PROJECT PROPOSAL

Investigation of Micro Bubble Drag Reduction (MBDR)and manoeuvring of vessels used for Inland Water Transportation (Shallow Water)

Submitted to

Ministry of Shipping

Government of India

under

National Technology Centre for Ports, Waterways and Coasts (NTCPWC)

Investigators

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Title of the project:Investigation of Micro Bubble Drag Reduction (MBDR) and manoeuvringof vessels used for Inland Water Transportation (Shallow Water).

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CONTENTS:

1. Summary of the proposal:

India has about 14,500 km of navigable waterways which comprise of rivers, canals, backwaters, creeks, etc. About 55 million tonnes of cargo is being moved annually by Inland Water Transport (IWT), a fuel - efficient and environment -friendly mode. Inland Waterways Authority of India (IWAI) is the statutory authority in charge of the waterways in India. It does the function of building the necessary infrastructure in these waterways, surveying the economic feasibility of new projects and also administration.In 2014, the Union Government announced the ₹5369 crore NW1 project spanning 1,400 kms from Allahabad to Haldiaon the river Ganga that would come up with technical and financial assistance of the World Bank (WB). The primary objective is to enable movement of cargo on vessels up to 1,500 to 2,000 tonnes.It has been decided to create a 1,400-km channel with a width of 45 metres and a minimum draft of 3 metres from Varanasi to Haldia to enable two vessels to pass smoothly. Moreover, DST Germany has been engaged to design ships / special vessels that can run on low draft but can carry high capacity.

It is understood that, vessels operating in shallow water experiences alteration of flow which leads to increase in drag as compared to operation in deep water. Considering operation / movement of vessels as planned by IWAI in shallow water, mostly with flat bottom, it is proposed to investigate **Micro Bubble Drag Reduction** (MBDR) in shallow water.MBDR is realized by injecting gas or air below the moving object (plate, ship etc.), which leads to two distinct Frictional drag-reducing phenomena, the bubble drag reduction, and the air layer drag reduction. With the injection of Micro Bubbles in shallow water, it is expected to compensate the increase in Drag by reduction caused due to presence of Micro Bubbles. In the Proposed Research, Experiments in towing tank will be performed for the estimation of resistance using model scale of a selectedhull withand without Micro Bubbles both in Deep and shallow water. The proposed study will include study at different speeds and different water depths. The research will also include CFD analysis at varied Air Flow rates to have optimum size of Micro Bubbles which induces maximum drag reduction.

2. Introduction

India has an extensive network of inland waterways in the form of rivers, canals, backwaters and creeks. The total navigable length is 14,500 km, out of which about 5200 km of the river and 4000 km of canals can be used by mechanised crafts. Freight transportation by waterways is highly under-utilised in India compared to other large countries and geographic areas like the United States, China and the European Union. The total cargo moved (in tonne kilometres) by the inland waterway was just 0.1% of the total inland traffic in India, compared to the 21% figure for United States. Cargo transportation in an organised manner is confined to a few waterways in Goa, West Bengal, Assam ,and Kerala. [1]

The government has ensured the passage of the National Waterways Act 2016 by which an additional 106 waterways were declared as NWs, taking the total to 111 NWs. In the first phase, 32 waterways, which are completely found to be viable, shall be developed.These include

- NW1 (Allahabad–Haldia stretch of the Ganges–Bhagirathi–Hooghly river system with length of 1620 km)
- NW2 (the Sadiya-Dhubri stretch on river Brahmaputra with a length of 891 km),
- NW3 (the West Coast Canal between Kottapuram and Kollam (168 km) together with the Udyogmandal canal (23 km) and the Champakkara canal (14 km) in Kerala with a total length of 205 km),
- NW4 (the Kakinada- Puducherry canals along the Godavari and Krishna rivers in Andhra Pradesh, Tamil Nadu and Puducherry with a total length of 1,078 Km),
- NW5 (the Brahmani river and Mahanadi delta rivers, integrated with East Coast Canal in Bengal and Odisha, with a total length of 588 km),
- NW6 (Lakhipur to Bhanga of river Barak in Assam with a distance of 121 km). [2]

