AUV Hydrodynamics In Shallow Water During Adverse Weather Conditions

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LONG-TERM GOALS

My long-term goal is to contribute, by means of an accurate hydrodynamics model, to efficient design, development and operation of autonomous underwater vehicles in energetic shallow waters. From a scientific viewpoint, the development of the AUV hydrodynamic model will contribute to a better understanding of wave-body-current interactions, nonlinear shallow-water waves, wave effects on stability and maneuverability of vehicles, and turbulent flows about under-water and near-surface vehicles.

OBJECTIVES

Existing hydrodynamics models used for the control of AUV motions are mostly based on the analysis of vehicle motion in infinite waters, *i.e.* in the absence of surface effects, originally developed for vehicle operations in deep- and mid-waters. These models are inadequate for AUV operations in shallow waters where boundary effects on the vehicle dynamics can be significant. The objective of the project, started in 1998, is to develop and test a robust hydrodynamics/dynamics model, including the effects of surface waves and bottom boundary, for the purpose of nowcasting and enhancing the performance of AUVs in shallow littoral waters. The hydrodynamics model will be of use even in deep-water applications as the AUVs have to continually operate close to the surface while seeking GPS fixes for navigation.

APPROACH

To state it briefly, the hydrodynamics model is based on accurate solutions to fully-nonlinear wave vehicle interactions in shallow water. The numerical algorithms are specially developed to obtain *viscous*, as well as *inviscid* for cases where viscous effects are negligible, solutions to the nonlinear AUV hydrodynamics problem. Specifically, we have developed finite-difference and boundary-integral algorithms to determine wave-exciting (diffraction) forces, hydrodynamic forces due to unsteady vehicle motions, wave and viscous drag, and vehicle response to surface waves. The simulations will be carried out for a wide range of parameters in developing the hydrodynamics model. One version of the model, which is computationally efficient, involves decomposition of the forces in terms of hydrodynamic force coefficients to allow straightforward integration of the model into controller algorithms. Laboratory experiments using scale models of AUVs will be carried out to validate the computational predictions and to complement the development of the hydrodynamics

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model. Upon integration of the hydrodynamics model into controller algorithm, field studies will be carried out to determine the performance of the hydrodynamics model. In developing the AUV hydrodynamics model, various auxiliary analyses will be also carried out some in collaboration with other researchers in the program. For example, numerical algorithms to integrate the rigid-body motion equations of the AUV subject to mechanical and environmental forces are developed. A blade-element analysis is developed for the design of propellers for Ocean Explorer (OEX) AUV with a direct-drive motor of limited availability of torque and power.

WORK COMPLETED

<u>The following tasks are completed during the period November 1998 - October 1999:</u>

1. Finite-Difference Analysis of Unsteady AUV Motion in Shallow-Water Waves: A finite-difference algorithm has been successfully developed by the PI to determine planar-motion response of an underwater vehicle to surface waves in shallow water. The algorithm is based on simultaneous analyses of wave-hydrodynamics and rigid-body dynamics equations of motion. Surge and heave responses of a Gertler-shaped body to shallow-water surface waves have been computed.

2. Boundary-Integral Analysis of Unsteady AUV Motion: A boundary-element method based on the Longuet-Higgins and Cokelet's mixed Eulerian-Lagrangian formulation has been developed by the PI to solve the unsteady motion of submerged bodies in shallow water. Preliminary results for heave and surge motions have been obtained.

3. Laboratory Scale Experiments Using AUV Models: The wave tank in the Department of Ocean Engineering at Florida Atlantic University has been refurbished to carry out laboratory-scale experiments of AUV-wave interactions.

4. Development of Blade-Element Algorithm for the Design of AUV Propellers: A blade-element method, based on the lift and drag coeffients of foil geometries, has been developed for the design of propellers for AUVs. The method was used to design a 3-bladed propeller for the Ocean EXplorer (OEX) AUV at Florida Atlantic University.

