PROJECT PROPOSAL

Hydrodynamic Study and Simulation of Multiple Ship Interactions in Inland Waterways and Shallow Waters

Submitted to

Ministry of Shipping

Government of India

under

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

Principal Investigator

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by

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CONTENTS:

1. Summary of the proposal

Via rivers and canals, India has thousands of kilometres of waterways with potential for efficient transport of large quantities of cargo such as agricultural, mineral and heavy-industry products. Compared to other means of cargo transport over land, that on waterways can be environmentally friendly and also cost-wise the most efficient provided efficient means of navigation are put in place. Navigation of multiple ships in confined waters is a challenging task because the hydrodynamic interactions occurring between ships and with channel boundaries can be quite complex, which if not properly managed through appropriate navigations, could lead to collisions between ships and with channel boundaries. In the proposed work, numerical models will be developed to determine the hydrodynamic forces and moments generated by the interactions which can be useful for designing efficient controllers for ship navigations in inland channels. The numerical results will be validated through comparison with experiments that will be carried out in the towing tank on the main Adayar campus of IIT Madras and in the new shallow water basin at the Thaiyur campus of IIT Madras. The hydrodynamic model can be integrated into control algorithms for navigation of multiple ships in confined waters.

2. Introduction

Hydrodynamics of ships is a complex problem to resolve because of flow nonlinearities and presence of deforming boundaries. The complexities are further compounded by interactions with other nearby ships and channel boundaries as that would occur in the case of multiple ships navigating in narrow channels. The interactions, in particular between ships in close proximity to each other, are unsteady and determined by several parameters including separation and stagger distances between the ships. A careful and a thorough investigation, as proposed here, is therefore warranted to develop efficient navigation tools and controllers for passage of ships in restricted waterways.

Study of hydrodynamic interactions between ships and in confined waters has been an area of active research for several decades now as can be evidenced in the works as early as that of Tuck and Newman (1974) to recent one by C-K Lee et al (2016). Earlier theoretical works were based on approximate theories such as the slender-body hydrodynamics and linearized free-surface conditions and while recent ones are based on computational fluid dynamics (CFD) software. For validation of theoretical and numerical results and models, experimental studies are vital.

A major finding of earlier works on ship-ship interaction, as in the case of a ship passing by another ship is that the approaching ship first experiences a repulsive force followed by an attractive force, both of which if not properly counteracted, will lead to collision of ships with the channel banks and also between ships. An active controller is necessary for keep the ships at safe distances from collisions. The performance of the controller can be vastly improved if a *feed-forward* element can be included based on an accurate hydrodynamic model. It is precisely here, i.e., development of the hydrodynamic model for multiple ship navigation narrow and restricted waterways, where the proposed work can make a substantial contribution.

Some of the drawbacks of existing methods are that either they are based on assumptions, such as linearized boundary conditions, which may not hold good for ships moving at large speeds (i.e., large Froude number) or that they are computationally too demanding as in typical CFD software that include, for example, turbulence which have little effect or only secondary effects on the hydrodynamic interaction forces between ships in narrow channels. These call for the development of efficient and accurate numerical model as proposed here which can work efficiently for model-based controllers for navigation of ships in restricted waterways.

3. Proposed Method of Computational Analysis

Here, we propose to develop a numerical method based on the boundary-integral algorithm (Yeung 1982) involving distribution of simple sources and dipoles, strengths of which are determined by the governing flow equation and boundary conditions. The gist of the method is that the Green's theorem (aka, Green's mixed distribution) is used for the solution of the Laplace equation governing the potential flow. The source strengths on the hulls and solid boundaries are determined by the no-flux condition. The dipole strengths on the free surface are determined by the combined free surface condition. The unknowns are then determined by solving the Greens theorem numerically. Upon determining the source and dipole strengths, one can evaluation the hydrodynamic pressure (using the Euler's integral) and, through integration of pressure, the hydrodynamic force and moments acting on the ships. The simulations will be carried for a range of parameters, including channel dimensions and separation/stagger distances between the ships. The simulated results will enable us to identify key parameters affecting the interactions and also critical instants of

maneuver due to the interactions. The numerical model and results will be validated by comparison with experiments are described in the next section.

