

Unreal Oceans: Using Unreal Engine 5 to Simulate Realistic Vessel Motion

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ABSTRACT

Current techniques for modeling vessel motion are quite complex and require sophisticated physical representations of the vessel and the environmental conditions, which is very resource-intensive and narrow in scope. This research leverages Gerstner wave simulations and floating body simulations in Unreal Engine 5 (UE5) to create a low-cost, flexible test asset that drastically reduces the resources necessary to create high-fidelity simulations of real maritime vessel motion. UE5's Gerstner wave and buoyancy functions provide a method that reduces the time and cost to generate realistic vessel motion simulations. The UE5 environment can be easily adjusted to simulate numerous environments and vessels, and the motion data can be exported readily for use on a real, physical test asset. The test asset of interest is a portable Stewart motion base that provides high-fidelity, simulated vessel motion for a variety of U.S. Department of Defense programs, including ordnance & weapon testing, electro-optic/infrared (EO/IR) testing, stabilized system testing, and target tracking algorithm development, among others. Increased access to this kind of high-fidelity simulation would benefit military programs with early developmental testing requirements and low technology readiness level (TRL) technologies that may be too high risk for full-up tests. The initial technical challenge of this effort was correlating the wave simulations in UE5 with realistic at-sea motion of a vessel. Once this relationship was established, the next step was to model additional vessels to ensure the virtual wave model was robust. This robust simulation will then be used to generate six-degree-of-freedom motion profiles that can be replayed on the motion platform system. In this way, any simulated vessel motion can be converted into real-world motion rapidly, and a library of profiles can be generated at very low cost. This research is currently in the stage of validating the simulated waves with established physical models to evaluate the fidelity of the virtual models, and creating initial motion profiles from a 3D modeled vessel simulated in the virtual wave environment.

ABOUT THE AUTHORS

Brandon Rudolph has been a research engineer with the NSWC Crane Electro-Optics, Science and Technology branch since 2019. Brandon earned an undergraduate mechanical engineering degree from Rose-Hulman Institute of Technology, with minors in electrical engineering and robotics. Brandon continued his academic career at Rose-Hulman, completing a Master's Degree in 2019 with a focus on human-machine interfaces and supernumerary robotic actuators. Since joining Crane, he has contributed to projects involving target tracking, synthetic EO/IR data generation, and virtual environment modeling.

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INTRODUCTION

The primary source for simulation of vessel motions in the Navy is through highly accurate and complex computational simulations, which are extremely valuable tools but which pose an issue for low technology readiness level (TRL) efforts and programs. Immature designs frequently undergo design changes that would benefit from repeated simulations for verification. The use of high-fidelity simulations incurs significant cost and time that can be cost-prohibitive for low TRL systems. For both large and small vessels, the basic logistics of planning and executing at-sea test events are both very costly and subject to the whims of nature. Providing a lower cost but sufficiently accurate method of simulation would drastically reduce the time and complexity of generating and using vessel motion profiles for testing systems for U.S. Navy-relevant vessels in realistic ocean environments. This research aims to provide a simplified tool to create reasonably accurate vessel motion profiles from virtual wave simulations and 3D vessel models in a virtual world engine. This simplified tool will enable the creation of new ship motion profiles at the point of need and the generation of a library of profiles at an extremely low cost and in a short amount of time. These motion profiles will be used with a physical motion simulator, e.g., a Stewart platform or six-degree-of-freedom (6DOF) motion base, to test and evaluate low-TRL systems much earlier in the design/development process than was previously feasible. This kind of simulation and testing pipeline will allow for more timely and useful testing of developmental military systems, including limited live-fire testing in some cases. The pursuit of this simulation toolset was broken up into several sequential phases: First, we simulated a realistic wave environment and evaluated its accuracy to the real world. Second, following the successful verification that the waves are of a reasonable accuracy relative to the expected real waves, the next step was to model relevant vessels in the virtual environment. Once modeled, the virtual waves and models interacting together can be used to generate translational and rotational motion data from the simulations. Finally, after validating the motion data, it can be used as the input data stream on a Stewart platform for physically replicating the vessel's motion in order to evaluate how U.S. Navy or other Department of Defense systems might respond on the real vessel. This last step extends this work beyond the virtual world into the realm of real physical simulations.

