# CFD SUPPORTED EXAMINATION OF BUOY DESIGN FOR WAVE ENERGY CONVERSION

Nadir Yilmaz, Geoffrey E. Trapp, Scott M. Gagan, Timothy R. Emmerich
Department of Mechanical Engineering, New Mexico Institute of Mining and Technology
801 Leroy Pl., Socorro, New Mexico, U.S.A.
e-mail: nadir@nmt.edu, gtrapp@nmt.edu, sgag01@nmt.edu, temmeric@nmt.edu

## ABSTRACT
An oscillating buoy power device (OD) is investigated as a potential wave energy converter. The OD moves up and down to convert wave energy to electricity by means of a mechanical or hydraulic system. In this work, a rectangular shape buoy (OD) is used to validate the CFD model against experimental data available in the literature. After the validation is demonstrated, various ellipsoidal buoy shapes of different aspect ratios are used as OD devices which are excited under the same wave conditions. Comparisons are made and results are presented based on buoy displacements which could be related to energy produced by the buoys.Results indicate the maximum displacement increases as the aspect ratio approaches 1:1:1 (sphere) which would result in the highest possible energy conversion.

**Keywords:** CFD, buoy, energy conversion, wave energy.

## INTRODUCTION
Buoys have recently been used as wave energy converters. There are various examples of buoy shapes and types. For instance, the backward bent duct buoy (BBDB) is a power-generation buoy design that relies on oscillating water column to capture energy. Although it was invented more than 20 years ago, improvement and modeling of the design has been limited. A study by Toyota et al. (2008) showed that a BBDP with an extension duct improves the conversion efficiency of the device. Their work involved a number of physical tests for five different BBDB models and from the experiments, the effects of BBDB hull shape and the primary conversion efficiency were obtained. Fig. 1 shows the BBDB concept.

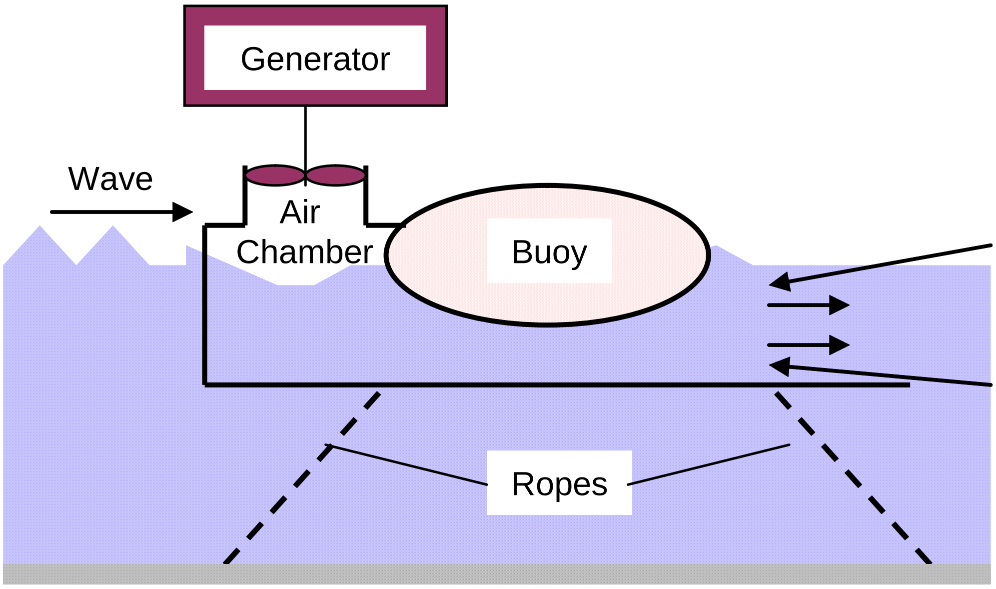


Fig.1. Sketch of the backward bent duct buoy (BBDB) concept.

