SMALL UNMANNED MARINE HYDROKINETIC PLATFORMS FOR POWER GENERATION IN COASTAL AND TIDAL WATERS

by

Adriana McKinney

A Dissertation Submitted to the Faculty of

the College of Engineering and Computer Science

In Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

Florida Atlantic University

Boca Raton, FL

May 2024

SMALL UNMANNED MARINE HYDROKINETIC PLATFORMS FOR POWER GENERATION IN COASTAL AND TIDAL WATERS

by

Adriana McKinney

This dissertation was prepared under the direction of the candidate's dissertation advisor, Dr. Manhar Dhanak, Department of Ocean and Mechanical Engineering, and has been approved by all members of the supervisory committee. It was submitted to the faculty of the College of Engineering and Computer Science and was accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

SUPERVISORY COMMITTEE:

Manhar Dhanak, Ph.D.
Dissertation Advisor

Hassan Mahfuz, Ph.D.

Tsung-chow Su (Apr 11, 2024 19:16 EDT)

Tsung-Chow Su, Ph.D.

Siddhartha Verma (Apr 12, 2024 07:46 EDT)

Siddhartha Verma, Ph.D.

Pierre-Philippe Beaujean, Ph.D.
Chair, Department of Ocean & Mechanical Engineering

Stella Batalama, Ph.D.
Dean, College of Engineering and Computer Science

Robert W. Stackman Jr.
Robert W. Stackman Jr. (Apr 13, 2024 13:53 EDT)

Robert W. Stackman Jr., Ph.D.
Dean, Graduate College

April 13, 2024

Date

ACKNOWLEDGEMENTS

Special thanks to Dr. Manhar Dhanak, Dr. Hassan Mahfuz, Dr. Tsung-Chow Su, Dr. Siddhartha Verma, Hugo Pimentel, John Frankenfield, Ed Henderson, Caleb Wilson, Theresa Wainwright, and Xavier Navarro for your continued support during this project and all through my time in the doctorate program. Your expertise, wisdom, guidance, and assistance have allowed me to form a strong foundation for the rest of my approaching career.

ABSTRACT

Author: Adriana McKinney

Title: Small Unmanned Marine Hydrokinetic Platforms for Power Generation in Coastal and Tidal Waters

Institution: Florida Atlantic University

Dissertation Advisor: Dr. Manhar Dhanak

Degree: Doctor of Philosophy

Year: 2024

The feasibility and optimization of small unmanned mobile marine hydrokinetic (MHK) energy platforms for harvesting marine current energy in coastal and tidal waters are examined. A case study of a platform based on the use of a free-surface waterwheel (FSWW) mounted on an autonomous unmanned surface vehicle (USV) was conducted. Such platforms can serve as recharging stations for aerial drones (UAVs), enabling extension of the UAVs' autonomous operating time. An unmanned MHK platform potentially meets this need with sustainable power harvested from water currents. For the case study, six different waterwheel configurations were field-tested in the Intracoastal Waterway of South Florida in support of determining the configuration that produced the most power. Required technologies for unmanned operations of the MHK platform were developed and tested. The data from the field-testing were analyzed to develop an empirical relation between the wheel's theoretical hydrokinetic power produced and the mechanical power harnessed by the MHK platform with various waterwheel configurations during field-testing. The field data was also used to determine the electrical power generated by the FSWW configurations during field-testing. The study has led to the development of standardized testing procedures. The empirical relation is used to examine predicted power production through scaling up different physical aspects of the waterwheel.

DEDICATION

I dedicate this achievement to my family, friends, educators, and colleagues. Many people have shaped me and my work, but without hesitation, I thank my family for teaching me to strive for my dreams and to do everything in excellence. I thank my friends for your motivational pep talks and unwavering support. You have been instrumental in my persistence and overall outlook as I navigated this journey. To my teachers and coworkers, thank you for explaining concepts and material in meaningful ways, for always working with me, and for contributing to this incredible journey. The lasting impression you all have left on me, and my acquired level of knowledge has been remarkable, and I will be grateful indefinitely. Thank you so much!

SMALL UNMANNED MARINE HYDROKINETIC PLATFORMS FOR POWER GENERATION IN COASTAL AND TIDAL WATERS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

NOMENCLATURE

MHK – Marine Hydrokinetic Turbine

WAMV – Wave Adaptive Modular Vessel 16ft

DOE – Department of Energy

FAU – Florida Atlantic University

FSWW – Free-stream Waterwheel

CDF – Computational Fluid Design

PTO – Power Take Off

AAS – Autonomous Anchoring System

CVT – Continuously variable transmission

MPPT – Maximum power point tracking

COTS – Commercial off the shelf

UAV – Unmanned Aerial Vehicle

USV – Unmanned Surface Vehicle

WPT – Wireless Power Transfer

WCP – Wireless Charging Platform

TEC – Tidal Current Energy Converter(s)

TSR – Tip Speed Ratio

RIB – Rigid Inflatable Boat

COLREGs –Collision Regulations

NEPA – National Environmental Policy Act

ICW – Intra-coastal Waterway

LiPo – Lithium Polymer Battery

mA – Milli Amperes

mAh – Milli Amp Hours

m – Meters

cm – Centimeter(s)

mm – Millimeter(s)

W – Watt(s)

MW – Megawatt(s)

ADCP – Acoustic Doppler Current Profiler(s)

IEC TS – International Electrotechnical Commission Technical Standard

m/s – Meters per second

CSV – Comma Separated Variable

Hp – Horsepower

Hz – Hertz

V – Volts

DC – Direct Current

lbs. – Pounds

kg – Kilogram

N – Newton

lbf –Pound Force

in. – Inch(s)

ft. –Feet

s – sec. – Second(s)

GPS – Golab Positioning System

IMU – Inertial Measurement Unit

RMS – Root Mean Squared

RPM – Revolutions Per Minute

HAWT – Horizontal Axis Water Turbine

VAT – Vertical Axis Turbine

1.0 INTRODUCTION

There is growing interest in commercial, military, and scientific research applications of battery-operated unmanned marine and aerial vehicles operating in coastal areas. For example, battery-operated aerial drones are utilized in applications in both military and civilian sectors for surveillance, shipping, data acquisition, agriculture, and search and rescue, among others. Often, there is a need for expanded drone mission operations (Junaid et al., 2017). However, high power consumption by the drone motors rapidly depletes the drone's onboard batteries, leading to limited flight times, ranging from fifteen to thirty minutes for small drones. Thus, drones and other autonomous vehicles would benefit from having readily available recharging stations along the coast. Optimizing drone recharging by eliminating the need for human intervention would vastly increase the capabilities of autonomous or independent drone missions. Multiple mobile recharge stations increase a drone's range drastically, as they can strategically navigate along the drone's intended flight path to enable battery recharge stops. Current literature offers limited research regarding such mobile sea surface or floating recharge stations, much less ones that are fully autonomous. Unmanned surface vessels (USV) have been developed for numerous other purposes (Caccia, 2005), (Few, 1999), (Majohr, 2000), (Manley, 1997), (Manley, 2000), and (Pascoal, 2000). Furthermore, development of small marine hydrokinetic, (MHK) turbines is in its infancy. Some scaled models have been tested in laboratory tanks, and a few full-scale prototypes have been tested in real-world environments (Starzmann, 2018), (Jeffcoate, 2015), (Bassett, 2022), and (Turnock et al., 2007). This study is motivated by the perceived need for such recharge stations in the coastal zone.

A mobile autonomous recharge station has several advantages in serving as a recharge station for unmanned aerial vehicles (UAVs). First, tidal and ocean current as well as wave energy resources are optimal near the ocean surface, while a surface station can also harness solar and offshore wind energy resources. Second, in view of its mobility, the recharge station can navigate to and anchor in hot spots of MHK energy resources to optimize its harnessing potential. Significant sources of MHK energy are due to tidal, riverine, and coastal currents. Harnessing these currents using an unmanned surface platform presents a challenge and requires several considerations, such as the type of current turbine employed, the onboard power conversion and storage technology, utilization of power captured and overall operation of the autonomous platform, as well as the challenges presented for deployment in the open in-water environment and the availability of adequate current resource.

This project explores the feasibility and challenges in the application of unmanned autonomous MHK platforms for harnessing currents in open tidal/coastal environments. A case study based on mounting a selected current turbine on an USV is undertaken. A sixteen-foot Wave Adaptive Modular Vessel (WAMV) with its autonomous navigation capabilities serves as the base USV for the MHK platform. It features two azimuth-capable electric outboard motors, an elevated payload deck, and a proprietary shock absorption system. The MHK Platform comprises of several support subsystems for the vessel to autonomously navigate to the resource location, anchor, deploy a current turbine, harness the power of the currents, and convert it to electric power, and store it onboard the platform for subsequent recharging of an unmanned aerial drone autonomously from the platform. Based on a trade study, a free-stream waterwheel (FSWW) turbine was selected as the turbine of choice for the MHK platform; the turbine was custom designed and developed for stable mounting on the USV. Environmental and operational design constraints for the system include effectively harvesting current resource with flow speeds ranging from 0.5-1.0m/s, harvesting at a maximum water depth of five meters to enable automated anchoring, and operating in zero sea state conditions (zero-meter wave height).

1.1 Dissertation Goals, Research Questions, & Objectives

The main goal of this study is to assess the feasibility and attributes of small unmanned mobile MHK platforms in harnessing currents and powering other unmanned systems through field-testing and operations optimization. This main goal can be subdivided into five supporting goals. First, identify field test sites that meet permitting requirements and assess their suitability. Second, develop procedures for field-testing and conduct tests under various measured background conditions for a series of system configurations. Third, acquire and analyze laboratory and field test data for assessment of system performance under corresponding test conditions. Fourth, determine the attributes and limitations of the system. Fifth, develop recommendations for optimization of the system and its operation.

This investigation is driven by the following research questions:

- Is a small autonomous unmanned surface platform-based MHK turbine feasible for capturing current energy in tidal channels, rivers, and coastal waters?

- What are the environmental and current resource considerations for deployment of such a MHK platform?

- How can the system be scaled up and its performance and operations optimized?

Furthermore, the following objectives are identified in support of addressing these research questions:

1. To conduct an extensive literature review and determine the state of the art of current research in small scale MHK turbines and their deployments.

2. To use an unmanned MHK platform, comprised of an MHK turbine onboard a WAMV USV, as a case study in assessing platform stability, the practicality of autonomous deployment, and the performance of such surface-deployed unmanned systems, including the feasibility of potential applications.

3. To plan and conduct in-water testing of the system and characterize its performance for power production under various operational conditions, including consideration of test site conditions, mitigation of environmental impacts, as well as permitting requirements.

4. To explore optimization of the system performance and its operation, including extension of the system to an array of such systems.

The background and the power harvesting theory for extraction of mechanical power from the flow by a free-stream waterwheel (FSWW) is discussed in **Section 2**. A literature review in **Section 3** examines the state of the art in development of MHK turbines and their typical field-testing conditions. **Section 4** details the MHK turbine and platform used for this investigation, while **Section 5** specifies the field-testing undertaken. The process used to analyze the data acquired during field-testing is provided in **Section 6** and the results are presented in **Section 7**. **Section 8** provides an analysis of the results and a discussion of the implications of the results, optimization considerations, and expectations for scaled operations. Conclusions and suggestions for future work are outlined in **Section 9**, while relevant appendices are included in **Section 10**. The bibliography is provided in **Section 11**.

2.0 BACKGROUND

The primary purpose of a MHK turbine is to extract energy from the water as it flows past the turbine. The turbine effectively converts the kinetic energy present in the flow into mechanical power. This conversion occurs as the turbine's shaft undergoes rotation when placed in the flow. Subsequently, through interaction with a power take-off (PTO) system, this mechanical power is further transformed into electrical energy. The amount of power available in the flow, P_f, the mechanical power, P_M, that can be harnessed, and the electrical power, P_E, that are a result of these transformations can be estimated based on simple considerations, similar to the methods and theory associated with harnessing the wind energy using wind turbines. The power available in the flow, P_f, can be found using the fluid mechanics continuity equation for mass flow rate as a function of density and as a result is estimated as,

$$P_f = \frac{1}{2}\rho A U^3 \tag{1}$$

where ρ, is the density of water in [kg/m^3], A, is the wetted capture surface area of the wheel blade in [m^2], and U, is the free-stream flow speed of the water in [m/s] (Manwell, 2009). This quantity represents the total power that can potentially be extracted from the kinetic energy of the present flow by a MHK turbine. The mechanical power, P_M, actually harnessed by the turbine in the flow is less than this and can be represented as follows (Manwell, 2009),

$$P_M = \frac{1}{2}\rho A U^3 C_P \quad (2)$$

where C_P, is the power coefficient, which represents the efficiency of the turbine, moreover the power produced divided by the theoretical flow power available. Thus,

$$C_P = \frac{P_M}{\frac{1}{2}\rho A U^3} = \frac{P_M}{P_f} \quad (3)$$

C_P, is typically expected to be bounded by a theoretical maximum limit called the Betz Limit of, $C_{Pmax} = \frac{16}{27}$ or 0.59 (Manwell, 2009). This theoretical maximum represents the maximum rotor power achievable. This cap is a result of three main causes of power loss, non-zero fluid dynamic drag, wake rotation, and the finite number of blades and their associated tip losses (Manwell, 2009). The electrical power, P_E, expected to be generated by the turbine can be expressed as,

$$P_E = P_f \cdot \eta_{tot} \quad (4)$$

where η_{tot}, is the total, "water to wire" efficiency of the turbine. Literature states that typically thirty to forty percent of the mechanical power captured by a turbine is converted to electrical power (Manwell, 2009). The low percentage being based on the Betz limit and losses due to design and manufacturing. Another useful quantity is the tip speed ratio (TSR), λ, given by (Manwell et al., 2009).

$$\lambda = \frac{\Omega \cdot R}{U} \quad (5)$$

where $\boldsymbol{\Omega}$ is the angular speed of the wheel in [rad/s] and $\boldsymbol{R}$ is the radius of the wheel in [m]. The above relations may be used to provide a basic prediction of the expected power production from the application of the FSWW turbine used in this case study (Figure 1). The plot was generated using $A = 0.349\text{m}^2$, which is the wetted capture area of each of the turbine's blades, $\rho = 1023.6\text{kg/m}^3$ as the density of the salt water in which the system is expected to be tested in, and flow speeds U, in the desired 0-1m/s range. In addition to estimated λ, and C_P values based on a computation fluid dynamics (CFD) investigation (Tran, 2022), and a selected value of $\eta_{tot} = 40\%$.

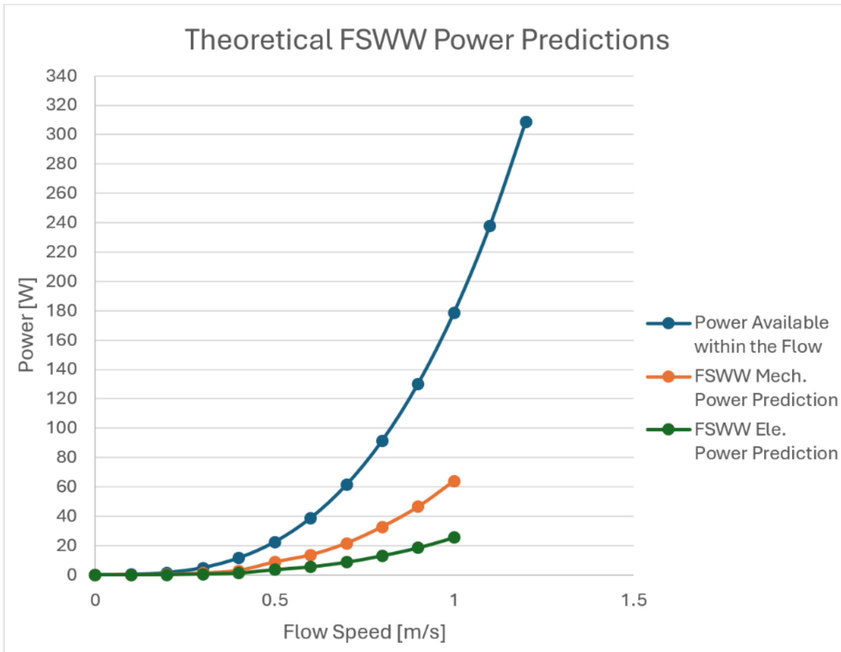


Figure 1: Estimated Prediction of FSWW Power Capture

Such basic estimates can be determined for other values of the parameters. The power estimated using equation (2) is in the absence of allowing for the influence of the flow rotation in the wake. When wake rotation is taken into account, the power dP of a small element of the blade element is given by (Manwell, 2009),

$$dP = \frac{1}{2}\rho A U^3 \left[\left(\frac{8}{\lambda^2}\right)\alpha'(1-\alpha){\lambda_r}^3 d\lambda_r\right] \tag{6}$$

where λ_r is the local speed ratio, α is the axial induction factor, and α' is the tangential induction factor, given by

$$\lambda_r = \frac{\lambda * r}{R} \tag{7}$$

$$C_P = 4\alpha - 8\alpha^2 + 4\alpha^3 \tag{8}$$

$$\alpha' = \left(-\frac{1}{2}\right) + \left(\frac{1}{2}\right)\sqrt{\left[1 + \frac{4}{{\lambda_r}^2}\alpha(1-\alpha)\right]} \tag{9}$$

The total extracted mechanical power, including wake rotation, is given by,

$$P_{Mrot} = \frac{1}{2}\rho A U^3 \int_0^{\lambda} \left[\left(\frac{8}{\lambda^2}\right)\alpha'(1-\alpha){\lambda_r}^3 d\lambda_r\right] \tag{10}$$

Equations (2) and (10) were used to compute and tabulate estimated power capture with and without inclusion of wake rotation for seven blade and eleven blade configurations, at two flow rates each (Manwell, 2009). The following physical characteristics of the wheel were taken as constants in the analysis: the wheel's full radius, $R = 0.4858$m; the radius at which the resultant force of the passing flow on the blade was applied, $r = 0.2381$m; the full diameter of the wheel, $D = 0.9715$m; the blade's wetted surface area, $A = 0.349\text{m}^2$; the axial length of the wheel, $L = 1.41$m; and the width of each blade, 0.2477m. Supporting TSR and C_P, values along with their associated flow rates were selected from the research of two colleagues, Sullivan Hess, and Adam Hall. Sullivan Hess conducted small scale tank tests to predict the expected power production using the FSWW turbine (Hess, 2020). Adam Hall created detailed power production models for this turbine based on his initial design for the PTO system (Hall, 2022). The resulting values using parameters selected from their work as inputs to this analysis are shown below, Table 1.

Table 1: C_p and TSR Data for Power Prediction

11 Blade Wheel Configuration		
U [m/s]	C_P	TSR

0.16	0.14	0.25
0.447	0.20	0.40
7 Blade Wheel Configuration		
0.5	0.45	0.65
1.0	0.40	0.70

The power predictions for the seven-blade wheel using the standard method at each flow speed are shown below, Table 2.

Table 2: 7 Blade Power Predictions without Wake Rotation

U [m/s]	C_P	P [W]
0.5	0.45	9.9321
1.0	0.40	70.6284

The power predictions for the eleven-blade wheel using the standard method at each flow speed are shown below, Table 3.

Table 3: 11 Blade Power Predictions without Wake Rotation

U [m/s]	C_P	P [W]
0.160	0.14	0.1013
0.447	0.20	3.1541

The power predictions for the seven-blade wheel allowing for the wake rotation at each flow speed are shown below, Table 4.

Table 4: 7 Blade Power Predictions with Wake Rotation

U [m/s]	C_P	λ	λ_r	α	α'	Power P_{rot} [W]
0.5	0.45	0.65	0.3186	0.1591	0.5813	6.5
1.0	0.40	0.70	0.3431	0.1330	0.5021	49.3

The power predictions for the eleven-blade wheel allowing for the wake rotation at each flow speed are shown below, Table 5.

Table 5: 11 Blade Power Predictions with Wake Rotation

U [m/s]	C_P	r/R	λ	λ_r	α	α'	Power P_{rot} [W]
0.160	0.14	0.5	0.25	0.1225	0.0378	0.7797	0.0563
0.447	0.20	0.5	0.40	0.1960	0.0561	0.5897	2.0357

After consideration it was determined that these methods would not produce an accurate prediction of the power to be produced by the FSWW. In response to this it was decided that an empirically accurate numerical expression for the power produced by the FSWW should be created. This expression was derived using the same continuity equation of fluid mechanics and mass flow rate as a function of density (Manwell, 2009). The power produced can be considered torque times angular speed of the wheel. Toque is the product of a resultant or concentrated force being applied to a radius or leaver arm. The full derivation is included in Appendix A, the resulting expression for C_P is shown here,

$$C_p = K(1 - \lambda\alpha)^2\lambda \tag{11}$$

where $\lambda = \Omega R/U$, and $K = gC_D$, when g is an empirical constant; the mechanical power harnessed, P_M, is then computed using equation (2). The empirical constant K is to be estimated from an analysis of the data acquired from the field experiments. Expression (11) also encapsulates the effect that each parameter of the wheel has on mechanical power production, which enables a parameter-based investigation of the scaling of the FSWW.

3.0 LITERATURE REVIEW

The global maritime industry is moving toward automation of near shore support in ports, open ocean shipping, and military operations (Strickland, 2017). Forty-six separate USVs have been developed by various contractors to address these differing needs (Strickland, 2017). Autonomous vehicles for several scientific uses have also been developed. Sea surface micro layer data collection has been achieved using automated catamarans (Caccia, 2005). Autonomous systems for sampling surface and near surface atmosphere measurements (Few, 1999), water monitoring for dolphin (Majohr, 2000), the collection of hydrographic and bathymetric data (Manley, 1997) and (Manley, 2000), and communications aids between main vessels (Pascoal, 2000) have all been developed. However, little to no mention is made for powering these types of vessels with renewable energy sources to reduce the need for human intervention or maintenance. That is where the MHK Platform excels, as it is designed to bolster autonomous navigation, anchoring, and FSWW deployment. Powering auxiliary devices with renewable sources nearly turns the MHK Platform into a support vessel, rather than it needing its own support vessel like many of the USVs in the existing literature.

Literature covers the use of small turbines for power generation in remote communities (Anyi, 2010). Citing the need for debris shedding and cheap floating structures. There are many investigations of marine hydrokinetic models and simulations. They typically use computational fluid design (CFD), MATLAB Simulink, blade element theory models, low-, mid-, and high-fidelity models from the national laboratory system (Neary, 2013). A couple of articles share results for lab experiments with scaled models (Jeffcoate, 2015) or tow tank tests (Cavagnaro, 2016) and (Schmitt, 2022). But only a handful of articles detail field-testing of full-scale prototypes in the real-world environment.

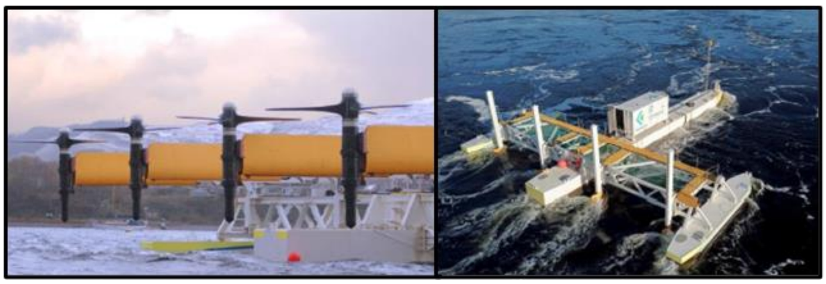


Figure 2: SIT in maintenance position (left) and deployed (right), (Starzmann, 2018)

Figure 2, shows four Schottel Instream Turbines (SIT) mounted to the PLAT-1. This system is one of the full-scale real-world tested cases found in literature (Starzmann, 2018). This platform is rated to produce 280kW and was tested in Scotland. International Electrotechnical Commission Technical Standard (IEC TS) 62600-200 was used to help determine the power produced by each individual turbine. The SIT 250 is a three-blade horizontal axis free-flow turbine with a planetary gearbox, asynchronous generator, and a hydraulic brake. These turbines are mounted to the three hulled PLAT-1 with SIT Deployment Modules. The PLAT-1 self-aligns in the oncoming flow using a mooring turret. The system was moored with a four-point spread using Raptor rock anchors. The test site, was located at the mouth of the Loch Etive in Connel, Oban Scotland. This site was ideal for tidal power generation due to its large tidal zone and localized fast flows due to a jet formed by the nearby Falls of Lora. Testing results show that the turbine located closest to the velocity measurement device had near exact agreement with the blade element method generated power predictions and in general the power produced during testing led to a high level of confidence in the design. Placement of the velocity measurement device in different areas on the PLAT-1 led to differing results, so future work will investigate device placement as well as a few different velocity measuring devices (Starzmann, 2018).

An earlier version of the same turbine was field-tested, suspended from a barge in 2015 at Queen’s University Belfast’s tidal site in Strangford Lough, Nl., Figure 3 (Jeffcoate, 2015).