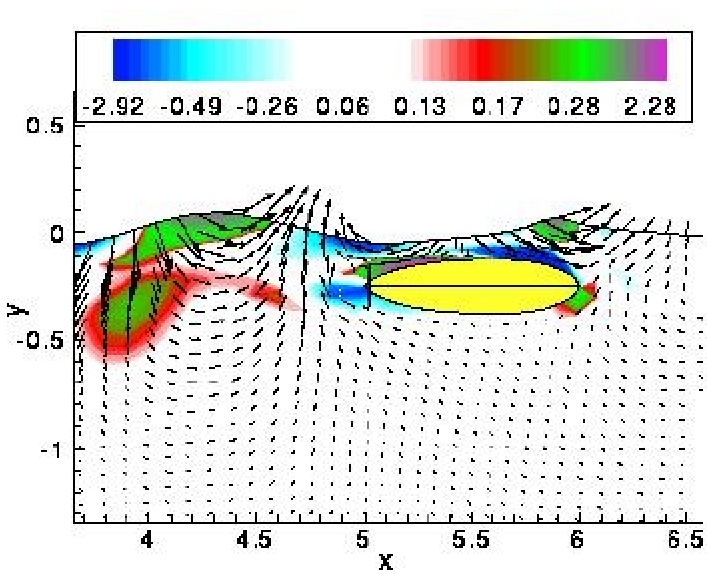
RESULTS

1. Unsteady AUV Motion in Shallow-Water Waves: Using the finite-difference algorithm developed for wave-body interactions [1], the wave diffraction and radiation forces corresponding to a Gertler body in shallow water have been computed. The results show that the generation of steep diffracted waves over a shallowly submerged vehicle, similar to the case shown in Fig. 1 below, could result in an up-wave drift force on the body which is a nonlinear phenomenon of surface waves. The results also show that a near-surface body undergoing surge oscillation could experiences heave force at twice the surge frequency, which too is a nonlinear phenomenon of surface waves [2, 3]. The wave diffraction and radiation forces have been computed for a range of parameters. By integrating the rigid-body equations concurrently, the open-loop motion response of a Gertler-shape AUV has been simulated. The horizontal drift of the vehicle in the presence of large-amplitude waves has been computed for a range of parameters such as incident wave-length and -amplitude, water depth and body-submergence.

2. Boundary-Integral Analysis of Unsteady AUV Motion: A boundary element method has been developed including the presence of surface waves. Preliminary results for heave motion of a submerged body have been obtained. These results will be compared with viscous results to quantify the importance of viscosity, for a range of parameters. Such a comparison is important in the development of the hydrodynamics model.

3. Laboratory Scale Experiments Using AUV Models: The wave tank facility at Florida Atlantic University has been refurbished for conducting model-scale experiments of AUV motion in shallow water waves. Sensors to measure incident-waves characteristics and to measure forces on the model AUV are being installed and programmed.

4. Design of a 3-Bladed Propeller for OEX-AUV: Using the blade-element method developed for the design of AUV propellers, a 3-bladed propeller was developed for the Ocean EXplorer (OEX) vehicle, with a torque-limited motor, to achieve a forward speed of 4 [knots] or more. The limiting torque of the direct-drive motor is 3.75 [N-m] at 600 [rpm]. The drag of the vehicle was estimated to be approximately 100 [N], without appendages. Incorporating wake effects empirically and using NACA 66-221 sections, a 3-bladed propeller of diameter 34 [cm] and maximum chord 3 [cm] has been designed [4]. At the sea trials, with acoustics (ACOMMS) sensor appendages, the vehicle was able to achieve a steady forward speed of 4 [knots].



1: Instantaneous velocity and cross-stream vorticity fields corresponding to large-amplitude wave diffraction over a near-surface Gertler body, with blue spectrum representing clockwise vorticity and red-green-purple spectrum counter-clockwise vorticity.

IMPACT/APPLICATIONS

1. The development of the hydrodynamics model for AUVs in a rigorous manner, as pursued in the present research, and its integration into design software would lead to the development of efficient underwater vehicles particularly for applications in the littoral regime.

2. The hydrodynamics model can be used for nowcasting the vehicle performance in various sea states, prior to a mission.

3. Using the hydrodynamics model and a record of vehicle motions, one can identify the presence of surface waves and large-scale eddies at a given site.

4. From a scientific viewpoint, the analysis carried out in this research will raise our level of understanding of the basic fluid-body interactions in the presence of waves and currents and in the vicinity of the sea floor, and thus contributing to the development of turbulence models for wave-body interaction problems.

TRANSITIONS

The present AUV hydrodynamics/dynamics model has been used in the preliminary design of mini-, ultra-modular AUV developed at the Florida Atlantic University.

RELATED PROJECTS

Once the development of the AUV hydrodynamics model is completed and its performance validated, the PI will assist other researchers in the program in their development of AUVs and AUV sensors for various missions in shallow and very-shallow waters.

PUBLICATIONS

[1] P. Ananthakrishnan, ``Radiation hydrodynamics of a floating vertical cylinder,'' *Journal of Engineering Mechanics*, Vol. 125, No. 7, pp. 836--847, 1999.

[2] P. Ananthakrishnan, ``Dynamic response of an underwater vehicle to surface waves,'' presented at the *Forum on Advances in Free Surface and Interface Fluid Dynamics*, Fluids Engineering Division Meeting, ASME, San Francisco, 1999 (to be submitted for review and journal publication).

[3] P. Ananthakrishnan and K. Zhang, ``Radiation and diffraction hydrodynamics of an underwater vehicle,'' *Bulletin of the American Physical Society*, Program of the 51st Annual Meeting of the Division of Fluid Dynamics, Philadelphia, November 1998.

[4] J. Cairns, K. Johnson, P. Ananthakrishnan, E. Larnicol, S. Dunn and S. Smith, ``Design of an AUV Propeller Based on a Blade-Element Method,'' *Marine Technology*, (under review), 1999.