Effect of Platform Oscillations on the Flow Field of an Off-Shore Wind Turbine using Particle Image Velocimetry

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Abstract

Renewable energy is one of the main focal points of research in the scientific community. As the demand for renewable energy increases, more research is being conducted on new forms of renewable energy and how to make the current forms more efficient. In this research, the effect of external oscillations on the flow-field and power generation of an off-shore deep water wind turbine is being investigated. The main problems investigated are if tidal movements and other natural forces are positively or negatively affecting the overall performance of a wind turbine and how the flow field around the propellers are affected. We believe that the tidal movements will increase the velocity of the blade as well as increase the blade's revolutions per minute. Particle image velocimetry and MATLAB was used to collect and analyze the particle velocity data collected. From the results, it was found have that the particle velocity vectors increased in magnitude compared to the control test with no tidal movement. This supports the initial prediction because the angular velocity of the turbine blade will lead to greater power generation by the wind turbine. Our findings report that tidal effects could potentially have a positive effect on the power generation of off-shore wind turbines.

Objective

The objective of this research is to investigate the effect of external oscillations on the flow-field of an offshore deep-water wind turbine (see Figure 1). By using a prototype wind turbine model in conjunction with a Steward Platform, a moving hexapod robot that can control a platform with six(6) degrees of freedom, different motions will be simulated on the turbine blade. With the use of particle image velocimetry (PIV), differences in the flow field of a static and dynamic wind turbine will be evaluated. In this report, a short introduction of the experiment is given, followed by the experimental setup and procedure, results of the data captured, a conclusion of the results and an appendix.

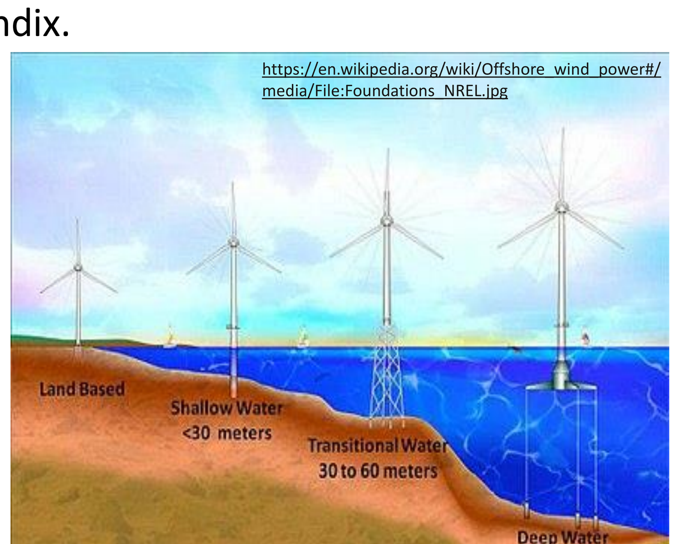

Figure 1: Offshore Wind Turbine Diagram

Setup/Procedure

Materials Used:

-40 Gallon Fish Tank
-Top-Mounted Track
-AOS S PRI Camera
-Dragon Laser, Continuous Wave, 3 Watts
-6DOF Hexapod
-Arduino Uno
-Waterproof ¼" Bearings
-Two-Spoke Propeller
-½" Threaded Rod
-Glass Powder

Setting up the Hexapod:

1. Mount the assembled hexapod to the track above the tank. Make sure that the moving platform is perfectly level.
2. Test the track in order to have a full sweep across the length of the track.
3. Upload the Arduino Code with desired parameters to the hexapod.
4. Attach the propeller to the platform section of the hexapod.

Setting up Laser and Camera:

1. Mount the camera normal to the motion of the hexapod. (The camera does not have to be in the center of the fish tank, but it is recommended.)(Figure 3)
2. Mount the laser parallel to the motion of the hexapod. Adjust the height of the laser accordingly.
3. Attach lenses to the laser in order to generate a vertical sheet. Use safety equipment as necessary.
4. The vertical sheet of the laser should pass through the blades of the turbine only (Figure 4).
5. After the setup is complete, calibrate the camera along with the laser using PIV software using calibration plates or other forms of calibration.

