

Retrofitting Integrated Wedge-Flap for Improvement of Resistance of High-Speed Displacement Vessel



Lijo Joseph and V. Anantha Subramanian

Abstract This paper reports the design for retrofitting of a high-speed displacement vessel for improving the speed because of deficiency in installed power for a 250-passenger ferry craft. The methodology is based on the evaluation of the integrated wedge-flap at the stern. High-speed displacement vessels operate at a steep region of the speed–resistance curve, and therefore, conservation of energy by drag reduction plays a major role in cost-effective operation of the vessel. The performance of the integrated wedge-flap at the stern is examined to recommend an appropriate design instead of an intuitive approach for the same. In a high-speed displacement vessel, various factors that lead to energy consumption are increased drag due to adverse dynamic trim, bow waves and unfavourable flow patterns in the stern region. The above-mentioned factors may also increase the wetted surface area of the hull, thereby increasing the overall drag and additional demand of power. The integrated wedge-flap is a combination of two appendages, namely wedge and stern flaps. The results from the study demonstrate that the integrated wedge-flap modifies the stern waves to flatter form, with reduction of the flow velocity below, resulting in increased dynamic pressure, improved trim and lift force with corresponding drag reduction. The numerical simulation of drag using commercial RANS code (Star-CCM+) shows the local influence of the energy saving appendage reinforced by validation with experiments. The study establishes a systematic method of introduction of the appendage to achieve significant drag reduction for the high-speed displacement hull form.

Keywords Integrated wedge-flap · Drag · Lift · Computational fluid dynamics · Dynamic trim · Dynamic pressure · RANS · Motion reference unit · Load cell · Dynamic fluid body interaction

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Nomenclature

C_b	Block coefficient
DFBI	Dynamic fluid body interaction
LBP	Length between perpendiculars
LOA	Length overall
LWL	Length of waterline
MRU	Motion reference unit
RANS	Reynolds-averaged Navier–Stokes equation
VOF	Volume of fluid

1 Introduction

With increasing demand for fuel conservation and emission reduction, it is very important to improve the drag characteristic and therefore propulsive power in ships. Among the many adaptations, the introduction of specific appendages is one of the means of reducing drag and bringing down the power requirement. Some of the recent innovations are stern flap, wedges and interceptor in the case of vessels with higher speed in the displacement range or dynamic lift range vessels. There are situations where ships for changes in operational conditions do not achieve the design speed, or may not have the required power to achieve the guaranteed speed. Under such situations, properly designed energy saving device or appendages can be retrofitted to the hull with not only saving of penalty but also saving power. This study presents the use of combining a wedge and a flap and therefore resulting in the integrated wedge-flap to examine and improve the speed of a displacement hull. As the name implies, the integrated wedge-flap is a combination of otherwise single entities of wedge and stern flap used as power saving device.

Integrated wedge-flap can be, in principle, an extended appendage spanning the breadth of the hull, which extends from under the bottom of the hull to aft beyond the transom, making an angle with the buttock plane of the ship. Muller-Graf [1] carried out experimental investigation on the effectiveness of different types of spray rail system in semi-displacement hull and found that properly shaped and arranged spray rail system along with transom wedge is the most effective device to reduce the hull resistance of semi-displacement hull with round bilge keel. Karafiath et al. [2] reported greater power improvement in the case of integrated wedge-flap than the wedge acting alone or flap acting alone. They observed that at low speed, the integrated wedge-flap remains submerged fully, and thereby causing increased drag. At high speed, the flow detaches cleanly from the trailing edge of the integrated wedge-flap and slows down the flow velocity from the aft-most portion of the ship to the point forwards of the propeller. The decrease in flow velocity leads to increase in dynamic pressure, which results in a lift force that makes the integrated wedge-flap to come out from the submerged condition. Due to that, there will be a favourable trim,