Cargo proposed to be transported in NW-1 includes cement, fly ash, iron ore, iron orefines, coal, steel shed, tyres, iron fines, iron ingots, Galvanized steel plain sheets,stone chips, furnace oil, high Speed diesel (HSD), lube oil, boulders, pulses,aluminium block, sand, chips, ship blocks, food grains, manganese ore, petroleumproducts, coke, cooking coal, rock phosphate, timber, peas, slag oil, and non-cookingcoal. As per the survey traffic, current traffic transported via rail & road betweenHaldia & Varanasi is 121426130 tonne. Traffic projection studies are carried out andas per the study, projected traffic for year 2045 is 4,80,11,367 tonne. Under NW-1, 6nos of terminals are proposed out of which planning for 3 terminals is completed. Asper the planning the cargo handling capacity for base year and year 2045 is given at Table No 1 below [3]

Table 1: Traffic Forecast for Planned Navigational Infrastructural Facilities

Sr. No	**Infrastructural Facility**	**Projected Cargo-2015 (MTPA)**	**Projected Cargo-2030 (MTPA)**	**Projected Cargo-2045 (MTPA)**
1	Sahibganj Terminal	2.24	4.39	9
2	Varanasi Terminal (withcurrent land)	0.54	1.22	1.22
3	Haldia Terminal	3.18		

On NW-1 (Haldia – Varanasi), Government has projected 20 MT cargo will be transported through 750 Vessels by 2020 and by 2045,another 2100 vessels will be operated on the same highway. The primary objective is to enable movement of cargo on vessels up to 1,500 to 2,000 tonnes. It has been decided to create a 1,400-km channel with a width of 45 metres and a minimum draft of 3 metres from Varanasi to Haldia to enable two vessels to pass smoothly. Moreover, DST Germany has been engaged to design ships / special vessels that can run on low draft but can carry high capacity. Least available depth for these vessels is 2.2m at Ghazipur-Varanasi with under keel clearance (UKC) of 0.3m – 0.5m. These vessels will operate at very low speeds of 10 knots where viscous resistance dominates. [4]

Resistance of ship's hull is considered to be major factor which directly affects its speed, power requirements and fuel consumption. The main objective of several existing techniques is to find efficient ways to reduce the total resistance of the ship's hull. To improve the Hydrodynamic performance of a ship, Naval Architects are targeting both components of Total Resistance (R_T) viz. Frictional drag (R_F) and Pressure drag (R_P).

Based on the study carried out in past for the drag reduction, various kinds of drag reduction technologies (both Frictional and Pressure drag reduction) are summarized as shown in Fig.1.

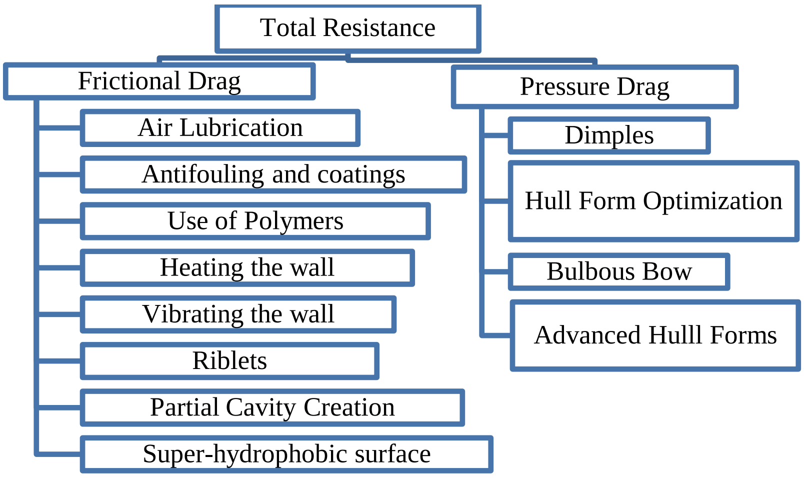

Fig. 1 Methods to reduce the Drag of a ship

For merchant vessels operating at lower speeds, R_F contributes to almost 60%-70% of the R_T. This forced researcher worldwide to focus their research on reducing R_F by

- Micro Bubble Drag Reduction (MBDR)
- Use of Polymers
- Antifouling and Coating
- Heating the wall
- Vibrating the wall
- Surface Morphology- Riblets
- Super-hydrophobic surface

Implementation of these methods through the boundary layer control reduces the surface drag of the underwater and floating vehicles by delaying the onset of turbulent flow in the boundary layer. These turbulent flows can occur in the boundary layer near solid surfaces and the associated friction reduces, as the flow velocity increases. This necessitates unabated research into drag reduction. Literature survey also suggests that emphasis of the research should be on reducing the drag by way of combining above drag reducing methods which reduces the drag even up to50%.

