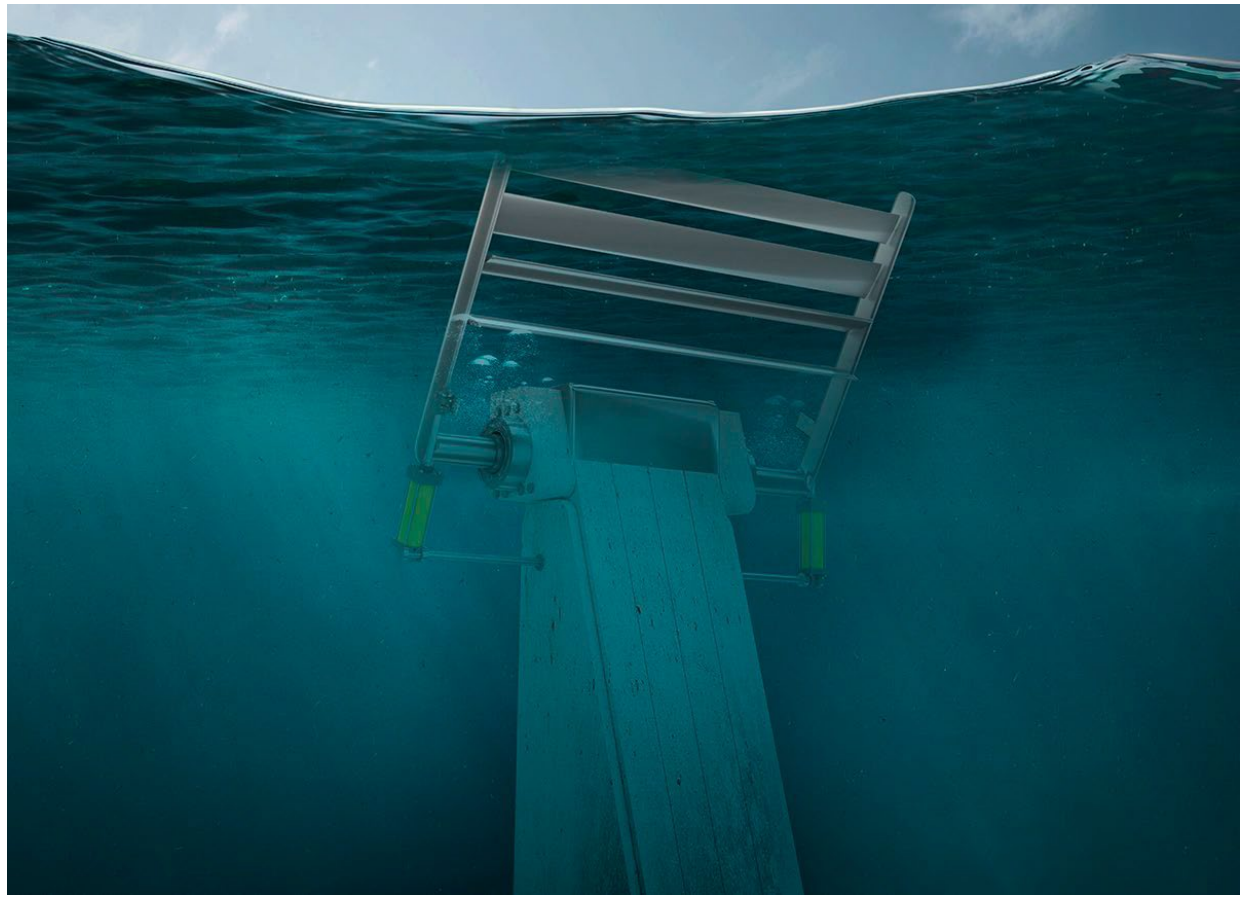
2.2.1.410 – Significant Cost Reduction Potential for Wave Energy Conversion Devices With Variable-Geometry Modules



Presenter: Nathan Tom

Organization: National Renewable Energy Laboratory

Email: nathan.tom@nrel.gov

Presentation Date: July 21st, 2022

Presentation Time: 10:50–11:15 a.m. EST

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Project Overview

Project Summary

•The Technology Commercialization Fund (TCF) award is built upon NREL's previous research exploring a bottom-fixed variable-geometry oscillating surge wave energy converter (VGOSWEC); however, unlike previous investigations, the VGOSWEC will be raised off the sea floor. Researchers believe that advances in offshore pilings and foundations, such as 3D printing, will provide low-cost and easily deployable structures. There are several benefits to designing a raised VGOSWEC, such as (1) reducing issues with sediment transport and environmental impacts near shore; (2) less expensive deployment and installation, as work boats will not risk grounding in shallow water; and (3) deeper water deployments to improve the wave resource.

