Ride the Wind: A Seakeeping Study of the Gyroscopic Effect of the Wind Turbine Rotor on a Moored, Tension-Leg Platform

Jackson Juska and Addie Lindyberg,
Advisor: Professor Adrian Onas

Abstract

This research investigates the gyroscopic effect of a spinning wind turbine on the motion of a moored, tension-leg platform in incident waves. We built and tested a model of a floating offshore wind turbine system in the Robinson Model Basin. The 1:100 scale model consisted of the NREL 5MW Reference Turbine with the MIT TLP #1 platform, which we modified. Despite significant uncertainty in the results, there is a clear difference between the motion of the platform when the rotor is spinning and when it is locked. We attribute this difference to the gyroscopic effect of the spinning rotor.

Background

Because it provides much potential for power, offshore wind is a very promising alternative to fossil fuels. However, most of the potential is over deep water (greater than 60 meters), where a fixed platform is not economically practical. Therefore, floating platforms can be used, though there are still challenges, such as providing turbine stability in rough water.

Gyroscopic Precession

A rotating body has both torque and angular momentum. The torque and angular momentum are directed perpendicular to the spinning motion of the rotor. As the torque increases, the angular momentum also increases. For example, a spinning bike wheel hanging from a string by its axis will stay upright. The angular momentum, which is directed out of the spoke of the wheel, resists gravity and causes the wheel to stay vertical. The torque causes the wheel to rotate around the string.

Objectives & Approach

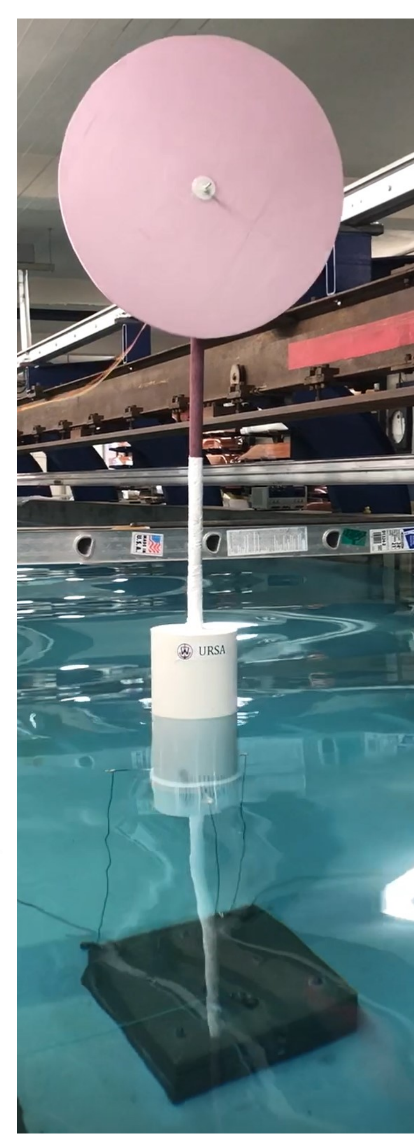
The objective of this thesis is to determine the inertial effect of that the rotating blades of a wind turbine will have on the motion of a Tension-Leg Platform (TLP) in incident waves. To meet this objective, we built a scale model of a TLP with a mass, spun by a motor, attached at the top of the tower to simulate the inertia of the rotating blades of the turbine. The model was moored in the Robinson Model Basin to reproduce the operating conditions of the platform and response to incident waves of different frequencies and amplitudes. By comparing the motion responses of the platform with and without the gyroscopic effect, we were able to draw conclusions on how rotational inertia affects platform

Technical Details

We scaled the blades of the turbine by the gyroscopic moment using Froude scaling, to a uniform disk. Using Froude scaling and the MIT TLP #1, we designed a model representative of a typical offshore turbine/platform system. We determined a scale of 1:100 was the largest our model basin could handle and the smallest feasible scale for construction. Our mooring arrangement was designed to avoid the natural frequencies of the system. The proper pre-tension avoids a surge natural period (typically below 25 seconds) and the proper material properties avoid the heave natural frequency (typically above 5 seconds).

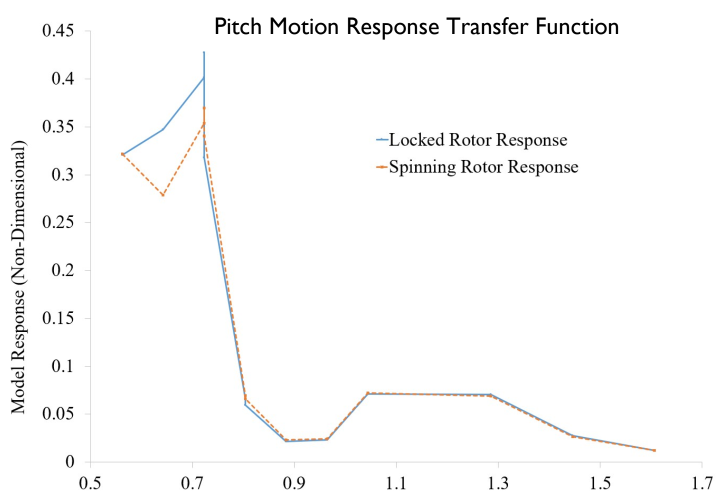
Testing

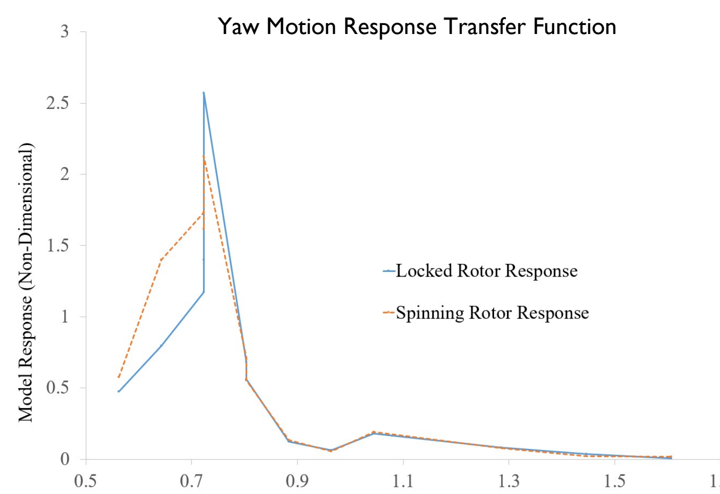
To isolate the gyroscopic effect, we had to test our platform under both a locked-rotor condition and a spinning-rotor condition. This was done for various wave conditions. For each of the spinning rotor tests, the rotor spun at a constant speed of about 121 RPM. We measured the acceleration in the surge, sway, and heave directions and we measured the angular velocity of the rotations about these axis respectively (labeled roll, pitch, and yaw).



Results

The pitch and yaw transfer functions (as shown below) indicate that there is a difference in motions between the locked and spinning rotor conditions for low-wave frequencies. The transfer functions for the two rotor conditions converge at higher wave frequencies. The gyroscopic precession amplifies the yaw motions and mitigates all other motions.





Jackson Juska:

Hometown: Avalon, NJ

Post-Graduation Plans: Mission Work

Addie Lindyberg:

Hometown: Stockton Springs, ME

Post-Graduation Plans: Working at Viking Systems