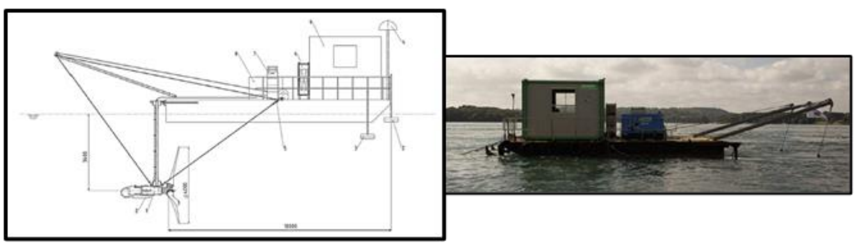


Figure 3: Schematic of deployed turbine (left), the barge with the turbine deployed (right) (Jeffcoate, 2015)

The turbine was tested with a maximum water depth of 15.8m and in flow speeds ranging from 0.4 to 2.5m/s. The test site is sheltered from most wave action, so the largest wave to disturb the platform was caused by the local ferry and was 0.5m in height. When the turbine was fully deployed its blade tips swept a distance from 1.4 to 5.4m below the surface. An acoustic doppler profiler was used to measure the wake of the turbine, the rotational speed of the shaft was measured with a speed sensor, and the signal response from an inverter was used to measure the power produced. Two load cells were also mounted to the frame and rotor to measure thrust on the unit. The barge had sonar mounted to the bow which monitored upstream for any animals or debris heading toward the turbine. Collisions were prevented by triggering an electric turbine brake when notified by the sonar. During testing, there were twenty-nine mammal sightings and six turbine shut downs, but there was no evidence found to suggest that any mammals were harmed during testing. Results show that the time averaged power output of the turbine was 19kW. Power efficiency increased as the flow velocity increased and the thrust on the unit reached 17kN at maximum flow (Jeffcoate, 2015).

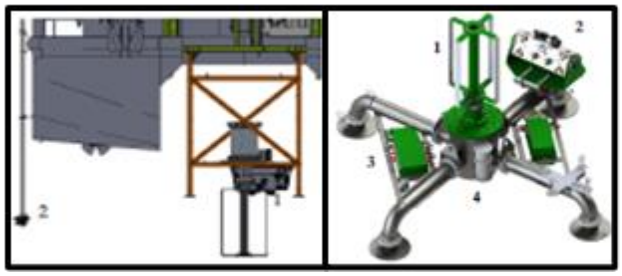


Figure 4: Schematic of deployed turbine lander (left) turbine lander (right) (Bassett, 2022)

This tidal turbine, Figure 4, was suspended from a moored barge and tested in a 6m deep tidal channel with flow speeds exceeding 2m/s in Agate Pass, WA. A stereo optical camera and a Blueview imaging sonar were mounted to the barge for collision monitoring. No fish collisions were recorded; however, debris and jellyfish did collide with the turbine. The noise created by the turbine was recorded, but distinguishing the turbine generated noise from the background noise proved to be challenging. Results show that the turbine reached peak efficiency at 2m/s flow speeds and had similar power production results to tests performed under propulsion. An effort and cost comparison was made between real world testing and propulsion testing, and the results indicate that testing under propulsion is much more effective, unless environmental monitoring is of paramount importance. It was found that operating under propulsion requires considerably less planning and oversight and leads to four times as much operating time than moored tests (Bassett, 2022).

Figure 5:The University of Southampton, UK, tidal mill with stream waterwheel (Turnock et al., 2007)

This 2m in diameter stream waterwheel, Figure 5, was installed onto a 4.5m Catamaran Hull by students completing their senior design project at the University of Southampton, UK. This configuration allowed for 0.4m blade submergence. Its first in water tests were conducted in flow created by a 15Hp rigid inflatable boat (RIB) engine with test flow speeds averaging 0.55m/s. Its second round of testing was conducted as it was towed behind a RIB which allowed for test flow speeds averaging 1.19m/s. Results show that the C_p to TSR relationship observed from field-testing was a mere fraction of theoretical expectations, Figure 6.

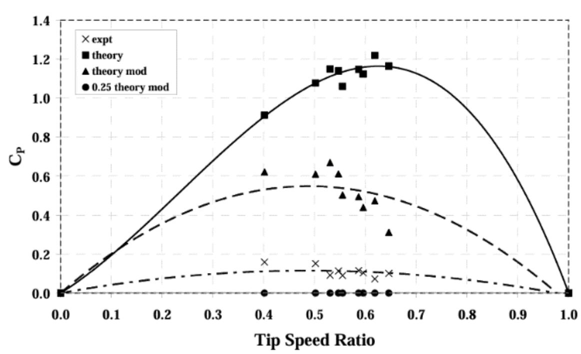


Figure 6: Comparison between experimental test data and BEM theoretical predictions (Turnock et al., 2007)

It was also found that the addition of a lifting hydrofoil used to accelerate the flow as it entered the waterwheel increased energy capture by a factor of 2.57 (Turnock et al., 2007).

A study comparing the power production of a tidal turbine tested in the field compared to the power production of the same turbine tested in a tow tank was conducted. It found that the overall power production of the same turbine tested in each of the test environments was well aligned after adding a blockage correction. It was also found that results were obtained for a larger range of conditions in the field tests versus the tow tank tests (Schmitt, 2022).

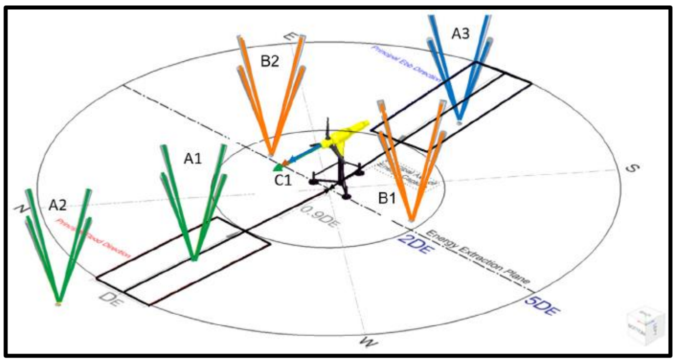


Figure 7: Measuring Instrument placement from DEEP-Gen IV TEC (Evans et al., 2023)

A 1MW three blade horizontal axis turbine with an 18m diameter was tested in Orkney, Scotland observing IEC TS 62600-200's performance measurement requirements. Which requires that two independently located, either inline or adjacent to the turbine, profilers be used to measure the performance of the turbine. This study used five acoustic Doppler current profilers (ADCPs) and one single beam ADCP configured around the turbine, Figure 7. The results suggest that instruments can be placed outside of the IEC TS recommended placements relative to the turbine and still provide accurate representations of the flow as it approaches the turbine. It was also found that at this test site, adjacently placed ADCPs, may not produce the accuracy required by IEC TS throughout the entire tide cycle, and should be avoided (Evans et al., 2023).

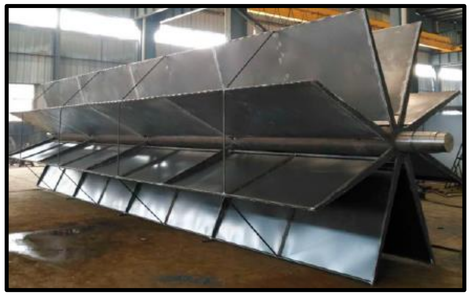


Figure 8: Waterwheel during field experiment (Zhao et al., 2020)

The waterwheel shown in Figure 8, was used in a investigation to verify numerical simulations which were developed to study the effects of differing blade submergence levels on power production and flow characteristics. Results show that the simulations were accurate to the power produced during experimentation, with an error of less than five percent. For this particular waterwheel, it was determined that peak performance was achieved with an immersed radius ratio of 82.7%. It was also found that the water-level difference between the up and down-stream areas was vastly increased at this immersion ratio, this immersion ratio also lent itself to creating more complex water flow which could create turbulent flow and local erosion.

Many of the turbines found in literature produce power in the kilowatt or megawatt range and would be used in larger arrays to tie into the power grid back on shore. The FSWW for the MHK Platform produces power in the tens of watts range and uses the power it generates to power an auxiliary system. None of the articles feature a crossover where the USV and the MHK turbine combine into one cohesive system. Which speaks to the novelty of this project and investigation. Combining a fully autonomous surface vessel with a renewable energy source enables it to keep itself deployed indefinitely or until the system encounters some other fatal error.

This literature review would be remiss if it failed to mention IEC TS 62600-200 and IEC TS 62600-202. These technical standards (TS) are released by the International Electrotechnical Commission (IEC) to aid MHK developers in the evaluation of commercial scale tidal current energy converters (TECs) and the prototypes predecessors. IEC TS 62600-200 specifically, provides a formal definition for TEC rated power, a systematic process for determining power performance, a uniform method for creating power curves, and a standardized means to report results (IEC/TS 62600-200, 2013). IEC TS 62600-202 details what is required for the development of a TEC prototype and its associated test plans. The device should be fully represented with physical models and technical drawings. Environmental characteristics should be thoroughly documented with mooring requirements, when necessary, and information regarding present energy resources. Clear testing goals should be identified prior to testing, and the limitations and accuracy of the collected raw data should be acknowledged and used to form sound conclusions (IEC TS 62600-202, 2022). The scope of IEC TS 62600-200 surpasses the capabilities and resources associated with this investigation, so it was not incorporated into the practices exercised throughout this investigation. However, many of the principles outlined in IEC TS 62600-202 were incorporated into this investigation and its associated field-testing.

Next it is pertinent to acknowledge MHKit an open-source data processing tool available for download on GitHub, developed by National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories.

This tool is meant to aid MHK developers in data analysis methods that best align with IEC TS 62600-200 requirements. It can be used on the python or MathWorks platforms and includes modules for data quality control, wave, river, tidal, power, loads, and mooring (MHKit, 2019). This investigation utilized the data processing tools provided in the quality control module on the MATLAB version of the kit, to help ensure the raw data was ready for processing. Each data set was checked using the time stamp check and the range check. However, MATLAB's "rmoutliers" function was used over the MHKit outliers feature.

4.0 MHK TURBINE & PLATFORM

Figure 9: The MHK Platform deployed for Testing, 12/5/23

This case study utilized a mobile unmanned MHK platform, based on deployment of the FSWW turbine from an autonomous USV, Figure 9, developed under funding from the Department of Energy (DOE) and the Office of Naval Research (ONR). The WAMV USV is a commercial off the shelf (COTS) vehicle. It is 4.88m in length, 2.44m in beam, and is powered by two 105Ah Lithium-ion Nickel Manganese Cobalt batteries. The USV has a factory weight of 181kg (400lbs). Designing the MHK turbine or the FSWW, required consideration of the structural limiting factors of the preexisting WAMV USV. The WAMV has a payload capacity of 350lbs, but after adding autonomous navigation instrumentation, the remaining payload was limited to 140lbs. This payload restriction, along with the rigid structure of the WAMV, created the initial design constraints for the MHK turbine. The obligatory low flow functionality of the turbine required it to operate within 0.5-1.0m/s range of the flow current speed. The performance of the MHK platform was to be verified under zero sea state conditions and in low boat traffic areas where the wheel would have minimized instances of interruption. To ensure safe anchoring, a 5m anchoring depth limit was introduced due to the maximum amount of line available in most COTS winches.

A trade study with seven different requirements, as listed in Table 6, was conducted to determine what type of turbine should be used for the project. This trade study took consideration of the design criteria, the operational practicality, and projected power output.

Table 6: Trade Study Requirements

Requirement Number:	Description:
1	The system must operate in the low-speed current flow of a coastal marine environment (~0.5 m/s)
2	The system must reach a power output of 300 W
3	The power output for the final device must be at least 50% of the predicted value for a given flow speed.
4	The system must be autonomously deployable from the WAMV platform.
5	The MHK, PTO, generator, and associated mounting structures must weigh less than 140 lbs.
6	The MHK device must completely clear the free surface in its stowed position.
7	The device should deflect/avoid environmental debris such as plastic bags and coconuts.

Three types of turbine designs were compared in the trade study, the FSWW, the Horizontal Axis, and the Vertical Axis turbines. The FSWW scored the highest, at 0.456, Table 7.

Table 7: Trade Study Results

Criteria	Free-stream Waterwheel		Horizontal Axis Turbine		Vertical Axis Turbine	
	Weight	Score	Weight	Score	Weight	Score
Low-Flow Operation ~0.5m/s	0.196	0.6	0.196	0.2	0.196	0.2
Power Output ~300W	0.130	0.667	0.130	0.167	0.130	0.167

Power generation of 50% of predicted level at flow.	0.130	0.455	0.130	0.273	0.130	0.273
WAMV autonomously deployable	0.152	0.545	0.152	0.182	0.152	0.273
Weight <= 140lbs	0.174	0.091	0.174	0.455	0.174	0.455
Clear free surface while stowed	0.130	0.385	0.130	0.308	0.130	0.308
Debris shedding	0.088	0.5	0.088	0.3	0.088	0.2
Final Score	0.456		0.269		0.275	

Next a risk analysis containing twelve criteria was performed for the same three turbine designs, Tables 8-10.

Table 8: Horizontal Axis Water Turbine (HAWT) Risk Register

Horizontal Axis Turbine		Probability of Occurrence 1-4	Impact of Occurrence 1-4	Overall Risk Low	Medium	High
1	Will not operate in ~0.5m/s current.	3	4			X
2	Does not reach power output of ~300W	3	3		X	
2.1	Power generation of at least 50% the predicted level for any given flow velocity is not reached (Efficiency ~50%).	2	1		X	
3	Autonomous Deployment Failure	2	2		X	
4	Weight Exceeds 140lbs (63.5kg)	1	3		X	
5	MHK does not clear the surface while stowed.	1	3		X	
6	MHK does not deploy smoothly.	1	1	X		
7	Is damaged/entangled by large (coconut sized) debris.	2	4			X
8	MHK drag exceeds anchor limits.	2	3		X	
9	Incurs instability of WAMV platform.	3	4			X
10	Flow concentrator does not perform as predicted.	1	2		X	
11	MHK deployment interacts with seafloor.	1	3		X	
12	Negative marine life impact.	2	2		X	

Table 9: Vertical Axis Turbine (VAT) Risk Register

Vertical Axis Turbine		Probability of Occurrence	Impact of Occurrence	Overall Risk		
		1-4	1-4	Low	Medium	High
1	Will not operate in ~0.5m/s current.	3	4			X
2	Does not reach power output of ~300W	4	3			X
2.1	Power generation of at least 50% the predicted level for any given flow velocity is not reached (Efficiency ~50%).	2	1		X	
3	Autonomous Deployment Failure	2	2		X	
4	Weight Exceeds 140lbs (63.5kg)	2	3		X	
5	MHK does not clear the surface while stowed.	3	3		X	
6	MHK does not deploy smoothly.	2	1		X	
7	Is damaged/entangled by large (coconut sized) debris.	3	4			X
8	MHK drag exceeds anchor limits.	2	3		X	
9	Incurs instability of WAMV platform.	3	4			X
10	Flow concentrator does not perform as predicted.	2	2		X	
11	MHK deployment interacts with seafloor.	1	3		X	
12	Negative marine life impact.	2	2		X	

Table 10: Free-stream Waterwheel (FSWW) Risk Register

Free-stream Waterwheel		Probability of Occurrence	Impact of Occurrence	Overall Risk		
		1-4	1-4	Low	Medium	High
1	Will not operate in ~0.5m/s current.	1	4		X	
2	Does not reach power output of ~300W	2	3		X	
2.1	Power generation of at least 50% the predicted level for any given flow velocity is not reached (Efficiency ~50%).	1	1	X		
3	Autonomous Deployment Failure	1	2		X	
4	Weight Exceeds 140lbs (63.5kg)	4	3			X
5	MHK does not clear the surface while stowed.	1	3		X	
6	MHK does not deploy smoothly.	1	1	X		
7	Is damaged/entangled by large (coconut sized) debris.	1	4		X	
8	MHK drag exceeds anchor limits.	2	3		X	
9	Incurs instability of WAMV platform.	1	4		X	
10	Flow concentrator does not perform as predicted.	4	2			X
11	MHK deployment interacts with seafloor.	1	3		X	
12	Negative marine life impact.	1	2		X	

The risk analysis determined that the FSWW was the lowest risk design when compared to the HAWT and the VAT. This determination was relative to potential damage due to debris impact, increased platform stability due to low submergence levels, and the likelihood of successful power generation at low flow speeds. With the results of both analyses showing that the FSWW was advantageous, it was selected for use as the MHK turbine. Due to the WAMV’s beam length the final length of the wheel was 1.41m with a diameter of 1m, which led to a water swept area of 0.349m^2. Seven, nine, and eleven blade configurations of the FSWW would be field-tested. The wheel, Figure 10 was constructed out of 3/16 Aluminum Blades, High Density Polyethylene (HDPE), and stainless-steel bolts.

Figure 10: Fabricated FSWW (9 Blade)

The MHK turbine is one subsystem within the MHK Platform. The PTO system, the autonomous anchoring system (AAS), the wireless charging platform (WCP), and the main control box with its supporting batteries complete the full platform, Figure 11.

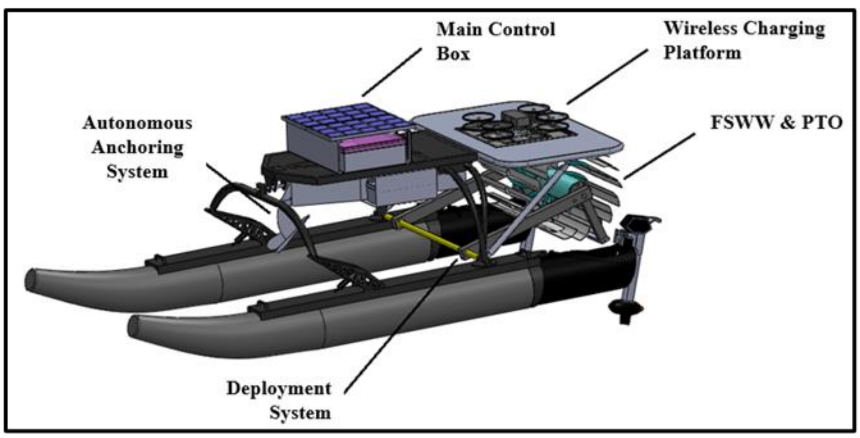


Figure 11: Modeled version of the MHK Platform with subsystems highlighted

Each of these systems was developed in house and plays a vital role within the platform. The MHK turbine and the PTO system are essential to generating power from the flow and could not do so individually, as the FSWW physically captures the kinetic energy from the flow and the PTO transforms this mechanical power into electrical power. The

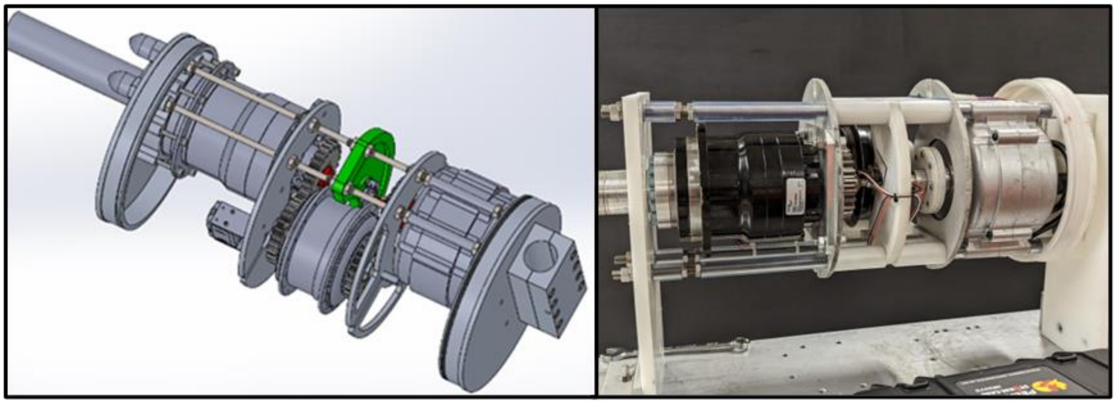


Figure 12: PTO SolidWorks Model (left) built out PTO assembled (right)

PTO, Figure 12, is what takes the rotation of the FSWW’s shaft and transforms it into electrical power. As seen in Figure 12, from left to right, the PTO consists of a one to thirty-five planetary gearbox, a NuVinci ball continuously variable transmission (CVT), and a Marsrock G100S permanent magnet generator. This configuration strives to ensure that the FSWW and the generator both rotate at their respective peak efficiencies, individually, and as a coupled system, in support of optimal power extraction. Initial models showed that this configuration when operated under maximum power point tracking (MPPT) would generate approximately 9, 24, and 58W of power at 0.5, 0.7, and 1.0m/s flow rates respectively (Hall, 2022). Since, extensive benchtop testing and control algorithms were conducted and have been developed for the PTO (Pimentel, 2024).

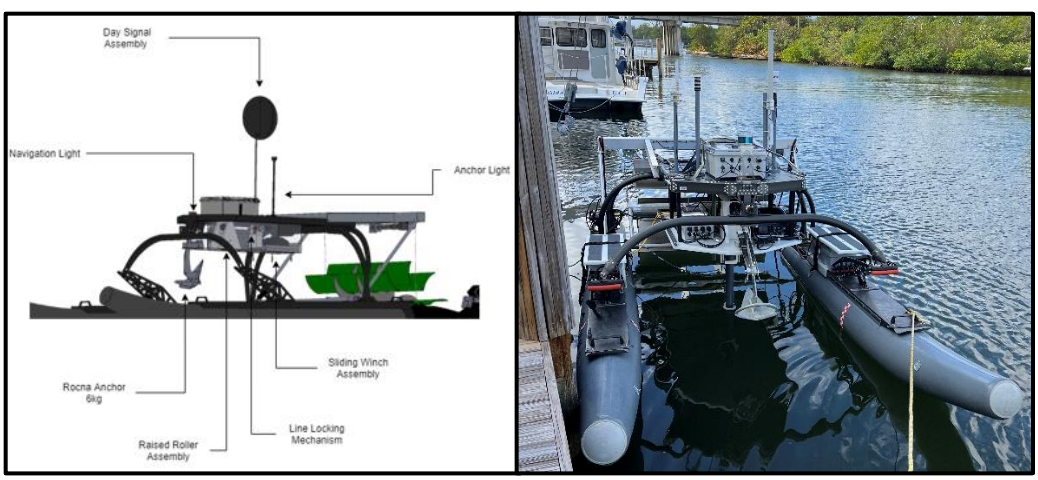


Figure 13: AAS SolidWorks model (left), built out sys. on the WAMV (right)

The AAS, Figure 13, is designed to payout the anchor and its line automatically at a seven to one scope, while ensuring the vessel stays in compliance with vessel collision regulations (COLREGs). This system operates the vessel's navigation lights and day signal assemblies, both used to signal the MHK platform's status to other vessels. A load cell located on the anchor line monitors the tension on the line while the vessel is at anchor. ORCAFLEX simulations determined that under expected operational conditions the vehicle would not experience anchor line tension above the system design limitations, see Appendix B for the ORCAFLEX report summary. These results were then verified with the anchor's holding capacity test, which proved failure at 2000N (450lbf). Due to the amount of anchor line that fits on the COS winch, the MHK Platform has a maximum anchoring depth of 5m. This subsystem was lab tested in 2021 (Frosrook, 2021) and was verified operational on the MHK Platform in December of 2023.

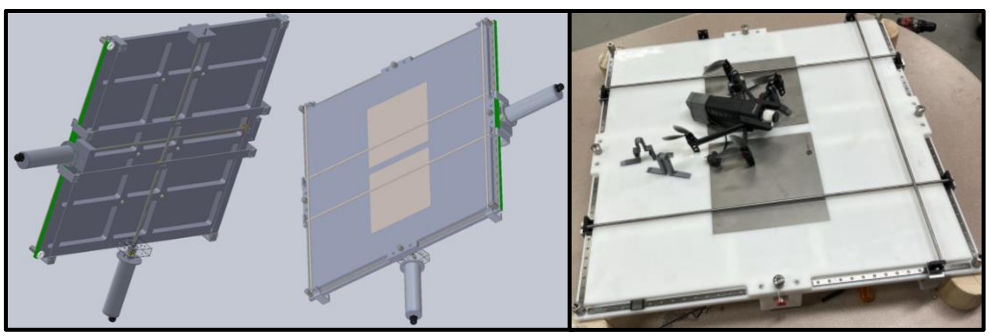


Figure 14: Wireless charging platform SolidWorks model (left) built out assembly (right)

The WCP, Figure 14, was designed to secure the drone to the MHK platform and enable its wireless recharging, while facilitating reliable and repeated drone take offs. The WCP consists of two main subsystems, a UAV restraint system, and a charging pad. The restraint system is designed as a parallel pusher that uses two motors to actuate four rods to the center of the charging pad, which then slip over custom UAV landing gear, holding the UAV in place for the duration of its charge. Autonomous recharging is achieved with wireless conductive contact charging. SkyCharge has provided FAU with a system that uses conductive contacts and proprietary DC to DC battery charging electronics to charge the UAV (McKinney, 2021). This system has been lab verified and is to be installed on the MHK platform prior to April 2024.

The drone selected for this project is the ANAFI Parrot, Figure 15, as it met university policy requirements. This drone weighs 320g (0.71lbs), has a twenty-five-minute flight

Figure 15: The retrofitted ANAFI Parrot, with costume landing gear

time, a 4km transmission range, two high density Lipo batteries, with 2700mAh capacity and a maximum charging power of 24W. When fully extended the drone's dimensions are 9.45in by 9.61in (ANAFI, 2021).