Another type of buoy which is simpler than BBDB is an oscillating buoy wave power device (OD). In addition to being simpler than the BBDB, the OD has the same capture width ratio but it has a much higher second conversion efficiency as well (Yonunling et al., 2002). A simpn oscillating buoy wave power device (OD) can be used to capture wave energy by an oscillating buoy. Compared to an oscillating water column wave power device as discussed above as an example, the OD has the same capture width ratio but it has much higher second conversion efficiency (Youngling et al., 2002). A simple sketch of the OD is shown in Fig. 2.
As seen in the figure, wave interacts with the buoy which is connected a mechanical device. Upon this interaction, the buoy oscillates and creates spring force which is converted to mechanical power.

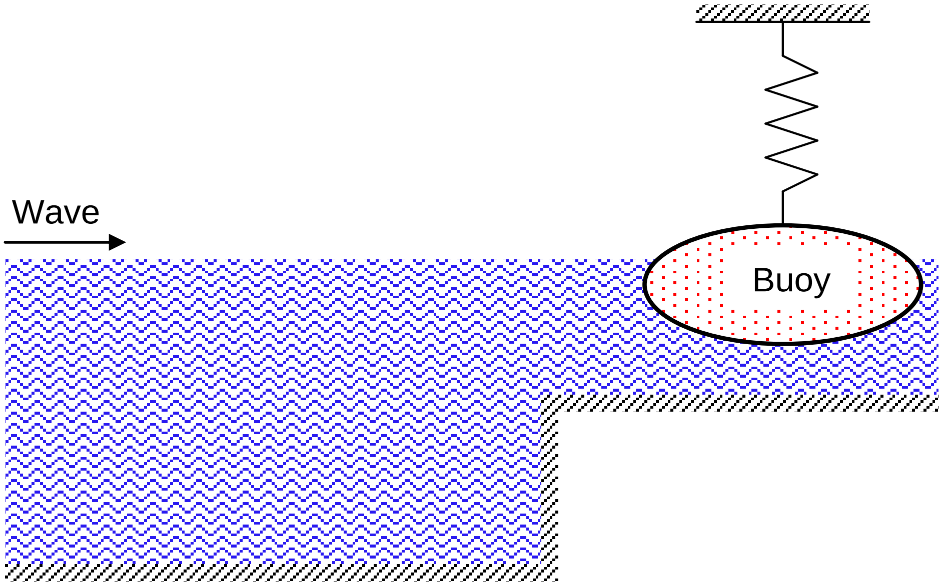


Fig.2. An oscillating buoy power device.

In this work, to ensure the validity of the created software model, a rectangular hexahedron buoy of the same dimensions outlined in *Hadzˇic´ et al.* (2005) was analyzed using the same wave properties also defined in the paper. Once the vertical displacement and motion of the two buoys were confirmed to be the same, the appropriate model setup and physics were used in the computational analysis for various ellipsoidal buoy shapes of several aspect ratios excited under the same wave conditions. Aspect ratios of ellipsoidal shapes were chosen between 0.25:1:1 (penny shape) and 1:1:1 (sphere). Results indicate the maximum displacement increases as the aspect ratio approaches 1:1:1 (sphere).

## COMPUTATIONAL ANALYSIS

The Flow-3D computational fluid dynamics software package (FlowScience, Inc., 2011) was used to perform the analysis found in the following sections of this report. The properties and initial values used to fully define the model set-up can be found in the following sections.

### Computational grid

The mesh was compromised of 193,282 block cells that were equally distributed throughout the render space contained within the previously defined boundary regions.

### Boundary regions

The boundary regions containing the computational mesh were defined along the faces of a rectangular hexahedron of dimensions 0.4m * 3m * 1m. The minimum and maximum x-direction faces were both defined as no-slip walls. The minimum and maximum z-direction faces were a no-slip wall and a symmetric boundary, respectively. The maximum y-direction face was defined as a pressure outlet, allowing water introduced by the wave to escape the computational mesh. The minimum y-direction face was defined as a wave boundary, which generated a Stokes wave of period 0.8s, amplitude 9cm, and mean wave depth of 0.4m.

