Defence Science Journal, Vol. 69, No. 4, July 2019, pp. 409-414, DOI : 10.14429/dsj.69.12893

Energy Conservation Method Combining Anti-spray Rail and Wedge Flap for High-speed Displacement Hulls

Lijo Joseph*, Naga Venkata Rakesh N. and V. Anantha Subramanian

Department of Ocean Engineering, IIT Madras, Chennai - 600 036, India
**E-mail: lijojoseph022@gmail.com*

ABSTRACT

The hydrodynamic mechanism and parametric influences of the wedge flap and the anti-spray rail in combination is investigates. A methodology with specific guidelines for incorporating these appendages with significant drag reduction is provided. Small crafts designs frequently require interventional changes to realise the desired guaranteed speed with their installed engine power. The appendages namely, the wedge, flap and anti-spray rails are used as retrofit measures or adapted in new hull forms, in isolation or in combination, to improve the drag and bring down the power requirement. A judicious combination of different appendages can result in significantly reduced drag and therefore power saving. The methodology combines the results of numerical and experimental investigations. The systematic study identifies the parameters for control namely, wedge flap size in terms of the chord length, its orientation vide the angle of the wedge flap, and the anti-spray rail location with respect to the water surface. The choice of the size of the wedge flap is a constrained problem since excessive wedge flap can cause problems related to length and hydrodynamic loading. This study establishes a solution by combination of a minimum integrated wedge flap with properly located anti-spray rail to reduce the drag. The study shows favourable influences due to local pressure and numerical results using a RANSE solver show good comparison with experimental test results. The methodology is a new approach towards drag reduction in new designs as well as drag control by retrofit.

Keywords: Integrated wedge flap; Anti-spray rail; Drag; Lift; Dynamic trim; Energy saving device

NOMENCLATURE

BWL	Breadth on water line
CAD	Computer-aided design
CFD	Computational fluid dynamics
EXPT	Experiment
ITTC	International towing tank conference
LBP	Length between perpendiculars
LWL	Length of the water line
MRU	Motion reference unit
MEMS	Micro electro-mechanical system
NS	Numerical simulation
RANSE	Reynolds averaged Navier Stokes equation
VOF	Volume of fluid
C_T	Total resistance coefficient
D	Experiment result
E	Comparison error
S	Simulation result
T	True value
U_{SN}	Uncertainty in simulation
U_D	Uncertainty in experiment
U_V	Total uncertainty

1. INTRODUCTION

Drag reduction devices in marine application, such as the wedge, flap and anti-spray rails are well known and are adapted in new hull form designs and also as interventional retrofit measures in built hulls. Their use may be in isolation or in combination, to improve the drag and bring down the power requirement. Literature reports in recent decades are available with regard to systematic studies on the effects of these appendages in bringing down the resistance of different hull forms. The choice of the size of the flap is a constrained problem since, an excessive length flap may be effective for drag reduction, but cause excessive ship length and structural loading problems. This problem is addressed by considering the triple combination of the individual devices of flap, wedge and anti-spray rail.

The stern wedge serves to deflect the downstream flow with resultant pressure build up, alteration of trim and consequent altered pressure component to reduce the drag. Figure 1 (A) shows the integrated wedge flap which serves to augment the lift and thereby improve the trim of the vessel. The important parameters of the integrated wedge flap are the chord length, span and wedge flap angle. Karafiath[1], *et al.* reported that the combination of wedge and flap gives greater power improvement than by either of the devices in isolation. At low speed there may be a penalty by way of increased drag; however, at high speed the flow detaches clean from the trailing edge of the integrated wedge flap, slowing down the flow velocity from the aft-most portion of the ship to the point near the propeller. The resulting dynamic pressure gives enough lift for the wedge flap to come out of the water. Consequently, there will be favourable trim change, decreased wetted surface

Received : 09 April 2018, Revised : 21 April 2019
Accepted : 03 June 2019, Online published : 15 July 2019

area and resultant drag reduction. Song[2], *et al.* studied the influence of interceptors, stern flaps, and their combinations on the hydrodynamic performance of a deep-vee ship to enhance the energy-saving capacity of ships. It was reported that the optimum speed range of the interceptor differs from that of the stern flap. Resistance-reduction performance of the stern flap was observed to be better over the Froude number range of 0.334–0.5; however, at values of Froude number greater than 0.5, the deep-vee ship installed with an interceptor demonstrated greater drag reduction. The decrease of residual component of resistance with stern flaps accounts for 93 per cent of the reduction in total resistance.