Intended Outcomes

•The VGOSWEC concept was developed under the assumption that cost reductions and improved system survivability will not be obtained until greater load shedding capability is designed in the wave energy converter (WEC) hull. The load shedding capability is enabled through the hydrodynamic control provided by variable-geometry modules (VGMs). When VGMs are combined with power take-off (PTO) control, the system can emphasize power production of load shedding. The TCF award continued the development of the VGOSWEC, adding a raised foundation, to demonstrate that the concept is a viable technology. To do so, the team completed a hydrodynamic analysis and validated against scaled wave tank tests at UMA.

Project Information

Principal Investigator(s)

- Nathan Tom (NREL)

Project Partners/Subs

- University of Massachusetts Amherst (UMA)
  - Co-Principal Investigator: Prof. Krish Thiagarajan Sharman

Project Status

Completed

Project Duration

- June 18, 2019
- September 30, 2021

Total Costed (FY19–FY21)

$100,689

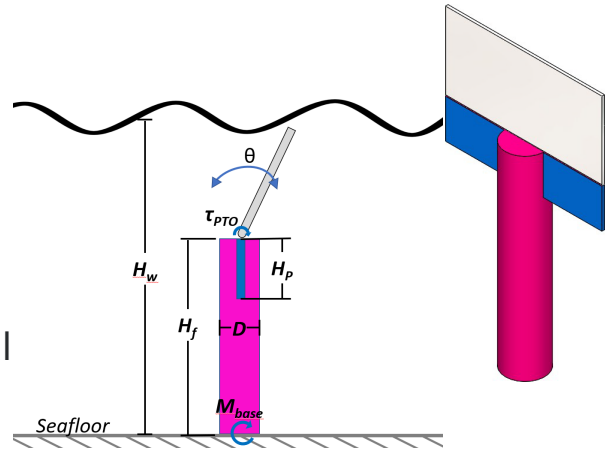
Project Objectives: Relevance

Alignment With Program Goals:

- The TCF award focused on contributing to the following R&D priorities of the marine energy program:
  - Foundational R&D:
    - The VGOSWEC technology provides a unique hydrodynamic modeling challenge that pushes the limits of linear hydrodynamic theory.
  - **System design and validation; supporting prototype testing, including in-water testing at multiple scales:**
    - The wave tank model was designed to improve the number of intermediate orientations of the variable-geometry modules (VGMs) to generate data sets for a wider number of operating conditions.
      - For example, proof-of-concept models previously studied only considered fully open or closed VGMs.
    - The TCF program was a valuable resource for the NREL and UMA team to receive matching funds to continue the development of the VGOSWEC technology through additional wave tank testing.
- The TCF award project results have been developed to help meet WPTO's long-term goal of significant deployment of grid-scale cost-competitive marine hydrokinetic (MHK) projects, driven by dramatic MHK technology LCOE reductions:
  - The load shedding capability provided by variable-geometry components and raising the VGOSWEC off the sea floor was expected to reduce peak loading while opening a wider number of deployment sites (compared to bottom fixed design), both of which would lead to a WEC design with competitive LCOE and broader deployment.

Project Objectives: Approach

This one-year TCF award was broken into five major tasks:



- Raised VGOSWEC hydrodynamic design
  - Determine the approximate optimum sizing of the VGOSWEC and the raised foundation.
- Preliminary techno-economic analysis
  - The incorporation of the raised foundation leads to additional structural costs that do not actively contribute to power generation, and size limitations may come from cost limits rather than technical limits.
- Fabrication of tank scale model of the raised VGOSWEC design
  - Transition the numerical design to physical hardware while incorporating sensors to measure quantities of interest to validate numerical models and prove the load shedding capabilities of the VGOSWEC.
- Wave tank testing of tank scale model
  - The incorporation of variable-geometry components and a raised foundation presented novel hydrodynamics that required validation from wave tank testing and further verification of proof of concept.
- Technology transfer and commercial outreach
  - The NREL/UMA team worked with the NREL Technology Transfer Office (TTO) to develop a technology-to-market plan.