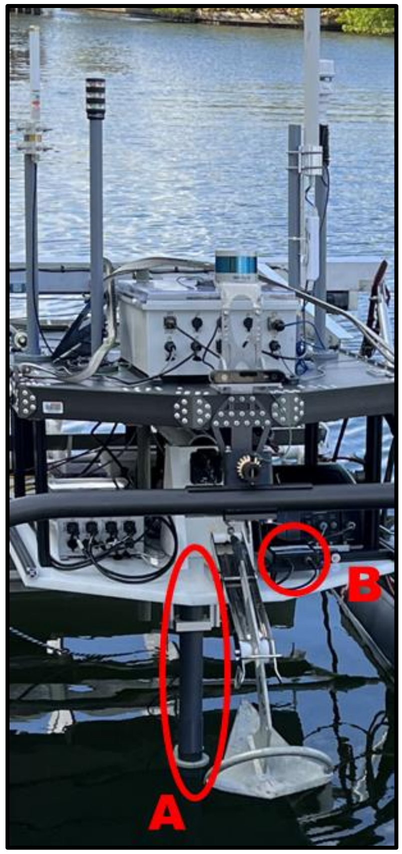


Figure 16: Flow sensor and sonar depth pinger as mounted on the MHK Platform

Figure 16, shows the main control box aboard the MHK platform, at the bow of the vessel on the top payload tray. This control box integrates all of the subsystems and controls the autonomous navigation of the vessel. The flow sensor, an AIRMAR ultrasonic speed sensor, used as part of the PTO data collection system is shown by callout A in Figure 16, while the sensor's transmitter is shown by callout B. A Blue robotics sonar depth pinger is also mounted to the same structure as the flow sensor shown by callout A, its simply positioned behind the flow sensor and submerges above the flow sensor as seen by the white structure on the dark grey post. The depth pinger is used by the AAS and the autonomous navigation system. All of these systems work together to form the MHK platform, which houses the MHK turbine and allows for this case study.

5.0 FIELD-TESTING

In this section the work required to conduct open water testing is described. The processes for acquiring environmental permits for field-testing, site-selection, field-testing procedures, and field-testing are outlined. The permitting phase of the investigation was completed in mid-2021. The site-selection phase was conducted between 2022 and January 2023. Then, field-testing was carried out during the month of February 2023, and subsequently between November 2023 and February 2024. The following subsections detail the work conducted as part of each of these processes.

5.1 Environmental Permitting

As this project received DOE funding, rigorous permitting processes were undertaken for potential field-testing sites. A National Environmental Policy Act (NEPA) review was conducted on a thorough field work plan. Following that, a third-party biological evaluation of the potential test sites was conducted. The biological evaluation considered the at risk and endangered species that live in and around the Intra-coastal Waterway (ICW) and coastal regions of Fort Lauderdale and Dania Beach, Florida. These animals included; the American Crocodile, the Green Sea Turtle, the Hawksbill Turtle, the Kemp’s Ridley Sea Turtle, the Leatherback Sea Turtle, the Loggerhead Sea Turtle, the North American Right Whale, the Southeastern Beach Mouse, the West Indian Manatee, the Piping Plover, the Rufa Red Knot, the Wood Stork, Beach Jacquemontia, Atlantic Sturgeon, the Giant Manta Ray, Shortnose Sturgeon, Smalltooth Sawfish, Boulder Start Coral, Lobed Star Coral, Mountainous Start Coral, Rough Cactus Coral, Pillar Coral, Staghorn Coral, and Elkhorn Coral (Scripter, 2021). The environments, habitats, and plants considered during evaluation and following permitting included, seagrass, and potential nesting grounds for protected birds, turtles, and manatees. This evaluation determined that the planned activities in the potential testing sites were not likely to have adverse effects on at risk wildlife and their habitats. These findings were provided in a written report to NEPA. NEPA filed for letters of concurrence from the National Fish and Wildlife Service and the National Marine Fisheries Service. These letters also deemed the MHK Platform testing as not likely to adversely affect wildlife if appropriate mitigation procedures were followed. Those steps included, briefing all testing staff on endangered species in the area prior to testing, stopping testing if any animals are spotted within a fifty-foot testing radius, obeying all posted no wake and speed limit signs, and to end testing for turtle nesting season March 1st through October 31st (McKinney, 2023). This entire permitting process took a year and a half. After the permitting phase of the project preparations for site-selection on the proposed potential testing sites began.

5.2 Site-Selection

New survey equipment, procedures, and data analysis protocols were created to determine which sites met the permitting agencies' requirements, as well as met the MHK Platform's design limitations. A sensor platform, Figure 17 was developed to

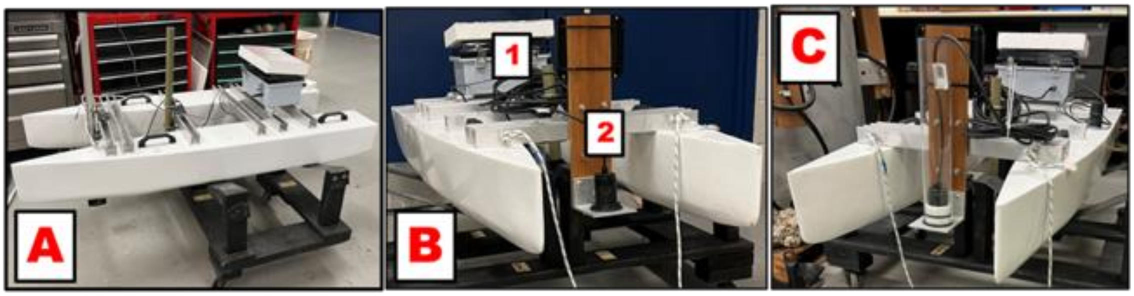


Figure 17: Site-selection Surveying's Sensor Platform (McKinney, 2023)

measure local site water depth and flow speed. A flow sensor, a BlueRobotics depth sensor, and an electronics box for powering the system and acquiring data were mounted on an existing catamaran structure, Figure 17 callout A. The first iteration of the sensor platform had a paddle wheel flow speed sensor. However, after preliminary tests, the paddle wheel flow speed sensor was replaced with an Ultra-Sonic flow speed sensor for improved data reliability, Figure 17 callout B and C. The electronics box holds a Teensy microprocessor, its supporting circuitry and a 12V battery (McKinney, 2023). After the sensor platform was deemed reliable, site-selection procedures and checklists were written. The test site criteria required by NEPA and the MHK platform's design were well defined and included in these procedures. Those criteria are sandy or muddy sea floor conditions, a maximum water depth of five meters and available flow speeds ranging from half to one meter per second. The MHK turbine and platform's design introduced the flow speed and water depth requirements, while the sea bottom conditions were set by NEPA. NEPA set these sea floor requirements to protect at risk sea grass species in South Florida waters. Then to begin determining which sites met the testing criteria, site-selection surveys were conducted. Each site survey required three tests. There was a test to examine the sea floor and determine the local water depth. A test to record flow speed of local currents and a test to identify boat traffic patterns in each area. GoPro video was taken to observe sea floor conditions at all the potential test sites. Once the GoPro video was examined, a potential field-testing site was eliminated if sea grass was detected on the sea floor. Instances of sandy, grassy, and rocky sea floor conditions are shown, Figure 18. The left-hand portion of Figure 18, shows what was deemed as sandy sea floor conditions, the middle portion of the figure shows what was considered grassy sea floor conditions, and the right portion of the figure shows what was classified as rocky sea floor conditions.

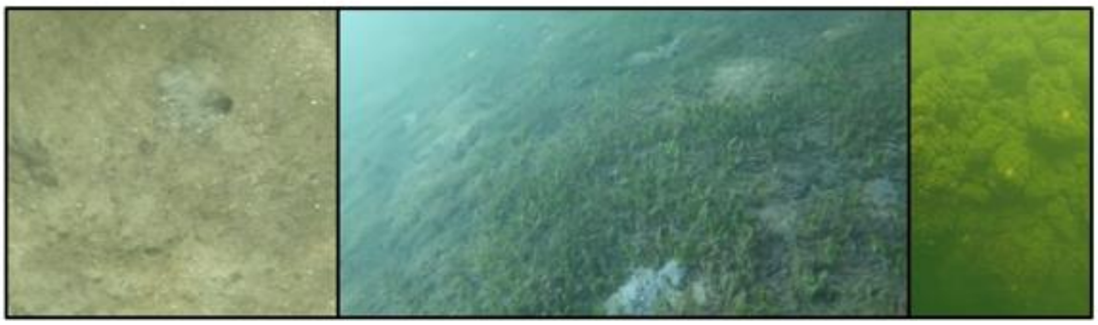


Figure 18: Sea Floor Conditions Used for Site Classification (McKinney, 2023)

As the sea floor characterizations were being filmed, water depth contour maps were

Figure 19: STRIKER Cast, Castable Sonar module (McKinney, 2023)

created with the Garmin STRIKER Cast, Figure 19. The sites with water depths exceeding five meters were eliminated as potential test sites. Next, the boat traffic and flow speed tests were conducted on the sites that remained. Full days were spent observing and systematically noting boat traffic at each site to identify periods of low traffic. This was important because it was believed that large boat wakes may hinder the performance of the FSWW. The flow sensor platform was anchored about nine to twenty-one meters offshore to collect water flow and depth readings for six-hour periods. Capturing high-to-low or low-to-high portions of the tide cycles.

Figure 20: Google Maps Image of the ICW near SeaTech

Overall, eight sites were tested, and two sites met the criteria to be considered full test sites, while one site was chosen for partial system testing. The potential test sites mainly included areas in the ICW near FAU SeaTech in Dania Beach FL, Figure 20.

Figure 21: Site 1.1 (McKinney, 2023)

Potential test site 1.1, Figure 21 contained areas of grassy sea floor conditions which disqualified it from being a test site even though it met water depth criteria Figure 22. The water depth contour maps shown in Figure 22, the right portion being a zoomed in

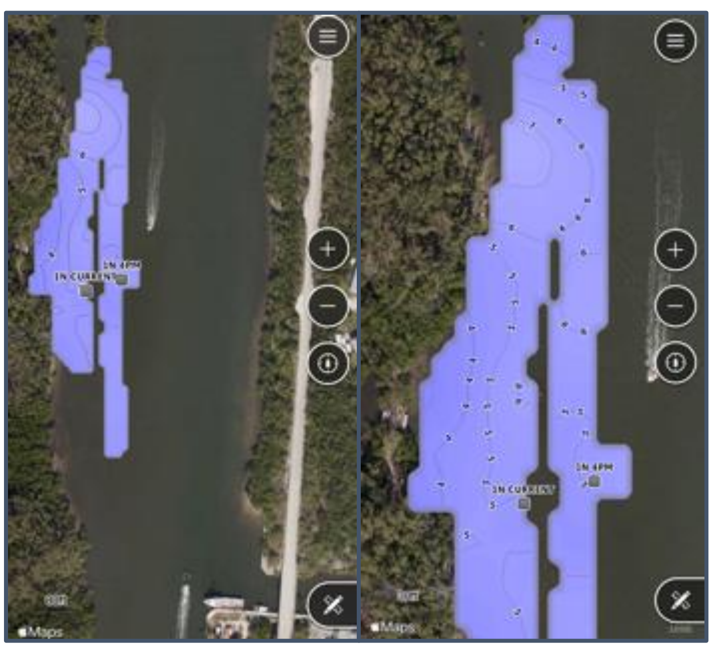


Figure 22: Depth Contour Maps of Site 1.1 (McKinney, 2023)

version of the left portion, show that the depth ranged from four to nine feet (max depth allowed 16.4ft). Site 1.2, Figure 23, was also eliminated due to the presence of sea grass.

Figure 23: 1.2 (McKinney, 2023)

The first site to meet the sea bottom conditions was site 1.3, Figure 24, with a sandy substrate. This site also met the depths requirements, falling under the five-meter limit.

Figure 24: Site 1.3, location left and middle, depth contour map right (McKinney, 2023)

Next a boat traffic survey was conducted, and this site was deemed to have moderate traffic with 54, 55, and 156 boats passing during each observation period. Furthermore, the wakes created by these passing boats did not seem to affect the sensor platform.

Figure 25, shows the flow speed results of surveying the site through two six-hour periods.

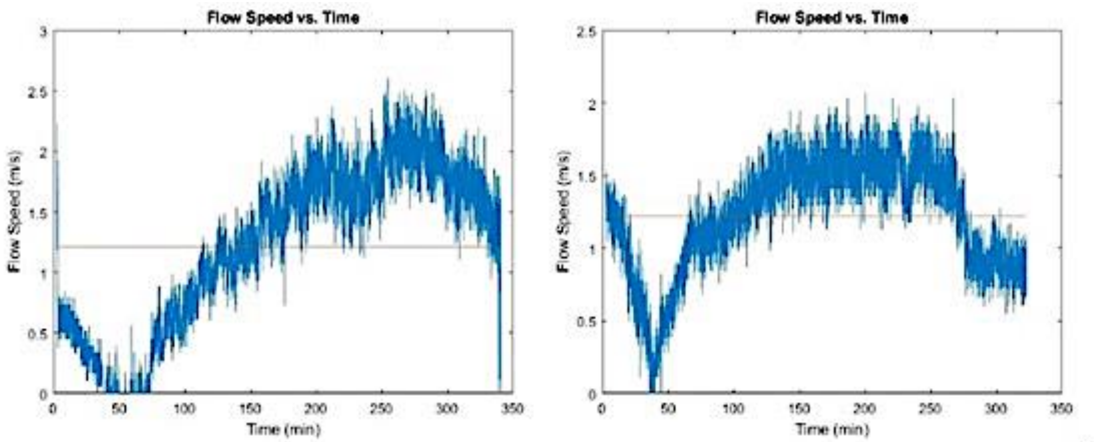


Figure 25: Current Speed Profiles 8/18/22 & 8/11/22 (McKinney, 2023)

The left graph from a low to high tide cycle on 8/18/22, with speeds ranging between 0.5 and 2m/s flow. The right graph shows a high to low tide cycle on 8/11/22, with flow speeds ranging from 0.5 to 1.75m/s. The next site to be eliminated was the Southern site, Figure 26. This site had severe changes in water depth ranging from five to eleven meters. It was also immediately apparent that boat traffic at this site was dangerously

Figure 26: Southern Site (McKinney, 2023)

high. Bridge Beach, Figure 27, was the next site to be eliminated, this time due to sea grass. This was despite meeting water depth requirements as seen in the contour map.

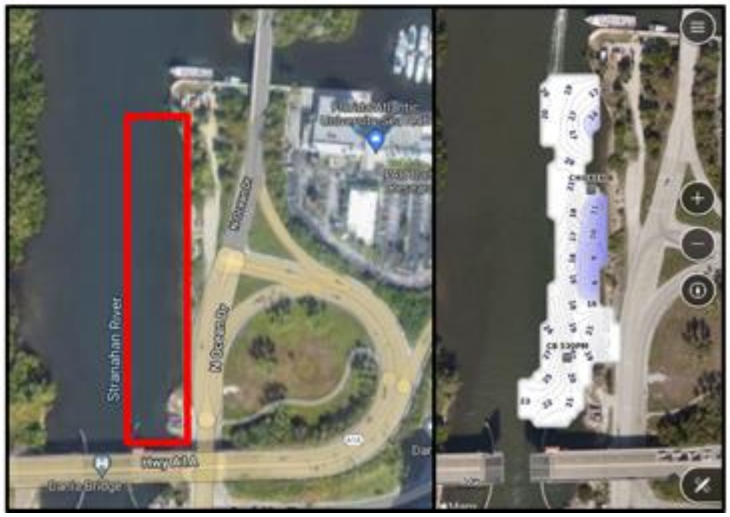


Figure 27: Bridge Beach (left) water depth contour map (right) (McKinney, 2023)

Following Bridge Beach, Port site, Figure 28, at 26°04'33.0"N 80°06'48.7"W, which is 2,496m from the launch point, and 153 by 19m in size, was eliminated due to concerns about maintaining a fifty-foot testing radius around the vessel and due to some very deep

Figure 28: Port Site and its contour map (shown in feet) (McKinney, 2023)

regions as seen in the contour map. The second site to meet all the requirements was Inlet site, Figure 29, at 26°05'17.4"N 80°06'46.3"W, 3,804m from the launch point, and 122 by

28m. This site had sandy sea bottom conditions, shallow water depths and a measurable flow.

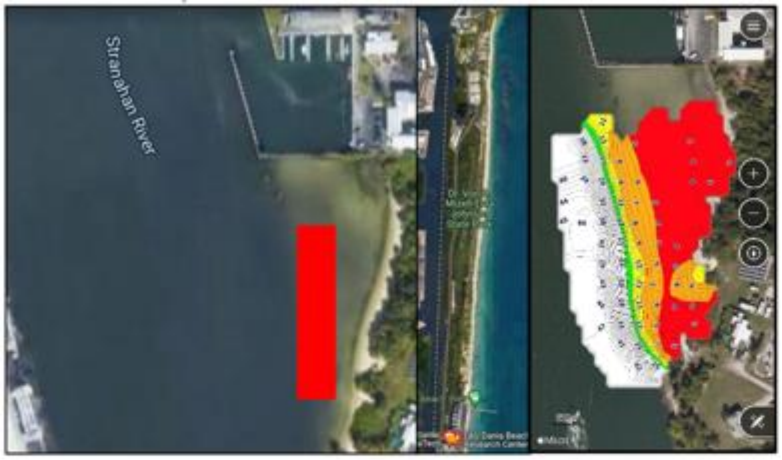


Figure 29: Inlet Site & its contour map (shown in feet) (McKinney, 2023)

Boat traffic studies of this site showed 124 boats pass the location during the low to high tide cycle and 148 boats pass during the high to low tide cycle. Figure 30, shows the flow speed profile for a low to high tide cycle (McKinney, 2023).

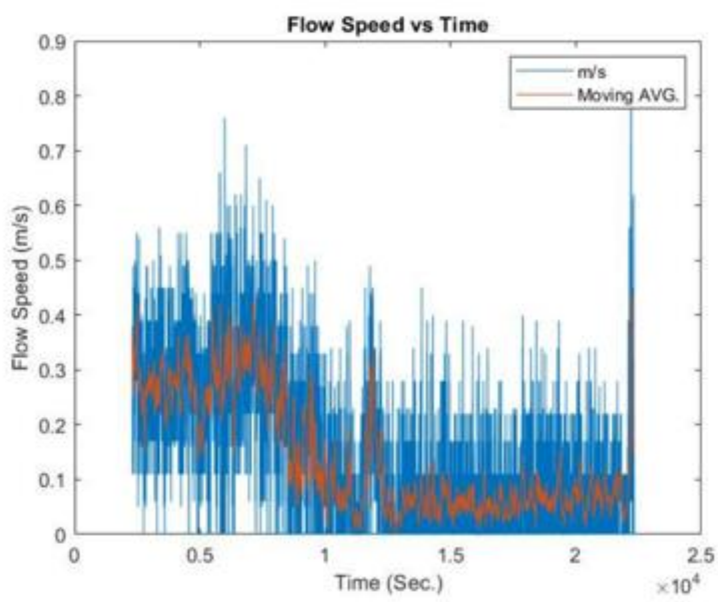


Figure 30: Current Profile 8/22/22 (McKinney, 2023)

This concluded the seven original testing site surveys, which yielded two sites that met criteria for full system testing. However, one additional site was surveyed due to its proximity to campus and visually impressive flow speeds. ICW Dockside, Figure 31, at

Figure 31: ICW Dockside with depth contour map (shown in feet)

26°03'19.6"N 80°06'52.8"W, 220m from launch point, and 9 by 20m in size, was tested. Based on the contour map this site ran on the deep end of the range, however the rocky sea floor conditions, flow speed, and proximity to SeaTech made this site acceptable. It was deemed that due to the site’s depth an auxiliary mooring line would be used rather than the on-board anchoring system to position the MHK platform during tests at this site. This meant that only the MHK turbine could be tested at this location, and a full system verification would need to be conducted at site 1.3 or Inlet.

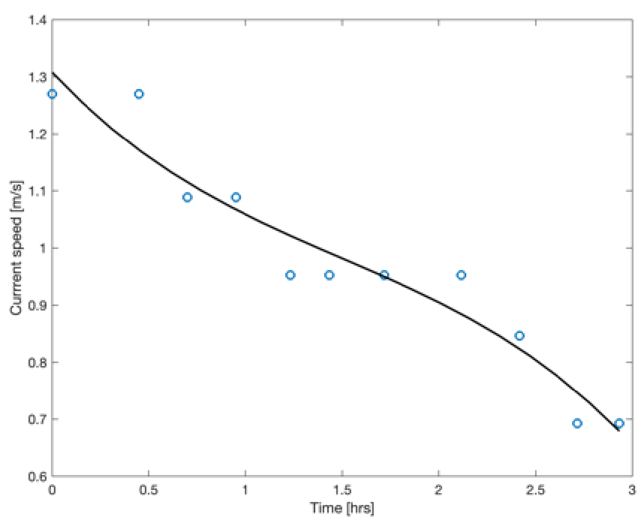


Figure 32: Flow Speed profile for ICW Dockside

Figure 32, shows the flow speed profile for this site, which matches the desired testing flow speeds.

After many surveys and much consideration two sites were selected for final field-testing of the MHK platform. Those sites being ICW Dockside and 1.3, Table 11, turbine testing would be conducted at ICW Dockside and fully system verification would be tested at 1.3.

Table 11: Site-selection Survey Results (McKinney, 2023)

Site	Sea Grass Present?	Water Depth	Boat Traffic	Flow Speed Range
1.1	Yes	1.2-2.13m	n/a	n/a
1.2	Yes	n/a	n/a	n/a
1.3	No	1.2-5.18m	54, 55, 156	0.5-2.25m/s
Southern Site	Yes	5-11m	n/a	n/a
Bridge Beach	Yes	1.8-8.23m	n/a	n/a
Port Site	No	1.5-3.96m	n/a	n/a
Inlet Site	No	0.91-3.35m	124, 148	0.0-0.5m/s
ICW Dockside	No	5.8-6.4m	n/a	1.3-0.6m/s

See Appendix C for site-selection procedures and day of testing sheets.

5.3 Field-testing Planning and Procedure Development

Immediately following site-selection, preparation for field-testing began. Consideration was given to the goal of field-testing, the number of test days needed, and the tests that were to be conducted. Two separate phases were identified as necessary for timely completion of system integration. One phase for autonomous navigation development and one phase for MHK platform testing and verification. Due to the turtle nesting season (during March-October), the MHK turbine and the AAS could not be deployed in the water as per permit requirements. That said, a second WAMV at SeaTech was outfitted with the same control box, batteries, and weights to mimic the loads of the MHK platform. This enabled autonomous navigation capabilities to be developed and tested during the MHK platform's testing blackout period. Site-selection had been completed in January of 2023 and autonomy work was scheduled to begin in May 2023.

The failure of the SeaTech boat davit in late January meant new procedures and equipment were necessary for May's testing. Normal protocol allowed for the vessels to be rolled out of the lab through the rollup door directly to their launch point from the SeaTech deck and davit. With that out of commission, steel ramps were created to enable the vessels to be rolled down the steps on the east side of campus, out the gates and into the SeaTech parking lot where they could be trailered and taken to the nearby finger lakes for testing. Procedures and checklists for these testing trips were created to ensure successful outings. The goal of autonomy testing days was to allow the software team to make adjustments to the code and see how the vessel reacted in real time. Usually, this type of testing could be conducted in the marina and in Whisky Creek near campus, but with the davit failure the nearest boat dock at Holland Park in Hollywood would be used. These trips necessitated a trailer, a truck to tow it, the SeaTech chase boat, and any auxiliary testing supplies that could usually be brought to the dock from the lab. During testing in the marina at SeaTech the chase boat was not needed because the testing WAMV could be observed from the deck and rescued with a kayak if the system encountered any unexpected behavior or failures. However, the chase boat was needed for Holland Park testing due to the area where testing would be conducted. Figure 33 shows the boat dock at Holland Park and the route south to North Lake, that the vessels

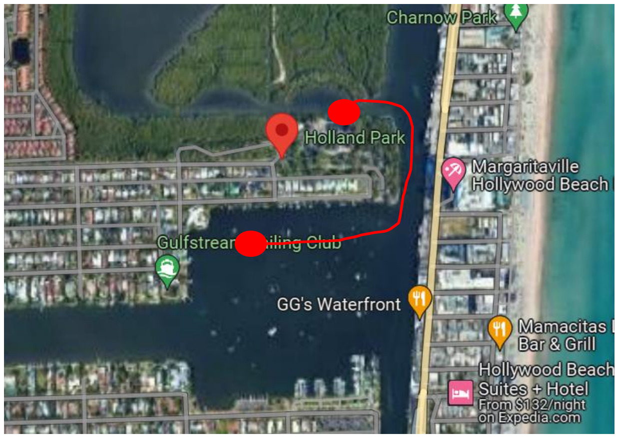


Figure 33: Halland Park boat launch with route to North Lake for WAMV testing

needed to traverse to get to a safe testing area. The location in North Lake where testing was to take place did not have a beach or dock nearby, so the software team had to be in the chase boat near the WAMV as they adjusted the code. Each time the chase boat was to be taken for testing, a float plan had to be submitted to the university at least four days in advance, to ensure the crews safety and to acquire a university approved captain for the chase boat. These added protocols and barriers created the need for extra planning and much more physical work from testing personnel. Work to develop autonomous navigation for the WAMV required a path planning controller, a station keeping controller, and a way point following controller. Achieving this level of development took all summer and would have continued well into fall of 2023. However, due to delays in getting the davit replaced and functioning properly and the trailer being returned to its home university in August, autonomy testing was only able to start back up in November. However, additional delays occurred after the new davit was installed and did not operate properly, requiring additional maintenance. The davit was not fully functional until December 2023, which marked the official start of field-testing. Despite these delays, autonomy tests were still preformed May 2023 – July 2023 at Holland Park. For these tests, a typical autonomy testing procedure was as follows. See Appendix D for the pretesting checklists. Push the vessels to the staging area in the SeaTech parking lot, trailer each one to Holland Park individually, and allow the full team to board the chase boat for testing. After boarding the chase boat, the WAMV was to be driven via remote control to the final testing location in North Lake, while the chase boat followed. Once at the testing location, the software team begins their work and the WAMV is monitored for safe keeping in between code adjustments. After roughly three hours of testing the vessels returned to the boat ramps and were then individually retrieved and trailered back to SeaTech. Complete autonomy testing procedures can be found in Appendix E.