3. Micro Bubble Drag Reduction (MBDR)

To investigate the drag-reduction and explore the practical applications in turbulent boundary layers, methodology of Micro Bubble Drag Reduction (MBDR)is becoming quite reliable technique. As shown in the fig 2, it is realized by injecting gas or air below the moving object (plate, ship etc.).

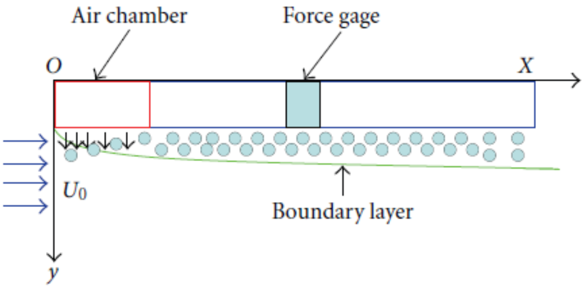

Fig 2. Schematic drawing of a microbubble injecting system(plate on top)

This leads to two distinct drag-reducing phenomena, the bubble drag reduction, and the air layer drag reduction. Experimental results of the air bubble drag reduction show that a significant drag reduction of greater than 50% could be made in the first few meters downstream of injection. [5]

Study using a super-water-repellent (SWR) surface and air injection has been made [6] with a tube of rectangular cross section, along with resistance tests on a horizontal flat plate, a 7.2-m-long tanker model, and a 12-m-long high length-to-beam-ratio model ship. These test results showed that the frictional resistance on the SWR surface was reduced by 80% at a speed of 4 m/s and 55% at 8 m/s. Also, at Froude number 0.20, the frictional drag on the SWR surface of the tanker bottom is reduced by about 40%. Schematic arrangement of the test is placed at Fig 3.

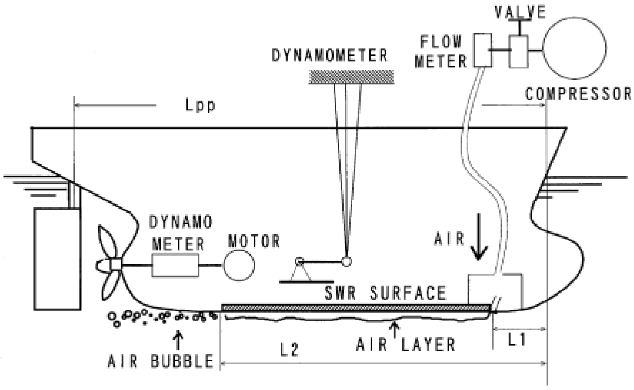

Fig 3 Schematic view of a model ship equipped with the SWR & A technique

Actual ship trails have been carried out [7] – [8] to understand a real energy-saving effect by MBDR. In fact, world's first trial carried out by Mitsubishi Heavy Industries, Ltd. (MHI) on a newly-built carrier. MSI had decided to develop this technology toward general carriers such as VLCCs and bulk carriers. As shown in the Fig 4, Air bubbles were discharged from the air blow-off portion mounted on the bottom of the hull and the air bubble flowcovers the bottom of the hull. From experiment, it was confirmed that, a net energy-saving of a maximum of 12 percent in a sea trial is possible.