### Geometric properties

The ellipsoidal buoy shapes were placed 2.11m away from the wave generating boundary and were floating in the 0.4m depth liquid water. Aspect ratios considered in the examination included 1:1:1, 1:1:0.75, 1:1:0.5, 1:1:0.375, and 1:1:0.25, where only the vertical axis component of the shape was being independently manipulated. The original spherical shape considered had a radius of 0.1m. Fig. 3. shows the ellipsoidal shapes of the five aspect ratios.

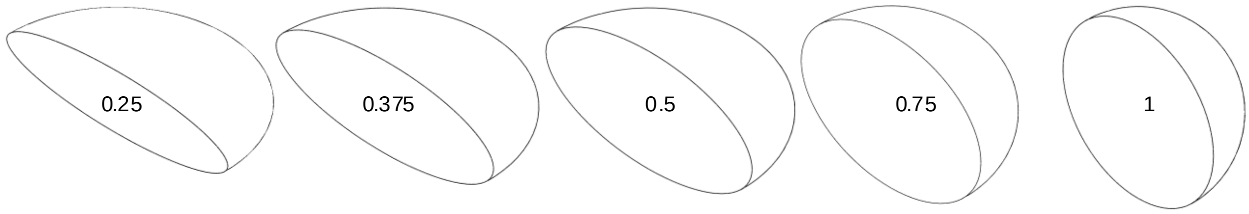


Fig. 3. Ellipsoidal shapes of various aspect ratios.

**Material properties**
Water was modeled using a density of 1000 kg/m$^3$. The density of all of the ellipsoidal shapes used was 680 kg/m$^3$.

**Models and physics**
The following physical models were used in the performed analysis:

- Gravity
- Moving objects
- Collision
- Viscous flow
- Turbulent flow

Gravity was defined as being in the downward direction with a magnitude of 9.81 m/s$^2$. The coefficients of restitution and friction were 1.0 and 0.0 respectively for the collision model. For the analysis, implicit moving object/fluid coupling was considered. The renormalized group (RNG) model was used in the turbulent modeling, and no-slip or partial slip with a coefficient of friction of -1.0 were used for the wall shear boundary conditions. The wind shear coefficient and vertical viscosity multiplier were 0.0 and 1.0 respectively for horizontal flow special options.

**RESULTS AND DISCUSSION**
To ensure the validity of the created software model, a rectangular hexahedron buoy of the same dimensions outlined in Hadzˇic´ et al. (2005) was analyzed using the same wave properties also defined in the paper. Once the vertical displacement and motion of the two buoys were confirmed to be the same, the appropriate modeling and physics used in the computational analysis were chosen. Fig. 4 shows the CFD simulation data for validation.