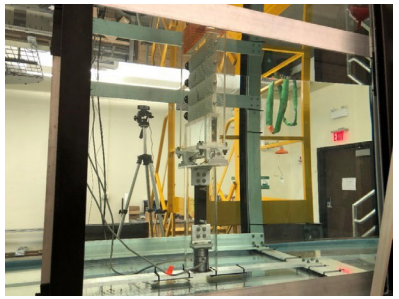


Photo from Jacob Davis, UMA

The goal of these tasks was to further develop the VGOSWEC concept in hopes of attracting collaborator(s) to license the concept or partner(s) to move the concept past small-scale wave tank tests.

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

The TCF award developed:

- Novel numerical models within WEC-Sim to model the performance of a raised VGOSWEC.
- A physical scaled VGOSWEC model with supporting instrumentation.
- A wave tank experimental data set of a raised variable-geometry point absorber WEC.
- Peer reviewed journal and conference publications to distribute knowledge and results.

Outcomes:

- The development and publication of VGOSWEC numerical models, compared against experimental data, provides confidence in available tools while highlighting novel areas of research to pursue.
- TCF results will attract an industry partner who can continue the concept development or adapt it to their own technology.
- Generated results provide further evidence of the viability of the variable-geometry technology.

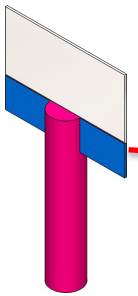
Project Timeline

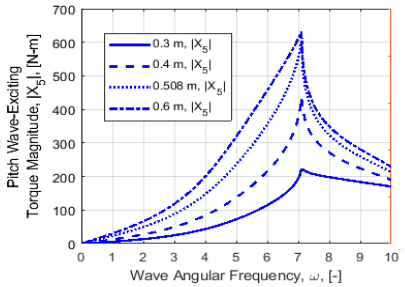
FY 2020

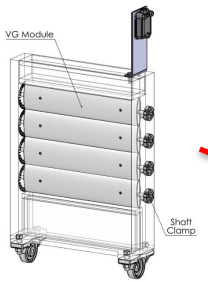
- TCF project kickoff
  - Assign project responsibilities and finalize project schedule.
- Hydrodynamic design of a raised VGOSWEC
  - Iterate on hydrodynamic design and VGM control operation given influence of the raised foundation.
- Preliminary techno-economic analysis
  - Follow the ACE methodology from the Wave Energy Prize to complete initial estimates.
- Begin design of VGOSWEC wave tank model
  - Identify key metrics to measure during tank tests.

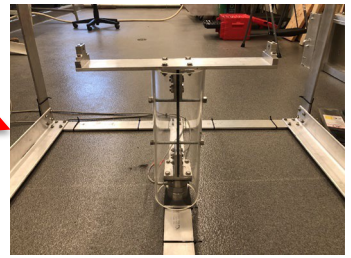
FY 2021

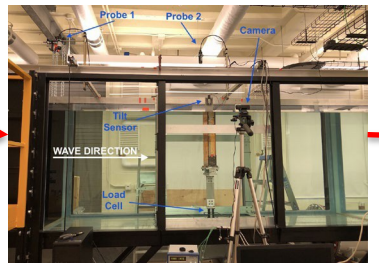
- Finalize design of the VGOSWEC wave tank model
  - Select experimental instrumentation, VGM design, and width to limit tank wall influence.
- Fabricate the VGOSWEC wave tank model
  - Complete procurement of materials and hardware, fabricate model, and complete swing tests for inertia.
- Complete wave tank tests of the VGOSWEC
  - Follow experimental test plan and record VGOSWEC performance to compare against numerical models.
- Develop technology-to-market strategy
  - Develop commercialization plan with NREL TTO.