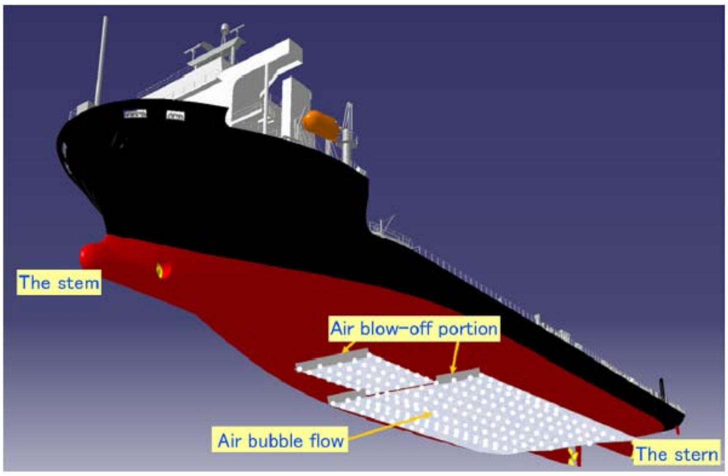

Fig 4 Air Bubbles discharged below the actual Hull

Research carried out in the past on MBDR concluded that,

(a) When microbubbles are introduced into the boundary, the density and turbulent viscosity of the fluid near the body will decrease, so the production and dissipation of turbulence kinetic energy will be lower, and then the frictional drag will decrease.

(b) An additional momentum source caused due to the injection of gas bubbles redistributes the flow structure of carrier phase within the boundary layer, by increasing the normal water velocities causing a noticeable reduction of the mean streamwise velocities, thereby lowering the resultant skin-friction coefficient along the wall surface.

(c) The higher the flow rate of gas injection, the thinner the film of liquid thereby reducing the shear stress and drag forces between water and wall.

(d) Reduction depends upon the volumetric concentration of the bubbles, and upon their location and distribution in the boundary layer. The bubbles are most effective when they are in the buffer layer.

Moreover, most of the research carried out in this field have opined that, further research is necessary as follows

(a) To re-develop or re-calibrate bubble coalescence based on the flow conditions.
(b) To carry out more systematic parametric studies on the dependence of turbulence descriptors on flow parameters like liquid and gas flow rates and bubble size. It might be particularly interesting to consider cases with varying bubble size at constant bubble number density and the other way around.
(c) To study the causes and effects of changes in fluid density and the turbulence modulation effects of air bubbles inside the boundary layer.
(d) Experimentally validate the simulation results using towing tank experiments of ship model.
(e) To study effect of MBDR in restricted area viz. motion in shallow water, restricted channel on reduction of frictional drag. It is opinion that, increase in drag for Inland and Coastal vessels where ship motion is restricted by channel width or depth will be compromised by reduction in friction frictional drag by MBDR. Also, motion in restricted area will assist the proper distribution of air bubbles below the hull.

4. Objective

The objective of the project is to study the effectiveness of MBDR in shallow water. It will includeexperimental and CFD analysis in reducing the dragof the vessel by injecting microbubbles of different size both in deep and shallow water. The study will be extended to find the effect of such vessels manoeuvring in shallow water.

The proposed investigation includes

(a) Carrying out model test for the selected hull at different speeds in deep water to determine its resistance without injection of microbubbles.

(b) Carrying out model test for the selected hull at different speeds in deep water to determine its resistance with the injection of microbubbles by varying air flow.

(c) Carrying out model test for the selected hull at different speeds in shallow water to determine its resistance at various shallow water depths without injection of microbubbles.

(d) Carrying out model test for the selected hull at different speeds in shallow water to determine its resistance with the injection of microbubbles by varying air flow.

(e) CFD analysis of flow surrounding the hull with and without injection of Microbubbles both in Deep and Shallow water.

(f) Carry out the experimental manoeuvring trials and numerical study of such vessels in shallow water

5. Literature review

Experimental studies [9] – [12] on flat plate has been carried out to understand the effect of Air Lubrication on reduction of drag. Effectiveness of five different gases - air, helium, carbon dioxide, argon and sulfur-hexafluoride to reduce the skin friction drag has been studied [9] at different freestream speed. From the study, it is concluded that, the density of a gas appears to play a minor role in its suitability as a drag reducer. Helium, the least dense of the gases tested, gave the best drag reduction performance.Experiments in the USA Navy's William B [10] – [11] has been conducted on a hydraulically smooth flat plate at various speeds. The mean bubble diameter developed was of size 300 μm. It is concluded that, at the lowest speed and highest air injection rate, buoyancy pushed the air bubbles to the plate surface and they coalesced to form a nearly continuous gas film giving near-100% skin-friction drag reduction. At the higher speeds, the bubbles generally remained separate and Skin-friction drag reduction was lost when the near-wall shear induced the bubbles to migrate from the plate surface. Here it is also concluded that, three distinct regions exist:

- Region I, where drag reduction grows linearly with gas injection rate;
- Region II, a 'transition zone' where drag reduction increases linearly with a much steeper slope than in Region I; and

- Region III, an ALDR zone characterized by a thin air film between the test-model surface and the liquid free stream where 90% ± 10% drag reduction is observed.