The anti-spray rail is effective for hulls with small length to beam ratio i.e., *LWL/BWL<6* where the spray wetted area can amount up to 50 per cent of the wetted area of the hull at rest Graf[3]. It was also reported that the combination of properly designed anti-spray rail along with the transom wedge can reduce the drag of semi-displacement hulls. In planing hulls, the anti-spray rails have the potential for reducing drag in the range of 5 per cent - 10 per cent Salas and Tampier[4]. The combination of anti-spray rail along with transom wedge was also reported as effective at transition high speeds to planing range. Bojovic[5], *et al.*. The mechanism behind the anti-spray rail is that it cleanly detaches the bow wave from getting on to the hull surface, thereby reducing the bow wave resistance component from total drag and thereby leading to improved drag characteristics.

The above literature review sets the objective, which is to explore the effectiveness of the wedge flap in isolation for different lengths and, weigh the option of limiting its length while combining the design with the anti-spray rail. The methodology is numerical investigation and validation with experiments in a towing tank under controlled conditions. The studies relate to a candidate built vessel and the results provide guideline applicable to similar displacement vessels in class and range.

2. PARAMETRIC STUDY

The parametric variants are the geometric characteristics of the integrated wedge flap mainly in terms of its non-dimensionalised chord length (taken as percentage of length of the vessel, LBP) and the wedge flap angle as defined earlier. The values are as given in Table 1.

Table 1. CFD solver parameters

Parameter	Settings
Solver	3D, RANSE, unsteady, implicit
Momentum discretisation	Second order upwind
Pressure discretisation	Standard
Pressure-velocity coupling	SIMPLE
Time discretisation	First order upwind
Multiphase flow model	Volume of fluid (VOF)
Interface capturing scheme	Modified HRIC
Turbulence model	Realisable κ-ε
Wall treatment	Two-layer all wall y+ treatment
Models for body motions	Gravity, equations of motion
Degrees of freedom	Vertical displacement (sinkage) and angular about transverse axis (trim)
Time step criterion	Courant no. < 1.0

2.1 Numerical Study to Investigate the Favourable Parameters of Retrofits

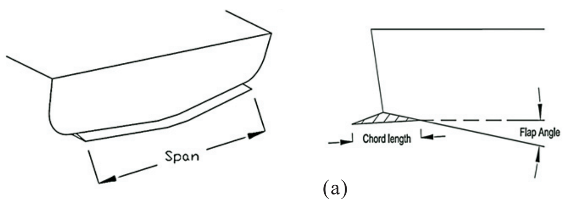
The numerical analysis employs the commercial RANSE code (Star CCM+) to perform the simulations. Taking advantage of the hull and the flow symmetry, the analysis models half the hull while considering the free surface effect as well as dynamic trim and sinkage. Cartesian grid technique is used to generate the unstructured mesh in the fluid domain and prism layers with high quality cells are used near the hull boundaries which are appropriate for the turbulence models employed. Domain dimensions and solver parameters follows the guidelines as per ITTC[6-7] as given in Table 1. The simulations are performed using model scale 1:15.95 for direct validation with experiment results. Figure 1(b) gives the hull form and Tables 2 and 3 gives the scope of numerical/experimental analysis and the principal particulars of the candidate vessel, respectively.

The grid independence study gives the optimum number of cells for the numerical analysis using refinement parameter √2. With the use of 2.3 million cells, the results stabilise to a value without much change of results and this is standardised for further analysis. The time step independent study uses the refinement parameter 2 to find the optimum time step. Based on the study, the time interval standard is 0.01 s for which no significant changes of results occur.

