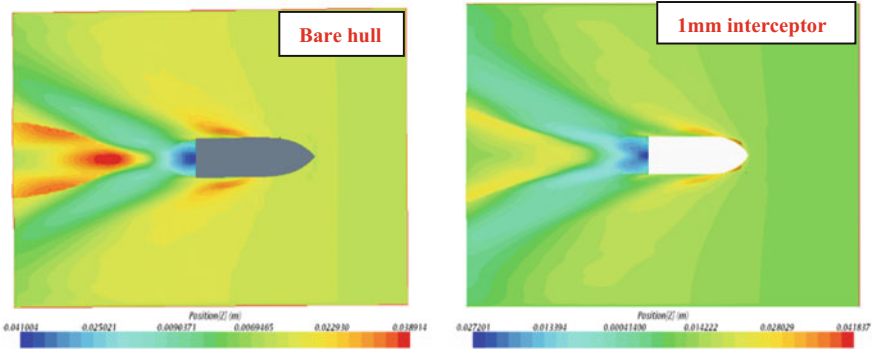
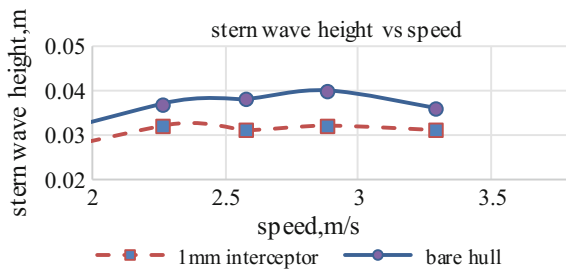


Fig. 8 Free-surface wave pattern for the bare hull and with interceptor at design speed

Fig. 9 Stern wave effect for bare hull and 1-mm-height interceptor



known as rooster tail. It has been observed that the best performance is reached by the interceptor of 1 mm height in comparison with bare hull.

5 Comparison of Resistance Between CFD and Standard Formulation

The numerical results of resistance described in the previous Sect. 4.1 are used as a reference to compare the standard Eqs. (2) and (3) proposed by Savitsky for bare hull. Srikanth and Datla [8] gave formulas to calculate drag produced by interceptor which says that the drag produced by interceptor is not very significant. Rest of the equations are used same as Savitsky [7]. So, Fig. 10 shows the comparison of CFD calculated resistance for the craft with interceptor of 1 mm height with Steen [9] and Srikanth and Datla [8] which follows the trend. Both Steen and Srikanth gave the formulations for added drag due to interceptor from the experimental results.

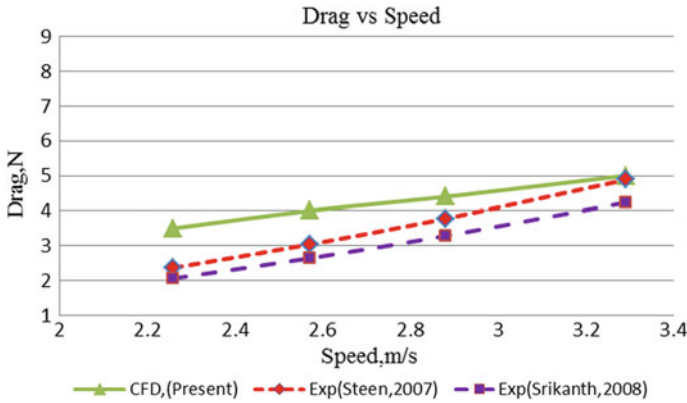


Fig. 10 Comparison between RANS prediction and those obtained by Srikanth and Datla [8] and Steen [9] with an interceptor

6 Conclusion

From this study, the following conclusions are envisaged:

- Stern interceptors represent viable mechanisms for reducing the powering of high-speed crafts.
- The stern interceptor causes the flow to slow down at the forward of the interceptor. This decreases flow velocity, increases pressure under the hull, and in turn causes reduction in resistance acting on ships aft body.
- The reduction in resistance is of 7% compared to bare hull.
- The trim of the craft is very less in case of the bare hull and so the resistance is increasing with speed as the wetted surface area is more.
- The stern wave height decreases with speed for the craft installed with interceptor when compared to the bare hull.
- Planing crafts experience large changes in trim due to interceptors, which can greatly affect the dynamic lift because of the pressure created at the transom due to the interceptor.

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