The second phase of field-testing was MHK turbine and platform verification. By the time this phase of testing was scheduled to begin the davit was supposed to have been fixed and ready to go. That said procedures and test plans were created with this as the operating idea, see Appendix F for the original testing schedule. Field verification of the MHK turbine was to determine how much power each FSWW configuration could produce. The FSWW would be tested under the seven, nine, and eleven blade configurations at both full blade submergence and half blade submergence levels. Then the MHK platform autonomy demonstration was to verify that the autonomous navigation and system integrations worked properly. Testing for the MHK Turbine was usually conducted as follows. First, the chase boat would be deployed using the davit so that the MHK platform’s anchor line and the buoy exclusion zone could be set prior to the MHK platform entering the water. Then the MHK platform would be deployed using the davit and it would be driven via remote control to the anchor line in the ICW Dockside location. The MHK platform would then be attached to the line by a team member aboard the chase boat and then the MHK turbine would be deployed via wireless communication from the shore-based observation team. The chase boat would return to shore and the team would begin recording data and monitoring the platform for a full high to low or low to high tide cycle. After the tide cycle had ended, the data recording would be stopped, the FSWW would be stowed, and the chase boat would return to the MHK platform, unhook it from the anchor line and allow it to be driven via remote control back to the davit for retrieval. Then the chase boat would recover the anchor lines and return to the davit area for retrieval as well. The MHK platform autonomy demonstration would require the same deployment methods as the MHK turbine tests; however, the chase boat would remain near the MHK platform (with the whole team abord) and detach it from the anchor line once the team was satisfied with the FSWW demonstration. Once the MHK platform was detached from the anchor line the software team would switch it into "Auto Mode" and the MHK platform would execute its autonomous mission. As the MHK platform executes its mission the chase boat and team would follow it for safety and to closely monitor its behavior, ensuring each task was completed as expected. Complete and detailed testing procedures for MHK turbine and MHK platform autonomy verification can be found in Appendix G.

It is important to acknowledge that with each deployment of the chase boat a university float plan had to be submitted at least four days prior to testing. With each planned day of MHK testing a full schedule was created to ensure the entire team knew exactly what to expect the day of testing, see Appendix H for these detailed schedules. Each day of testing also required a "day of environmental testing sheet". These sheets recorded the testing conditions for each deployment and any miscellaneous notes the observation team had during testing, see Appendix I for these completed environmental testing sheets. Each day of MHK turbine testing created a raw data file generated by the PTO control box, sent back to the shore-based team, and recorded on the monitoring team's laptop. The data within these data csv files was recorded at a 10Hz sampling rate. The raw data will be provided to the DOE and eventually posted for public use, through their internal processes.

5.4 Field-testing

Field-testing of the MHK turbine began in December 2023, as shown by the schedules in Appendix H. Figures 34-36 show the FSWW in each of its three configurations.

Figure 34: FSWW 7 Blade Configuration, 12/5/23

Figure 36: FSWW 9 Blade Configuration, 12/12/23

Figure 35: FSWW 11 Blade Configuration, 1/31/24

The final MHK turbine test took place February 29th, 2024, as one of the team members had to verify the performance of a new PTO control algorithm. However, this investigation will only be considering the data files from testing completed on Jan. 10th, Jan. 16th, Jan. 17th, Jan 19th, Jan. 24th, and Jan 31st of 2024 as these were the days with the most ideal and consistent testing conditions. Table 12 shows which FSWW configurations were tested each day.

Table 12: FSWW Testing Configurations

Test Date	Blade Number	Submergence Level
1/10/2024	7	Full Blade
1/16/2024	7	½ Blade
1/17/2024	9	Full Blade
1/19/2024	9	½ Blade
1/24/2024	11	Full Blade
1/31/2024	11	½ Blade

The MHK platform autonomy verification demo took place February 16th, 2024. The procedures provided in the appendices were followed during all MHK turbine and platform tests.

6.0 DATA ANALYSIS

Data acquired during field-testing were produced in comma separated variable (csv) files. Each file had twenty-eight columns of data recorded with a sampling rate of 10Hz. The data analysis conducted involved a data preprocessing phase, followed by data processing. Each dataset was run through the same data preprocessing for repeatability and data consistency. Out of the twenty-eight columns the quantities of interest were total time elapsed (the dataset's running timer), the flow speed, the FSWW rotations per minute (RPM), the voltage produced by the generator "Vg", and the current produced by the generator "Ig". This limited dataset was run through MHKit's (QC Module, 2019) quality control module. The data was processed using the time check and range functions of this MHK toolkit. These functions ensure that only data with valid time stamps and within the expected range were included in the final dataset. This second csv file was created so that the MHKit processed data could be run through two more preprocessing functions from MATLAB. Next outliers were removed from the data, the data arrays sizes were matched, and MATLAB's moving average function was applied to them, with a window span of 1000s. The data processing phase required that each dataset, which represented a unique FSWW configuration, be utilized to determine the theoretical estimate of the mechanical power produced and the empirically determined estimate of the power produced during field-testing, the actual electrical power produced by the wheel during field-testing, the resulting expressions' C_P, the efficiency η_{tot} for electrical power generation, a C_P versus TSR curve, and a C_P/K versus TSR plot. To achieve this, variables which were to be taken as constants in the power equations were entered into the MATLAB script. Variable “A” in equation (2) and (11) in Section 2, was set to 0.349 for full blade submergence, and 0.349/2 for half blade submergence, note the units attached to these quantities is m^2 for area. Variable “R” in equation (2) and (11) in Section 2, was set to 0.4858 for the radius of the wheel, note the unit attached to this quantity is m. Variable “p” or ρ from equation (2) and (11) in Section 2, was set to 1023.6 for the density of salt water, with the representative unit of kg/m^3. C_D, or the coefficient of drag for the blades was taken at 1.98, the coefficient of drag for a flat plate, was used as a conservative approximation. See Appendix J for the interpolation investigation of C_D for a flat plate to C_D for a hollow semi-cylinder. The blade on the FSWW has a curvature of 0.925, while a semi-cylinder has a curvature of 0.2105 and a flat plate has zero curvature. A traditional interpolation was conducted to show that the blade curvature could justify a C_D value of 2.14, as the C_D value for the semi-cylinder is 2.3. However, seeing as this could potentially artificially increase the amount of power produced by the wheel, 1.98 was used. This leaves λ or TSR and α. TSR was found using the physical radius of the wheel, R, and the experimental data captured for the rotations of the waterwheel, and the flow speed. The raw data provided the rotations of the FSWW in RPM, however equation (2) and (11) requires the units be radians per second. This conversion was done using the following equation,

$$W_{rad/_s} = \frac{RPM * 2\pi}{60} \tag{12}$$

where RPM was the moving average array of wheel rotations in RPM. TSR was computed using the following equation,

$$\lambda = TSR = \frac{W_{rad/s} * R}{U} \tag{13}$$

where U was the moving average array for day of flow speed. Finally, the value of α in equation (11) was systematically varied during the tuning of the empirical model fit. The value of α that resulted in the highest correlation coefficients between the theoretical curve and the experimentally determined power were adopted for the final empirically determined expression for C_p. The theoretical curve for the mechanical power expected from the FSWW was derived from Pimentel's torque model, which was based on bench top testing (Pimentel, 2024). The torque determined from Pimentel's model was multiplied by the angular speed of the FSWW (in rad/s), to provide the theoretically determined power curve, denoted as "Ph". This theoretical power curve was used to tune the empirical model fit "Pa" in this case study. Once "Ph" and "Pa" had been set with their optimal α value, K was determined by taking the ratio of the mean value of "Ph" over the mean value of "Pa". Each dataset or FSWW configuration had a unique K value. A table representing each dataset's average flow speed and K value is displayed in the results section. A corresponding K versus Flow Speed plot is also included. Other plots depicting the comparison between the theoretically determined power and the curve fit based on equations (2) and (11) are also provided in the next section for each dataset. The mechanical power coefficient C_P is determined using the following equation,

$$C_P = \frac{P_a}{P_f} \tag{14}$$

where P_f is the power available in the flow equation (1), and P_a is the power computed using the curve fit equations (2) and (11), or "Pa". C_{Pe} for the electrical power generated by the wheel was found with the following equation,

$$C_{Pe} = \frac{V_g * I_g}{P_f} \tag{15}$$

where V_g is the moving average array for voltage generated during testing, I_g is the moving average array for the current generated during testing, and again P_f is the power available in the flow. See Appendix K for the MATLAB scripts associated with data processing for this case study.

7.0 RESULTS

The results of the processing and analysis of the data acquired during field-testing of the FSWW for its various configurations are described here. Table 13 shows the results for the numerical expression of the empirical curve fit for each dataset.

Table 13: Numerical Expression Results

Test Date	Blade Number	Submergence Level	Empirical Curve Fit $P = \frac{1}{2}\rho AKU^3\left(1 - \frac{4}{5}\lambda\right)^2 \lambda$	Empirical Curve Fit Correlation Coefficient
1/10/2024	7	Full Blade	$K = 0.7037$	0.86
1/16/2024	7	½ Blade	$K = 0.4818$	0.88
1/17/2024	9	Full Blade	$K = 0.7127$	0.79
1/19/2024	9	½ Blade	$K = 0.8207$	0.86
1/24/2024	11	Full Blade	$K = 0.6184$	0.87
1/31/2024	11	½ Blade	$K = 0.1408$	0.78

In Tabel 13, the empirical curve fit is based on equation (2) and (11) with $\alpha = 0.8$, see discussion in Section 8.

Now the plots, starting with results from 1-10-24.

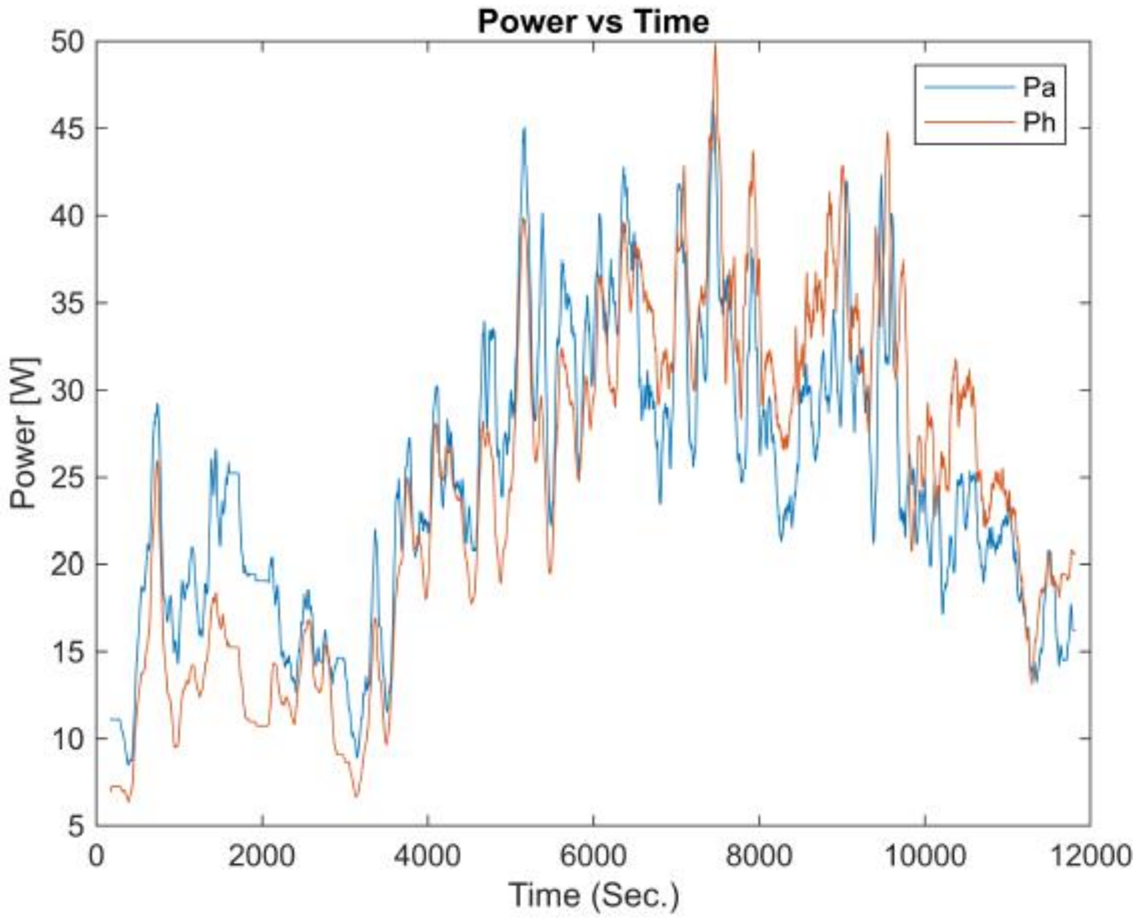


Figure 37: 1-10-24, Numerical Expression vs Theoretical Power, Correlation Coefficient = 0.8609

Figure 37 shows the fit between Ph and Pa for the 1-10 data, this α and K value correspond to these two curves having a correlation coefficient of approximately 0.9, which indicates a high correlation between the two curves.

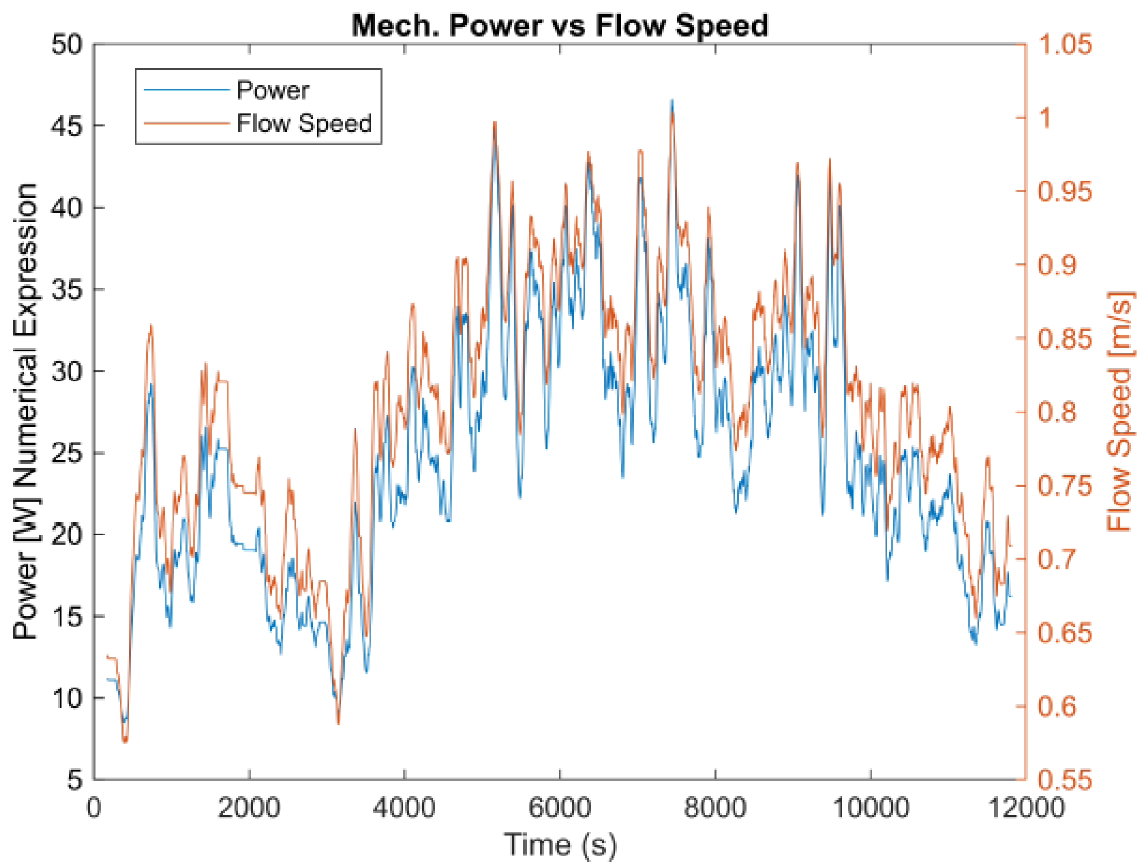


Figure 38: 1-10-24, Numerical Expression Power & Flow Speed vs Time

Figure 38 shows the mechanical power produced in blue, by the FSWW on 1-10 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle produced power ranged from approximately 20W to 40W.

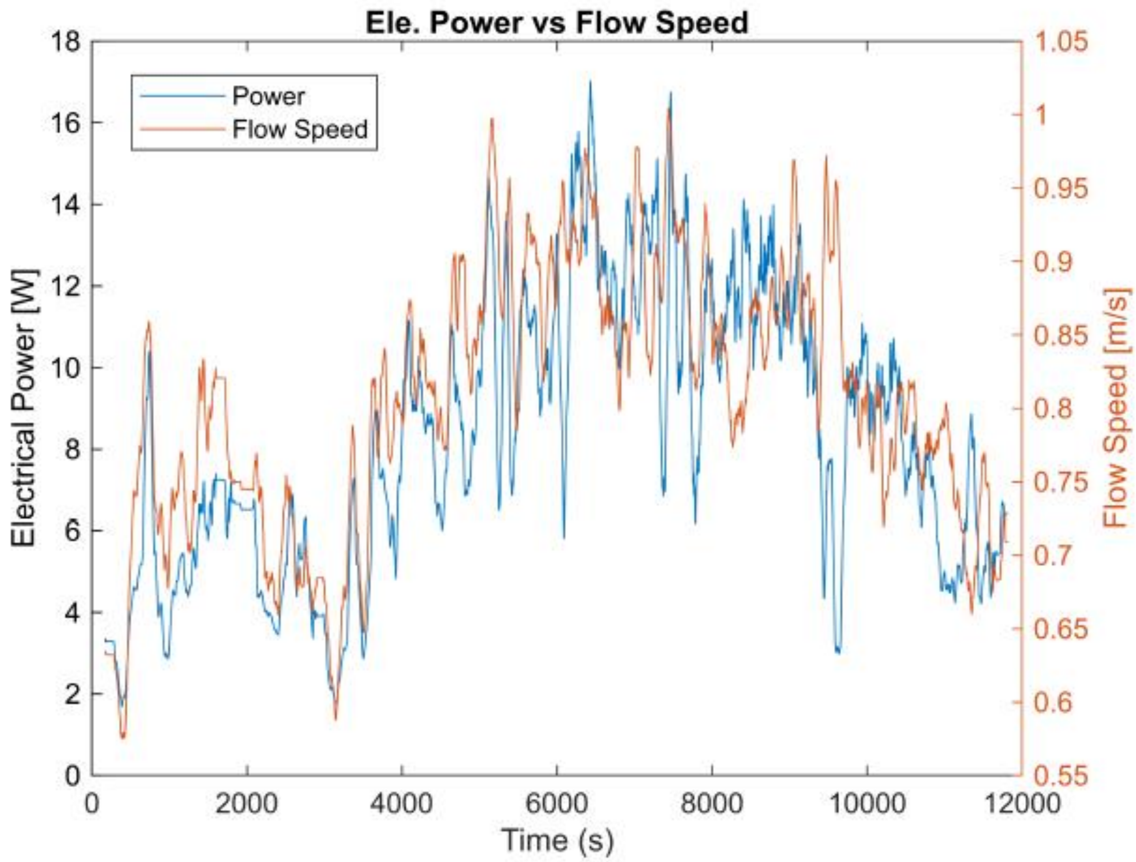


Figure 39: 1-10-24, Electrical Power Generated & Flow Speed vs Time

Figure 39 shows electrical power produced in blue, by the FSWW on 1-10 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that much of the tide cycle produced electrical power ranging from approximately 8W to 15W.

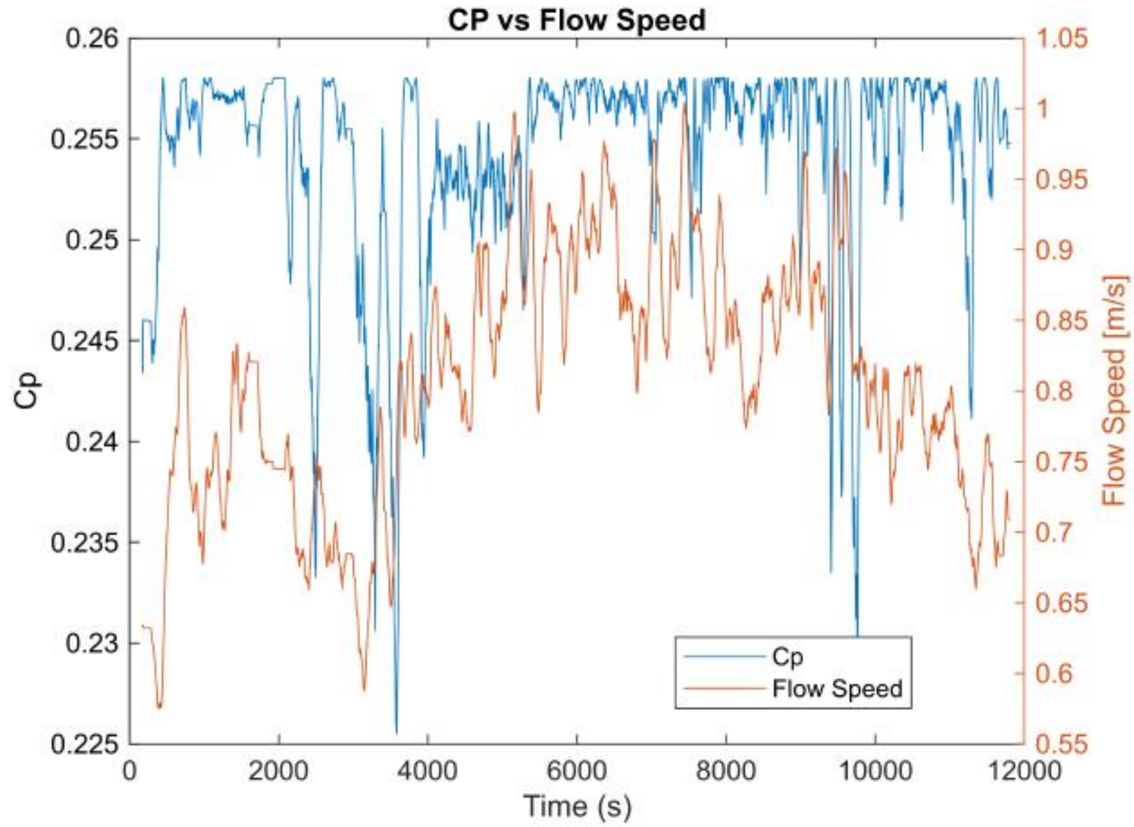


Figure 40: 1-10-24, Numerical Expression Power's C_P & Flow Speed vs Time

Figure 40 shows C_P of the mechanical power created in blue, by the wheel on 1-10 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows a C_P that remained above 22% for the entire deration of testing but reached and sustained 25.5% for much of the test.

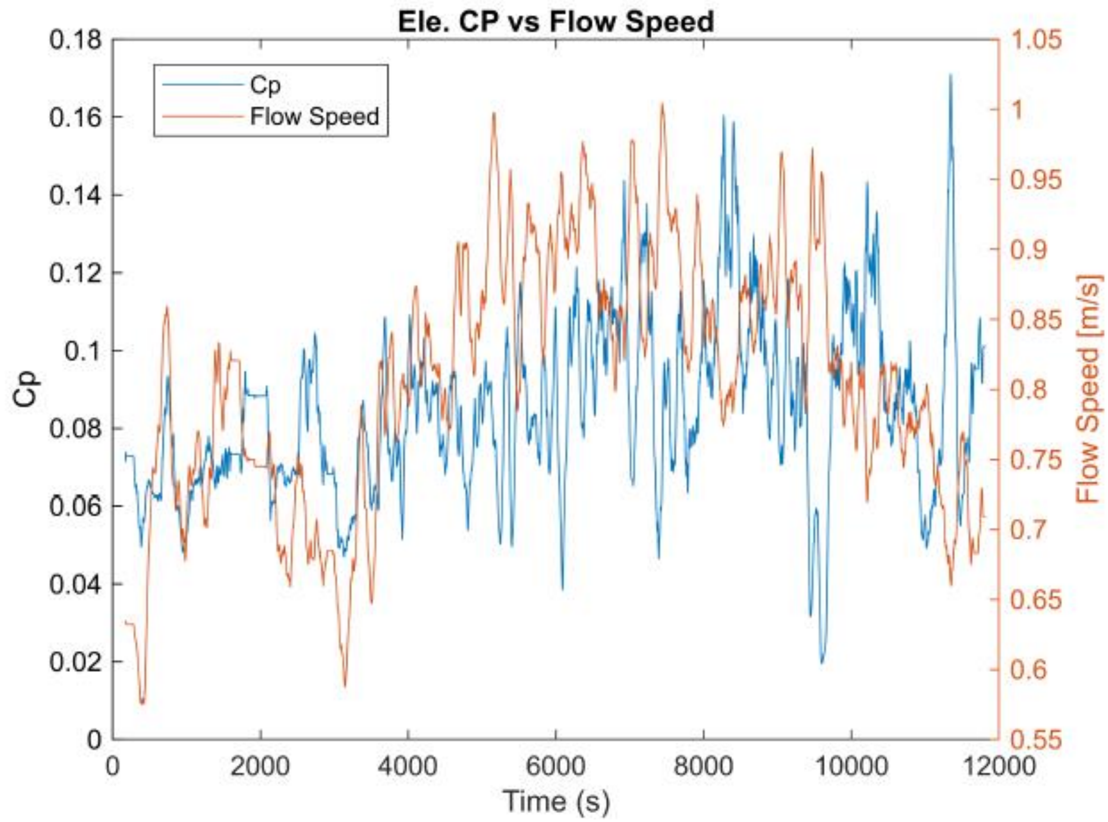


Figure 41: 1-10-24, Electrical Power's C_P & Flow Speed vs Time

Figure 41 shows the C_P electrical power produced in blue, by the wheel on 1-10 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the C_P ranged between 8 to 12%.