4. Scale-Model Experiments in Shallow Water Basin

Model tests, based on Froude number scaling, will be carried out in the shallow water basin to validate the computational model and results obtained as described in the previous section. Resistance stain gages will be used to measure the hydrodynamic forces and moments acting on the ships as one ship passes another for various separation distances and speeds. The experimental results will be used for the validation of the numerical results obtained using the boundary-integral algorithm (as discussed in the previous section)

5. Project Timeline

Task	0-6 months	7-12 months	13-18 months	19-24 months
Development of the numerical algorithm	X	X		
Numerical simulation of hydrodynamic interactions between ships in channels for various parameter		X	X	
Development of experimental set up			X	
Experimental study and validation			X	X
Final report and publications				X

6. Scientific Merits and Tangible Outcomes

The project will

i. Result in the development of an efficient and robust algorithm and software for the study of hydrodynamic interactions between ships in narrow channels.
ii. Contribute to better understanding of ship-ship and ship-channel interactions
iii. Lead to development of efficient navigational tools and controllers for ships operating in inland channels.

The project will involve participation of MS/PhD scholar form the basis for one MS thesis and one PhD dissertation.

7. Budget

Personnel cost @50000 pm x 12x 2	= Rs 12,00,000/-
Hardware cost for computing	= Rs 04,00,000/-
Graphics and post-processing software	= Rs 02,00,000/-
Model making and model testing	= Rs 60,00,000/-
Contingencies (including travel)	= Rs. 05,00,000/-
Total Direct Cost	= Rs 83, 00,000/-
Indirect Cost	
(Overhead at 20% of Direct Cost)	= Rs. 16,60,000/-

Total Cost (Direct + Indirect) = Rs 99,60,000/-

(Rupees ninety nine lakhs and sixty thousand Only)

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8. Expertise of the PI and the Institute

The Ocean Engineering program at IIT Madras is internationally well-known for its research activities in Naval Architecture, Offshore Structures, Coastal Engineering, Marine Hydrodynamics and Ocean Energy Conversion. The infrastructure and facilities are in place for the proposed project.

The PI P. Ananthakrishnan has more than 25 years of research experience in the area of Marine Hydrodynamics, in particular on topics related to (i) Development of Numerical Methods for Nonlinear Wave-Body Interactions in Inviscid and Viscous Fluid and (ii) Investigation of Floating Mono-Hull and Twin-Hull Hydrodynamic Problems. The expertise will help to successfully execute the proposed project.

9. References

[1] E. O. Tuck and J. N. Newman, (1974). "Hydrodynamic interaction between ships", *Proceedings of the 10th Symposium on Naval Hydrodynamics*, Cambridge, Massachusetts, USA, pp. 35–70.

[2] C-K. Lee, S-B. Moon and T-G. Jeong, (2016). "The investigation of ship maneuvering with hydrodynamic effects between ships in curved narrow channel,"

International Journal of Naval Architecture and Ocean Engineering, vol. 8, pp. 102–109.

[3] R. W. Yeung (1982). "Numerical methods in free-surface flows," *Annual Review of Fluid Mechanics*, pp. 445-499.

10. Curriculum Vitae (4 pages) of the PI.

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EDUCATION

Ph.D., 1992, Naval Architecture & Offshore Engineering, University of California, Berkeley, USA

M.S., 1985, Ocean Engineering, Florida Atlantic University, USA.

B.Tech, 1983, Naval Architecture, Indian Institute of Technology Madras, Chennai, India

EMPLOYMENT HISTORY

3/2016 – now, Faculty, Dept. of Ocean Engineering, Indian Institute of Technology Madras, India.

3/2014 – 4/2014, Visiting Faculty, Laboratoire de recherche en Hydrodynamique, Énergétique et Environnement Atmosphérique,Ecole Centrale de Nantes, France

1993-2015, Faculty, Department of Ocean Engineering, Florida Atlantic University, USA

1992-1993, Postdoctoral Researcher, University of California at Berkeley, USA

AREAS OF RESEARCH INTEREST

Marine Hydrodynamics, Naval Architecture, Water Wave Mechanics, Wave-Body Interactions in Inviscid and Viscous Fluids, Numerical Methods for Free-Surface Flows, Underwater Vehicle Dynamics, Ocean Energy, Biomimetic Propulsion, Hydro-Elasticity, Dynamical Oceanography, Air-Sea Interactions.