BACKGROUND AND MOTIVATION

This paper focuses on modeling and simulating small maritime vessel motion using Epic Games' Unreal Engine 5 (UE5) as the virtual world framework. In order to reproduce small-boat motion accurately, it is necessary to model both the craft itself and the water environment that will interact with the craft. The latter topic is our starting point for this work. With the plan of using the UE5 game engine to create realistic motion profiles of small craft, the problem of setting up and running complex simulation software is greatly reduced, but it is uncertain if the results from a game engine will retain enough fidelity to real-world physics for the results to be acceptably realistic. Since game engines are designed to create video games, a faithful representation of physics is not necessarily the highest priority. Even so, the underlying computations are based on real, physical models. The first task of this effort was to create a water or wave environment in UE5 based on physical models, and then evaluate how closely it resembles a real maritime environment.

This research is focused primarily on modeling small maritime vessels because they are often subject to the resource limitations relating to high-cost simulations mentioned previously. Small boats typically operate in lower wave conditions, which fall within Sea States 0-2 on the Douglas Sea Scale. The Douglas Sea Scale is designed to estimate the roughness of the sea based on wave height for the purposes of navigation. Sea States 0-2 encompass wave heights from 0 to 0.5 meters, and small craft most typically operate in those conditions. The World Meteorological Organization (WMO) recommends that wave height rather than sea state be used to describe wave conditions, but notes that it is a common practice for national meteorological services to use the Douglas scale (World Meteorological Organization, 2020). Table 1 shows the Douglas Sea Scale with Degree (or Sea State), the corresponding ranges of wave heights in meters, and descriptions of the wave surface.

Table 1: The Douglas Sea Scale

Degree	Wave Height (m)	Description
0	No Wave	Calm (Glassy)
1	0-0.10	Calm (Rippled)
2	0.1-0.50	Smooth
3	0.50-1.25	Slight
4	1.25-2.50	Moderate
5	2.50-4.00	Rough
6	4.00-6.00	Very Rough
7	6.00-9.00	High
8	9.00-14.00	Very High
9	>14.00	Phenomenal

Note that the intention of this project is to obtain a simulation environment in which one can provide Douglas Sea Scale values (i.e., Sea State) to characterize the wave conditions of the virtual ocean qualitatively and obtain relevant vessel motion profiles. The intended application of the motion profiles is to mimic small boat motion on a physical motion platform for test and evaluation purposes. The conditions in which small boats operate is typically within Sea States 0-2 on the Douglas Sea Scale, which corresponds to maximum wave height of 0.5 meters. It also is worth noting that this method of generating vessel motion profiles is a significant improvement over some previous processes, which were based on relatively straightforward mathematical combinations of sinusoids across the six degrees of freedom for rigid-body motion (i.e., roll, pitch, yaw, surge, sway, and heave), and which had no direct correlation to the Douglas Sea Scale or other real world approximation of ocean waves.

A common method of modeling ocean waves is through the use of Gerstner waves (Tessendorf, 2001). Gerstner waves are a solution to the Euler equations for periodic wave motion (Gerstner, 1802) and are a good candidate for producing accurate simulations of ocean waves. Because of the relatively low computational requirements and realistic solutions, Gerstner wave simulations have been incorporated into modern gaming engines, such as UE5. This foundation of potentially realistic wave motion, combined with its low cost, made UE5 the tool of choice for this effort.