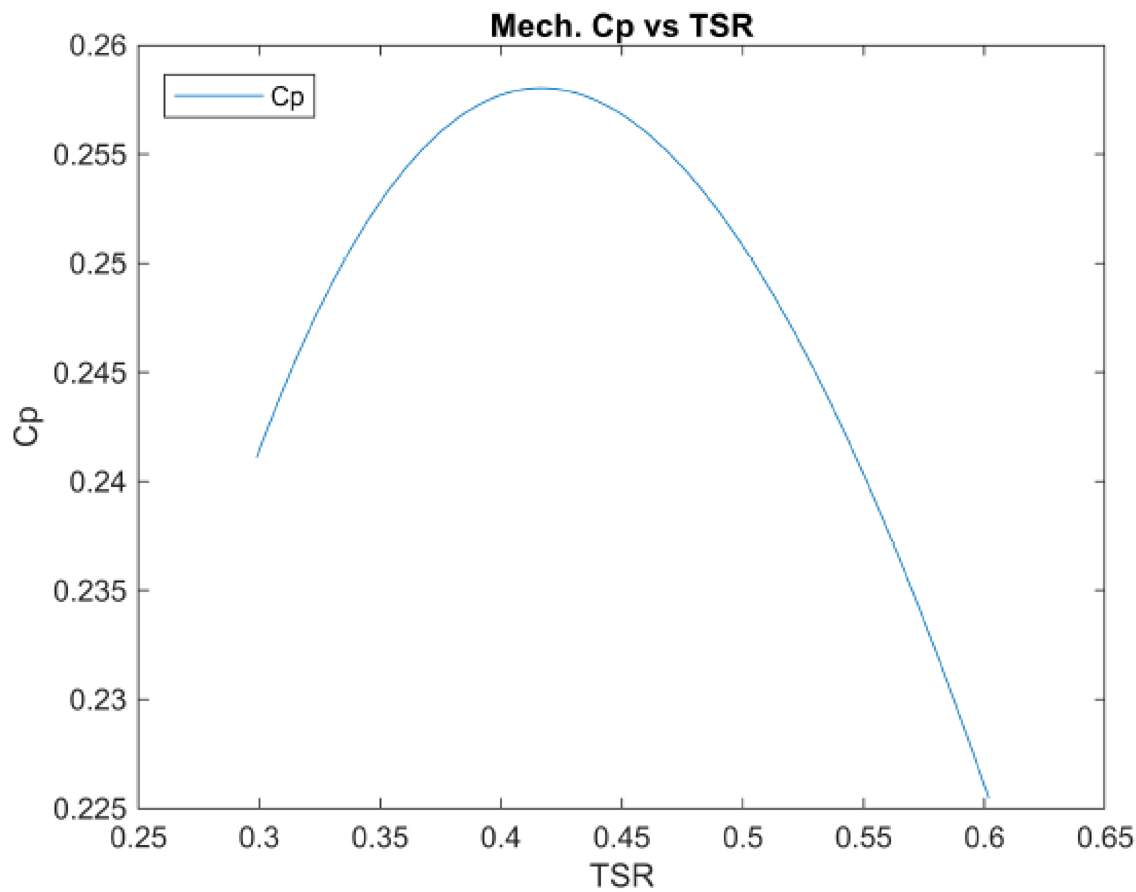


Figure 42: 1-10-24, Numerical Expression Power's C_P vs TSR

Figure 42 shows the C_P of the mechanical power produced versus the wheel's TSR for 1-10. It can be seen that C_P starts around 24% with a TSR of 0.3, and peaks at around 25.7% with a TSR of 0.4, and dips to 22.5% at a TSR of 0.6.

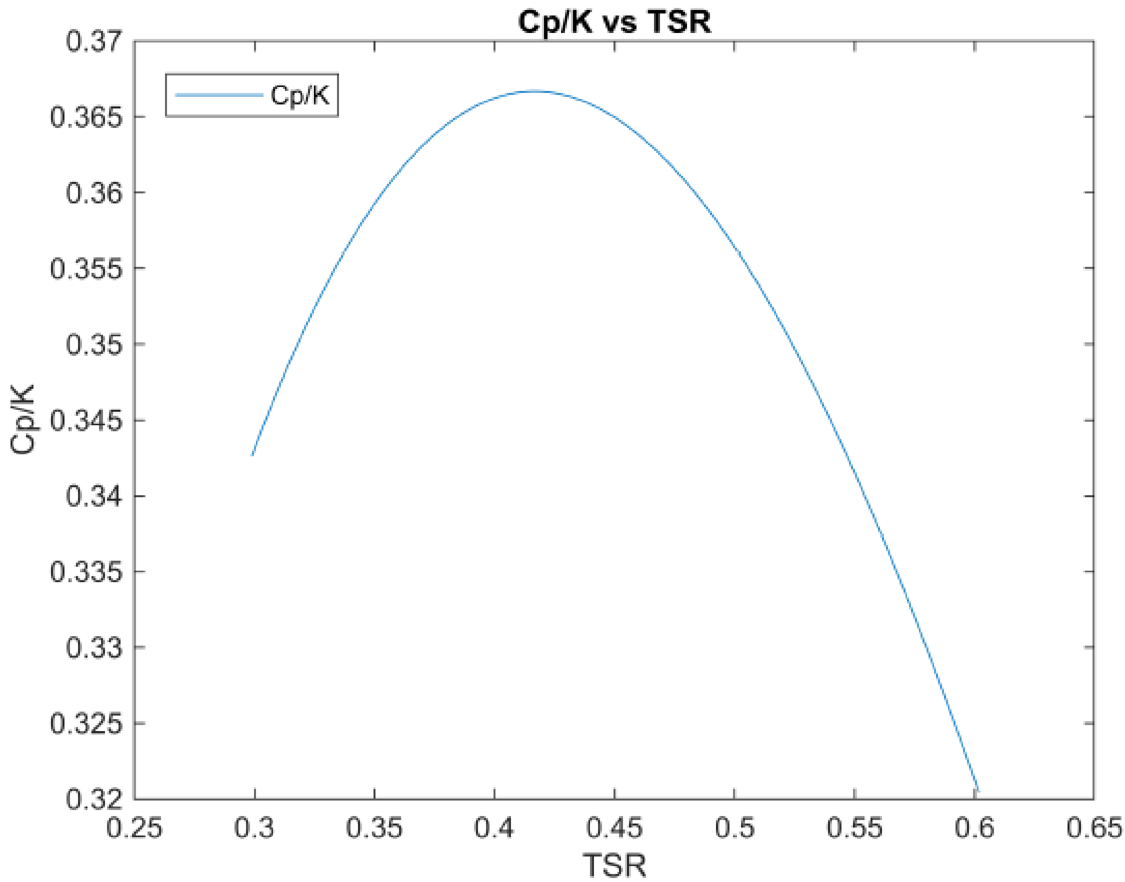


Figure 43: 1-10-24, Numerical Expression Power's C_P/K vs TSR

Figure 43 shows the mechanical power's C_P/K versus the wheel's TSR for 1-10. It can be seen that the C_P/K starts around 34% with a TSR value of 0.3, peaks at the value of nearly 37% with a TSR of 0.4 and returns to 32% at a TSR of 0.6.

Now the graphical results for 1-16-24.

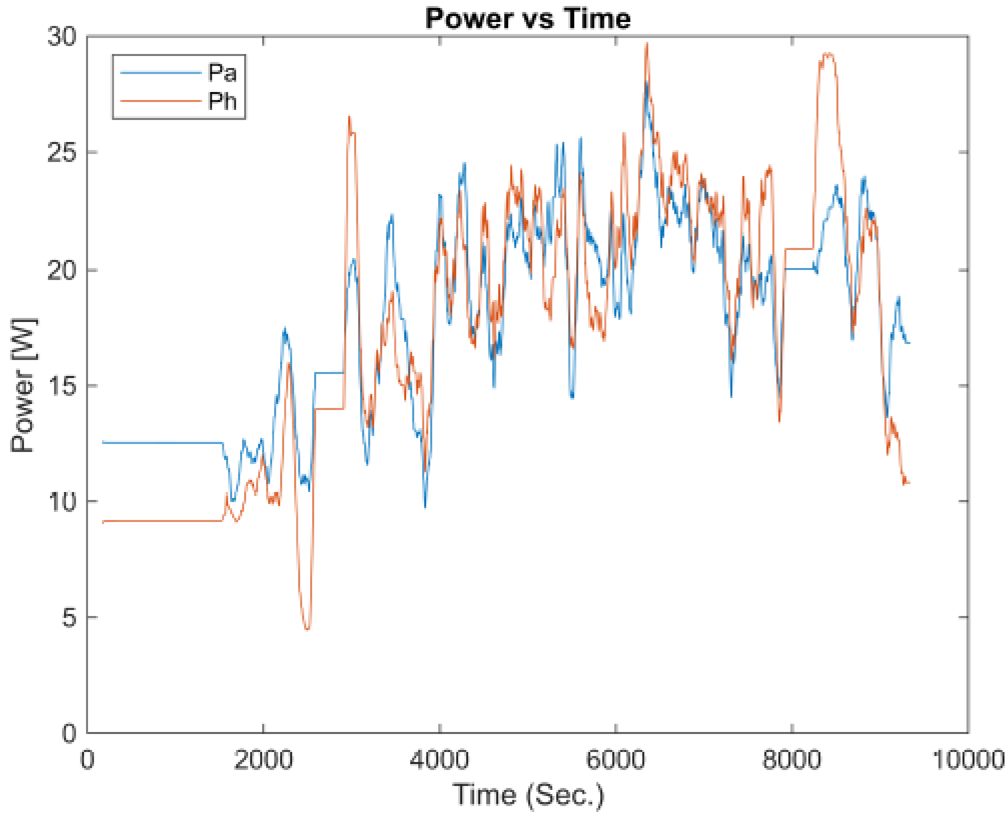


Figure 44:1-16-24, Numerical Expression vs Theoretical Power, Correlation Coefficient = 0.8831

Figure 44 shows the fit between Ph and Pa for the 1-16 data, this α and K value correspond to these two curves having a correlation coefficient of approximately 0.9, which indicates a high correlation between the two curves.

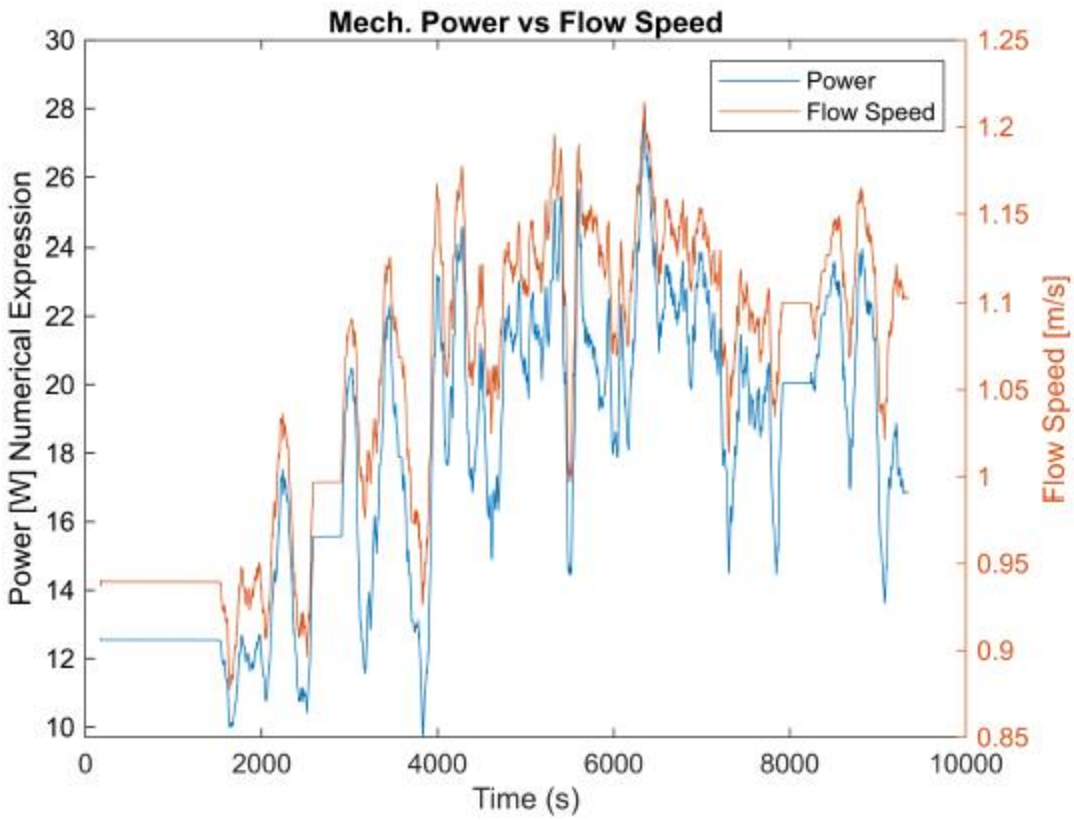


Figure 45: 1-16-24, Numerical Expression Power & Flow Speed vs Time

Figure 45 shows the mechanical power produced in blue, by the FSWW on 1-16 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle produced power ranged from approximately 18W to 24W.

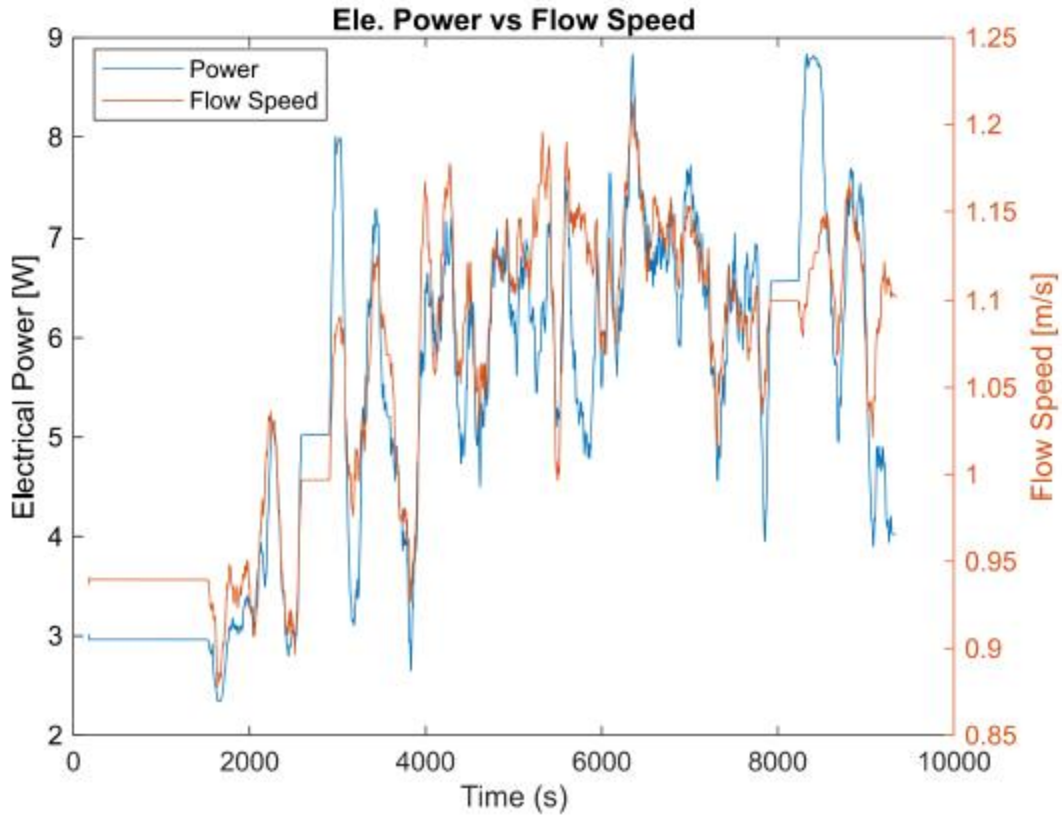


Figure 46: 1-16-24, Electrical Power Generated & Flow Speed vs Time

Figure 46 shows electrical power produced in blue, by the FSWW on 1-16 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that much of the tide cycle produced electrical power ranging from approximately 5W to 7W.

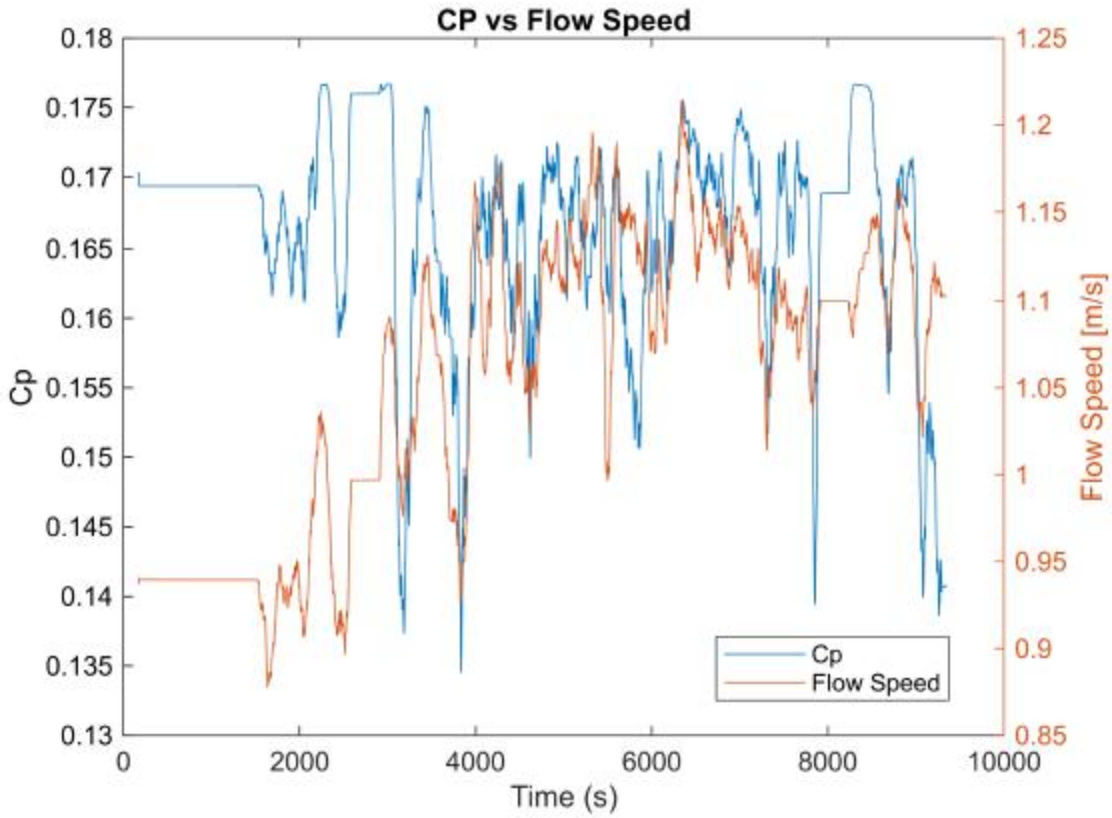


Figure 47: 1-16-24, Numerical Expression Power's C_P & Flow Speed vs Time

Figure 47 shows C_P of the mechanical power created in blue, by the wheel on 1-16 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that the wheel had a C_P that was sustained around 17% for much of the tide cycle.

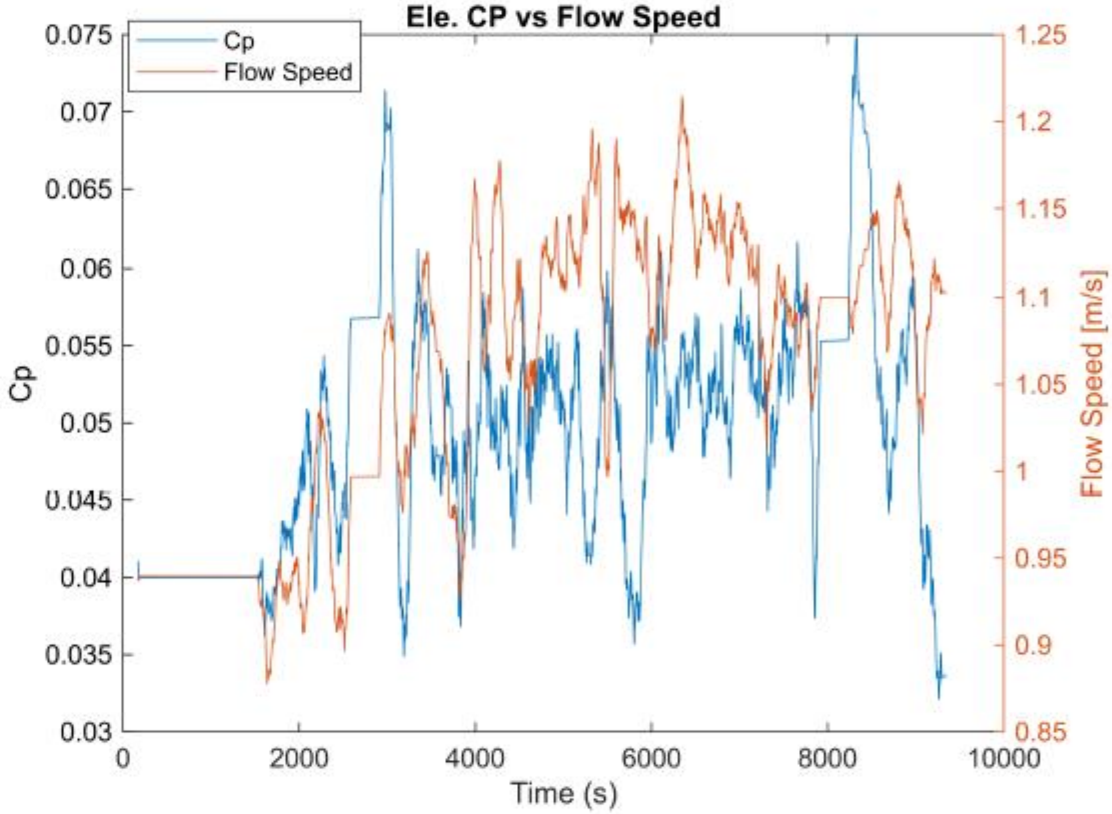


Figure 48: 1-16-24, Electrical Power's C_P & Flow Speed vs Time

Figure 48 shows the C_P of the electrical power produced in blue, by the wheel on 1-16 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the C_P ranged from 4.5% to 6%.

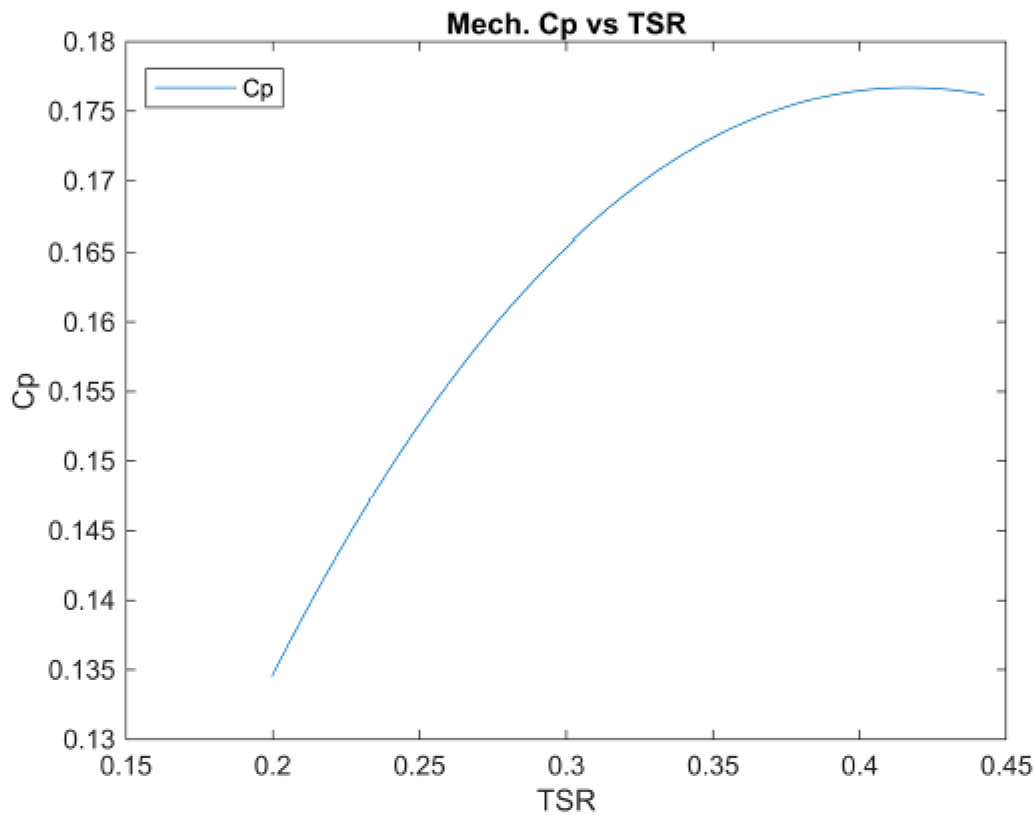


Figure 49: 1-16-24, Numerical Expression Power's C_P vs TSR

Figure 49 shows the C_P of the mechanical power produced versus the wheel's TSR for 1-16. It can be seen that C_P starts around 13.5% with a TSR of 0.2, peaks at around 17.5% with a TSR of 0.4, and sustains that until the end of testing at a TSR of 0.45.