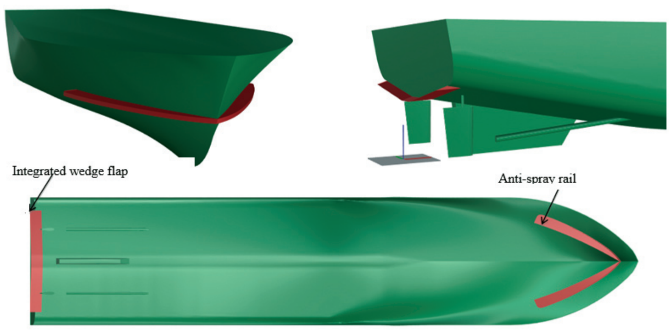
Table 2. The parameters, conditions and modes of analysis for the present study

Parameter	Values	Modes
Chord length of wedge flap	1.5, 2.0, 2.5, 3.0, 4.0, 5.0 (as a percentage of LBP)	NS*
Angle of wedge flap	9 to 15 degrees in steps of 1 degree increment	NS
Anti-spray rail location	3 different levels above draught line (20% , 30% and 40% of draft)	NS
Speed as a function of *Fn*	0.27-0.37	NS/EXPT
Conditions of hull tested	Hull without appendages	NS/EXPT
	Hull with integrated wedge flap	NS/EXPT
	Hull with integrated wedge flap and anti-spray rail	NS/EXPT

NS* - numerical study



(a)



(b)

Figure 1. (a) Definition terms for the integrated wedge flap and (b) Hull modelled for numerical analysis.

Table 3. Principal data of vessel

LOA	47.50 m
LBP	44.12 m
Beam	10.00 m
Depth	4.30 m
Mean draft	2.10 m
Design speed	15.0 knots
Block coefficient	0.544
Froude number	0.37
Model scale	15.95

3. EXPERIMENTAL VALIDATION

Table 4 gives the test matrix for the towing tank experiments performed for the purpose of validation of the numerical analysis based results. The tests are performed in a towing tank of dimensions 82.0 m long 3.2 m wide 2.5 m deep as per the ITTC guidelines in[8]. The model scale for the tests is 1:15.95 and the Froude number spans from 0.27 to 0.37. Sensitive high precision force measurement transducer, dynamic trim measurement using the Motion Reference Unit (MRU), data acquisition and automation of the towing carriage form part of the measurement system. Figure 2 shows the view of the hull used for experiments.

Figure 2. Hull used for the experiment.

4. RESULTS FROM THE NUMERICAL STUDY

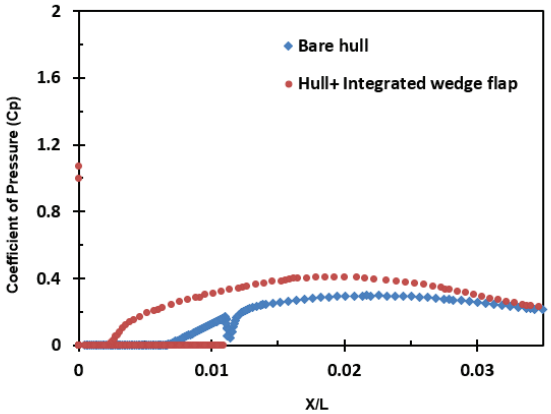
The investigations with the integrated wedge flap fitted to the hull and with different chord lengths, establish improved performance with increasing chord length. The analysis shows that the flow velocity underneath the hull in the stern region slows down in the presence of the wedge flap, this consequently leads to higher pressure distribution in and around the region of the stern. The increased pressure causes decreased (favourable) trim by stern and this change causes reduced drag characteristics. Figure 3(a) shows the pressure distribution at the wedge flap region. Figure 3(b) shows that with increase in the wedge flap length over the range 1.5 per cent to 5 per cent of the ship length (LBP), there is monotonic reduction of the drag. The same figure also shows that the wedge flap angle of 12 degrees gives optimum reduction of drag. Figure 3(c) shows the pressure contours and examination of the stern region shows that in the presence of the wedge flap the pressure distribution at the stern is higher than in the case of the hull without appendages.