Performing the Experiment:

1. Pour two (2) tablespoons of glass powder into a pint of filtered water. Mix until the powder is fully mixed with the water.
2. Pour the mixed solution into the fish tank.
3. Mix the solution with the water already inside the tank.
4. For a control run, the hexapod shall move along the track while the camera is recording with no motion uploaded to the hexapod.
5. For the experimental run, start both the motion of the hexapod and the track simultaneously. Record the appropriate data.
   Note: Before running any of the tests, make sure that the water inside the tank is still and that there is no currents anywhere inside the tank.
6. Process the data using MATLAB or any other coding software.

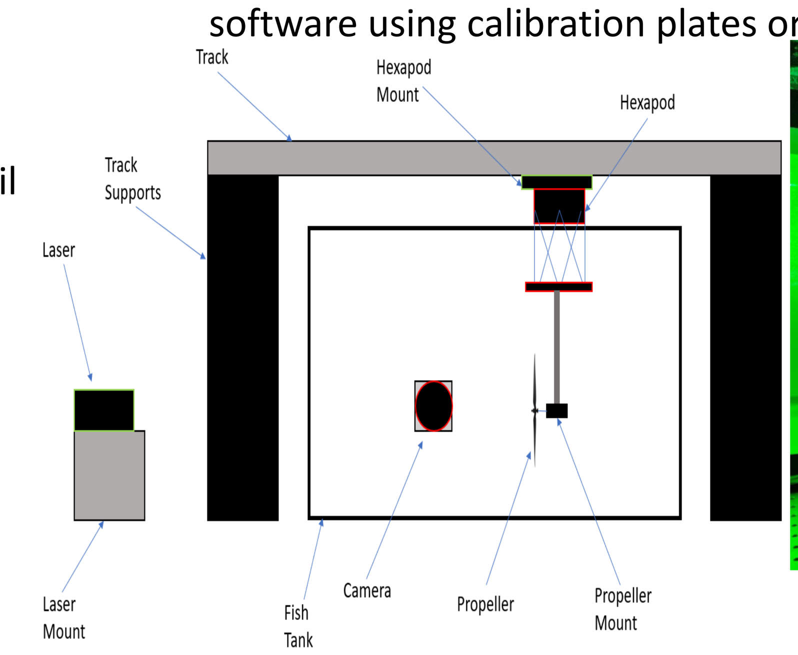

Figure 2: Schematic of Testing Apparatus

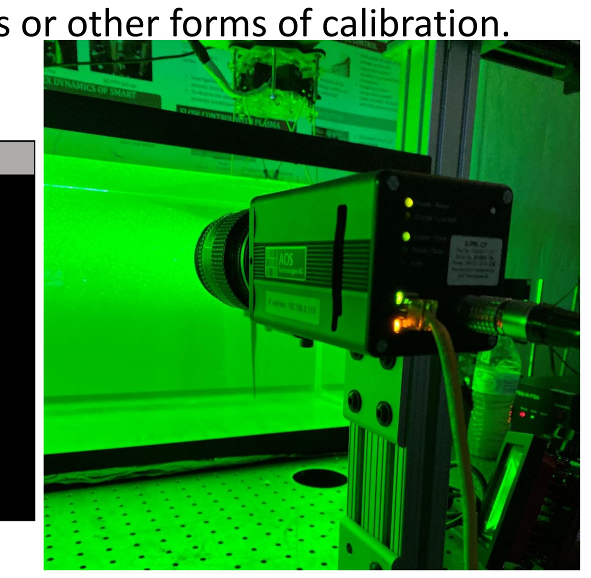

Figure 3: Camera Mount

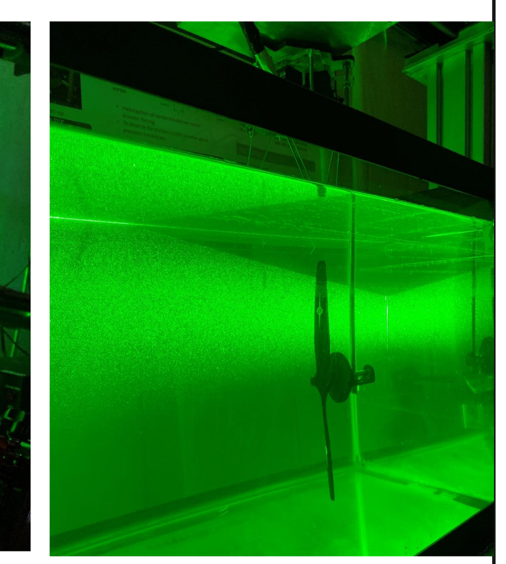