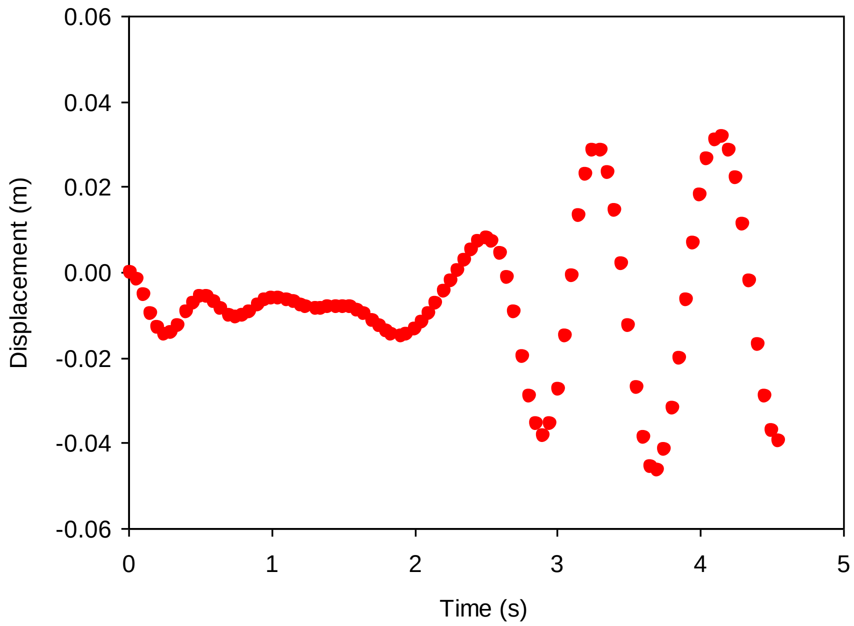


Fig.4. Displacement of a rectangular shape box under certain wave conditions as outlined in the study of Hadzˇic´ et al. (2005).

Fig. 5 shows displacement-time curves of the five buoy shapes. As seen in the graph, the maximum displacement (the difference of the peak points) occurs in case of the sphere. As the aspect ratio decreases, displacement reduces as well. In order to convert energy from the buoy oscillations, the buoy would be attached to a spring. Thus, the maximum displacement can be related to energy created by spring tension-compression. The simplified analysis would be to use a linear spring. Then, the energy would be proportional to the square of the displacement. Since the spherical shape results in the highest possible displacement, energy created by the buoys of the different aspect ratios can be calculated relative to the spherical buoy. Fig. 6 shows energy reduction (relative to the spherical buoy) as a function of the aspect ratio. As seen in the figure, using a buoy like a circular flat plate (1:1:0.25) would capture 50% of the maximum possible energy of the spherical buoy.

