# Power producing buoy for strategic applications: Prototype and Testing – Q3 Report

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| Grant No. | HR0011-09-2-0002 |
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# Summary

In the third quarter of this project a review meeting was held at MBARI on December 17, 2010 that summarized the progress made in the first stage of the project. Results were presented that highlight the analysis and testing performed to date. This analysis forms the basis for the design decisions necessary to begin the prototype development and testing stage of the project. With these results completed, the project will be moving forward with prototype testing and the plan for the second stage of this project were discussed. A number of good questions were raised during the review and the bulk of this quarterly report is devoted to addressing those issues.

# Activities

1. Utilized the numerical model developed so far in this project to perform a parametric design study of wave-energy extraction concepts that involved a submerged reaction mass.
2. Began CFD work with Airflow Sciences Corporation to evaluate the suitability of the assumptions made in the numerical modeling.
3. Held a meeting at MBARI to review the results of stage one of the project.

# Technical Status and Results

The main technical results from the work to date are captured in the meeting presentation slides and supporting plots. These can be accessed at the following location:

– The slides themselves are at: www.mbari.org/staff/hamilton/DARPA/Dec17_V2.ppt
– The remaining pages in the binders are at: www.mbari.org/staff/hamilton/DARPA/FlatPlateResults-LinearDamping.pdf and www.mbari.org/staff/hamilton/DARPA/FlappingFoilResults-LinearDamping.pdf

During the meeting a number of good questions came up and additional analysis has been done to address these, in particular:

- Jim Bellingham pointed out that the performance of the various possibilities should be also viewed from the point of view of alternative metrics that measure power production in terms of mass of the deployed structure, or another measure of platform size or cost. To this end the power production estimates presented previously have been re-plotted relative to platform mass and are shown in figure 1. This figure indicates that the power per deployed kilogram drops as the platform becomes larger. This initial result indicates that a minimum size platform should be selected for the power generation needs. It should be noted however that the designs analyzed were not optimized for minimum weight and as the designs are refined we will continue to evaluate this power performance metric.

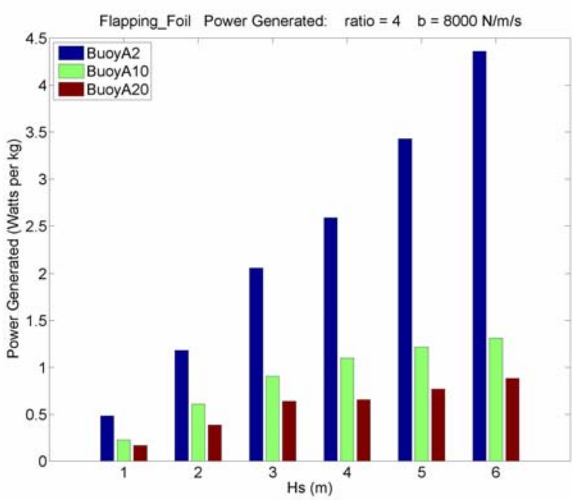


Figure 1: Power generated per deployed kilogram for submerged foil concept.

- Dave Hammond raised the point that a linearized frequency domain analysis of the dynamics might also be of use to determine where the resonance frequencies of the system are, and to determine if the why these systems don't seem to exhibit the same "peaked" response that is present in other spring-mass-damper devices. Such an analysis has been carried out and the results are presented in Figure 2-4. This analysis is fully linearized and differs from the time-domain calculations in two important details. The drag force on the submerged element is linearized about a mean velocity point that cooresponds to the mean vertical velocity of the water surface. This differs from the time-domain analysis where the quadratic depenedence of drag on the bodies drag is included. Additionally, the linearized frequency domain analysis assumes the tether acts as a perfectly linear spring, exerting a downward force on the submerged element when the two bodies get close together. This is different than the time domain analysis in which the tether exerts no force when it goes slack.

The frequency domain results shown in Figure 2-4 do shed some light on why the system behavior seems to have a wide response band and isn't tuned to one particular resonance frequency. These plots show the results from a frequency domain two body analysis in which the surface expression and the submerged element are connected by a spring/damper system in a manner similar to the time domain analysis. The results show the response amplitude operator (RAO) for the surface expression and submerged element. This results is the expected motion amplitude that results from an input wave with a unit amplitude at the specified frequency. Phase information is not shown, the two bodies can have the same response amplitude but still have relative motion if they are out of phase with one another. The bottom plot in each figure shows the power dissipated in the damping element (power take-off device). For the small system (BuoyA2) there is a very mild resonance around a frequency of 4.75 radians/second. The larger systems are more heavily damped and the resonance feature becomes even less significant.