Figure 4: Laser Sheet after Complete Setup

Results

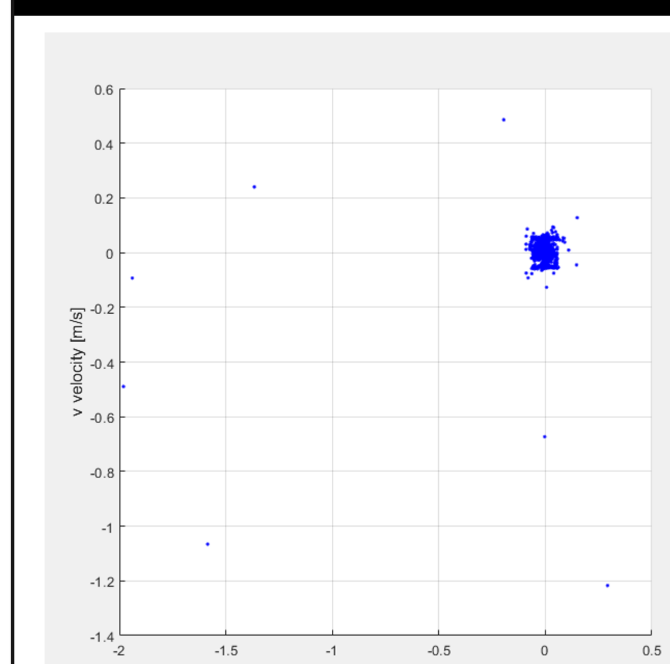

Figure 5: Run 1 Velocity Diagram

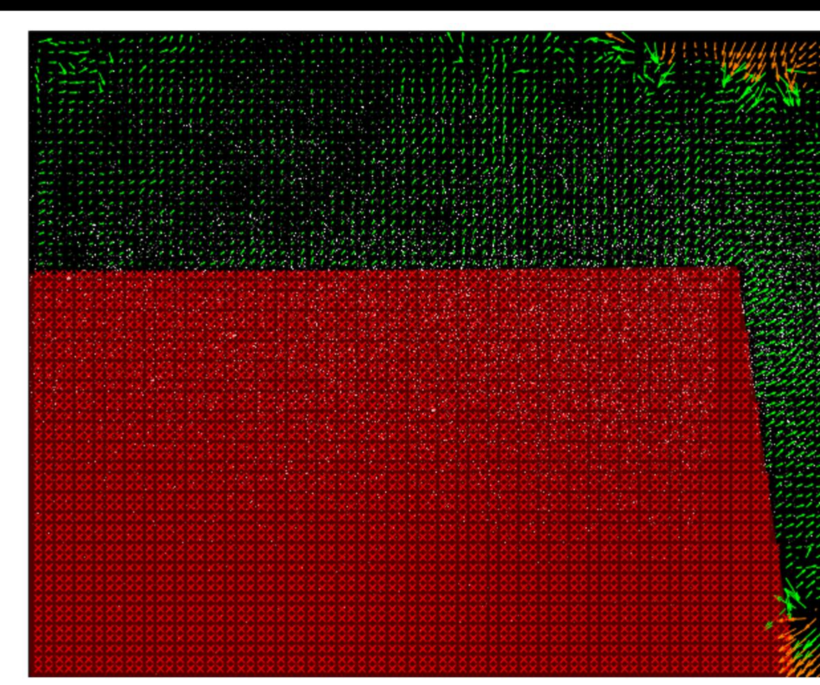

Figure 6: Initial PIV Velocity Vector Solution

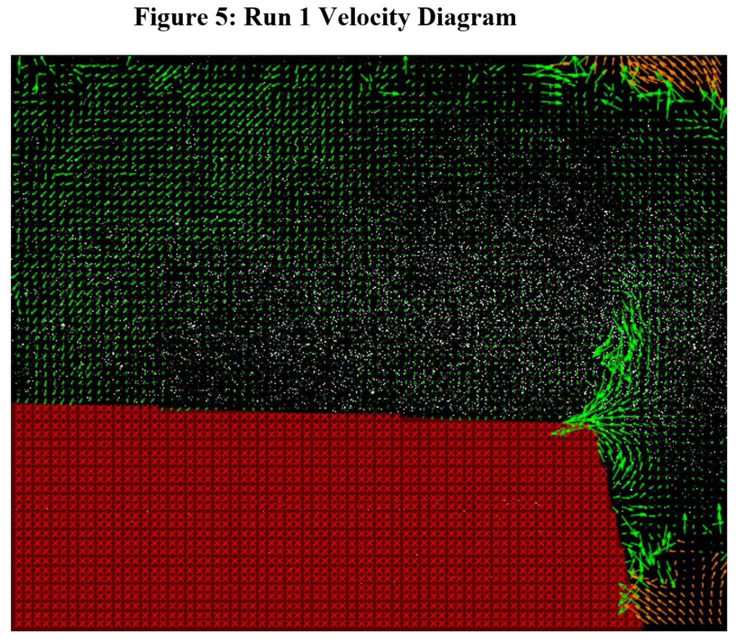

Figure 7: PIV Velocity Vector Solution at the midpoint of Run 1

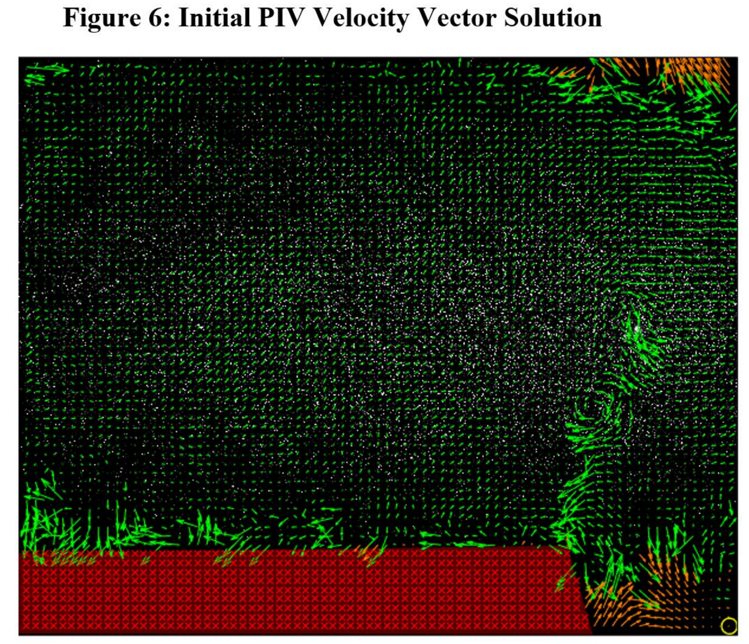

Figure 8: PIV Velocity Vector Solution at the end of Run 1

Run 1 (No sinusoidal oscillation of apparatus)