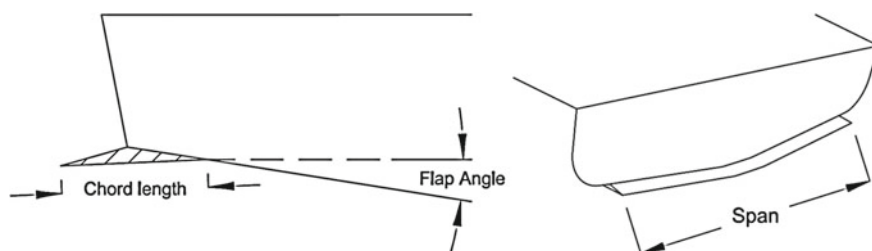


Fig. 1 Integrated wedge-flap

Table 1 Principal particulars of the vessel

Type of vessel	250-passenger ferry
LOA	47.50 m
LBP	44.12 m
Beam	10.00 m
Depth	4.30 m
Mean draft	2.10 m
Design speed	15 knots
Cb	0.544
Froude number	0.37
Model scale	15.95

decrease in wetted surface area, and these results in drag reduction. Later investigators experimented with the applicability of different hulls such as displacement, semi-displacement and planing hulls (Fig. 1).

Many researchers have reported the improvements due to wedge, spray rail or their combinations in the case of semi-displacement vessels [3] and high-speed vessels [4] and stern flaps Yaakob et al. [5]. Cumming et al. [6] reported that longer chord length results in improved resistance. Salas et al. [7] conducted numerically and experimentally the effect of individual appendages on the range of crafts from displacement, semi-displacement and planing hulls. These studies collectively touch upon different aspects of the influence of the appendages as drag reducing devices. This work reports the specific effect of the wedge-flap assessed through numerical simulation and validated from the experiments.

The principal particulars of the vessels are given in Table 1.

2 Parametric Study

As a specific case study, the approach here is to vary the chord length of the integrated wedge-flap through a range of distance, which is chosen from available literature guidelines. Firm guideline length is not available; however, a reasonable range can

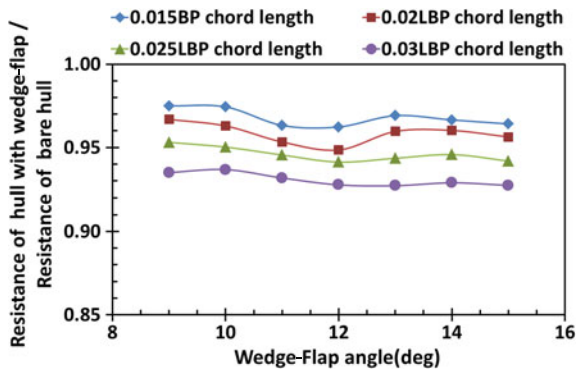


Fig. 2 Reduction of drag using different wedge-flap parameters

be selected from consideration of the fact that the flap length cannot be excessive since structurally it will require increased thickness to take the hydrodynamic load, and thereby adding its own drag. Other parameters are flap angle and flap span. On these considerations, the lengths have been chosen as 1.5, 2.0 and 3.0% of LBP. Wedge-flap angles are chosen in range from 9.0° to 15.0° with an increment of 1.0° . From the literature, it is found that the maximum reasonably possible span across the transom without impinging on the wake of the corners of transom and without requiring significant curvature of flap will give better performance [2]. The simulation has been performed for the Froude number ranging from 0.27 to 0.37.

Results of parametric study are given in Fig. 2; it is observed that at 12.0° flap angle, all the wedge-flaps with different chord length are giving higher reduction in resistance and also with increase in chord length the performance is getting better slightly. From the structural point of view, higher chord length is avoided. The more favourable wedge angle is 12.0° and chord length is 2.0% of LBP.

3 Computational Analysis

Computational analysis is performed by using commercial RANS code-based software, STAR-CCM+. Computational analysis is carried out by following the recommendations of ITTC 7.5-03-02-03 [8]. Taking advantage of symmetry, half of the model is used for analysis in order to bring down the convergence time. Analysis is carried out on model scale to facilitate direct comparison. The simulation has been performed for bare hull and hull with integrated wedge-flap (Fig. 3).