6. Methodology

For this investigation, Hull form of Merchant vessel with flat bottom will be selected for the analysis and the study on this selected hull form will be carried out in following stages.

Stage 1

- Survey on selection of hull form operating in shallow water considering injection of Micro Bubbles below it.
- Manufacture of scaled model of hull.
- Experimental prediction of resistancein deep water both with and without injection of Microbubbles at different speeds of the ship and at different rate of air flow rate.

Stage 2

- Experimental prediction of resistancein shallow water both with and without injection of Microbubbles at different speeds of the ship and at different rate of air flow rate by varying depths of water.

Stage 3

- CFD analysis to establish resistance estimates in deep water both with and without injection of Microbubbles at different speeds of the ship and at different rate of air flow rate.
- CFD analysis to establish resistance estimates in shallow water both with and without injection of Microbubbles at different speeds of the ship and at different rate of air flow rate.
- CFD Analysis to optimize the air flow rate to have size of Micro Bubbles giving least resistance at different water depths.

Stage 4

- Experimental investigation of maneuveringin shallow water both with and without injection of Microbubbles at different speeds of the ship and at different rate of air flow rate by varying depths of water.
- Numerical investigations of the above.

7. Timelines for the study is as tabulated: -

Task	0-6 months	7-12 months	13-18 months	19-24 months	25-30 months	30-36 months
Literature review	X					
Model manufacture and experimental tests in deep water without injection of Micro Bubbles	X	X				
Experimental tests in deep water with injection of Micro Bubbles		X				
CFD analysis and validation		X				
Experimental tests in shallow water without injection of Micro Bubbles			X			
Experimental tests in shallow water with injection of Micro Bubbles			X			
CFD analysis and validation			X	X		
Maneouvering tests in deep water without injection of Micro Bubbles				X		
Maneouvering tests in deep water with injection of Micro Bubbles					X	
CFD analysis of manoeuvring tests						X
Report writing						X

8. Cost Projection:

The study is envisaged to be completed in two years. The requirement is in the way of manpower for executing design and experimental analysis, hardware component for experiments and computing, licenced software to executing the analysis.

Grant	1st year	2nd year	3rd year	Total
1. Research Staff				
P.O. (Ph.D) (02)	873600	960960	1057056	**2891616**
P.A. (M.S)(03)	1170000	1287000	1415700	**3872700**
2 Model making and model testing	15,00,000	450000	450000	**2400000**
3 Creation of false bottom for entire towing tank	13,00,000	-	-	**1300000**
4 Hard ware cost for computing	8,00,000	700000		**1500000**
5. Specific Equipment for conduct of manoeuvering in shalow basin		8,00,000	8,00,000	**1600000**
6. Computational licences	6,00,000	6,00,000	6,00,000	**1800000**
4. Contingency	100000	100000	100000	**300000**
5. TA /DA	100000	250000	250000	**600000**
6. Total	6443600	5147960	4672756	**16264316**
7. Overheads (at 20%)	1288720	1029592	934552	**3252864**
Grand total	7732320	6177552	5607308	**19517180**

Grant total Rs 1,95,17,180/-
(Rupees one crore ninety five lakh seventeen thousand one eighty only)

9. Usefulness of the study

As per the Government projection, by 2045 almost 2100 vessels will be operated on National Waterway No 1 and if one considers all 111 National Waterways are fully operational in future, one can imagine consumption of fuel and in turn the pollution. As mentioned earlier, all these vessels will operate in shallow water, where resistance of vessel increases drastically due the alteration flow around it. Hence, study of this kind whereby injecting Micro Bubbles will help in reducing the resistance of the vessel hence fuel savings and reduction in transportation cost and also it will reduce the air Pollution. The test also include manoevering studies of such low draft vessel in restricted waters.