Though Fig. 3(b) shows monotonic drag reduction with increased chord length, this is not of practical use since the wedge flap cannot have unlimited chord length. With increasing chord length, the cantilever flap is bound to experience increased stresses on the material of the wedge flap at the root point of connection to the hull. Also the wedge flap is an appendage increasingly vulnerable to damage as its length increases. Elementary strength calculation of the wedge flap shows that with increasing length, the thickness of the material increases from 13 mm to 36 mm. Therefore, the chord length has a constraint with an upper limit from strength consideration as well as from its extended dimension.

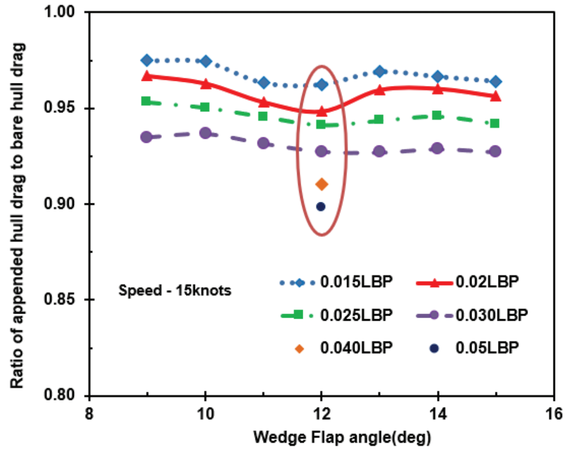
Figure 4(a) gives the drag reduction due to the influence of the anti-spray rail positioned at different height locations above the mean draught of the vessel. All these results portray the influence when taken in conjunction with the presence of the wedge flap at the stern. The three locations of the anti-spray rail represent different heights i.e., at 0.2 T, 0.3 T and 0.4 T above the draught line. In all these cases, the wedge flap chord length is constant 2 per cent of LBP and the wedge flap angle at the optimum 12 degrees as already established. A low position

Table 4. Test conditions performed in towing tank for validation

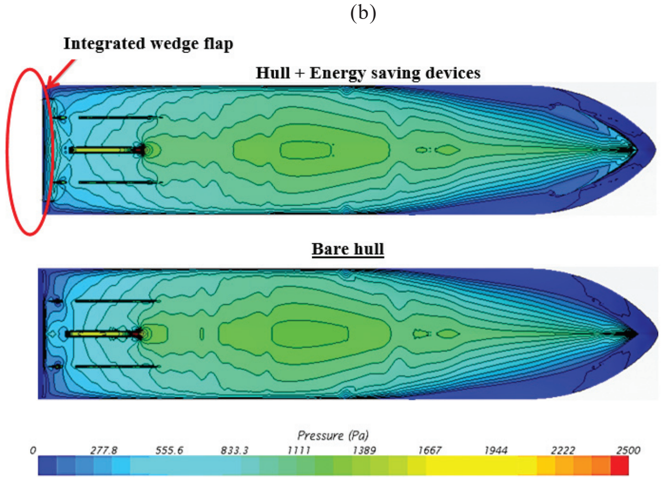
Conditions tested in towing tank Speed as a function of Fn (0.27-0.37)	Wedge flap angle (°)	Chord length of integrated wedge flap (% of LBP)	Location of anti-spray rail above draught line (% of draft)
Hull without appendages	-	-	-
Hull with integrated wedge flap	12.0	2.0	-
Hull with integrated wedge flap and anti-spray rail	12.0	2.0	30



(a)



(b)