For this project to succeed, any virtually generated waves must be evaluated for accuracy through comparison to an established real ocean wave approximation and/or real wave data. The Joint North Sea Wave Observation Project (JONSWAP) wave spectrum is an approximation of wave behavior based on real-world measurements (Hasselmann et. al., 1973). JONSWAP is a modification of the Pierson-Moskowitz wave spectrum, which approximates wave spectra with the assumption of a fully developed sea produced by winds blowing over hundreds of miles for several days. Unlike Pierson-Moskowitz (Pierson and Moskowitz, 1964), JONSWAP assumes that the wave spectrum is never fully developed and continues to develop wave-on-wave interactions for long distances. These extra considerations provide a more representative approximation of real wave motion, and as such the JONSWAP spectrum will be used to validate the virtual waves generated within UE5.

Once the generated waves are verified as accurate, the next step is to create motion profiles of naval vessels by using a combination of UE5 waves and buoyancy functions acting on 3D vessel models. By monitoring a point on the vessel model, any number of full six-degree-of-freedom (6DOF) motion profiles can be produced and exported for the vessel in that wave environment. These motion profiles will be verified against reference motion profiles from highly accurate calculations, such as those created by U.S. Navy hydrodynamicists and vessel designers, in order to assess the level of realism in the lower-fidelity simulation. Once validated, the 3D vessel models and ocean environment can be easily changed or replaced to rapidly develop a library of motion profiles for a wide variety of vessels and sea states. Additionally, it will be easy to generate motion profiles for specific locations on a vessel to simulate specific weapon system or equipment locations due to the built in features of UE5. Creating a repository of virtually generated sea states and motion profiles enables live, real-world testing with physical motion systems such as Stewart platforms, which is a final goal of this research. This kind of live, physical replication of vessel motion would make it significantly easier to evaluate low-TRL systems by facilitating testing that does not need to occur on the actual vessel.

WAVE MODELING

Unreal Engine 5 is primarily a game development engine, and hence it is designed to create cosmetically convincing, but not necessarily realistic, virtual environments. The UE5 Gerstner wave generator exhibits this issue, and the virtual waves lack any direct correlation to real-world waves or weather conditions. However, it is possible to generate Gerstner waves based on established JONSWAP parameters, namely wind speed and fetch length. Deriving the relationship between the UE5 implementation and the JONSWAP parameters allows for a direct comparison between virtually generated waves and the expected wave in the JONSWAP model. A manual implementation of Gerstner waves has already been done within a UE5 plugin called “Physical Water Surface” by Unreal Engine user Theokoles. Physical Water Surface (PWS) is claimed to be JONSWAP accurate, but this claim has not been externally verified, so that verification was performed as a part of this effort. PWS uses the same parameters that determine significant wave height for the JONSWAP spectrum. Significant wave height is defined as the height of the top 33% of waves, measured from trough to crest, over a given time interval. By inputting identical parameters into both PWS and the JONSWAP equations, the accuracy of PWS can be directly compared with JONSWAP and evaluated across multiple wave conditions.

The JONSWAP equation for significant wave height is shown in Equation 1, where $H_{1/3}$ is the significant wave height in meters, F is the fetch length (the distance of water over which the wind blows) in kilometers, and U is the wind speed in meters per second.

$$H_{1/3} = 0.0163F^{0.5}U \tag{1}$$

For consistent evaluation, the significant wave height from JONSWAP was treated as the maximum wave height to relate the virtual waves to the Douglas Sea Scale. While some significant waves will have a slightly greater or lesser magnitude, the Douglas Scale is qualitative by design and thus would have similar fluctuations and would not capture the absolute maximum, so comparing the two quantification methods is reasonable. The motion platform also has its own physical motion constraints, so this research is limited to sea conditions with wave heights up to 0.5 meters.