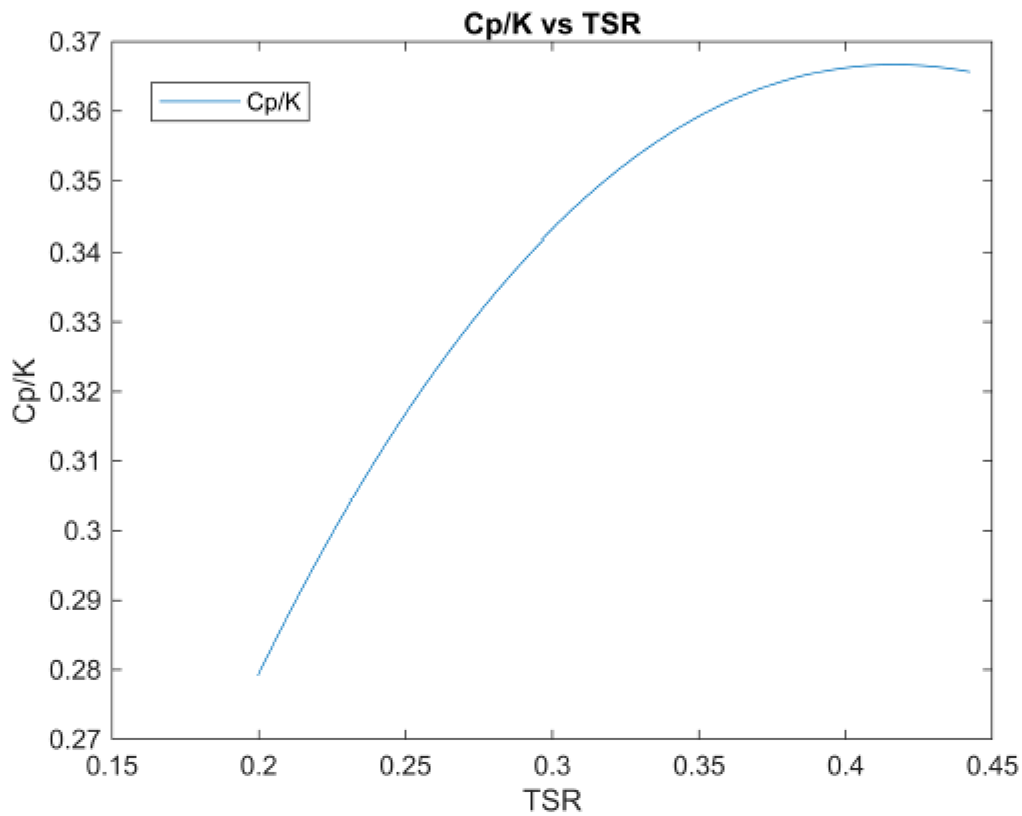


Figure 50: 1-16-24, Numerical Expression Power's C_P/K vs TSR

Figure 50 shows the mechanical power's C_P/K versus the wheel's TSR for 1-16. It can be seen that the C_P/K starts at around 28% with a TSR value of 0.2, peaks at around 37% with a TSR of 0.4, and sustains that until the end of testing with a TSR of 0.45.

Now the graphical results for 1-17-24.

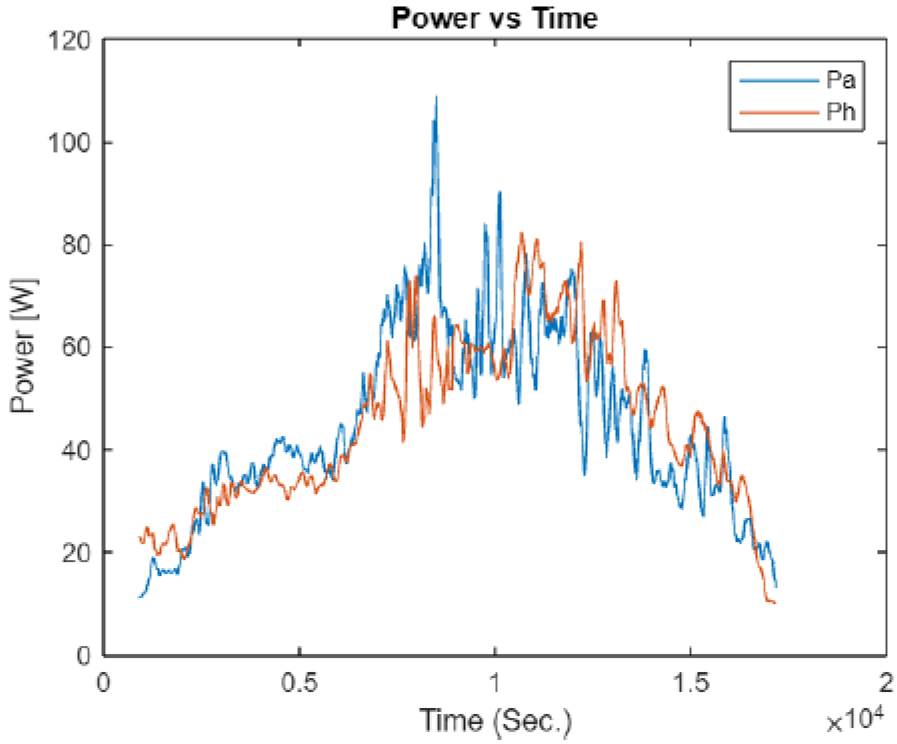


Figure 51: 1-17-24, Numerical Expression vs Theoretical Power, Correlation Coefficient = 0.7882

Figure 51 shows the fit between Ph and Pa for the 1-17 data, this α and K value correspond to these two curves having a correlation coefficient of approximately 0.8, which indicates a strong correlation between the two curves.

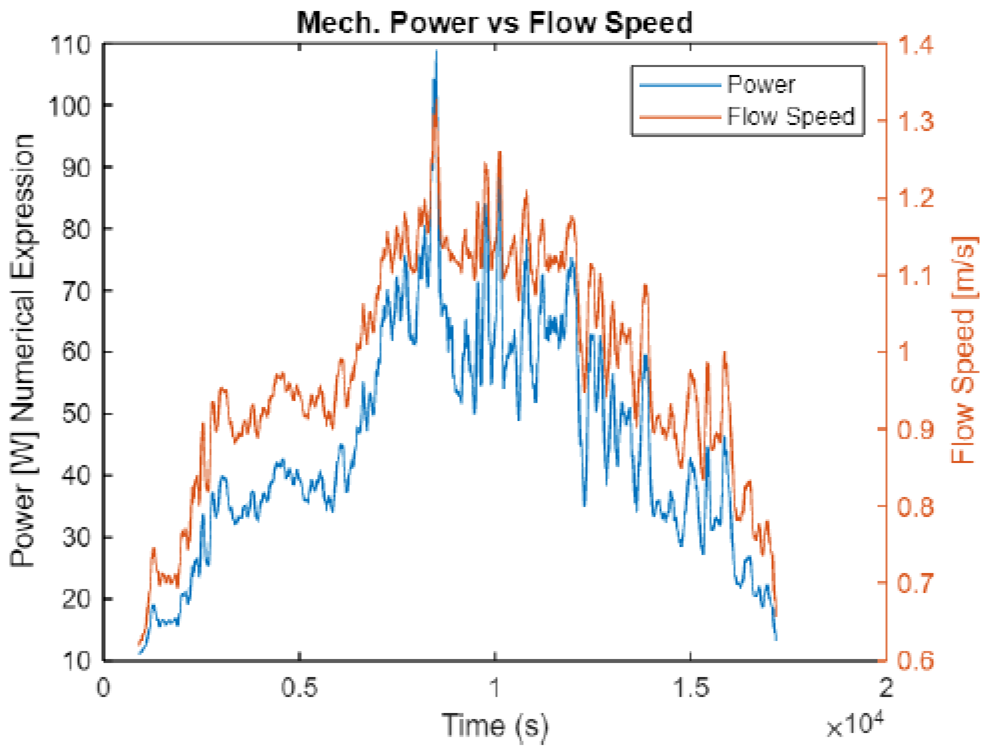


Figure 52: 1-17-24, Numerical Expression Power & Flow Speed vs Time

Figure 52 shows the mechanical power produced in blue, by the FSWW on 1-17 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that the power matches the flow speed very well, peaking around 100W with sustained production around 70W.

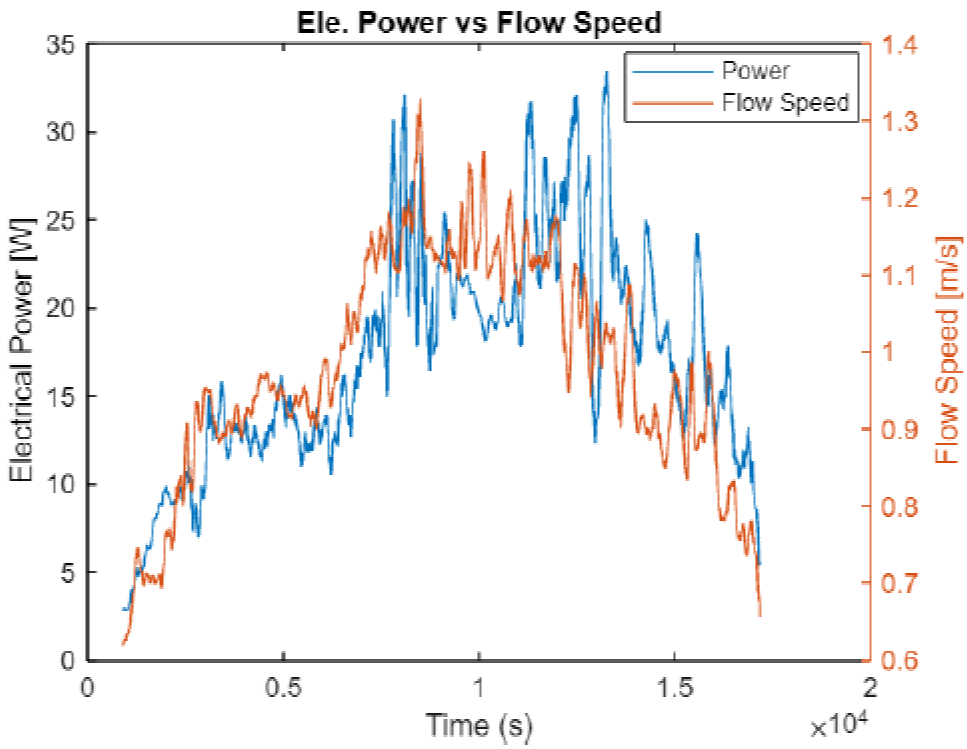


Figure 53: 1-17-24, Electrical Power Generated & Flow Speed vs Time

Figure 53 shows electrical power produced in blue, by the FSWW on 1-17 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that much of the tide cycle produced electrical power ranging from approximately 15W to 30W.

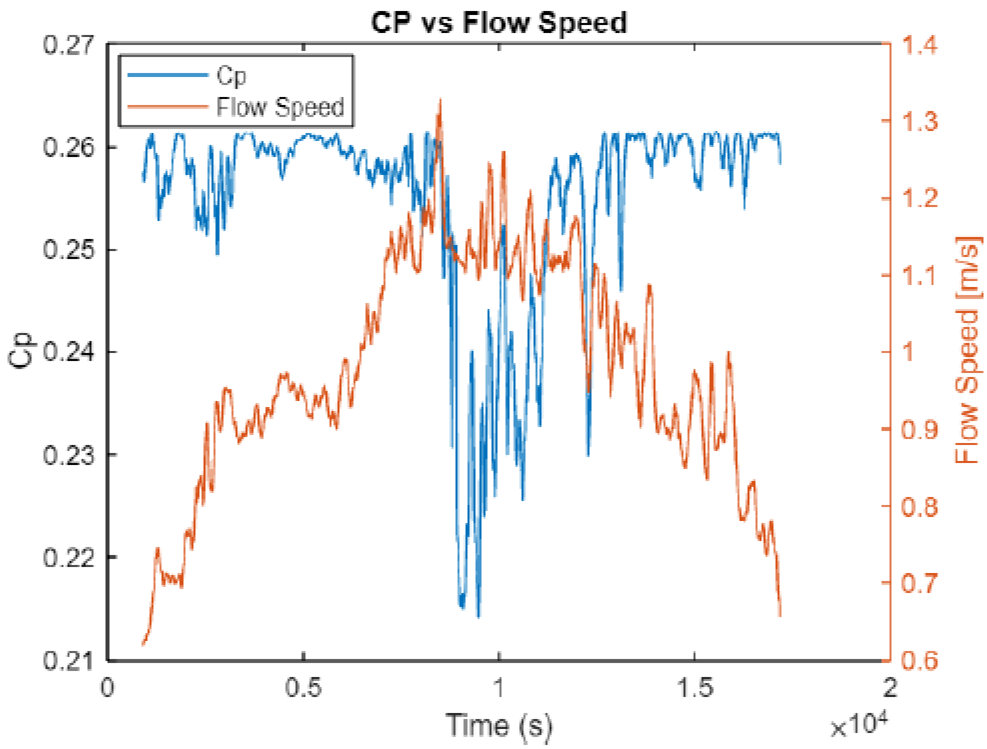


Figure 54: 1-17-24, Numerical Expression Power's C_P & Flow Speed vs Time

Figure 54 shows C_P of the mechanical power created in blue, by the wheel on 1-17 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the wheel's C_P stayed around 26% however, it fell to between 22 and 24% during the halfway point in the tide cycle.

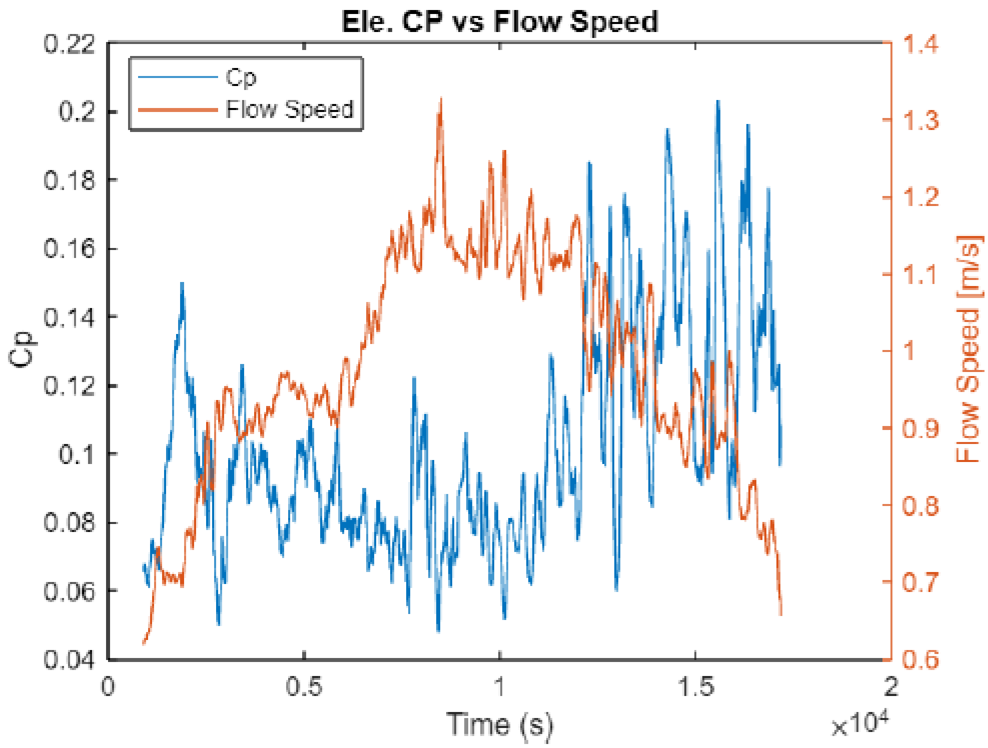


Figure 55: 1-17-24, Electrical Power's C_P & Flow Speed vs Time

Figure 55 shows the C_P of the electrical power produced in blue, by the wheel on 1-17 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the C_P stayed between 6% and 11%, only rising to between 12% and 20% for the last portion of the tide cycle.

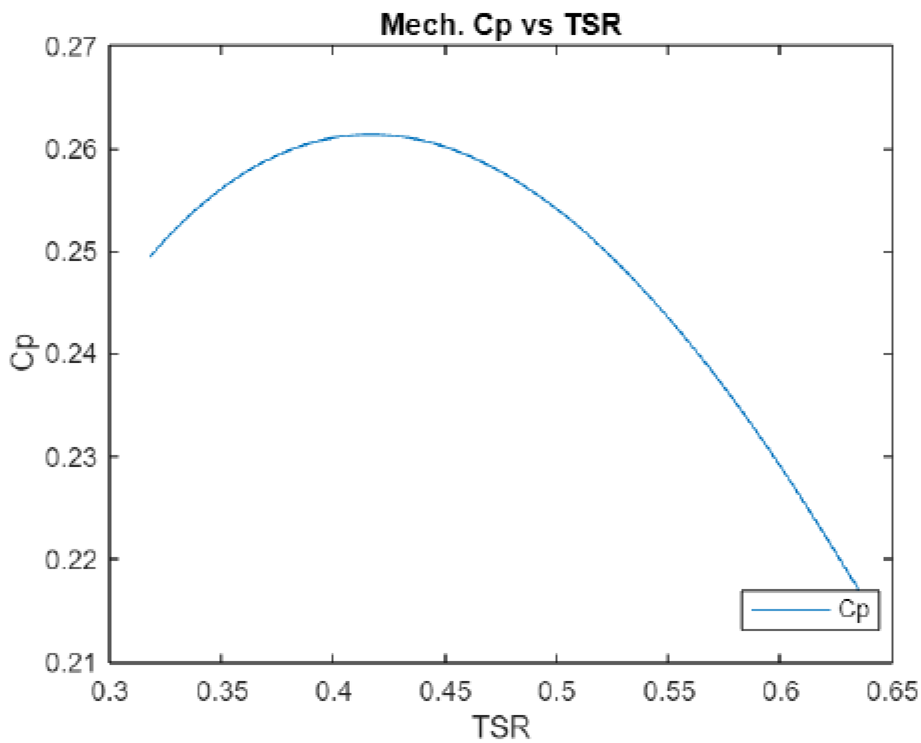


Figure 56: 1-17-24, Numerical Expression Power's C_P vs TSR

Figure 56 shows the C_P of the mechanical power produced versus the wheel's TSR for 1-17. C_P starts at 25% with a TSR of about 0.32, peaks at around 26% with a TSR of about 0.4 and ends the test around 21% with a TSR of 0.65.

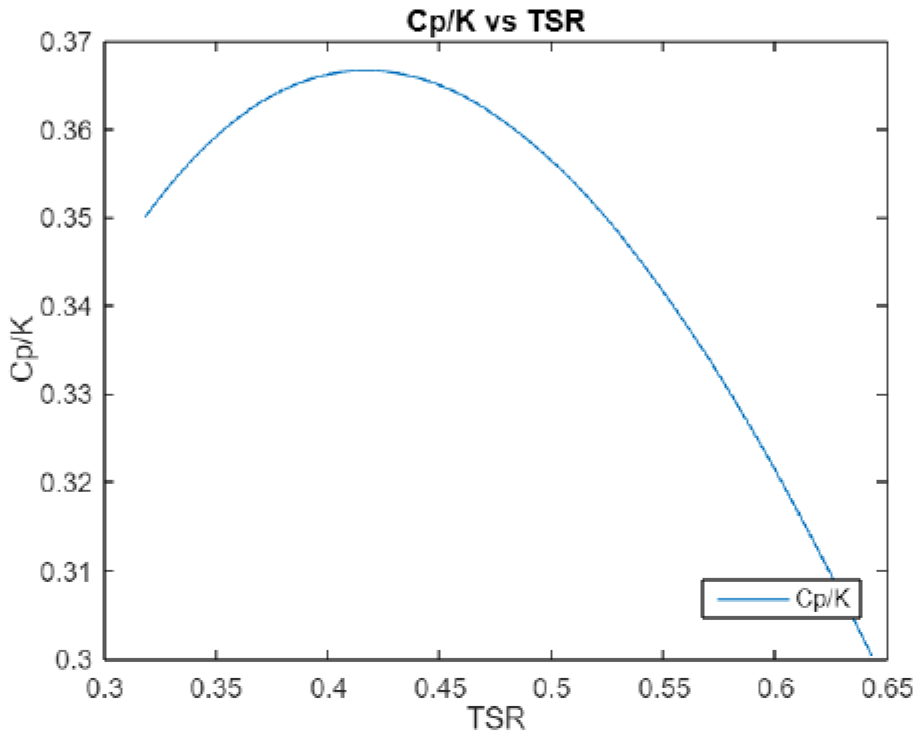


Figure 57: 1-17-24, Numerical Expression Power's C_P/K vs TSR

Figure 57 shows the mechanical power's C_P/K versus the wheel's TSR for 1-17. It shows the C_P/K starting at 35% with a TSR value of about 0.32, peaking at the value of nearly 37% with a TSR around 0.4, returning to a C_P/K of 30% and a TSR of 0.65.

Now the graphical results for 1-19-24.

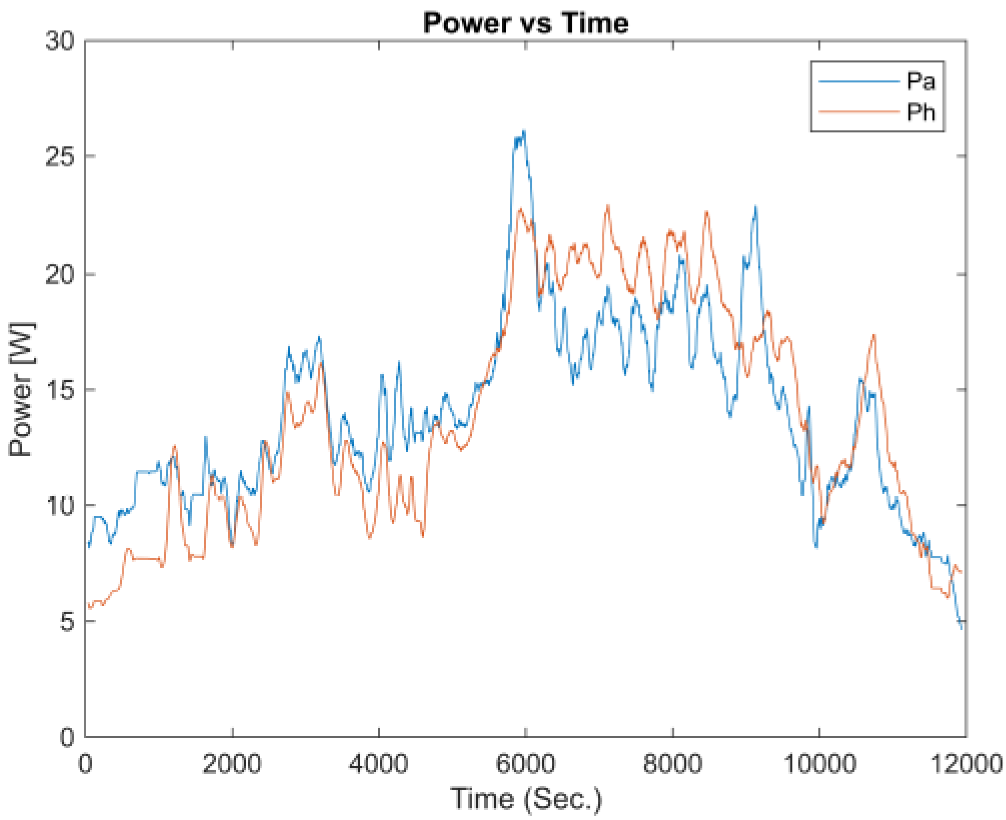


Figure 58: 1-19-24, Numerical Expression vs Theoretical Power, Correlation Coefficient = 0.8630

Figure 58 shows the fit between Ph and Pa for the 1-19 data, this α and K value correspond to these two curves having a correlation coefficient of approximately 0.9, which indicates a high correlation between the two curves.