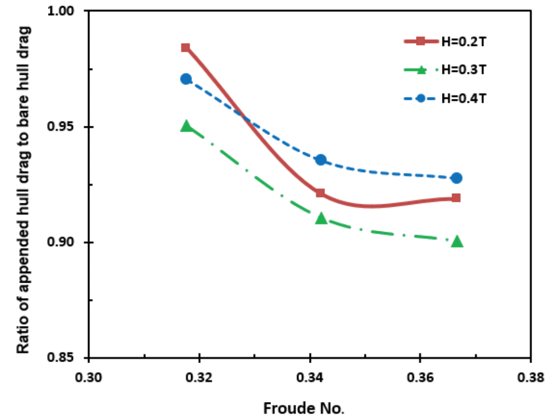


(c)

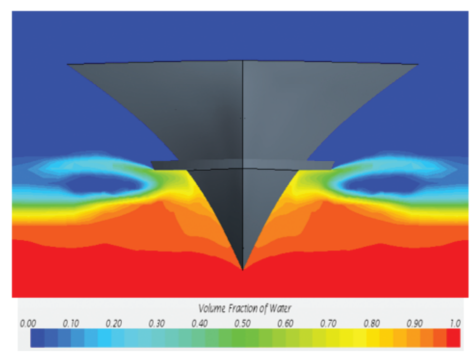
Figure 3. (a) Pressure distribution in the region of integrated wedge flap, (b) Drag reduction as a function of wedge flap angle, and (c) Pressure contours in hull with integrated wedge flap and bare hull.

of the anti-spray rail may cause it to submerge and render it less effective. Similarly, a high position of the anti-spray rail may be equally ineffective since it may not suppress the bow wave and spray for drag reduction. With correct positioning, the anti-spray rail favours correct trim of the vessel to bring down the drag. Figure 4(b) shows the effect of anti-spray rail positioned at favourable location, where it is cleanly detaching the bow waves from hull surface.

Figure 5(a) makes a very interesting observation from the overall study. An integrated wedge flap alone with large (5 per

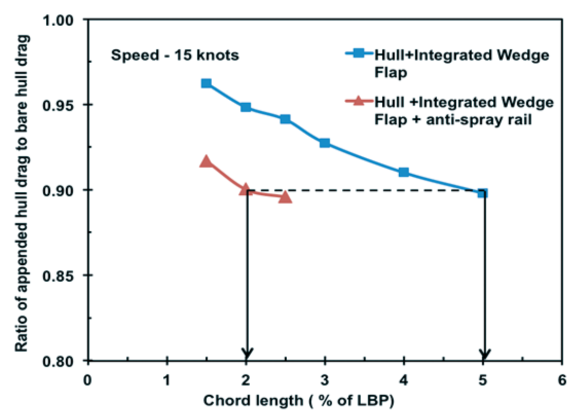


(a)

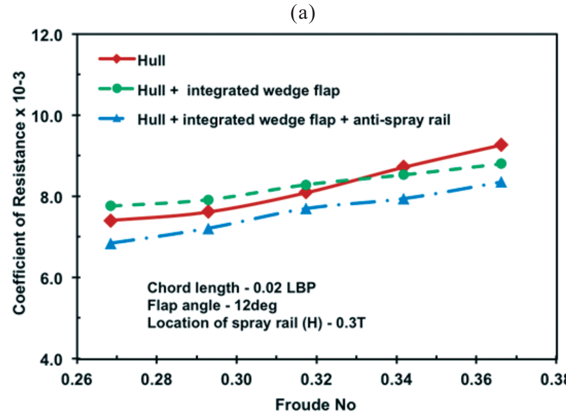


(b)

Figure 4. (a) Effect of anti-spray rail position on drag and (b) Effect of anti-spray rail at favourable location.



(a)



(b)

Figure 5. (a) Effect of combining wedge flap with anti-spray rail in drag reduction (b) Total resistance coefficient vs. Froude no.

cent of LBP) chord length achieves 10 per cent drag reduction. However, combining a small (2 per cent of LBP) chord length wedge flap with an anti-spray rail gives the same effective 10 per cent drag reduction. This is the most valuable outcome of this study. Figure 5(b) shows the total resistance coefficient in the three cases viz., hull without appendages, hull with wedge flap and hull with wedge flap and anti-spray rail.

