Energy producing buoy for strategic applications: Design Trade Study – Q1 Report

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Summary

In the first quarter of this project, we've succeeded in establishing a team for this project and have gotten a good start on the technical work. In addition to the PI's, this team includes one existing MBARI research technician, a new MBARI engineering hire and three contractors. Because the main effort of this project is to perform a performance analysis and trade study related to the problem of wave-energy conversion for a station-keeping buoy platform, the team selected has strong representation in the fields of marine hydrodynamics, numerical modeling, and computational fluid mechanics. On March 11, 2009, the technical team met as a group at MBARI to introduce the project, discuss the project plans, and determine how the various contractors will work together to achieve the stated goals. This meeting was successful in establishing the options for the contractor interaction, and led to the subsequent consideration of several important technical details. Work has been ongoing at MBARI through the quarter to formulate the computational modeling framework needed to analyze the range of wave-energy extraction concepts identified. This framework is written in the Matlab programming language and forms the base of the analysis planned for this project. Concurrent with the development of this tool, analysis of global wind, wave, and solar data has been performed to characterize the environment the station-keeping buoy will need to operate in. This analysis is important to allow the modeling results to be used to establish long-term performance predications for specific concept designs. On April 16, 2009, a project kick-off meeting was held at MBARI with DARPA personnel and support staff. As of the end of Q1, 41% of the budget allocated for this effort has been spent. Plans for the next quarter include the use of the computational tools developed so far to establish some initial results for the various concepts under consideration. Additionally, in the next quarter the computational contributions of the contractors will be included in the modeling effort to refine the initial results.

Activities

1. Hired an engineer that will be dedicated to the project. (Sreeram Radhakrishnan, CV attached)
2. Hired consultant William Webster as a technical advisor to the project. (CV attached)
3. Held a technical meeting at MBARI with subcontractors Airflow Sciences, Marine Innovation and Technology, and consultant William Webster: March 11, 2009.
4. Held a project kick-off meeting with DARPA personnel: April 16, 2009.
5. Began development of software toolbox to perform numerical modeling relevant to the project.
6. Completed a global environmental-condition analysis.
7. Visited Roy Kornbluh at Stanford Research Institute (SRI) to discuss the applicability of their "artificial muscle" technology to this project.
8. Visited Sid Chao at CIIIS to evaluate the applicability of the "ferro-fluid" linear generator system to this project.

Technical Status and Results

The main technical work performed during this quarter involves the development of the computational framework needed to perform time-domain simulations of the various concepts under consideration for a station-keeping wave-energy conversion device. These concepts all require very similar modeling capabilities to analyze; all devices involve a floating body in waves and a device to harness energy from the relative motion of two or more bodies. The framework developed effectively solves for the motion of one or more bodies that are acted on by outside forces such as the wave field, currents wind, and any wave-energy extraction devices included in the system. This computational toolbox that is being developed is modular enough to allow various elements such as floating buoys, submerged foils, linear power take-off generators, submerged turbines, and wind turbines to be combined in nearly any arrangement. Adding new elements to the system requires only defining the forces that act on that element as a function of the elements position history throughout the time-domain simulation.

The analysis of such systems is fundamentally straightforward and involves the solution of Newton's equations of motion (force = mass times acceleration). Although the solution of this type equation is straightforward, the evaluation of the forces acting on the various parts of the system can be complicated.

For instance, the forces acting on a body floating in waves depends on the hydrodynamic behavior of the particular shape and size of the body. Further complicating this is the fact that as existing waves cause a floating body to move, this motion then causes the body itself to generate waves which add an additional force that acts on the body, further modifying it's motion. This feedback causes a "memory effect" in which the forces acting on the body at the current time depend not only on the bodies current velocity, but also on the velocity history of the body. Fortunately, systems this complicated problem has been solved by previous researchers (at least for linearized systems, which is an assumption made throughout this projects wave-body interaction numerical analysis and is one reason that subsequent validation of the simulation results via prototype or model testing is important). As of the end of the first quarter of this project, the work to include wave-body interactions of this type has been completed and the simulation framework has the capability to model the motion of a floating body in waves. Additional validation of this work via comparison with standard solutions and other simulation codes is ongoing.