SPONSORED RESEARC PROJECTS

PI, Hydrodynamics of Autonomous Underwater Vehicles (AUVs) in Littoral Waters, US Office of Naval Research, 1994-2000

Co-PI, Hydrodynamics of Remotely Operated Unmanned Underwater Vehicles (RPUUV), Center for Coastal Security, US Office of Naval Research, 2001-2003

Co-PI, Development of Tools (Hydrodynamics and Design) for Transformational Crafts (T-Crafts), US Office of Naval Research, 2004-2014

PI, Hydrodynamic Analysis of Gulf Stream Current Turbine, Southeast National Marine Renewable Energy (formerly Center for Ocean Energy Technology), 2009-2011.

Co-PI, Hydrodynamics of Wave-Adaptive Modular Vehicle, US Office of Naval Research, 2012-2014

Co-PI, Hydrodynamic Analysis for Station-Keeping of Underwater Vehicles in Shallow Water Waves, Naval Engineering Education Consortium (NEEC), US Office of Naval Research, 2013-2015.

Co-PI, Collaborative Research - Optimized Harvesting of Hydrokinetic Power from Ocean Currents, National Science Foundation, 2013-2016

PUBLICATIONS – BOOK CHAPTER

J. Kaihatu and P. Ananthakrishnan, Mechanics of Ocean Waves, in *Handbook of Ocean Engineering*, Springer-Verlag, 2016.

SELECTED REFEREED PUBLICATIONS

1. P. Ananthakrishnan, Effects of free-surface nonlinearity and viscosity on the radiation hydrodynamics of a floating twin rectangular hull, *Applied Ocean Research*, 51: 138-152, 2015
2. P. Ananthakrishnan, ``Hydrodynamic analysis of flapping foils for the propulsion of underwater and near-surface underwater vehicles,'' *Proceedings of the 2014 ASME Offshore Mechanics and Arctic Engineering Conference*, San Francisco, 2014.
3. P.Ananthakrishnan, ``Radiation hydrodynamics of a surface effect ship,'' *Proceedings of the 2013 ASME Offshore Mechanics and Arctic Engineering Conference*, Nantes, France, 2013.
4. M.Dhanak, P. Ananthakrishnan, K. von Ellenrieder and J. Frankenfield, ``Seakeeping characteristics of a wave-adaptive modular unmanned surface vehicle,'' *Proceedings of the 2013 ASME Offshore Mechanics and Arctic Engineering Conference*, Nantes, France, 2013.
5. P.Ananthakrishnan, ``Effects of viscosity and free-surface nonlinearity on the wave motion generated bya twin-hull,'' *Proceedings of the 2013 ASME Offshore Mechanics and Arctic Engineering Conference*, Rio de Janeiro, Brazil, 2012.
6. F. Lakitosh and P. Ananthakrishnan, ``Analysis of ship hull vibrations induced by wave and slamming forces," *Proceedings of the 2013 ASME Offshore Mechanics and Arctic Engineering Conference*, Rio de Janeiro, Brazil, 2012. (winner of best paper award)
7. A.Goly and P. Ananthakrishnan, ``Hydrodynamic analysis of a gulf-stream turbine using the vortex lattice method,'' *Proceedings of the IEEE Oceans Conference*, Seattle, 2011
8. O.Saout and P. Ananthakrishnan, ``Hydrodynamic and dynamic analysis to determine the directional stability of an underwater vehicle near a free surface,'' *Applied Ocean Research*, 158-167, 2011(one of the top ten papers most downloaded in 2012)
9. P. Ananthakrishnan and J. Chafin, ``Inviscid and Viscous Flow Analysis of Multihull Ships Under Forced Oscillations in a Free Surface," p. 229-237, *Proceedings of the VIII International Conference on Hydrodynamics*, Nantes, France, October 2008.
10. D. Lysogorski, W. Hartt and P. Ananthakrishnan, ``A modified potential attenuation equation for cathodically polarized marine pipelines and risers,'' *The Journal of Science and Engineering, Corrosion* , pp. 684-687, August 2003
11. P. Pierson, K. Bethune, W. Hartt and P. Ananthakrishnan, ``A new equation for potential attenuation and anode current output projection for cathodically polarized pipelines and risers," *The Journal of Science and Engineering, Corrosion*, pp. 350-361, April 2000.