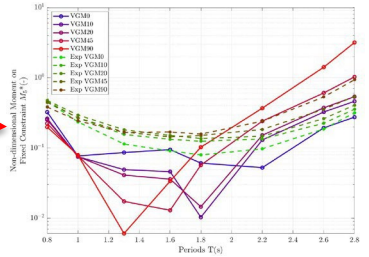






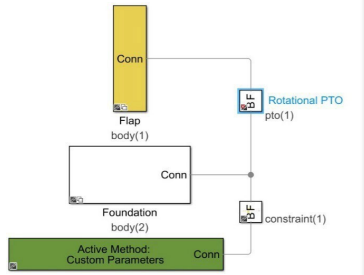






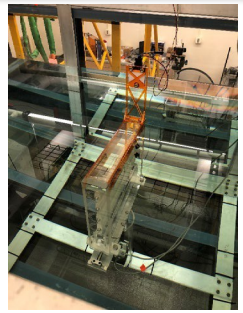
Photos from Jacob Davis (UMA)

Project Budget



WEC-Sim Model

Total Project Budget – Award Information		
DOE	Cost Share	Total
$100.6K	$100.6K ($20K NREL/$80.6K UMA)	$201.2K


Physical Model
Photo from Jacob Davis

FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	Costed	Costed	Total Costed
$0K	$27.8K	$72.8K	$100.6K

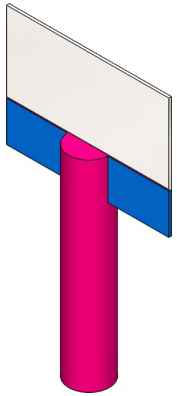
- The Technology Commercialization Fund (TCF) provides funding to mature, promising energy technologies across DOE labs.
- TCF proposal was awarded in FY19; however, there were delays in project kickoff due to subcontracting between NREL and UMA.
  - The award required establishing an intellectual property management plan (IPMP) as well as a separate subcontract, which took from the end of FY19 to mid-FY20 to finalize.
- The TCF award required a 50% collective cost share from NREL and UMA with a final 20/80 split between the two organizations.
  - The total project budget was approximately $200K, with NREL receiving $40K and UMA receiving $160K.
  - NREL focused on numerical model development, while UMA focused on model design, fabrication, and testing.

End-User Engagement and Dissemination

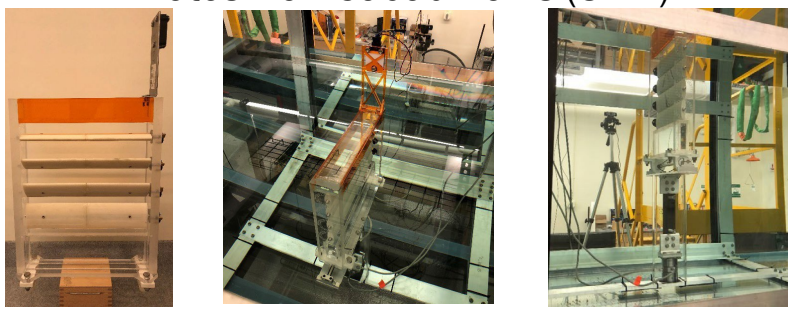
- The TCF award was active for approximately one year, which limited the time available to generate and present results prior to project completion.
  - However, the TCF award project results were shared with an external advisory panel (EAP) that oversees a larger project on the development of variable-geometry WECs, which overlaps with the TCF award.
    - Received feedback from the EAP midway through the project, which helped guide final design and analysis choices.
    - Desire to share results with the marine energy industry in hopes of attracting collaborator(s) to continue development or adapt the technology to their needs.
- The NREL PI, Nathan Tom, participated in an Energy I-Corps short course sponsored by DOE's Office of Technology Transition.
  - The course, titled "Creating Market Pathways for Technology: Customer Discovery," was focused on providing insight into commercializing DOE technology.
  - The course included developing a value proposition for the technology and customer (end-user) outreach.
- The technical team presented TCF results at peer reviewed international conferences.
  - Three conference papers were presented on the development of the raised VGOSWEC concept.
- General public dissemination was highlighted through an NREL news article.
  - "A Window Into the Future of Wave Energy" includes pictures, animations, and video.