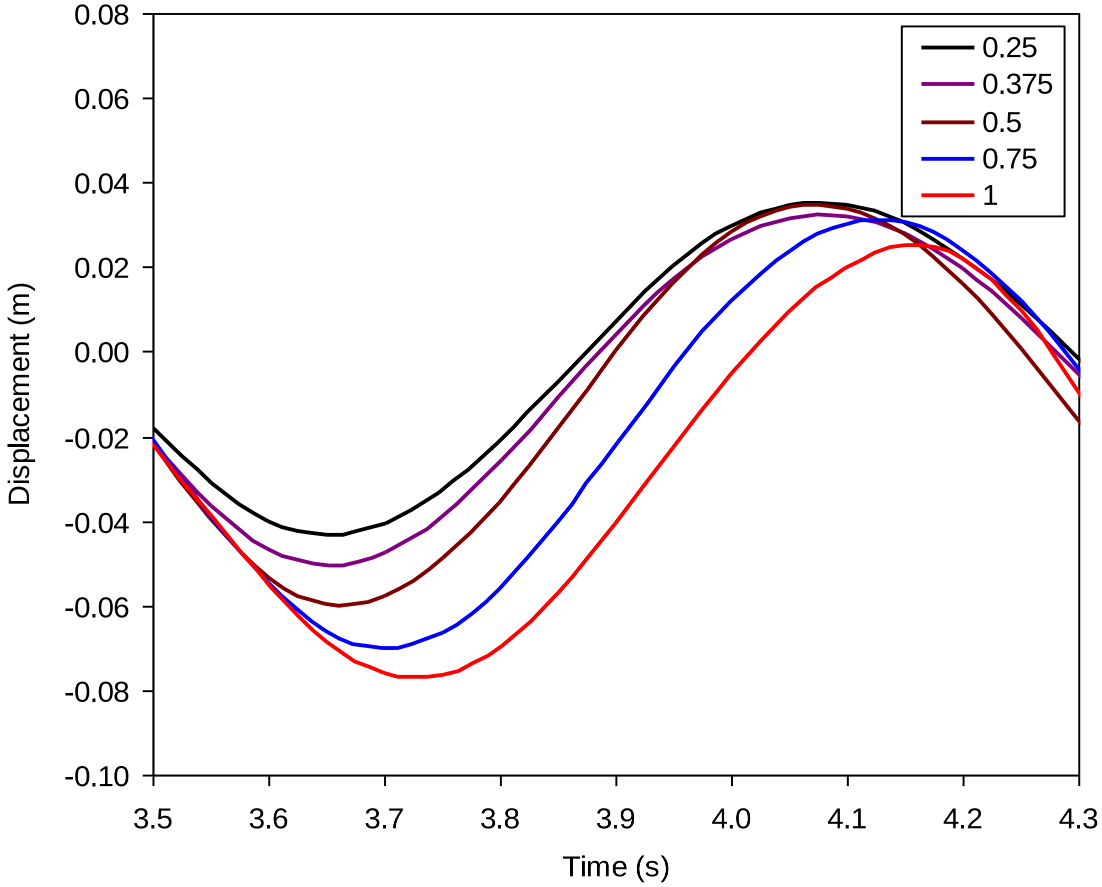


Fig.5. Displacements of the ellipsoidal buoys of the five aspect ratios.

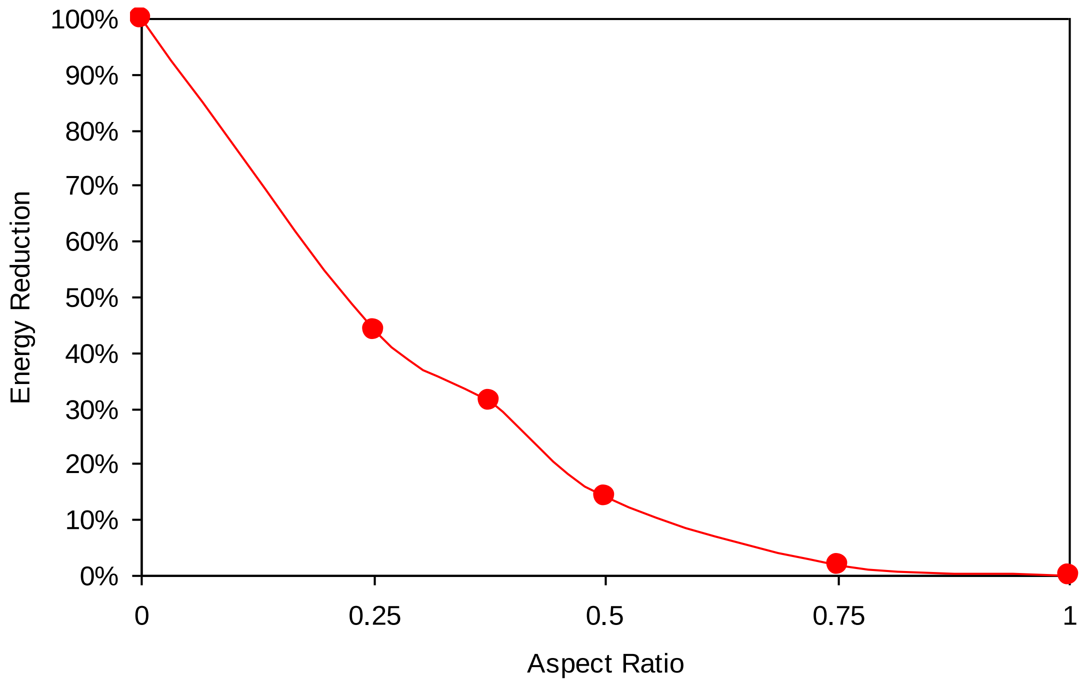


Fig.6. Energy reduction relative to the spherical buoy (1:1:1) as a function of the aspect ratio.

**CONCLUSIONS**

In this work, an oscillating buoy power device (OD) is investigated as a potential wave energy converter. The OD moves up and down to convert wave energy to electricity by means of a mechanical or hydraulic system. Ellipsoidal buoy shapes of the five aspect ratios are used as OD devices which are excited under the same wave conditions. Comparisons are made and results are presented based on buoy displacements which could be related to energy produced by the buoys.Results indicate the maximum displacement increases as the aspect ratio approaches 1:1:1 (sphere) which would result in the highest possible energy conversion. As compared to the spherical buoy, it is discussed that a flat circular plate shape buoy would capture 50% of the possible energy.

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