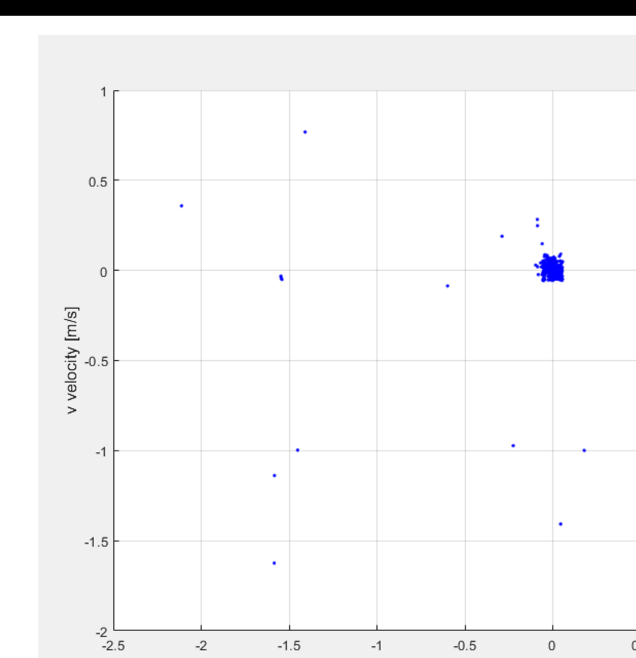

Figure 9: Run 2 Velocity Diagram

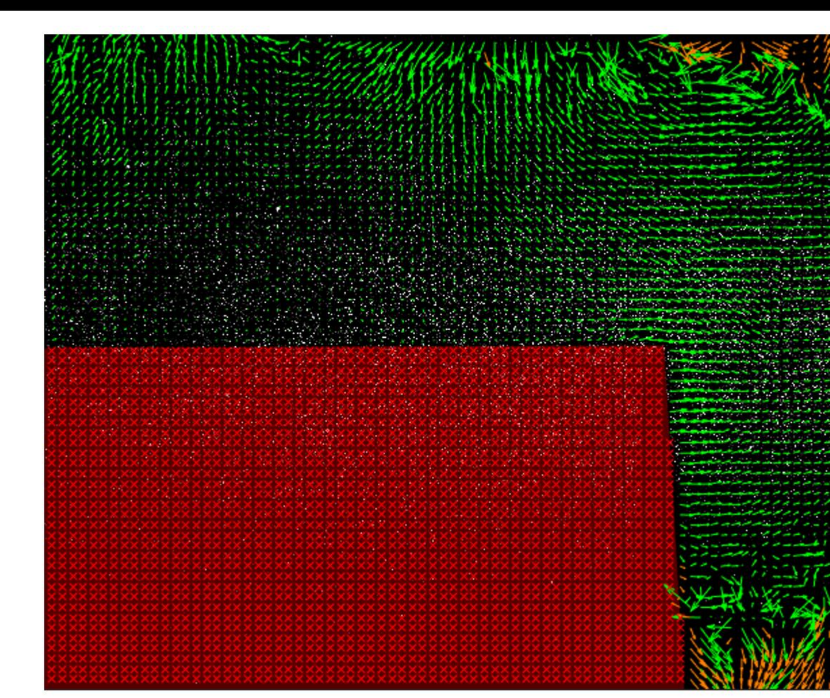

Figure 10: Initial PIV Velocity Vector Solution

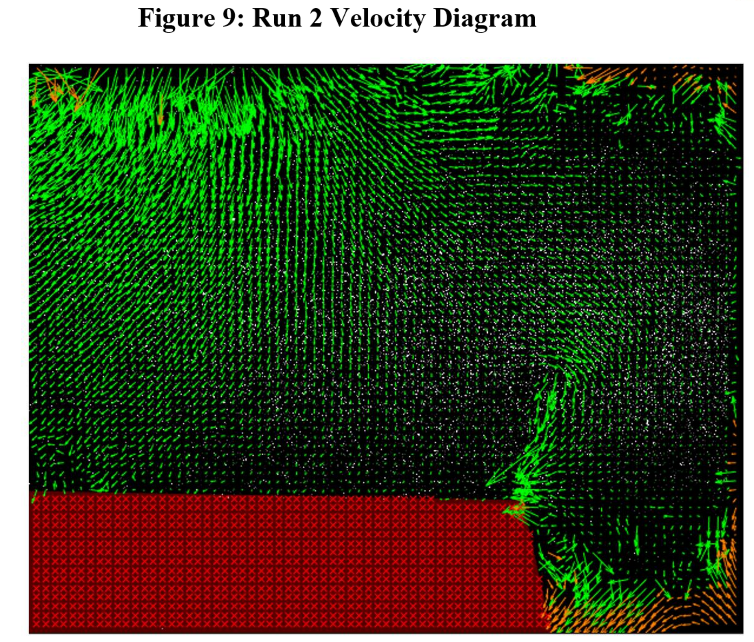

Figure 11: PIV Velocity Vector Solution at the midpoint of Run 2

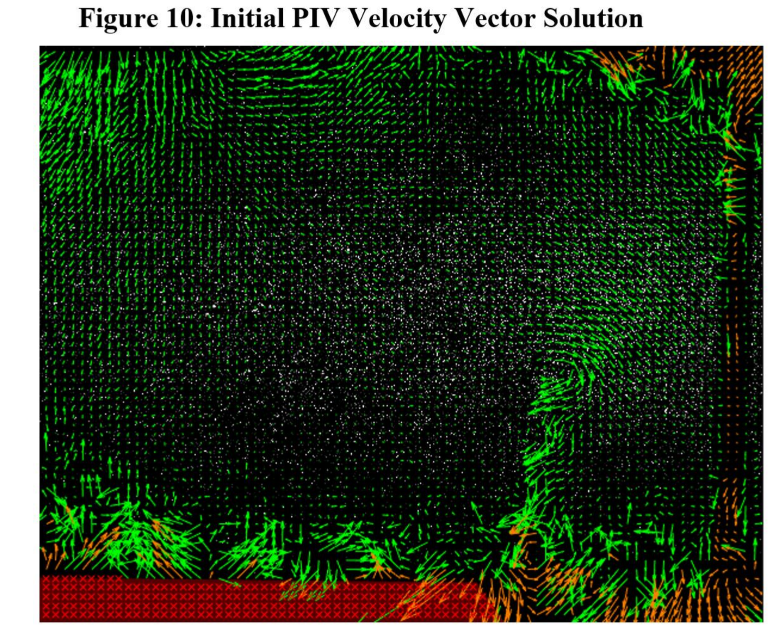

Figure 12: PIV Velocity Vector Solution at the end of Run 2

Run 2 (Applied sinusoidal oscillation of apparatus)

Discussion

After processing the images collected in MATLAB, it is observed that the oscillating motion had a positive effect on the velocity vectors of flow and vortexes formed as a result. When analyzing the results in the velocity graph of the vectors from both runs, it is seen that in Run 2, there was a greater magnitude of vectors in both the u and v direction. Visually, after analyzing the results in figures 6-8 and 10-12, the flow field affected by the propeller blade yielded more vortexes and motion in the line of action of the blade in the 2D plane. The data suggests that the propeller velocity was greater in Run 2 than in Run 1, as expected.

Conclusion

From the results, it is observed that the velocity of the propeller blade was increased due to the added oscillations of the testing apparatus as predicted before conducting the experiment. This suggested that the propeller revolutions per minute was increased in Run 2 (Figure 9), which results in greater power generated by the wind turbine. However, the oscillations were exaggerated compared to natural forces that an actual offshore wind turbine will experience. This leads to the idea that the effect caused by the wave oscillations will be less in magnitude in a real-life application. Also, the visual results of the PIV images show that the fluid around the propeller blade will be affected greater with tidal wave oscillations with more vortexes and increase in fluid velocity.

Future Work

To further enhance this research and learning experience, the following measures can be taken:

- Increase the scale of the wind turbine model to have a more accurate representation of a wind turbine.
- Upgrade hardware used in Steward Platform in order to have smoother, more accurate motion in order to represent realistic tidal movements.
- Extend track that the Steward Platform will travel along to capture more data in one run.
- Use different types of propellers and compare the flow field and power generation of each.

Acknowledgements

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