12. P. Ananthakrishnan, ``Radiation hydrodynamics of a floating vertical cylinder in a viscous fluid," *Journal of Engineering Mechanics*, vol. 125, No.7, pp. 836-847, 1999
13. P. Ananthakrishnan, ``Heave oscillations of a submerged vertical cylinder in a viscous fluid," *International Journal of Offshore and Polar Engineering* , vol. 8, No. 3, pp. 173--181, 1998
14. P. Ananthakrishnan, ``Nonlinear diffraction of waves over a submerged body in a real fluid," *Proc of the Eighth International Offshore and Polar Engineering Conference*, Montreal, 1998.
15. P. Ananthakrishnan, ``Analysis of rigid-body oscillations near the free surface of a viscous fluid," *Developments in Theoretical and Applied Mechanics*, vol. 19, pp. 512--526, 1998.
16. P. Ananthakrishnan and R. W. Yeung, ``Viscosity and surface-tension effects on wave generation by a translating body," *Journal of Engineering Mathematics*, vol. 32, pp. 257--280, 1997.
17. P. Ananthakrishnan, ``Heave oscillation of a submerged vertical cylinder," *Proceedings of the Seventh International Offshore and Polar Engineering Conference*, Honolulu, vol. III, pp. 672--679, 1997.
18. P. Ananthakrishnan and R. W. Yeung, ``Nonlinear interaction of a vortex pair with clean and surfactant covered free surfaces,'' *Wave Motion*, vol. 19, pp. 343--365, 1994.
19. R. W. Yeung and P. Ananthakrishnan, ``Vortical flows with and without a surface-piercing body," *Proceedings of the Nineteenth Symposium on Naval Hydrodynamics*, Seoul, Korea, pp. 219--240, 1992.
20. R. W. Yeung and P. Ananthakrishnan, ``Oscillation of a floating body in a viscous fluid," *Journal of Engineering Mathematics*, vol. 26, pp. 211--230, 1992.

SELECTED NON-REFEREED PUBLICATIONS

1. P. Ananthakrishnan, Free-Surface effect on hydrodynamics performance of flapping foils, *Bulletin of the American Physical Society*, 67th Annual Meeting of the APS Division of Fluid Dynamics, San Francisco, vol. 59, 2014.
2. P. Ananthakrishnan, Nonlinearity, viscosity and air-compressibility effects on the Helmholtz and sloshing resonant wave motions generated by an oscillating twin hull in a free surface, *Bulletin of the American Physical Society*, 65th Annual Meeting of the APS Division of Fluid Dynamics, San Diego, vol. 57, 2012.
3. P. Ananthakrishnan and J. Chaffin, ``Oscillation of Multiple Bodies in a Free Surface," *Bulletin of the American Physical Society*, *60th* Annual Meeting of the APS Division of Fluid Dynamics, vol. 53, 2007.
4. P. Ananthakrishnan, ``Nonlinear Wave, Vortex and Submerged-Body Interactions in Inviscid and Viscous Fluids," *Bulletin of the American Physical Society*, *60th* Annual Meeting of the APS Division of Fluid Dynamics, vol. 50, 2004.
5. P. Ananthakrishnan and L. Martel, ``Simulation of AUV motion in shallow water," *Proceedings of the Oceans Community Conference'98*, Baltimore, 1998.
6. P. Ananthakrishnan and K. Zhang, ``AUV motion in a wave field," *Proceedings of the IEEE OCEANS'98 Conference*, Nice, France, 1998.
7. J. Cairns, E. Larnicol, P. Ananthakrishnan, S. Smith and S. Dunn, ``Design of AUV propeller based on a blade element method," *Proceedings of the IEEE OCEANS'98 Conference*, Nice, France, 1998.
8. P. Ananthakrishnan, ``On the evolution of body-generated vortex rings underneath a free surface," *Proceedings of the 12th Engineering Mechanics Conference*, San Diego, 1998.
9. P. Ananthakrishnan, S. Vantouroux, K-Q. Zhang and S. M. Smith, ``Nonlinear dynamics and hydrodynamics considerations in the design of an autonomous underwater vehicle,", *Proceedings of the Oceanology International'98 Conference*, vol. 3, pp. 119--128, Brighton, UK, 1998.