Performance: Accomplishments and Progress

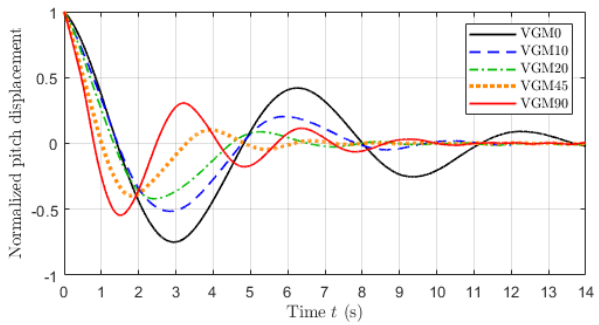
- The major technical accomplishment of the TCF award is successful completion of a wave tank test of a scaled model of the raised VGOSWEC concept.
  - Structural design and techno-economic analysis showed that the foundation would be a significant cost contributor, roughly equal to VGOSWEC, requiring the foundation to be designed from concrete to improve the ACE score.
  - Hydrodynamic models found, when raised, and for longer waves, wave pressure could escape below the OSWEC.
    - Novel design addition of pressure plates (blue sections; right) placed below OSWEC to divert wave pressure on OSWEC.
  - Experiments accurately measured pitch motion as well as the forces & moments at the foundation base.
    - Experimental timeseries were post-processed and compared with numerical results, showing reasonable agreement.
  - Load shedding capability of the VGMs was verified through reduced foundation loads during experiments.
- Preliminary TCF award results have shown that the raised variable-geometry oscillating surge wave energy converter remains a worthwhile technology for continued development.



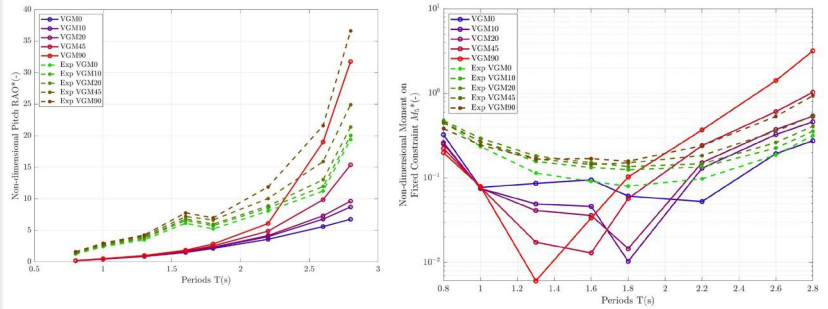
Photos from Jacob Davis (UMA)



Successful fabrication and testing of physical model.



Free decay tests show varying hydrodynamics.



Experimental versus numerical model comparison.

Performance: Accomplishments and Progress (cont.)

- The TCF award has led to several peer reviewed technical papers and special recognition at an international conference:
  - Presentation by Jacob Davis (M.S. student at UMA) on the TCF award development at the ASME IMECE 2020 NSF poster session, which won "Best Outreach Effort."
  - Three peer reviewed conference papers:
    - Nguyen, N., Davis, J., Thiagarajan, K., Tom, N., and Burge, C. 2021. "Optimizing power generation of a bottom-raised oscillating surge wave energy converter using a theoretical model." *Proceedings of the 14th European Wave and Tidal Energy Conference*.
    - Burge, C., Tom, N., Thiagarajan, K., Davis, J., and Nguyen, N. 2021. "Performance modeling of a variable-geometry oscillating surge wave energy converter on a raised foundation," *Proceedings of the ASME 40th International Conference on Ocean, Offshore and Arctic Engineering*.
    - Husain, S., Davis, J., Tom, N., Thiagarajan, K., Burge, C., and Nguyen, N. 2022. "Influence on structural loading of a wave energy converter by controlling variable-geometry components and the power take-off." *Proceedings of the ASME 41th International Conference on Ocean, Offshore and Arctic Engineering*.
  - One peer reviewed journal paper:
    - Choiniere, M., Davis, J., Nguyen, N., Tom, N. Fowler, M., Thiagarajan, K. 2022. "Hydrodynamics and load shedding behavior of a variable geometry oscillating surge wave energy converter (OSWEC)." *Renewable Energy*, 194, 875-884.
    - Two additional journal papers are currently being written.
  - TCF award technology-to-market plan.

Q&A