10. Expertise and Existing facilities at IIT Madras

The Ocean Engineering Department at IIT Madras primarily does research on fundamental problems of Ocean Engineering and Naval Architecture in the broad areas of Wave Hydrodynamics, offshore structures, Port and harbour structures and advanced marine vehicles. The major field of research at Ocean Engineering department are:-

(a) Offshore Structures (Fixed, floating and compliant).

(b) Marine Vehicles (Ships and underwater vehicles).

(c) Marine Hydrodynamics and Coastal Processes.

(d) Port, Harbour and Coastal Structures.

(e) Materials in Marine Environment.

(f) Ocean Energy.

Apart from contributing to the advancement of knowledge in these fields, the Department has significantly contributed to many projects and missions of national importance. Recognizing the shortage of trained manpower and gaps in knowledge in the broad field of naval hydrodynamics, the Naval Research Board has set up a 6-year plan starting in 2007 for The National Program in Marine Hydrodynamics based in the department. One of main objectives of this program is to foster research in this field through collaboration and mentoring with other academic institutions where good potential for research exists.

The department is also equipped with following world class facilities: -

(a) Towing tank: Tank of 85 m length, 3.2 m width and 2.8 m depth with a variable carriage speed upto 5 m/s.

(b) Wave basin: 30m X 30m X 3m deep wave basin equipped with Multi-element wave maker (MEWM) (52 paddles) capable of producing short crested waves & Long crested wave maker (LCWM) capable of producing regular and random waves.

(c) Deep water wave flume: 90m X 4.0m X 2.8 m (maximum depth 2.5 m)

wave flume.

(d) Shallow water wave flume: 72.5m X 2.0m X 2.7m (h=1.0 to 2.0m) wave

(e) flume.

(f) Wave cum current flume: 30.0m X 2.0m X 1.8m (h=1.5m) wave flume.

(g) Glass flume and PIV facility.

(h) Shallow wave basin: 19.7m X 16.5m X 1.0m (h=0.6m) wave basin.

(i) Model making facility.

(j) Ocean optics and imaging lab.

(k) Structural dynamics lab.

(l) Structural testing lab.

11. References

[1] IWAI official webpage http://iwai.nic.in/index.php?lang=1

[2] Report on IWAI work of NW -1 http://www.thehindu.com/business/Economy/IWAI-gears-up-to-start-moving-cargo-on-NW1-by-2019/article17114308.ece

[3] Consolidated Environmental Impact Assessment Report of National Waterways-1 :Volume –3, http://documents.worldbank.org/curated/en/190981468255890798/pdf/SFG2231-V1-REVISED-EA-P148775-Box396336B-PUBLIC-Disclosed-12-5-2016.pdf

[4] Conference on जलमार्गविकासयोजना , भारत , organised by Indian Waterways Authority of India (IWAI) on 23rd January 2016 at Hotel RAMADA, Powai, Mumbai

[5] Sudhir Sindagi, R Vijaykumar, “Frictional Drag Reduction: An EFD and CFD based review of Mechanisms”, RINA – MARHY 2016, Nov. 2016

[6] Kazuhiro Fukuda, Junichiro Tokunaga, Takashi Nobunaga, Tatsuo Nakatani, Toru Iwasaki, and Yoshikuni Kunitake, “Frictional drag reduction with air lubricant over a super-water repellent surface”, Journal of Marine Science & Technology (2000) 5:123–130.

[7] E.J. Foeth, “Decreasing frictional resistance by air lubrication”, 20th International Hiswa Symposium on Yacht Design and Yacht Construction, Maritime Research Institute of the Netherlands (MARIN)

[8] Shuji Mizokami, Chiharu Kawakita, Youichiro Kodan, Seijiro Higasa, Ryosuke Shigenaga, “Experimental Study of Air Lubrication Method and Verification of Effects on Actual Hull by Means of Sea Trial”, Mitsubishi Heavy Industries Technical Review Vol. 47 No. 3 (September 2010)

[9] A. A. Fontaine and S. Deutsch, “The influence of the type of gas on the reduction of skin friction drag by microbubble injection”, Experiments in Fluids 13, pp 128- 36 (1992).