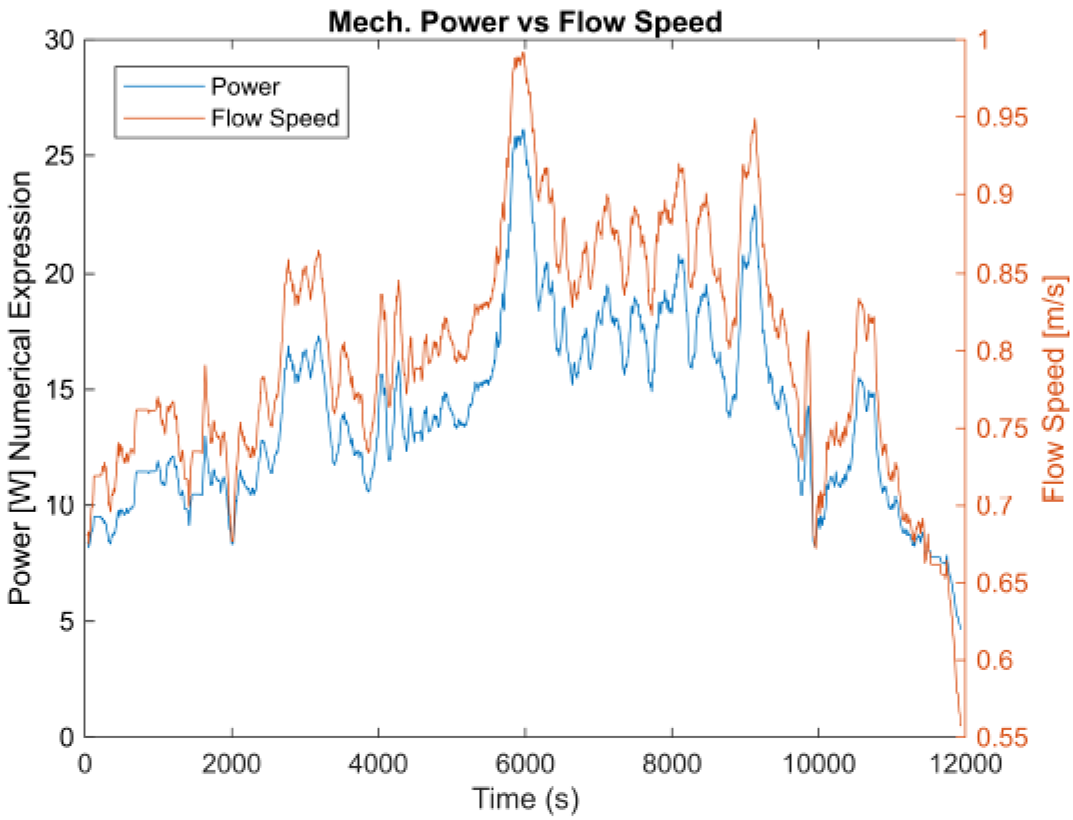


Figure 59: 1-19-24, Numerical Expression Power & Flow Speed vs Time

Figure 59 shows the mechanical power produced in blue, by the FSWW on 1-19 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle produced power ranged from approximately 15W to 20W.

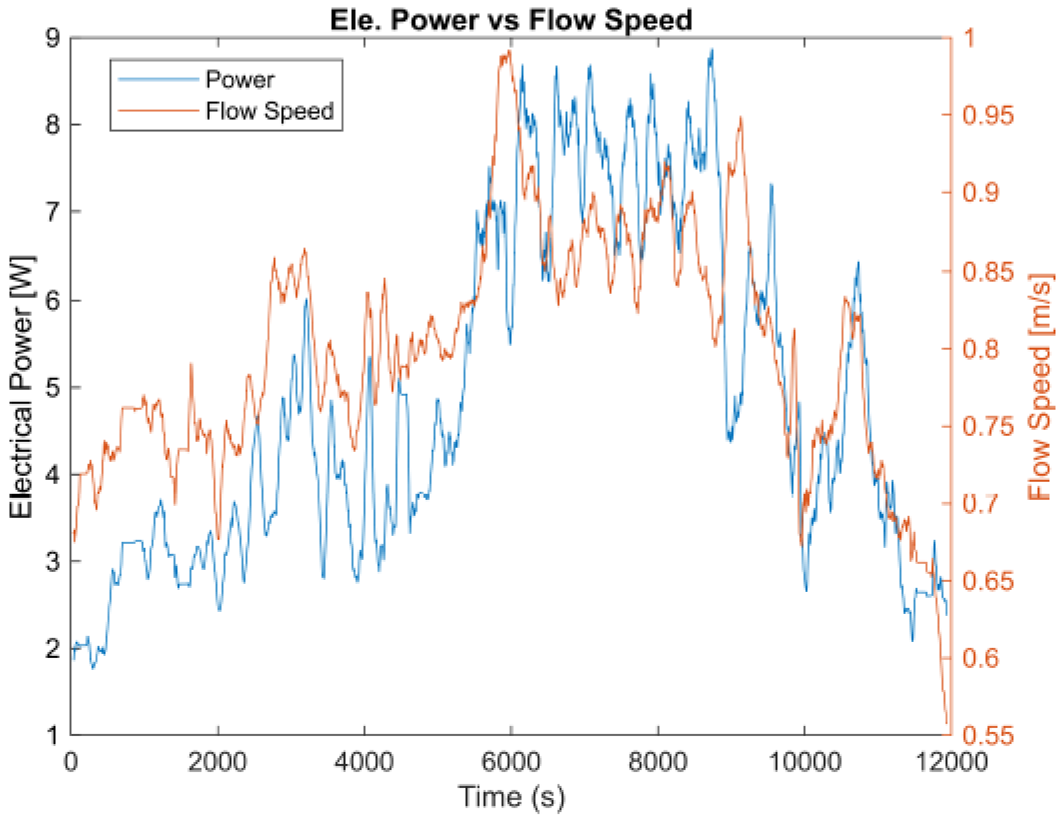


Figure 60: 1-19-24, Electrical Power Generated & Flow Speed vs Time

Figure 60 shows electrical power produced in blue, by the FSWW on 1-19 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that the first half of the tide cycle produced electrical power ranging from approximately 3W to 5W, while much of the second half produced power ranging from 6W to 9W.

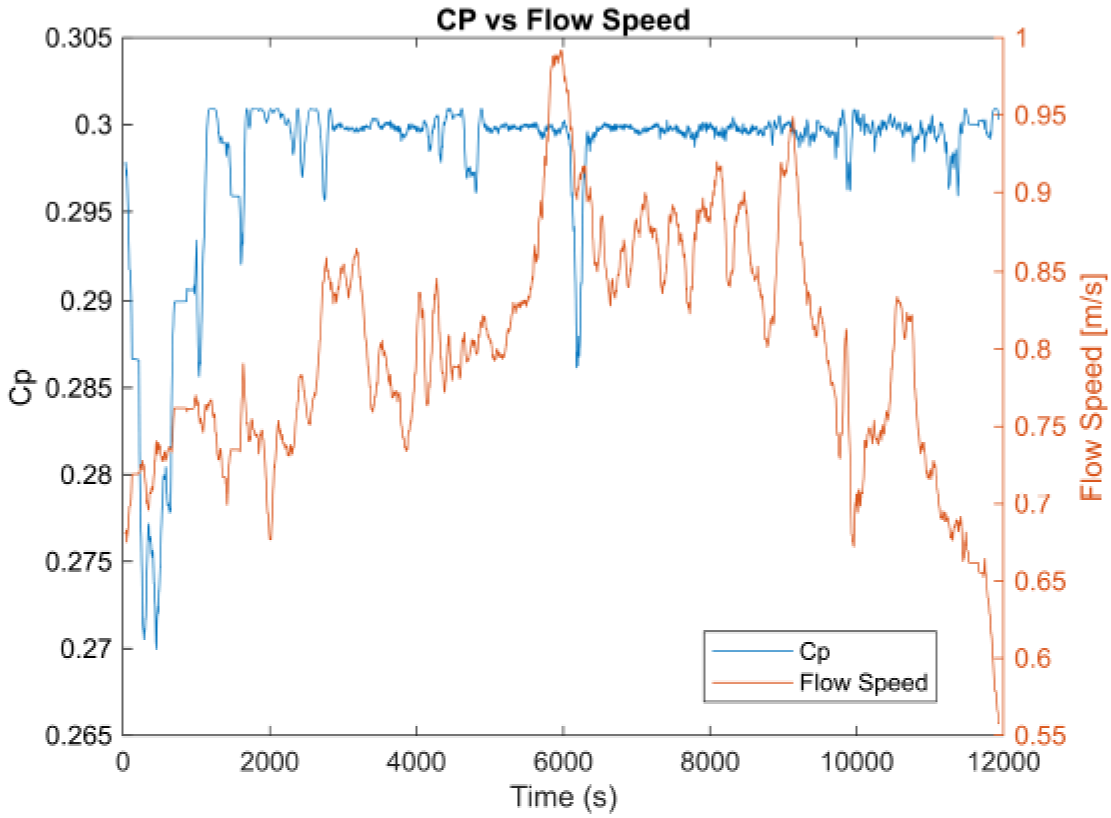


Figure 61: 1-19-24, Numerical Expression Power's C_P & Flow Speed vs Time

Figure 61 shows C_P of the mechanical power created in blue, by the wheel on 1-19 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the C_P was right around 30%.

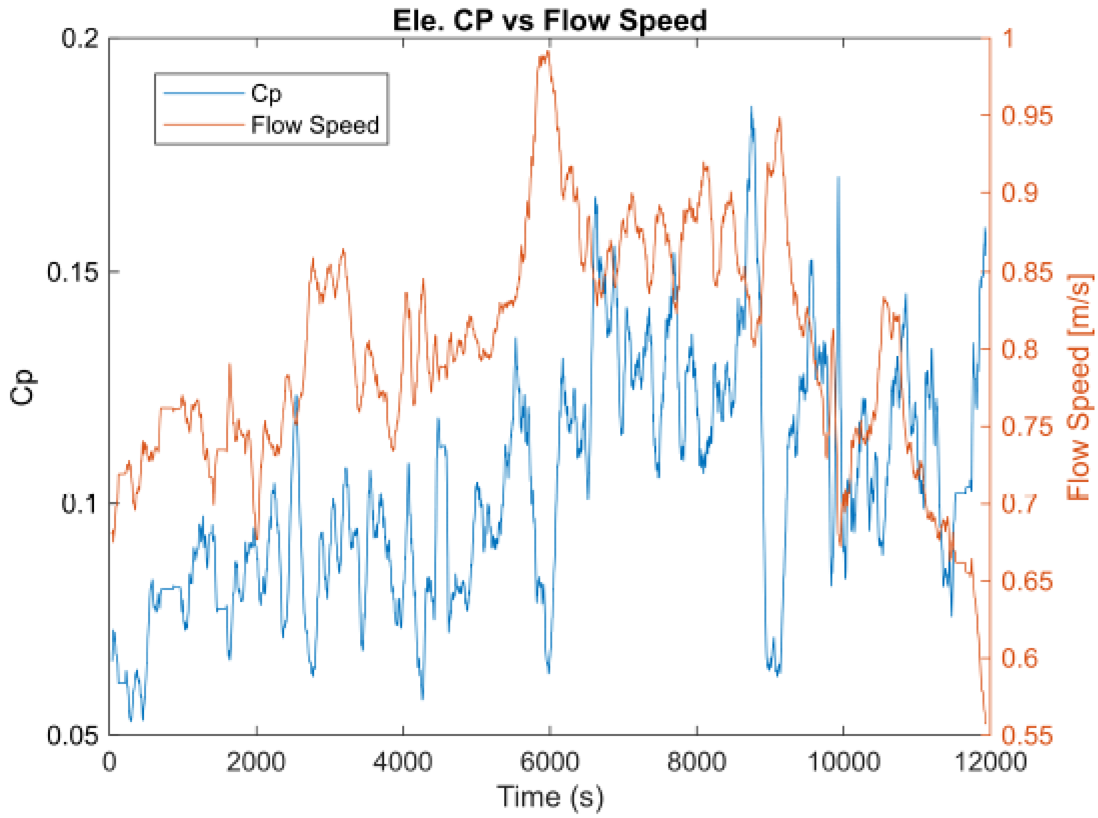


Figure 62: 1-19-24, Electrical Power's C_P & Flow Speed vs Time

Figure 62 shows the C_P of the electrical power produced in blue, by the wheel on 1-19 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle C_P ranged from 10% to 15%.

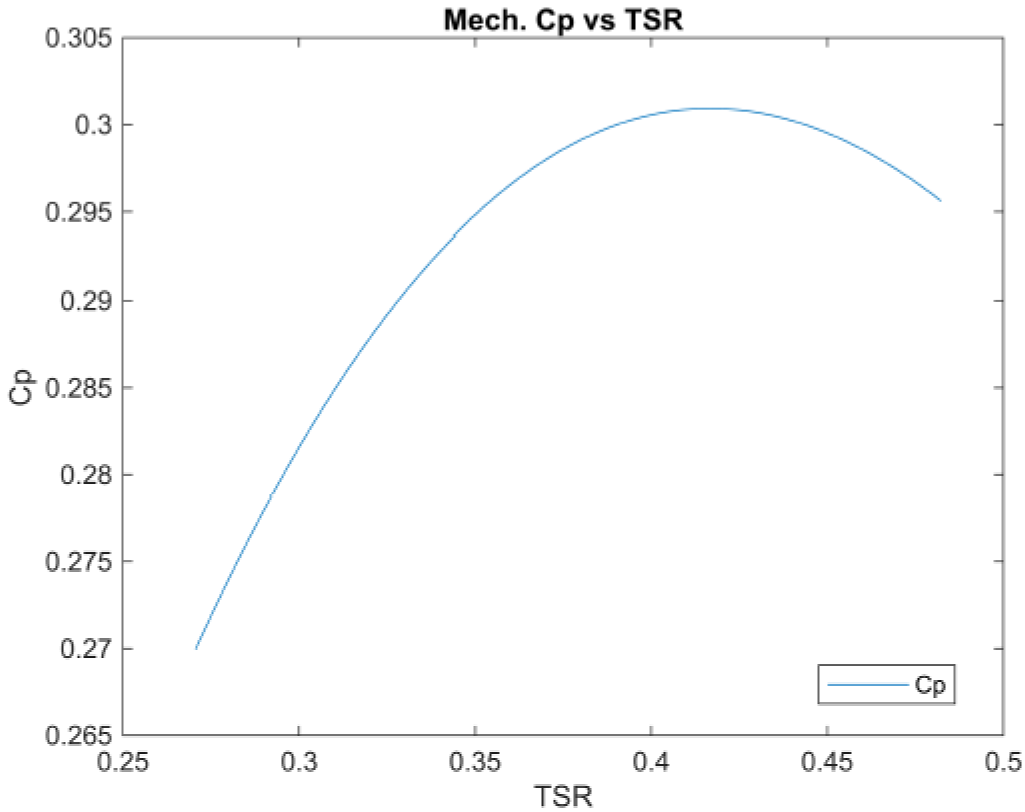


Figure 63: 1-19-24, Numerical Expression Power's C_P vs TSR

Figure 63 shows the C_P of the mechanical power produced versus the wheel's TSR for 1-19. This shows that C_P starts at around 27% with a TSR of 0.27, peaks at around 30% with a TSR of 0.4, and returns to a C_P of 29.5% with a TSR of 0.5 at the end of testing.

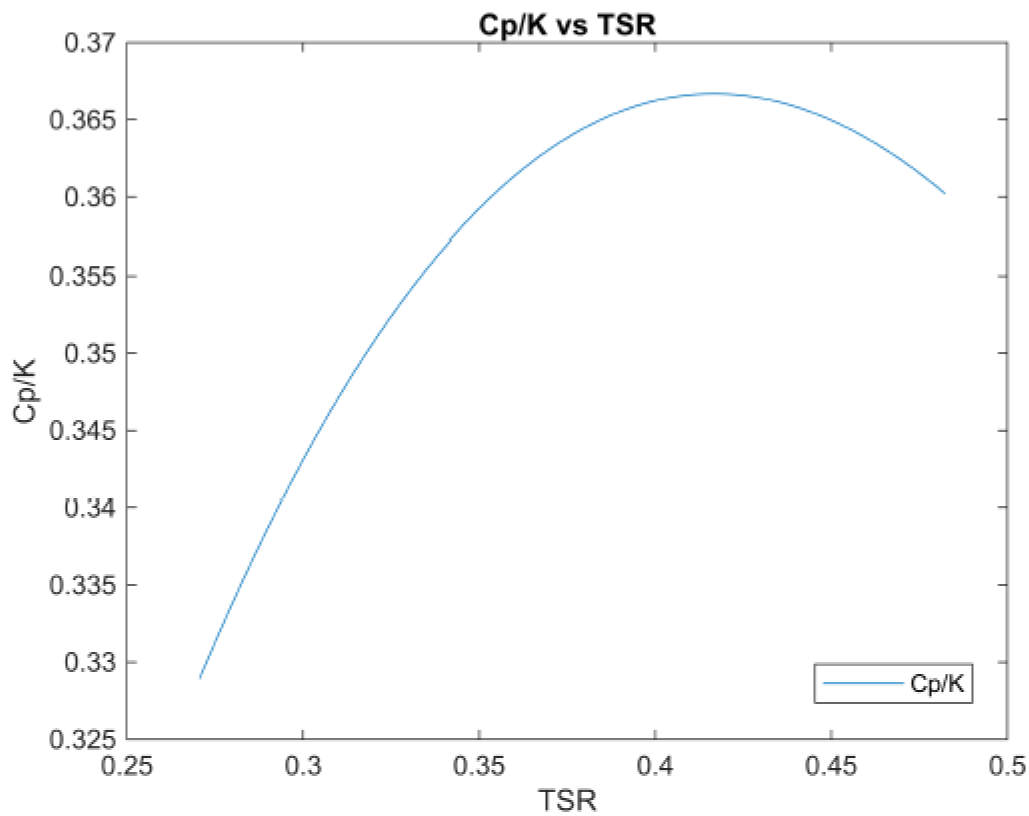


Figure 64: 1-19-24, Numerical Expression Power's C_P/K vs TSR

Figure 64 shows the mechanical power's C_P/K versus the wheel's TSR for 1-19. Here the C_P/K starts at around 33% with a TSR value of 0.27, peaks at the value of around 36.5% with a TSR of 0.4 and returns to 36% with a TSR of 0.5.

Now the graphical results for 1-24-24.

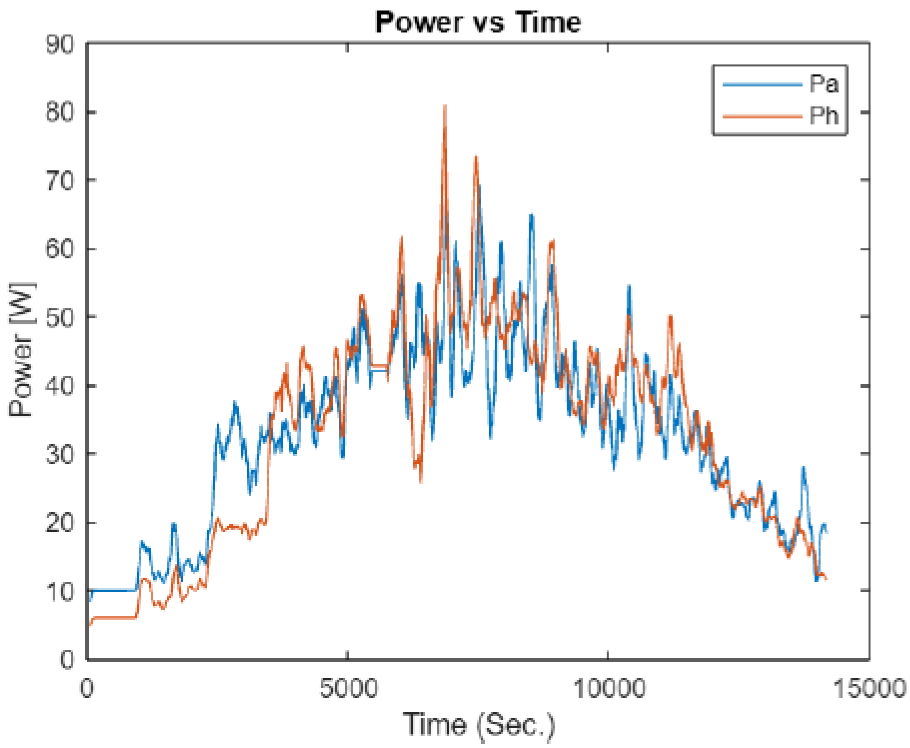


Figure 65: 1-24-24, Numerical Expression vs Theoretical Power, Correlation Coefficient = 0.8734

Figure 65 shows the fit between Ph and Pa for the 1-24 data, this α and K value correspond to these two curves having a correlation coefficient of approximately 0.9, which indicates a high correlation between the two curves.

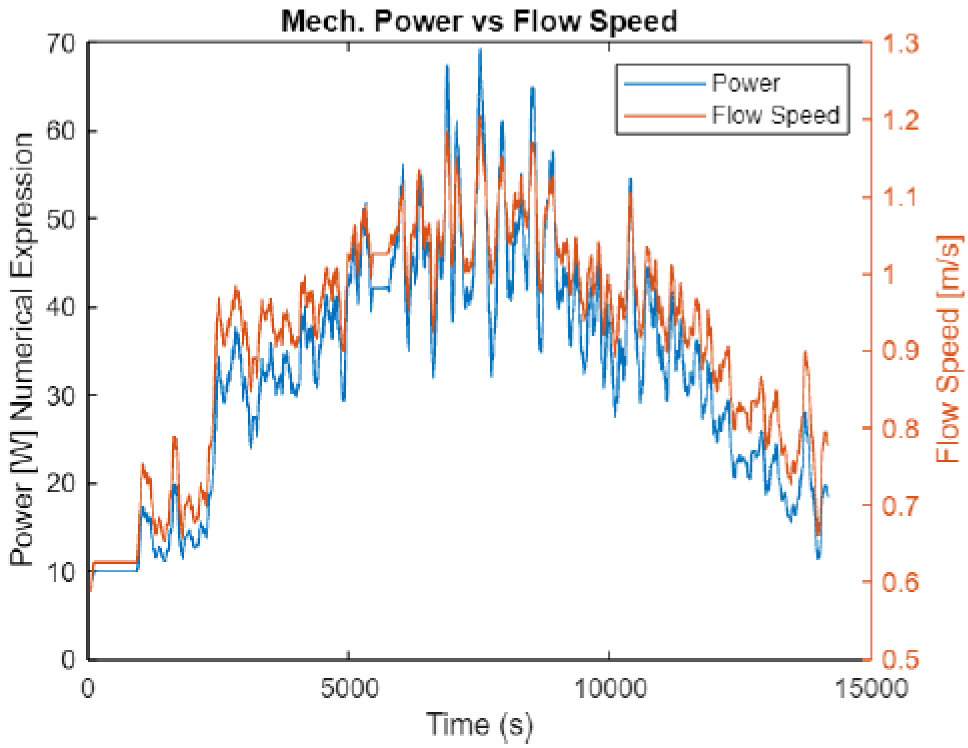


Figure 66: 1-24-24, Numerical Expression Power & Flow Speed vs Time

Figure 66 shows the mechanical power produced in blue, by the FSWW on 1-24 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle produced power ranged from approximately 30W to 55W.

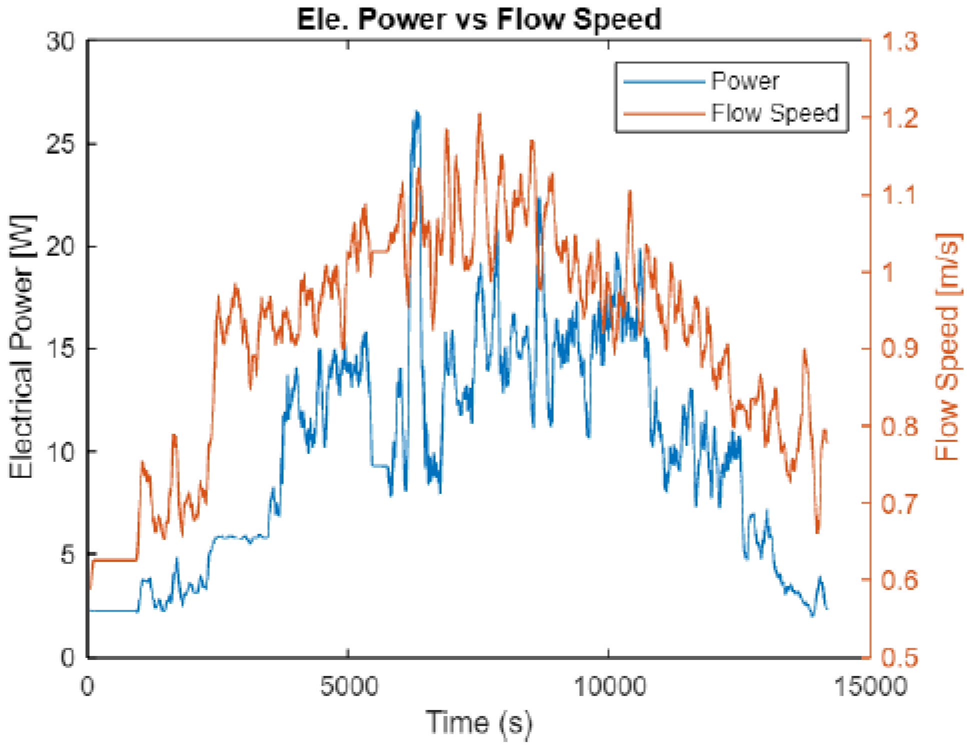


Figure 67: 1-24-24, Electrical Power Generated & Flow Speed vs Time

Figure 67 shows electrical power produced in blue, by the FSWW on 1-24 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that much of the tide cycle produced electrical power ranging from approximately 10W to 20W.