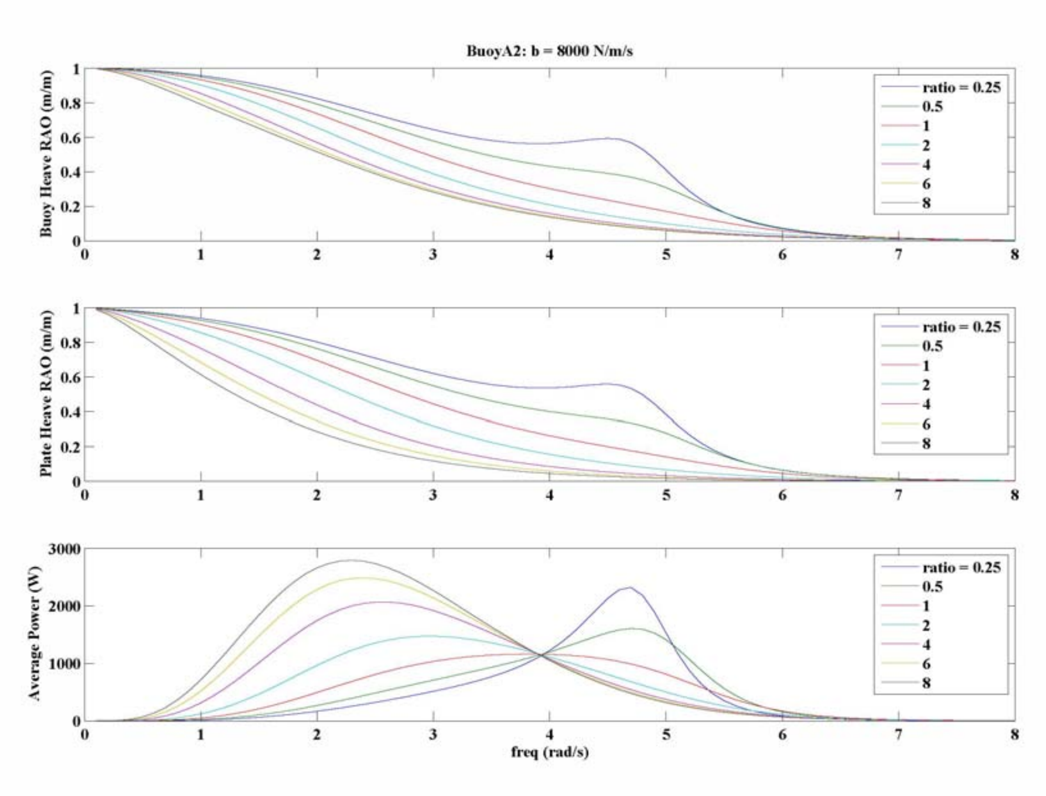


Figure 2: Frequency domain RAO's and PTO take-off dissipation for a Buoy with 2 square meter waterplane surface.