[10] Wendy C. Sanders, Eric S. Winkel, David R. Dowling, Marc Perlin, Steven L. Ceccio, “Bubble friction drag reduction in a high-Reynolds-number flat-plate turbulent boundary layer”, Journal of Fluid Mech. (2006), vol. 552, pp. 353–380

[11] Brian R. Elbing, Eric S. Winkel, Keary A. Lay, Steven L. Ceccio, David R. Dowling, Marc Perlin. “Bubble-induced skin-friction drag reduction and the abrupt transition to air-layer drag reduction”, Journal of Fluid Mech. (2008), vol. 612, pp. 201–236

[12] Jing-Fa Tsai, Chi-Chuan Chen, “Boundary Layer Mixture Model for a Microbubble Drag Reduction Technique”, ISRN Mechanical Engineering Volume 2011, Article ID 405701, 9 pages

ANNEXURE 1:

Brief bio data of the Principal Investigators

Dr R Vijayakumar, is an assistant professor in Ocean Engineering Department IIT Madras. He had served in **Indian Navy** for the past 21 years and retired as Commander. He is a graduate of Naval Architect from the Cochin University of Science and Technology, Cochin. He has done a PG Diploma in Naval Construction from Indian Institute of Technology, Delhi, and M Tech in Ocean Engineering from Indian Institute of Technology, Madras and Ph.D. from Indian Institute of Technology Delhi. On completion of his graduate training, he joined the Corps of Naval Constructors of the Indian Navy. He had worked in various capacities in Indian Navy as Naval Architect Designer in Directorate of Naval Design and in Naval Dockyard Visakhapatnam and Mumbai. His fields of interest include Warship Design, Ship Hydrodynamics, Ship Dynamics and Computational Fluid Dynamics (CFD) and green ship initiatives.

Details of Publications

A. Refereed Journal Publication

1. Manoj nair, Abilash MT, **Vijayakumar R,** Arnab Das "Embedded control System for underwater glider based on PSOC5LP" **International Journal of Computers & Electronics Research** Vol 3, Issue 2, Apr 2014, pp 72-76

2. **Vijayakumar R,** Singh SN, V Seshadri "CFD prediction of Hot exhaust from the funnel of a Naval Ships in presence of Ship Superstructure" International Journal of Marine Engineers, **Proceedings of Royal Institute Naval Architecture**, Part A1 2014 . Vol. 156, pp 1-24.

3. Danio Joe, Shashank R V, **Vijayakumar R**, Arnab Das, "*Concept Design of autonomus underwater gliders"* **International journal of innovative Design and Development***Vol 1, Issue 10, Dec 12 pp 176-189*

4. **Vijayakumar R,** Rao SK, Shashank R V **"**CFD studies on cylindrical bodies moving concentrically inside a very long tubes"**International journal of innovative Design and Development***Vol 1, Issue 10, Dec 12 pp 135-144*

5. **Vijayakumar R,** Singh SN, Seshadri V, Kulkarni PR*, "Flow visualization studies of exhaust smoke interaction with superstructure and Intake on generic Naval Ships"***Naval Engineering Journal**, American Society of Mechanical Engineers Sep 2012; pp129-143

6. **Vijayakumar R,** Singh SN, Seshadri V, Kulkarni PR*"Optimising funnel height to avoid smoke nuisance problem"***Journal of Ship Technology**, Volume 4,NO2, Jul 2008, pp30-40

7. Ananthа Subramanian V**, Vijayakumar R, "***An inverse design approach for minimising wake at propeller plane using CFD"***Ocean Engineering Journal** Vol 33, Issue 2 Feb 2006, Pages 119-136

B. International Conference

8. Makkar I S, **Vijayakumar R,** Singh SN, Seshadri V "Study of Dynamic Flow Effects Due to Ship Air Wake and rotor Downwash Interaction on Warship."International Conference on Advance Technologies in Naval Design Construction and Operation WARSHIP 2016 Bath UK 15 -16 Jun 16

9. **Vijayakumar R**, Singh SN, Seshadri V “Effect of Gas Turbine intake location on the smoke ingress problem in Naval Ships”, International Conference on Advance Technologies in Naval Design Construction and Operation WARSHIP 2016 Bath UK 15 -16 Jun 16

10. Praveen B, **Vijayakumar R,** Singh SN, Seshadri V “Numerical investigation on ship airwake for helideck for different configuration of Hanger shapes on Generic frigate “, International conference on computational and experimental Marine Hydrodynamics MARHY 2014, Chennai, India 3-4 Dec 2014