For mesh generation, unstructured meshes are used on the surface as well as for volume meshing. Surface remesher helps for generating surface mesh or remeshing the surface imported from the CAD software. Triangular meshes are formed on the surface by employing surface remesher as shown in Fig 4.

Trimmer mesh model is used to generate volume meshes, which forms hexagonal grids with minimum skewness and trimmer cells. To capture the boundary near the wall and to simulate turbulent velocity profile, prism layer mesh model is used along with volume mesh to generate orthogonal cells near the wall. Volume mesh used for the simulation with domain parameters is shown in Fig. 5. Boundary conditions are shown in Table 2.

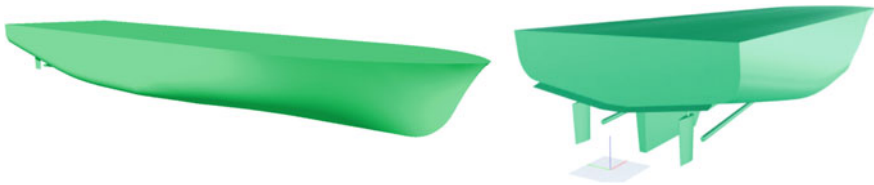


Fig. 3 Ship hull used for numerical analysis



Fig. 4 Surface meshed using surface remesher

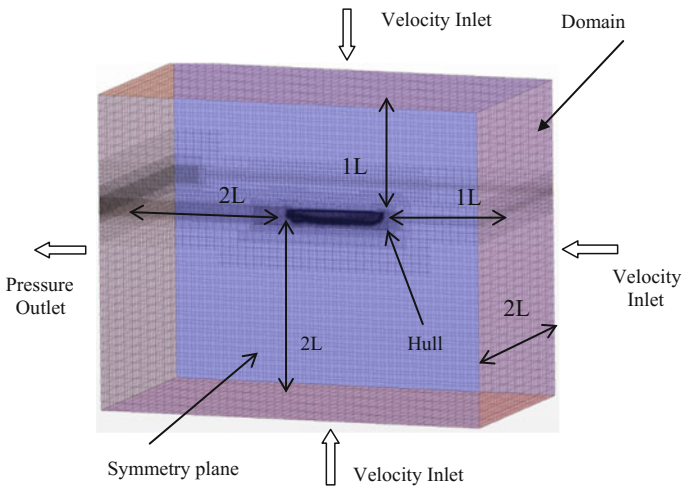


Fig. 5 Volume mesh used for the simulation

Table 2 Boundary conditions

Faces	Physical boundary	Boundary condition
1	Domain inlet	Velocity inlet
2	Domain outlet	Pressure outlet
3	Domain top	Velocity inlet
4	Domain bottom	Velocity inlet
5	Domain side wall	Symmetric plane
6	Domain symmetry	Symmetric plane
7	Hull	Wall

Equation of motion of the body for the 6DOF is solved using Reynolds-averaged Navier–Stokes equation. Realizable K –epsilon turbulence model is used to solve the Reynolds stress in the Reynolds-averaged Navier–Stokes equation. The interaction between hull and fluid is captured using dynamic fluid body interaction (DFBI). Free surface is captured using VOF model. Two-layer All Y+ wall treatment is used along with k –epsilon turbulence model to solve viscous layer near wall. Segregated flow is used to solve flow equations. Implicit unsteady solver is used to control the update of the calculation at each physical time and controls the time step size.

As an observation, low-speed simulation shows that the wedge-flap gives adverse effect in reducing drag, and at higher speeds, there is drag reduction. The integrated wedge-flap improves the pressure distribution at the aft region at higher speed. Pressure contours are shown in Fig. 8. The pressure distribution along the length is shown in Fig. 9, and the influence of the wedge-flap is evident in the increased pressure at the stern region. The wedge-flap improves the dynamic trim at higher speed, see Fig. 7. Figure 6 shows the comparison of total drag.