The significant drag reduction requires validation through experiments. The results below show comparison with experiments. Figure 6 compares experimental results with those from the numerical simulations in all the three cases. The experiments carried out pertain to the hull without any appendages in the first case and the hull with both wedge flap and anti-spray rail in the second case. The results clearly validate the numerical simulation results. The numerical simulations also give insights into the mechanism of the flow pattern, the kinematics of the flow and the resultant reason for drag reduction by pressure alterations and favourable trim changes.

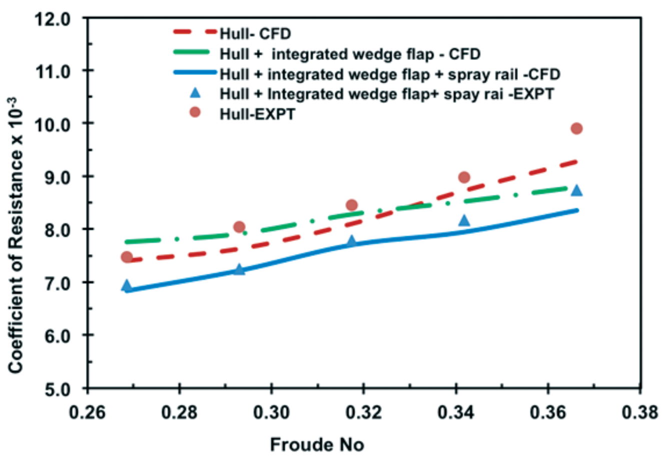


Figure 6. Validation of CFD results using experiment.

5. VERIFICATION AND VALIDATION

Verification and validations are carried out by following the methodology recommended in ITTC[9-10] which are based on Stern[11] the total simulation uncertainty (U_{SN}) is obtained as 34.52 per cent.

Towing tank total uncertainty (U_D) is evaluated as per the guidelines in ITTC[12]. Taking 95 per cent of confidence interval level, the total experiment uncertainty (U_D) is found to be 0.377 per cent ($\pm$ 0.12 N).

$$U_V^2 + U_S^2 + U_D^2$$

Validation is achieved by comparing total error (E) and total uncertainty (U_V). Total error (E) is the difference between experiment (D) and simulation (S) values. Total error (E) is obtained as 2.997 per cent compared to the finest mesh. Whereas the total uncertainty is found to be, 34.523 per cent compared to finest mesh.

Here $|E| < U_V$, means error lies within the uncertainty range so validation is achieved, as given in the Table 5.

Table 5. Verification and validation

$\%U_{SN}$	$\%U_D$	$\%U_V$	$\%\|E\|$
34.52	0.377	34.52	2.99

6. RESULTS and CONCLUSIONS

- The studies cover the investigation of drag on a high-speed displacement vessel in the Froude range of 0.27 to 0.37.
- The integrated wedge flap alone is effective only above the Froude no. range 0.3 and the anti-spray rail alone is not effective throughout the range.
- The larger chord of the integrated wedge flap gives better performance compared to the smaller chord length. However, incorporating both anti-spray rail and integrated wedge flap results in drag reduction to an order twice that due to the solitary integrated wedge flap alone.
- The combination of integrated wedge flap and anti-spray rail gives better performance throughout the Froude number range of 0.27 to 0.37.
- Experimental results from towing tank test validate the findings and establish the significant drag reduction possible with the fitting of the wedge flap and anti-spray rail combination. The CFD simulations provide insight into the mechanism of drag reduction.
- The combination of integrated wedge flap and anti-spray rail gives a reduction of 11.0 per cent of drag compared to the unappended hull at Froude number 0.37. This gives a power saving of 13 per cent. For comparison, an integrated wedge flap alone achieves 6.0 per cent reduction of drag.
- As a general remark, to reduce the full-scale flap manufacturing cost and to simplify construction, flap ends can be rounded (radiused), with a radius equal to flap chord length.