RESULTS

The PWS plugin was used to generate ocean waves based on combinations of wind speed and fetch length. Every simulation was allowed to run for 10 minutes, generating a minimum of 100 significant waves for each simulation. The vertical displacement of a single point on the waves, located at the origin in this case, was tracked for the duration of the simulation and its z-position data was recorded. Wind speed and fetch length combinations were limited to those that fell into Sea State 0-2 according to the expected JONSWAP values. Each simulation was repeated three times to avoid spurious results. The mean of the simulated significant wave heights was calculated and then compared to the expected JONSWAP value. Figure 1 shows a 30-second sample from one of the wave simulations, with the significant waves highlighted in red.

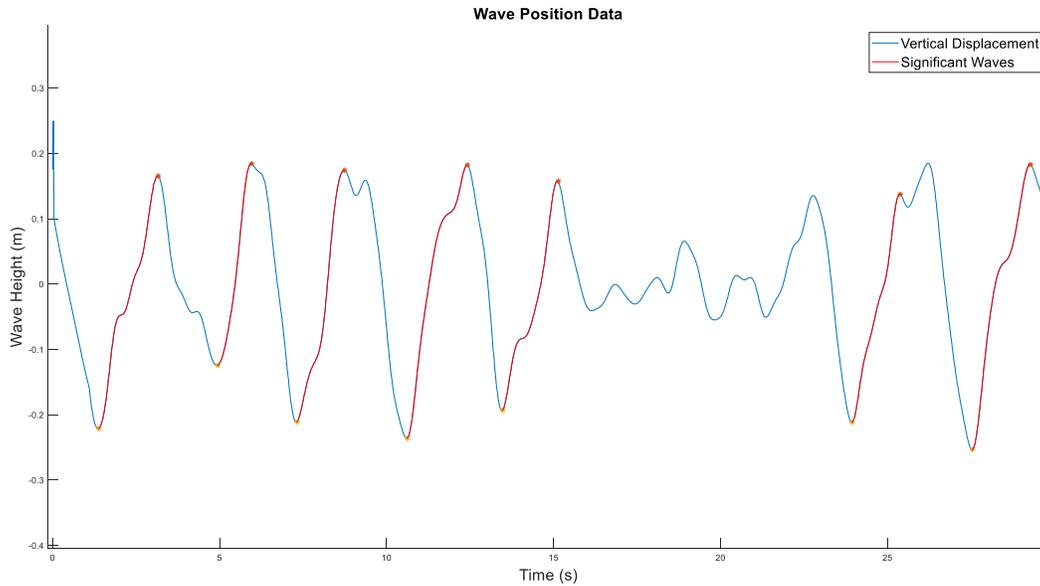


Figure 1: Sample of Virtual Wave Data

Table 2 shows the comparison of the simulated significant wave heights compared to the significant wave heights expected by JONSWAP. The largest percent difference between the UE5 generated waves and the expected JONSWAP value was 13.99%, and the smallest difference was only 0.85%. The average percent difference across all parameter combinations was 5.96%. This means that the virtually generated waves provide an approximately 94% accurate rendition of real waves according to the JONSWAP spectrum, at least in terms of wave height. This level of fidelity in the virtual wave model is a very good foundation for producing accurate 3D motion profiles of vessel motion. Any inaccuracy in the wave behavior will be passed along to any resulting motion profiles, so having virtual waves that are 94% accurate is a significant benefit.

Table 2: Comparison of ne 5 Gerstner Wave Heights with Expected JONSWAP Wave Heights

	Fetch Length (km)								
	50			100			300		
Wind Speed (m/s)	H _{1/3} (JONSWAP)	H _{1/3} (Unreal)	% Difference	H _{1/3} (JONSWAP)	H _{1/3} (Unreal)	% Difference	H _{1/3} (JONSWAP)	H _{1/3} (Unreal)	% Difference
1	0.1153	0.1286	11.55%	0.1630	0.1776	8.94%	0.2823	0.2868	1.57%
2	0.2305	0.2286	0.85%	0.3260	0.3300	1.22%			
3	0.3458	0.3187	7.82%	0.4890	0.4806	1.72%			
4	0.4610	0.3965	13.99%						