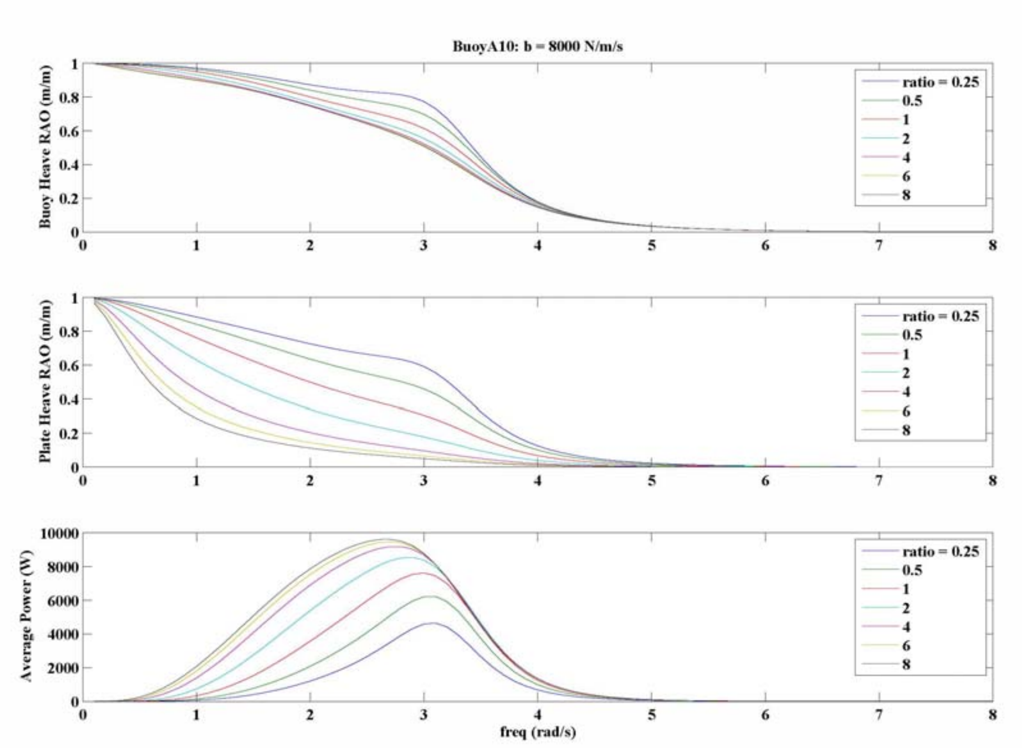


Figure 3: Frequency domain RAO's and PTO take-off dissipation for a Buoy with 10 square meter waterplane surface.

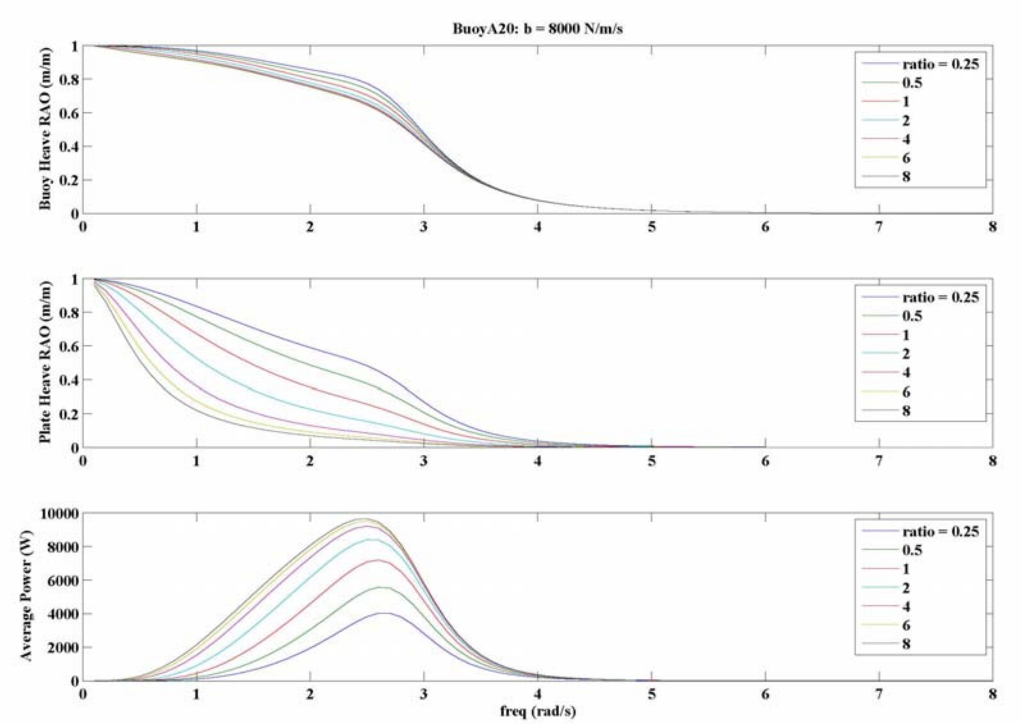


Figure 4: Frequency domain RAO's and PTO take-off dissipation for a Buoy with 20 square meter waterplane surface.