REFERENCES

1. Karafiath, G.; Dominic, C. & Cheng, W. L. Stern Wedges and Stern flaps for improved powering - U.S. Navy Experience. *SNAME Transactions,* 1999, **107**, 67-99.
2. Song, K.W.; Guo, C.Y.; Gong, J.; Li, P. & Wang, L.Z. Influence of interceptors, stern flaps, and their combinations on the hydrodynamic performance of a deep-vee ship. Ocean Engineering, 2018, **170,** 306-320. doi: 10.1016/j.oceaneng.2018.10.048
3. Müller-Graf, B. The effect of an advanced spray rail system on resistance and development of spray of semi-displacement round bilge hulls. Proceedings of the 1st International Conference on Fast Sea Transportation FAST '91. Trondheim, norway, 1991, pp. 125-142.
4. Salas, M. & Tampier, G. Assessment of appendages effect on forward resistance reduction. *Ship Sci. Technol.,* 2013, **7**(13), 37-45. doi: 10.25043/19098642.82
5. Bojovic, P.; Sahoo, P. K. & Salas, M. Effect of stern wedges and advanced spray rail system on calm water resistance of high speed displacement hull forms. *In* Proceedings of the Pacific 2004 International Maritime Conference. Ed. Laurie Prandolini. Sydney: Pacific 2004 International Maritime Conference Managers, 2004. 170-179.
6. Practical Guidelines for Ship CFD Applications - 7.5-03-02-03. ITTC - Recommended Procedures and Guidelines, 2014.
7. Practical Guidelines for Ship Resistance CFD - 7.5-03-

02-04. ITTC - Recommended Procedures and Guidelines, 2014.

8. Resitance test - 7.5-02-02-01. ITTC - Recommended Procedures and Guidelines, 2011.
9. Uncertainty Analysis in CFD, Verification and Validation Methodology and Procedures. ITTC - Recommended Procedures and Guidelines, 2008.
10. Uncertainty Analysis in CFD, Verification and Validation Methodology and Procedures. ITTC - Recommended Procedures and Guidelines, 1999.
11. Stern, F.; Wilson, R.V.; Coleman H. W. & Paterson, E.G. Comprehensive Approach to Verifaction and Validation of CFD Simulations - Part 1: Methodology and Procedures. *J. Fluids Eng.,* 2001, **123**(4), 793-802. doi: 10.1115/1.1412235
12. General Guidelines for Uncertainty Analysis in Resistance tests - 7.5-02-02-02. ITTC - Recommended Procedures and Guidelines, 2014.

CONTRIBUTORS

Mr Lijo Joseph has a Masters by Research (MS) from the Department of Ocean Engineering, IIT Madras. He is presently a lecturer in the SNGCE College of Engineering at Cochin. His research interests are in the field of numerical and experimental ship hydrodynamics. The theme of the paper blends with his four years of work on energy conservation in high speed displacement hull towards higher Energy Efficiency Design Index (EEDI), highly relevant towards green ship.
He has planned and executed the in depth hard work of carrying out both numerical simulations and experiments, followed by the analysis of test results of the present work. He also carried out the verification and validation.

Mr Naga Venkata Rakesh N. is currently a PhD Scholar and Project officer at the Department of Ocean Engineering, IIT Madras. He received his Master's in Ocean Engineering, IIT Madras in the year 2013. His research interests are in the fields of experimental and numerical hydrodynamics and with special focus on hydrodynamic optimisation of wake adapted marine propellers.
He is part of the core team in performing the simulations, experiments and analysis of the results for the present work.

Prof. V. Anantha Subramanian has been with the Department of Ocean Engineering, IIT Madras for the last 36 years. His major area is Naval Architecture and Ocean Engineering with specialised interest in computational fluid dynamics applications, computer aided ship design, ship hydrodynamics, design and testing and optimisation related to ships and floating bodies. He has been intensely involved in teaching, research, sponsored research and consultancy projects with the shipbuilding and design industry, both within India and abroad.
The present research work is an effort under his supervision.