The next phase in developing the simulation toolset was modeling a small vessel in the virtual 3D world and recording the vessel’s motion resulting from interactions with the virtual waves. The vessel chosen for this phase was a 41-foot United States Coast Guard utility boat (CG41) because an accurate 3D model was readily available and the vessel has a length of 12.5 meters, well within the “small vessel” category of immediate interest for this project. To assess the combination of the wave environment and the vessel, UE5 buoyancy functions were applied to the CG41 model. The model was then placed in the virtual wave environment and allowed to interact with the waves for 2 minutes. During the simulation, 6DOF rotational and translational motion data was collected at a fixed point in the vessel model. Figure 2 shows a still frame of the simulation of the CG41 model in the UE5 virtual wave environment along with a

sub-set of the positional and rotational motion data that was collected. All of the motion data was collected at 50Hz and was exported into a .csv file format so it would be compatible with the Stewart platform software package.

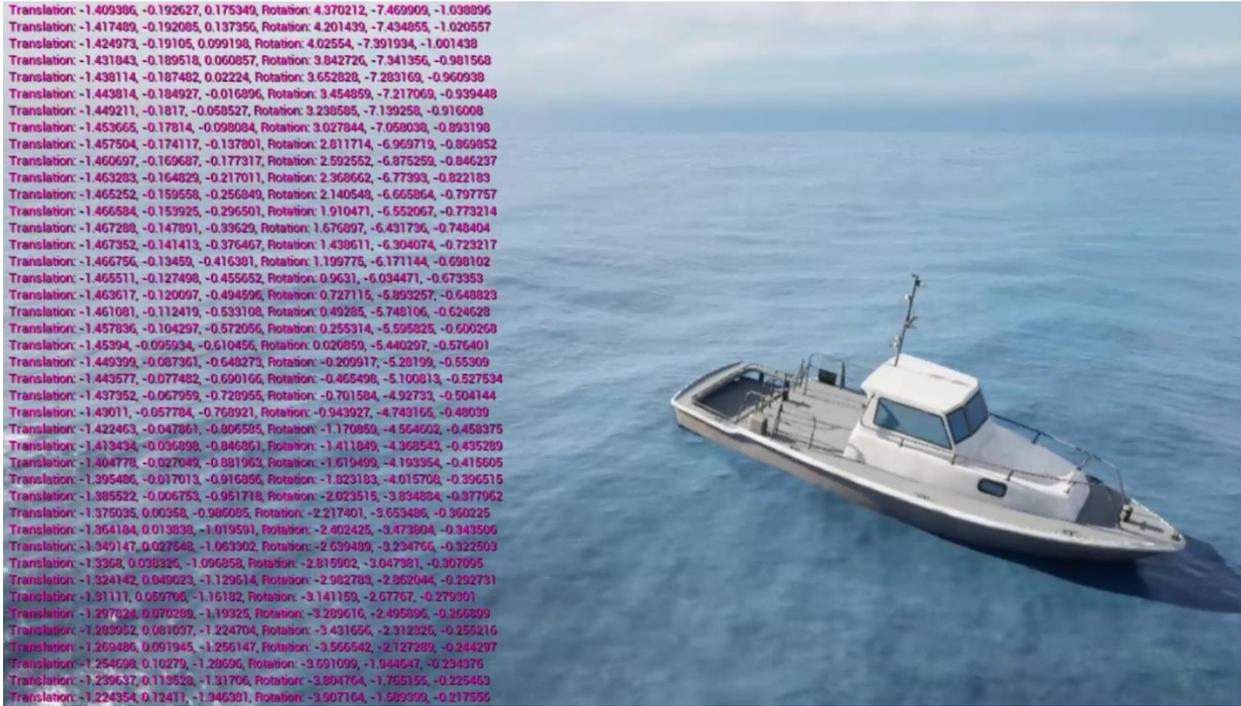


Figure 2: Motion Data Stream (left) and 3D Model of CG41 Simulated in the UE5 Wave Environment (right).