11. Manoj nair, Abilash MT, **Vijayakumar R,** Arnab Das Implementation of embedded platform for Underwater Glider Prototype IWCEM 2014, Pune, India 18-20 May 2014 pp 263-267

12. Makkar I S,**Vijayakumar R** Numerical Resistance & Self Propulsion Simulations for Early-Stage Ship Design EvaluationIWCEM 2014, Pune, India 24-26 May 2013 pp

13. **Vijayakumar R**, Vivek Tewari, B PraveenDevelopment of Tools for Evaluating the Operational Effectiveness of Competing Hull Forms in the Design of Ship for Seakeeping, IWCEM 2014, Pune, India 24-26May 2013 pp 113-119

14. Praveen B, **Vijayakumar R**,Singh SN, Seshadri V “A review of problem of warship helo interaction and efforts underway for possible solution” ICSOT 2013, RINA, IIT Kharaghpur India 12-13 Dec 2013 pp163-177

15. Nishanth R, **Vijayakumar R** “Roll and pitch control mechanism in underwater gliders” International Conference on Recent Trends in Mechanical Engineering ITM University, Gurgaon India 16 Nov 2013 pp1-13

16. Pratheek Jha, Ajeet kumar, **Vijayakumar R**, “Path planning of Underwater Vehicles”International Conference on Recent Trends in Mechanical Engineering ITM university, Gurgaon India 16 Nov 2013 pp 415-427

17. Rao SK, **Vijayakumar R** “Reliability analysis of ship structure using NESSUS “ IWCEM 2013, Pune, India 18-20 May 2013

18. **Vijayakumar R**,Rao SK, Arnab Das “Identifying Bilge keel Vortex shedding induced structural failure on ships using CFD” IWCEM 2013, Pune, India 18-20 May 2013

19. Rao SK**, Vijayakumar R** “ *Underwater Explosion and effect on Structures”*International journal of innovative Design and Development *Vol 1, Issue 10, Dec 12 pp207-234*

20. **Vijayakumar R**, Seshadri V, Singh SN, Kulkarni PR "A Wind Tunnel Study on the Interaction of Hot Exhaust from the Funnel with the Superstructure of a naval ships" Oceans 2008, Kobe, Japan 18-21 April 2008

21. **Vijayakumar R,** Singh SN, Seshadri V, Kulkarni PR*"Optimisation Of GasTurbine Intake Location To Avoid Smoke Ingress Problem In Naval Ships"*International Conference in Ocean Engineering, ICOE 2009 IIT Madras, Chennai,2-5 Feb 2009 pp 996-1006

C. National Conference

22. **Vijayakumar R ,** Balaji Srinivasan" CFD simulation of Bilge keel vortex sheding on Naval Ships" INCAM 2013, IIT Madras, Chennai, India,5-7 Jul 2013 pp258-259

23. **Vijayakumar R**, Jaipriya J, Kulkarni PR "Use of CFD as a design tool in reducing underwater Acoustic Signature" Symposium on Underwater Signature management, Goa, India, 07-08 Oct 2013.pp 38-42.

24. **Vijayakumar R.,** Singh S.N. Seshadri V. "CFD Analysis for the Design of Optimum Geometry of the Orifices in the PC pipes for ensuring uniform feed rate of Coal through various Coal Burners in a Boiler" Proceeding of the Conference Indian Power stations 2009, Power plant O&M event, New Delhi, 13-15 Feb 2009, pp756-764

25. **Vijayakumar R,,** "CFD Method in determining wake at propeller plane- A Case Study", National Convention of Naval Architects 24-26 Nov 2005 Mumbai pp 1-12

D. Other Publication

26. **Vijayakumar R,** "Scaling Laws for modelling in Wind Tunnel", CGML 2008, Institution of Naval Architects (Delhi Chapter), pp 58-64.
27. **Vijayakumar R.,** Ripon Paul, "Hull form optimization for improved wake Characteristics using Rankine source Distribution method", CGML 2004, Institution of Naval Architects (Delhi Chapter), pp 133-141
28. **Vijayakumar R.,** "Impregnation of wood for enhanced life", CGML 2002, Institution of Naval Architects (Delhi Chapter), pp 140-146.

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