To test and demonstrate the coupling of the floating body solution to submerged elements, the simple case of a submerged flat plate connected by an idealized linear generator to a floating buoy has been analyzed. In this simulation, an existing wave-field causes the buoy to move (heave, pitch and surge), this motion is coupled to a submerged flat plate via a spring/damper system that represents a linear generator. As expected, significant wave energy is converted but dissipated due to the viscous drag forces experienced by the submerged plate moving perpendicularly through the water. Nevertheless, some energy is being dissipated by the generator element. Simulations to characterize the exact performance of such a system concept are on-going.

In addition to the submerged flat plate, a simplified analysis of the behavior of a submerged foil has also been developed. The submerged foil hydrodynamics *may* also suffer from the complication of being a time-dependent phenomenon that has important memory effects. Due to the relatively long periods of the wave exciting forces, it is not yet clear if a quasi-static analysis of the foil behavior will be sufficient. To address this unknown, two approaches will be taken, one is based upon the theoretical behavior of linearized lifting flows, which will provide some guidance but may not be sufficient because of the large angles of attack experienced by a submerged foil in this application. The final evaluation of the need to include the time-dependent flow behaviors will likely require CFD (computational fluid dynamics) of this case, with and without the time-dependant effects. Fortunately, there is no fundamental reason that the time-dependent effects can't be included in the analysis, but it may increase the computation cost of the CFD work required.

Work to date on the submerged foil case has assumed that quasi-static behavior is valid and utilizes standard lift-drag behaviors of hydrofoils. The coupling of this simplified foil model to a floating body in an incoming wave-field has indeed shown that the submerged foil is capable of propelling at a slow rate of speed by converting wave energy. These results are very preliminary and quantitative estimates of the performance of such systems can not yet be stated. Nevertheless, this simplified foil model will be useful in designing and sizing the systems that will be analyzed by more sophisticated CFD techniques.

In addition to the simulation work performed, the environmental condition analysis that was started as part of the original trade study has been completed. This analysis collects global observations of wind, wave, and solar power levels, analyzes the correlations between different sources, and ground truths the global satellite observations with buoy observations at a few locations. The intention of this work is to allow a prediction of a given concept designs performance at any specified location based upon the combination of the global condition statistics and the simulation based performance predictions.

On April 15th, a visit to Roy Kornbluh at Stanford Research Institute (SRI) was made to evaluate the possible application of SRI's "Artificial Muscle" technology to this energy buoy project. This technology is interesting and may have an application if the analysis performed as part of this project requires a linear generator device. Linear generators are typically very inefficient and if such a device is to be included in the prototype and demonstration platforms, specific technology for this element must be identified. The SRI project is primarily related to the development of the artificial muscle components, their understanding of wave-dynamics and ocean engineering is less developed. There may be a good opportunity to collaborate with this group to provide the analysis capability they need to determine a suitable application of their technology. Unfortunately, their statements about the efficiency of their technology were not clear, but it was discussed that if we provided a force and motion range estimate, they'd be able to characterize their system suitably for inclusion into our modeling.

On April 29th, a visit to CIIIS in southern California was made to evaluate the suitability of the ferro-fluid linear generator technology under development there. Like the SRI technology, this could be a solution if a linear generator element is required by our designs. Unfortunately, the technical knowledge and ability of this group seemed very rudimentary and it's difficult to imagine them producing a useable technology without significant help. They were completely unable to provide efficiency and performances estimates and were using highly suspect extrapolation techniques to estimate the power production capabilities of their system.

Budget and Spending

As of 5/8/2009, $118,166.40 has been spent out a budgeted $287.829.00. Attached to this report is the MBARI budget status report for this project. Because the spending rate is not sufficient to utilize the allocated funds within the original four month project period of performance, a non-cost extension request was made on 5/13/2009.

Plans

In the next quarter of this project, the tools that have been developed so far will begin to be used to perform design studies on the various concept designs that are being considered for the energy buoy. As initial results become available, the contractor involvement will increase as refined models that include the CFD analysis of the submerged foil case are analyzed. Additionally in the next quarter, plans for model testing of certain elements of the proposed system will be made.

Attachments

1. MBARI Grant Status Report
2. William Webster CV
3. Sreeram Radhakrishnan CV