Figure 3 shows a sample of the motion data from one of the CG41 simulations, separated into the 6 degrees of freedom. At this stage in the project, all motion data was collected at the vessel’s center of gravity, although this will be changed in the future depending on the specifics of the intended test requirements.

Figure 4 shows a representation of the simulation and data pipeline for this project. The steps shown in the figure establish a clean, repeatable process pipeline that starts from a realistic virtual environment, adds in the vessel’s responses to that environment, and then leads smoothly to the physical test asset. At this stage in the project, the team has only begun work on the middle step in earnest. The next step in the project will be to use the generated motion profile on the Stewart platform to demonstrate full functionality of the UE5 to real world testing toolset. Completing this toolset/pipeline validation is anticipated within the next few months.

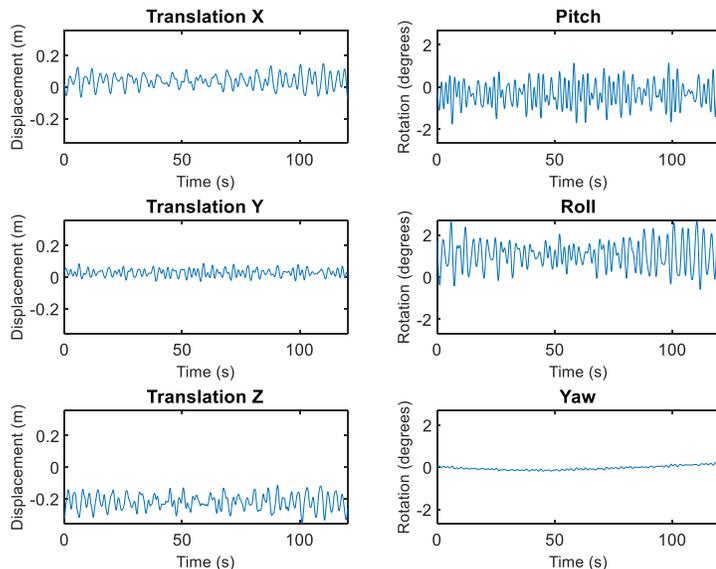


Figure 3: Motion Data from a CG41 Simulation



Figure 4: Visual Representation of the Simulation Toolset Data Pipeline. Virtual Waves (left), Generation of Motion Data with Vessel Model (middle), and Real World Testing on a Stewart Platform (right)

CONCLUSION AND FUTURE WORK

This research has validated that UE5 Gerstner wave simulations can be generated that are, on average, within 6% of the JONSWAP spectrum for significant wave height using identical parameters of wind speed and fetch length. In conclusion, that virtual wave environments created in a game engine can be a good approximation for real-world waves. Virtually generated but reasonably accurate wave environments and 3D vessel models are a promising alternative to complex and costly full-fidelity seaway/vessel simulations when working with developmental or low-TRL technologies. For initial testing and evaluation purposes where system designs are subject to change and testing is iterative, this simulation toolset (i.e., virtual wave and vessel modeling leading to motion simulation with a real, physical motion system) could be very useful and cost-effective. Exporting the motion data out of UE5 in a format that is directly readable by the motion platform control software was a significant milestone in creating the simulation toolset, as that enables real-world testing in the future. The next step of this research is to place 3D models of relevant U.S. Navy vessels into the virtual wave environment and utilize UE5's buoyancy functions to generate 6DOF motion profiles at various points on the vessel. The accuracy of these 6DOF motion profiles will then be compared to corresponding results from very high fidelity hydrodynamic vessel design and analysis programs, which represent the gold standard for performance comparison. These comparisons will be performed by using the same vessels and wave/seaway conditions to assess the correspondence between the resultant vessel motion in the low-cost, game engine pipeline and the reference dataset.

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