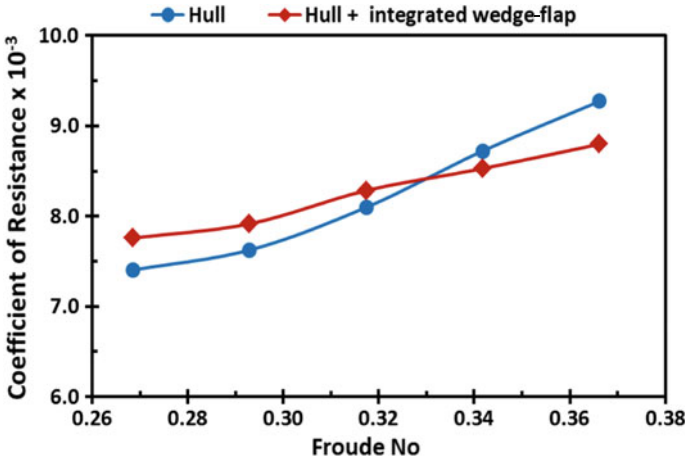


Fig. 6 Total resistance coefficient versus Froude number

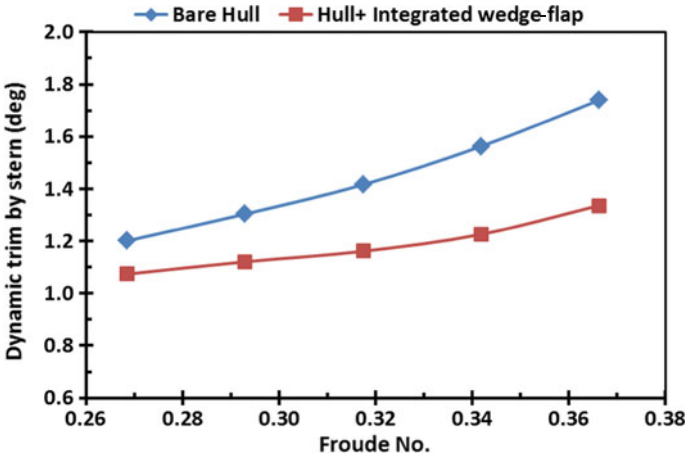


Fig. 7 Dynamic trim versus Froude number

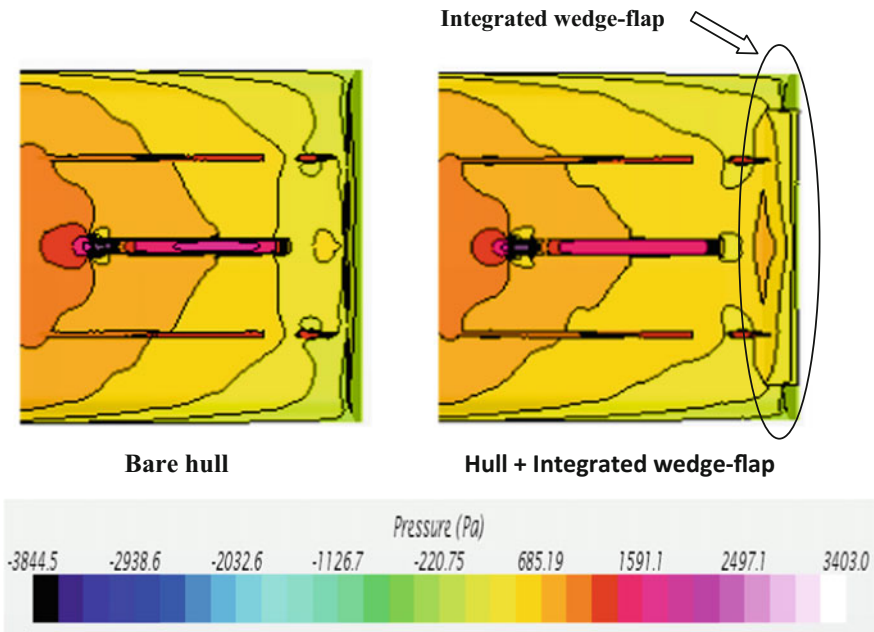


Fig. 8 Pressure distribution contours on the aft region of the hull

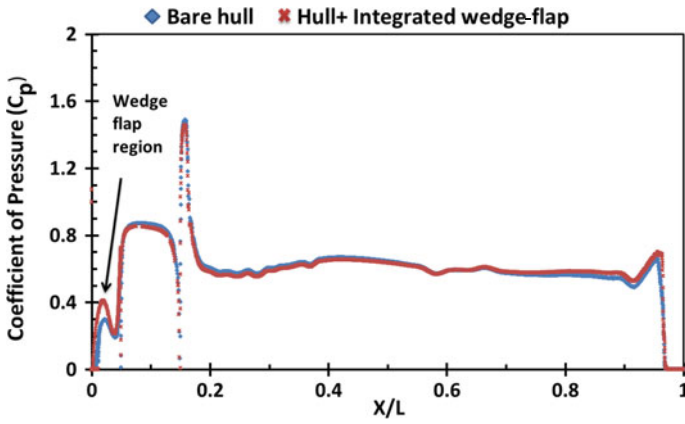


Fig. 9 Pressure variation along length of ship from stern to bow



Fig. 10 Hull used for the experiment



Fig. 11 Integrated wedge-flap attached to the hull

4 Experiment and Validation

Experiments were conducted for validation and confirmation of the results. Tests were done as per *ITTC 7.5-02-02-01* [9]. The model scale is **1:15.95**. The tests measure both drag and trim. Comparison is shown in Fig. 12.