10. P. Ananthakrishnan, ``Scattering of waves by a submerged body,'' *Proceedings of the ONR Workshop on Free-Surface Turbulence and Bubbly Flows*, Pasadena, 1998.
11. P. Ananthakrishnan, ``Nonlinear wave radiation and diffraction by a near-surface body,'' *Bulletin of the American Physical Society*, Program of the 45th Annual Meeting of the Division of Fluid Dynamics, San Francisco, 1997.
12. P. Ananthakrishnan, ``Hydrodynamics of waves and vortices generated by an oscillating body,'' *Proceedings of the 1997 ASME Fluid Engineering Division Summer Meeting*, Paper: FEDSM97-3396, Vancouver, 1997.
13. P. Ananthakrishnan, ``Generation of waves and vortices by an oscillating body a nd their interactions,'' *Proceedings of the U.S. Office of Naval Research Workshop on Free-Surface and Wall-Bounded Turbulence and Turbulent Flows*, California Institute of Technology, Pasadena, 1997.
14. P. Ananthakrishnan, ``Numerical modeling of nonlinear air-sea interactions,'' *Bulletin of the American Physical Society*, Program of the 49th Annual Meeting of the Division of Fluid Dynamics, Syracuse University, 1996.
15. P. Ananthakrishnan, ``Radiation hydrodynamics of a slightly-submerged body,'' *Proceedings of the 11th ASCE Engineering Mechanics Conference*, Ft. Lauderdale, pp. 832--835, 1996.
16. P. Ananthakrishnan, ``Nonlinear free-surface flow about oscillating bodies,'' *Bulletin of the American Physical Society*, Program of the 44th Annual Meeting of the Division of Fluid Dynamics, Syracuse University, 1996.
17. P. Ananthakrishnan, ``Analysis of nonlinear air-sea interactions,'' *Proceedings of the Forum on Advances in Numerical Modeling of Free Surface and Interface Fluid Dynamics*, ASME, Publication FED-Vol. 234, pp.175--182, 1995.
18. P. Ananthakrishnan, ``On vortex breakdown in swirling free-surface flows,'' *Bulletin of the American Physical Society*, Program of the 48th Annual Meeting of the Division of Fluid Dynamics, University of California at Irvine, 1995.
19. P. Ananthakrishnan, ``Nonlinear interaction between air flow and water waves,'' *Proceedings of the U.S. Office of Naval Research Workshop on Free-Surface and Wall-Bounded Turbulence and Turbulent Flows*, California Institute of Technology, Pasadena, 1995.
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21. P. Ananthakrishnan and R. W. Yeung, ``Free-surface and submerged-body interactions in a viscous fluid,'' *Proceedings of the Symposium on Vorticity and Free-Surface Interactions, Twelfth U.S. National Congress of Applied Mechanics*, University of Washington, Seattle, 1994.
22. R. W. Yeung and P. Ananthakrishnan, ``Oscillation of a slightly-submerged cylinder in a viscous fluid,'' *Proceedings of the Seventh International Workshop on Water Waves and Floating Bodies*, Val de Reuil, France, 1992.
23. R. W. Yeung and P. Ananthakrishnan, ``Free-surface flows in a viscous fluid,'' *Proceedings of Office of Naval Research Free-surface Vorticity Workshop*, University of California at San Diego, 1992.
24. R. W. Yeung and P. Ananthakrishnan, ``Large-amplitude oscillation of two-dimensional bodies in a viscous fluid with a free surface,'' *Proceedings of the Sixth International Workshop on Water Waves and Floating Bodies*, Woods Hole, 1991.
25. R. W. Yeung and P. Ananthakrishnan, ``Solution of nonlinear water-wave and wave-body interaction problems using a new boundary-fitted coordinates method,'' *Proceedings of the Fourth International Workshop on Water Waves and Floating Bodies*, Oystese, Norway, 1990.

SERVICE: PROFESSIONAL

- Served as reviewer for articles submitted to Physics of Fluids, Journal of Computational Physics, Computers and Fluids, Journal of Offshore Mechanics and Arctic Engineering, Journal of Offshore and Polar Engineering etc.
- Reviewed proposals submitted to National Science Foundation (NSF) and Sea Grant College Programs.
- Served as external reviewer for tenure and promotion of faculty members at University of Michigan and University of Hawaii.