Ocean wave energy is present only down around 0.5-1.0 radians per second, well below the theoretical peak power generation point shown in figures 2-4. However, The power numbers shown are for a wave amplitude of 1m, which can not physically exist at the higher frequencies. For this reason it is useful to make a comparison of the power predictions that result when the power response spectra are multiplied by the expected wave spectra for different conditions. Figure 5 shows the wave-energy distributions for a range of significant wave heights as predicted by the Pierson-Moskowitz spectrum. Table 1 compares the results from the linearized and non-linear analysis. As expected, better agreement exists at the low wave amplitudes.

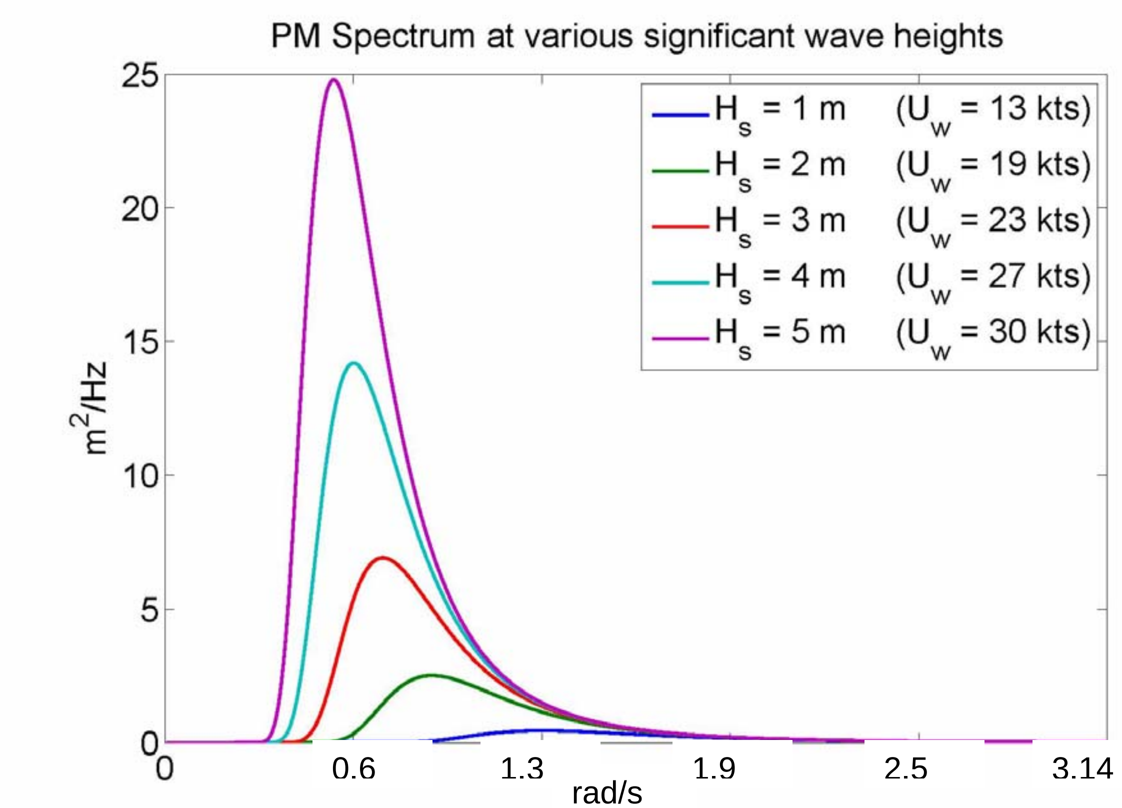


Figure 5: Pierson Moskowitz spectrum at various wave-heights

| | **Hs = 1 m** | **Hs = 3 m** | **Hs = 5 m** |
|---|---|---|---|
| **Buoy A2** | 255W/240W | 700W/850W | 960W/1250W |
| **Buoy A10** | 1035W/980W | 3000W/2600W | 4225W/3500W |
| **Buoy A20** | 1070W/1400W | 3220W/3650W | 4580W/7200W |

Table 1: Comparison of linearized frequency domain results with non-linear time-domain results for a plate size ratio of four and a PTO damping coefficient of 8000 N/m/s. In each cell the first number is the expected power dissipation by the PTO system for the non-linear analysis and the second number is the same result predicted by the linearized analysis.

# Budget and Spending

As of 12/25/2009, $379,175 remains out of a budgeted 606,636 for year one of the project. Year one of the project ends on March 26, 2010 so the rate of spending is consistent with the original plans. Attached to this report is the MBARI budget status report for this project.

# Attachments

1. MBARI Grant Status Report