See Figs. 10, 11, 13, 14, 15 and 16; Table 3.

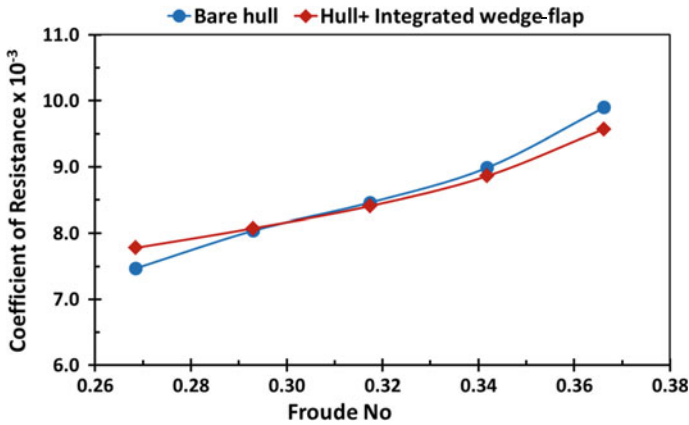


Fig. 12 Coefficient of resistance versus Froude number

Table 3 % Reduction in resistance by incorporating wedge-flap from CFD and EXPT

Sl. No.	Froude number	Coefficient of resistance				% Reduction in resistance with wedge-flap	
		Bare hull		Hull + wedge-flap		EXP	CFD
		EXP	CFD	EXP	CFD		
1	0.27	7.47E-03	7.41E-03	7.78E-03	7.76E-03	-4.16	-4.77
2	0.29	8.04E-03	7.63E-03	8.07E-03	7.92E-03	-0.46	-3.81
3	0.32	8.46E-03	8.10E-03	8.41E-03	8.28E-03	0.63	-2.31
4	0.34	8.99E-03	8.72E-03	8.86E-03	8.53E-03	1.41	2.25
5	0.37	9.90E-03	9.27E-03	9.57E-03	8.80E-03	3.30	5.12

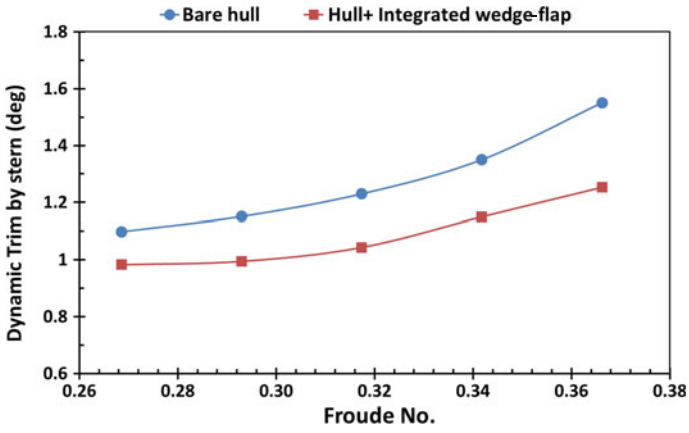


Fig. 13 Dynamic trim versus Froude number

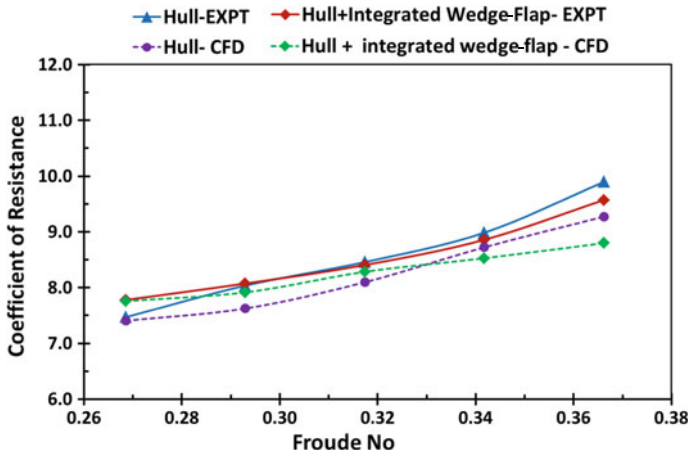


Fig. 14 CFD and experimental results comparison

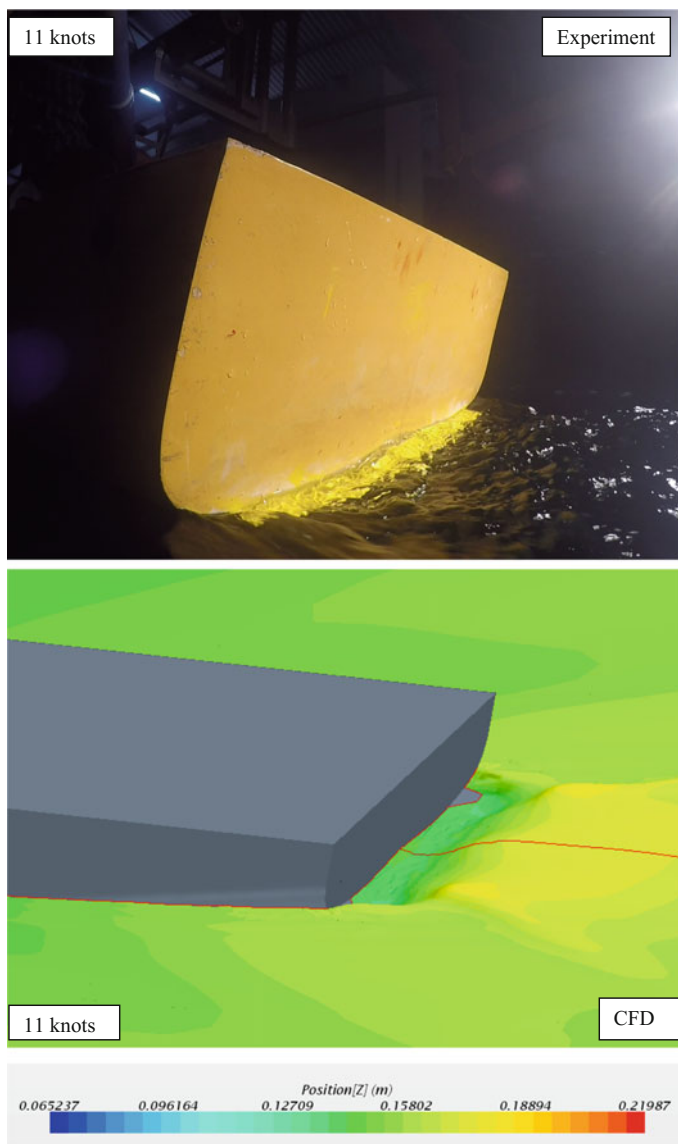


Fig. 15 At 10 knots speed, integrated wedge-flap is fully submerged

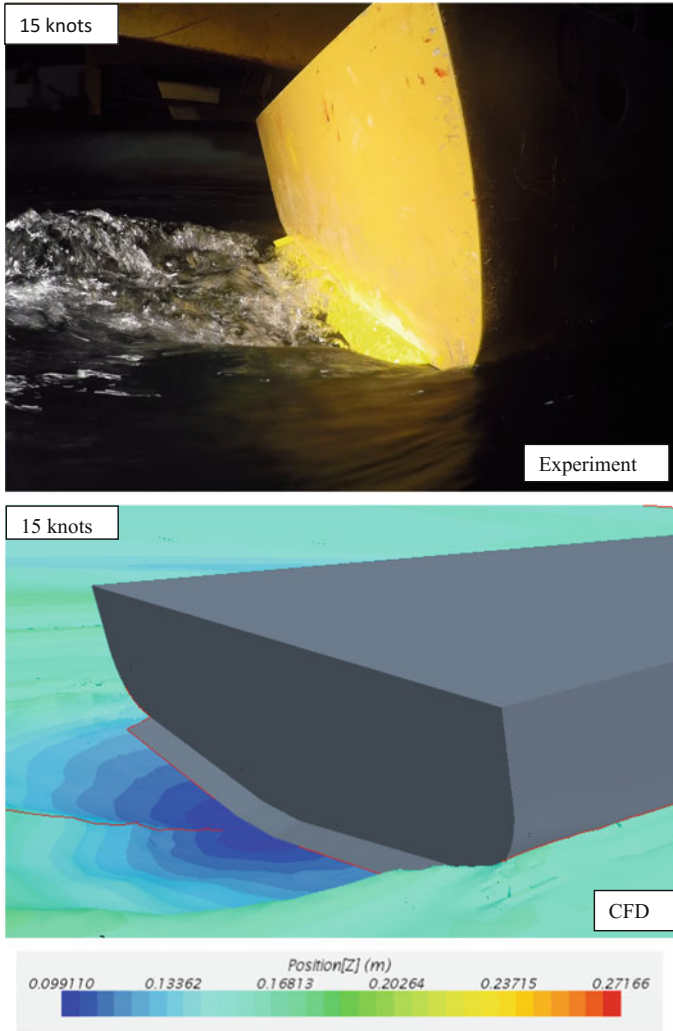


Fig. 16 Wedge-flap causes flow separation at 15 knots

5 Results and Conclusion

- Studies have been conducted on high-speed displacement vessel in a Froude range of 0.27–0.37.
- Hull attached with integrated wedge-flap provides adverse effect in reducing total drag at Froude number less than 0.32, but higher the Froude number its effect is being improved.
- Larger chord of integrated wedge-flap gives better performance compared to smaller ones.
- Experiment results from towing tank test show good agreement with CFD results.
- At design, Froude number of 0.37, integrated wedge-flap is reducing drag of 5.12% compared to bare hull.
- To reduce full-scale flap manufacturing cost and to simplify construction, flap ends can be rounded (radiused), with a radius equal to flap chord length.

In conclusion, the investigation provides a valuable tool and guideline for the design and retrofitting of an integrated wedge-flap. The retrofitting has resulted in the vessel achieving the guaranteed speed overcoming the earlier deficiency in engine power.

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