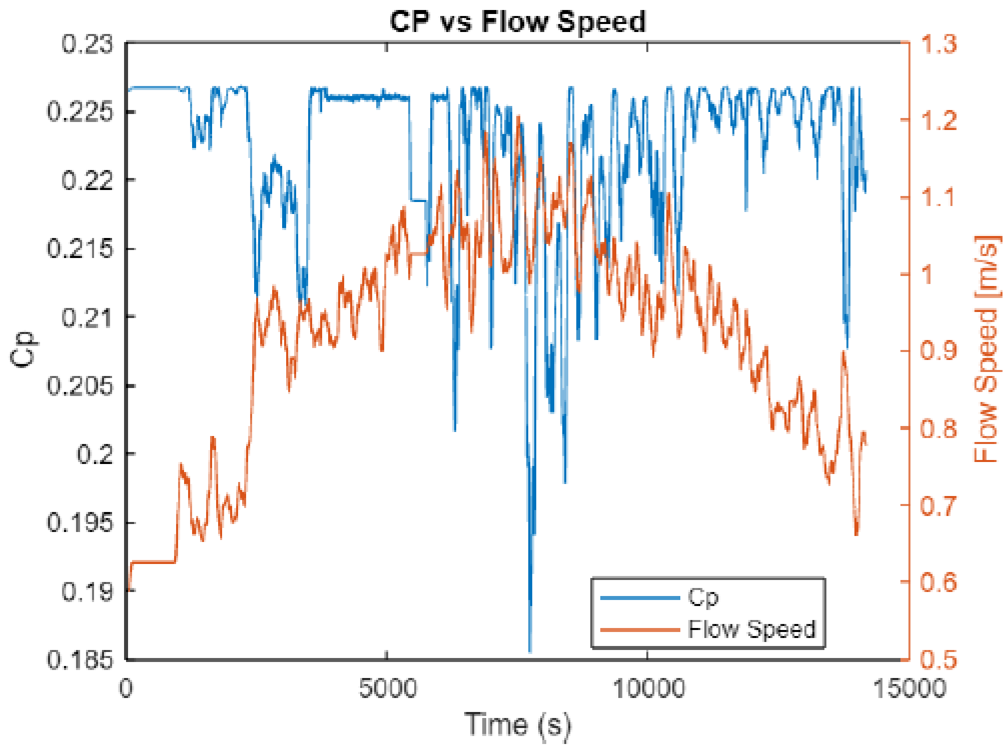


Figure 68: 1-24-24, Numerical Expression Power's C_P & Flow Speed vs Time

Figure 68 shows C_P of the mechanical power created in blue, by the wheel on 1-24 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the wheel's C_P stayed at about 22.7%.

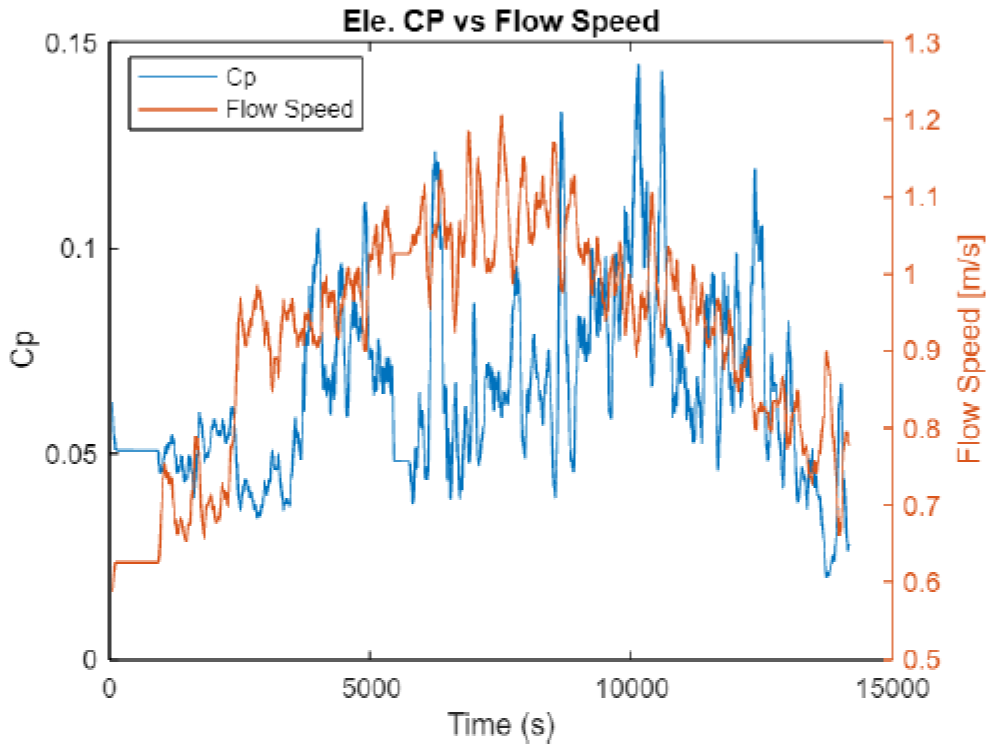


Figure 69: 1-24-24, Electrical Power's C_P & Flow Speed vs Time

Figure 69 shows the C_P electrical power produced in blue, by the wheel on 1-24 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the C_P hovered between 5 to 11%.

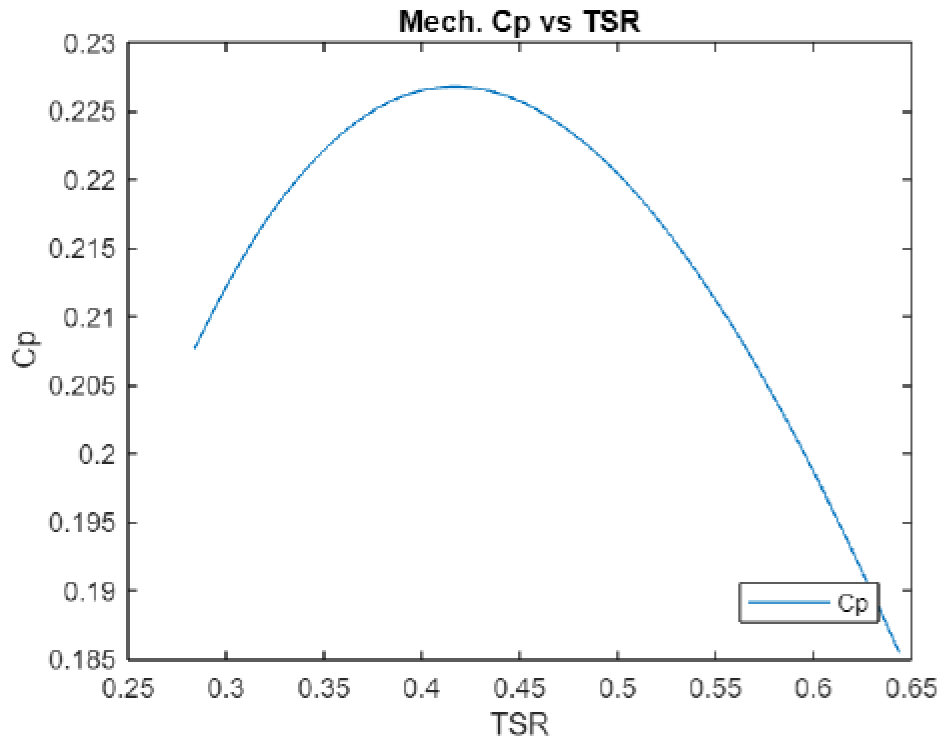


Figure 70: 1-24-24, Numerical Expression Power's C_P vs TSR

Figure 70 shows the C_P of the mechanical power produced versus the wheel's TSR for 1-24. It can be seen that C_P starts at around 21% with a TSR of 0.27, it peaks at around 22.5% with a TSR of 0.4 and returns to 18.5% with a TSR of 0.65.

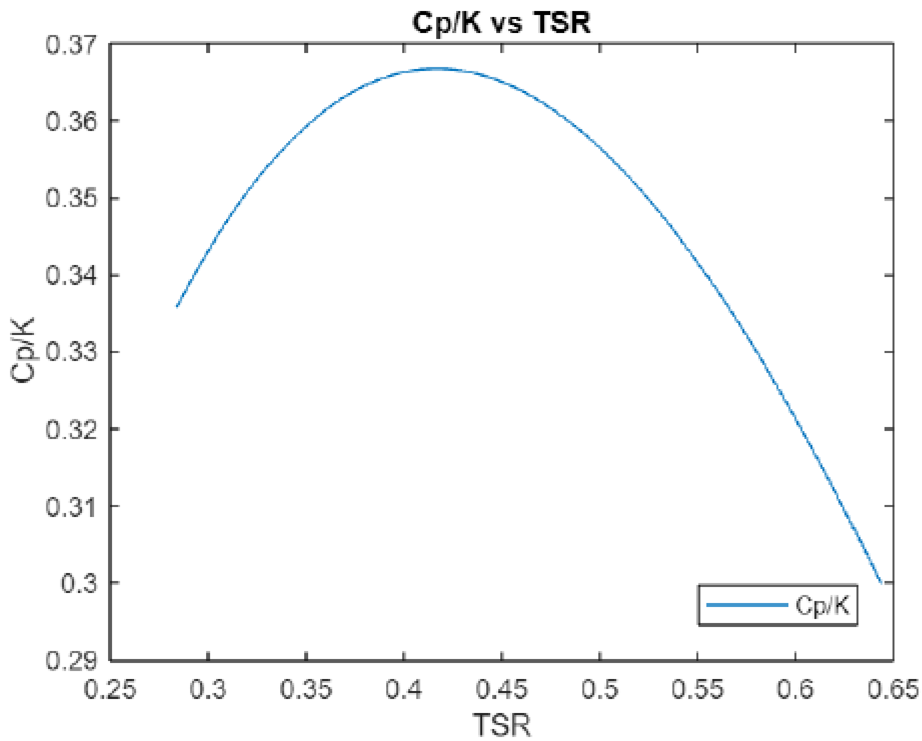


Figure 71: 1-24-24, Numerical Expression Power's C_P/K vs TSR

Figure 71 shows the mechanical power's C_P/K versus the wheel's TSR for 1-24. Here the C_P/K starts around 33.5% with a TSR value of 0.27, peaks at the value of nearly 37% with a TSR of 0.4 and returns to 30% with a TSR of 0.65 by the end of testing.

Now the graphical results for 1-31-24.

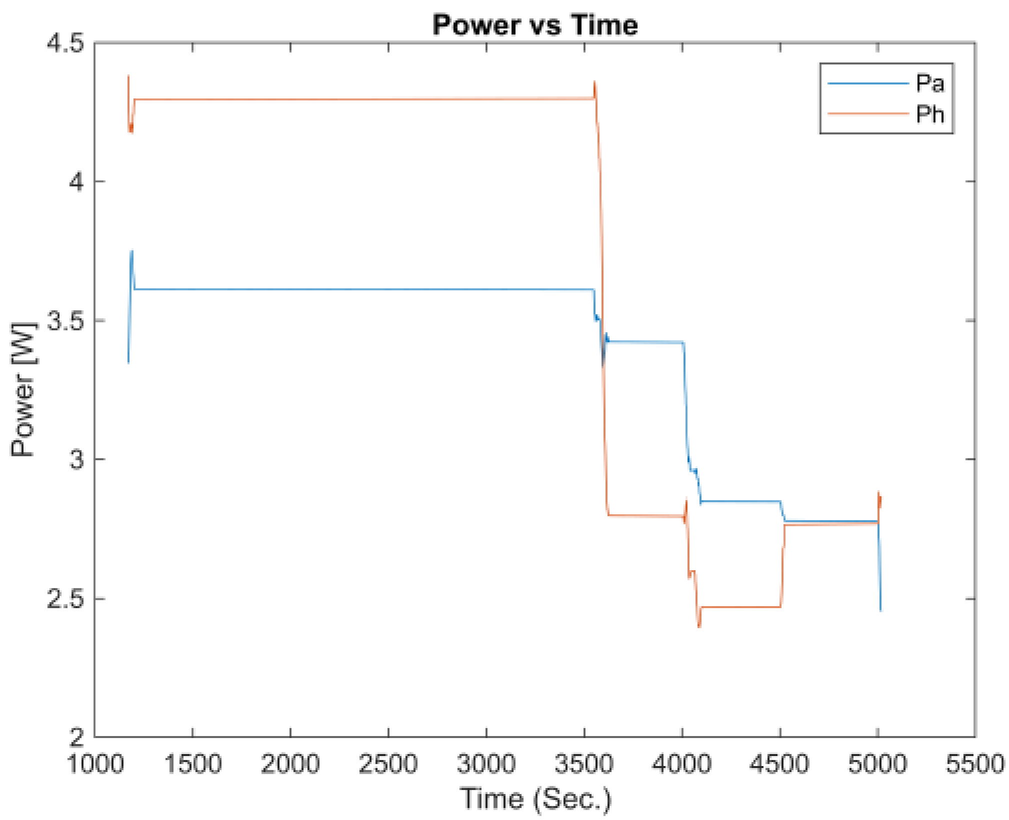


Figure 72: 1-31-24, Numerical Expression vs Theoretical Power, Correlation Coefficient = 0.7842

Figure 72 shows the fit between Ph and Pa for the 1-31 data, this α and K value correspond to these two curves having a correlation coefficient of approximately 0.8, which indicates a strong correlation between the two curves.

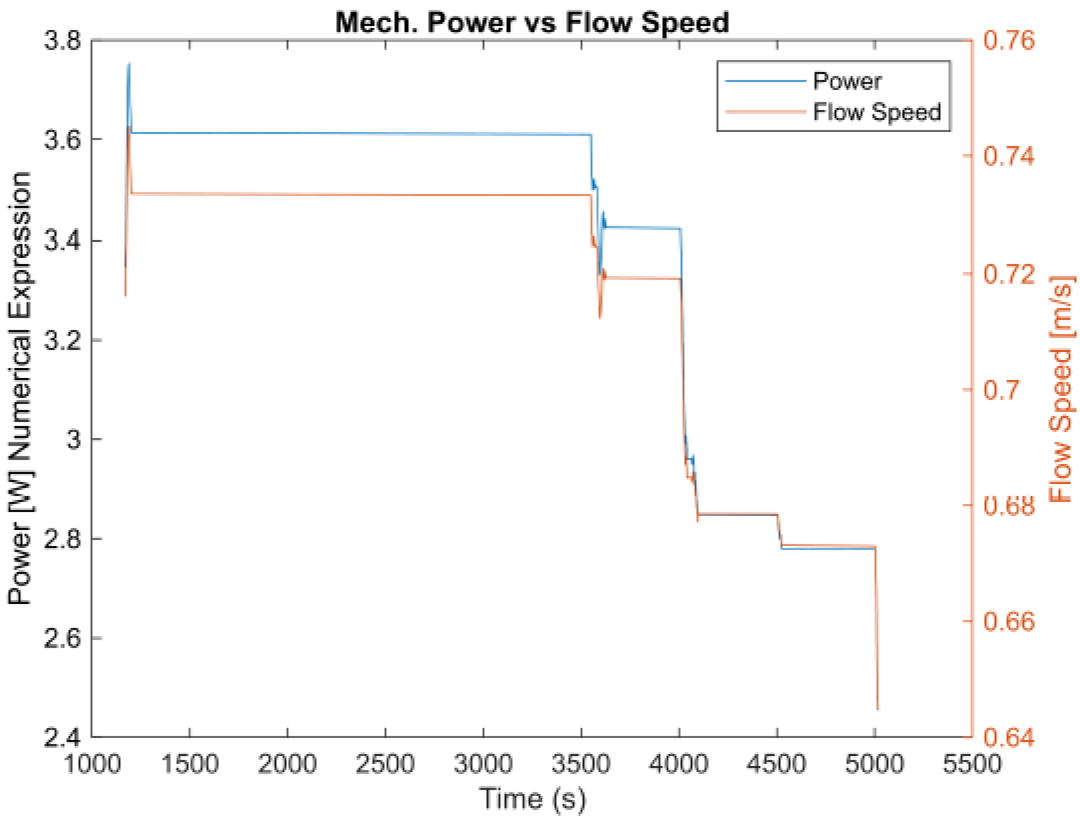


Figure 73: 1-31-24, Numerical Expression Power & Flow Speed vs Time

Figure 73 shows the mechanical power produced in blue, by the FSWW on 1-31 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle produced power was 3.6W.

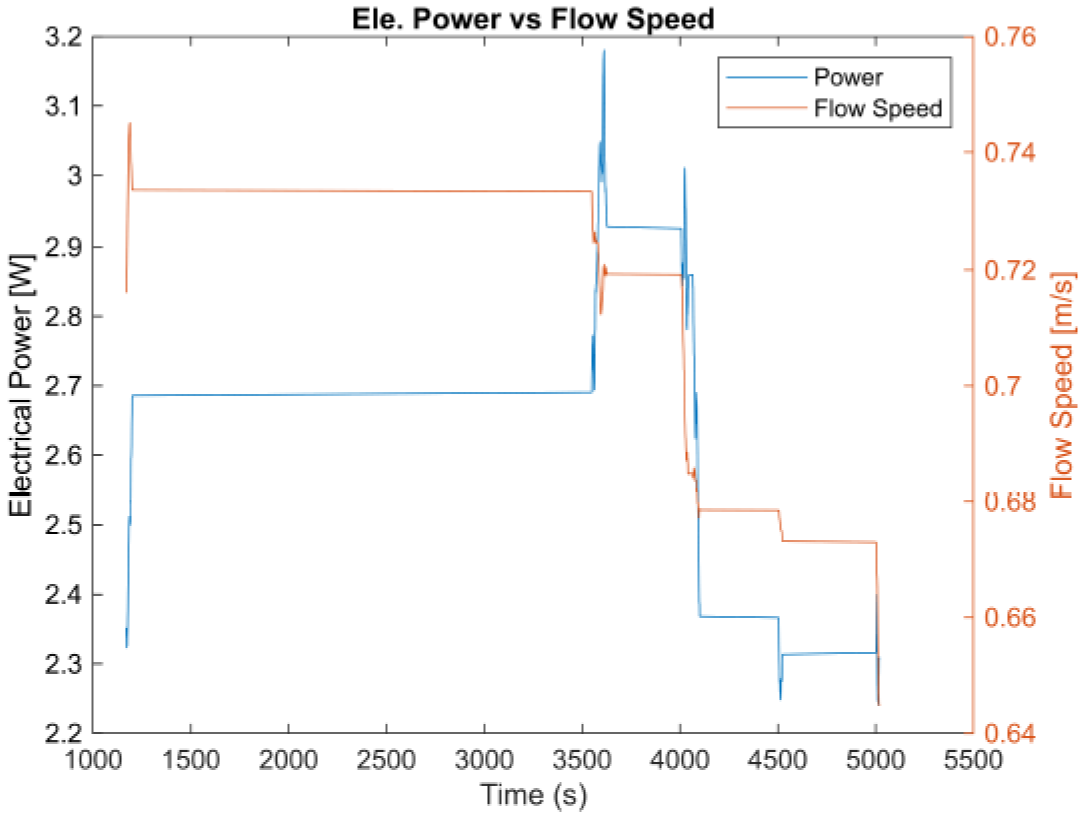


Figure 74: 1-31-24, Electrical Power Generated & Flow Speed vs Time

Figure 74 shows electrical power produced in blue, by the FSWW on 1-31 in relationship to the flow speeds experienced by the wheel, shown in orange. This plot shows that much of the tide cycle produced electrical power ranging from approximately 2.6W to 3W.

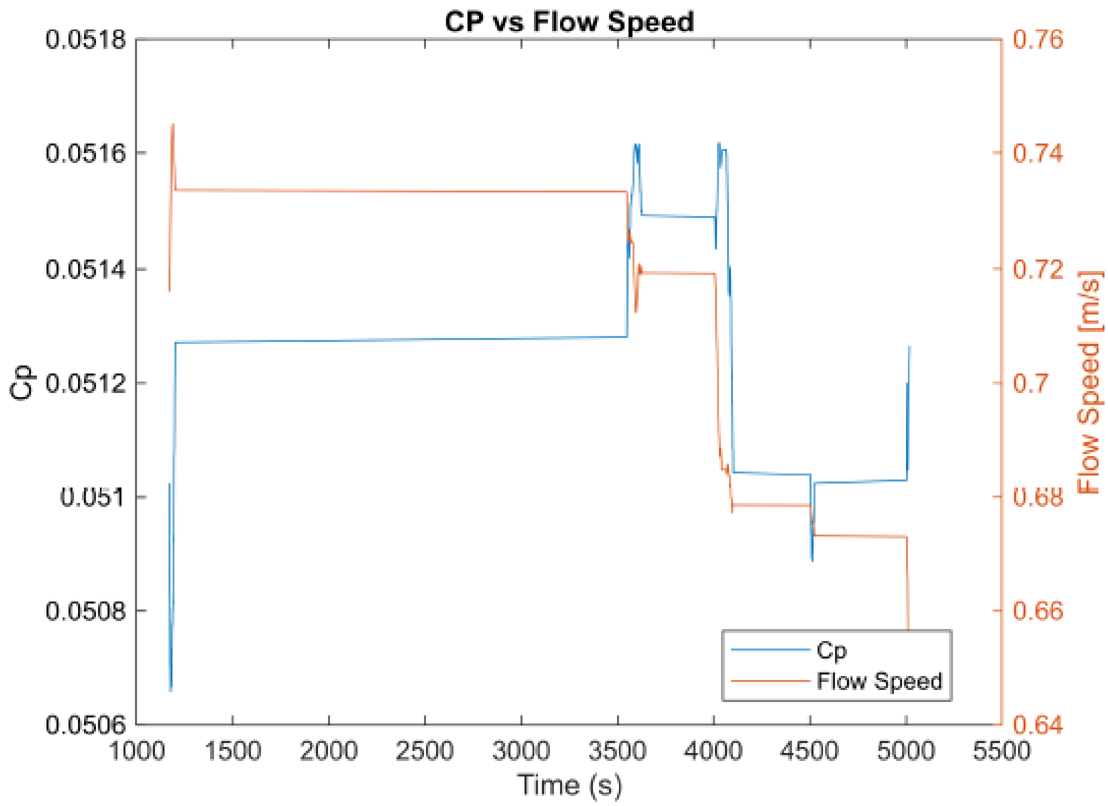


Figure 75: 1-31-24, Numerical Expression Power's C_P & Flow Speed vs Time

Figure 75 shows C_P of the mechanical power created in blue, by the wheel on 1-31 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the wheel's C_P hovered around 5.12%.

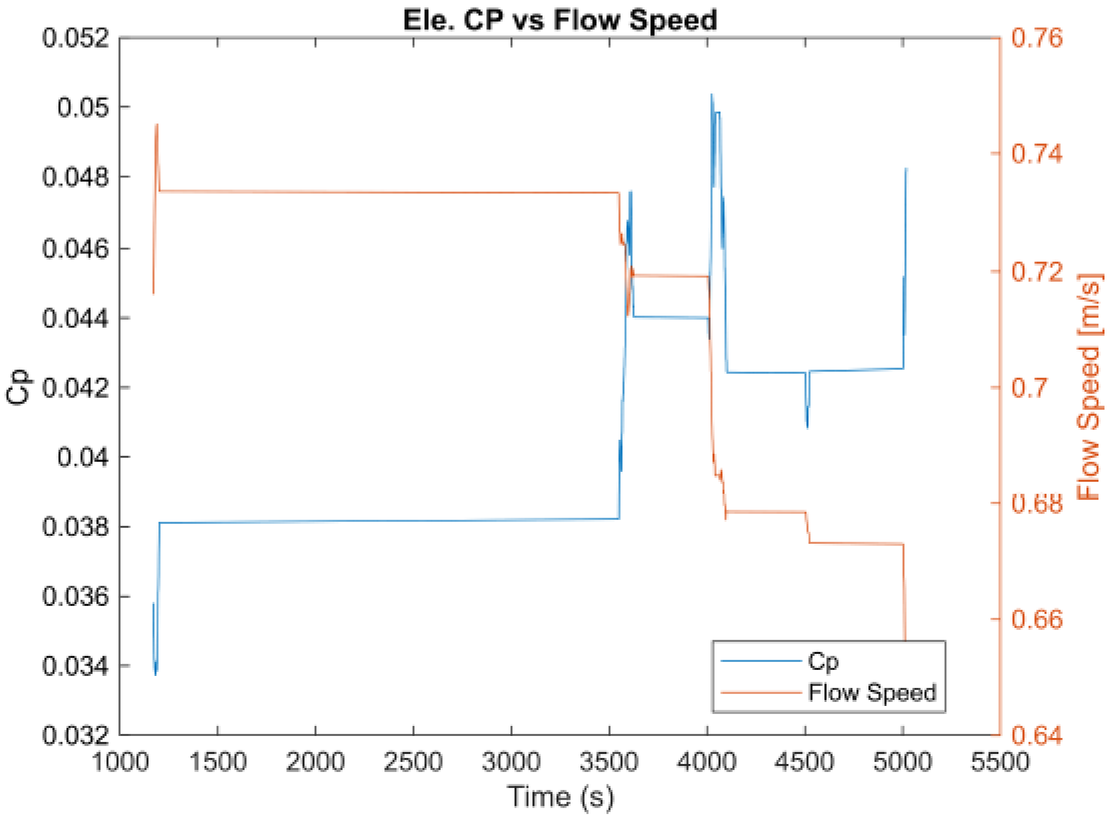


Figure 76: 1-31-24, Electrical Power's C_P & Flow Speed vs Time

Figure 76 shows the C_P electrical power produced in blue, by the wheel on 1-31 in relationship to the flow speed experienced by the wheel, shown in orange. This plot shows that for much of the tide cycle the C_P hovered between 3.8% and 4.5%.

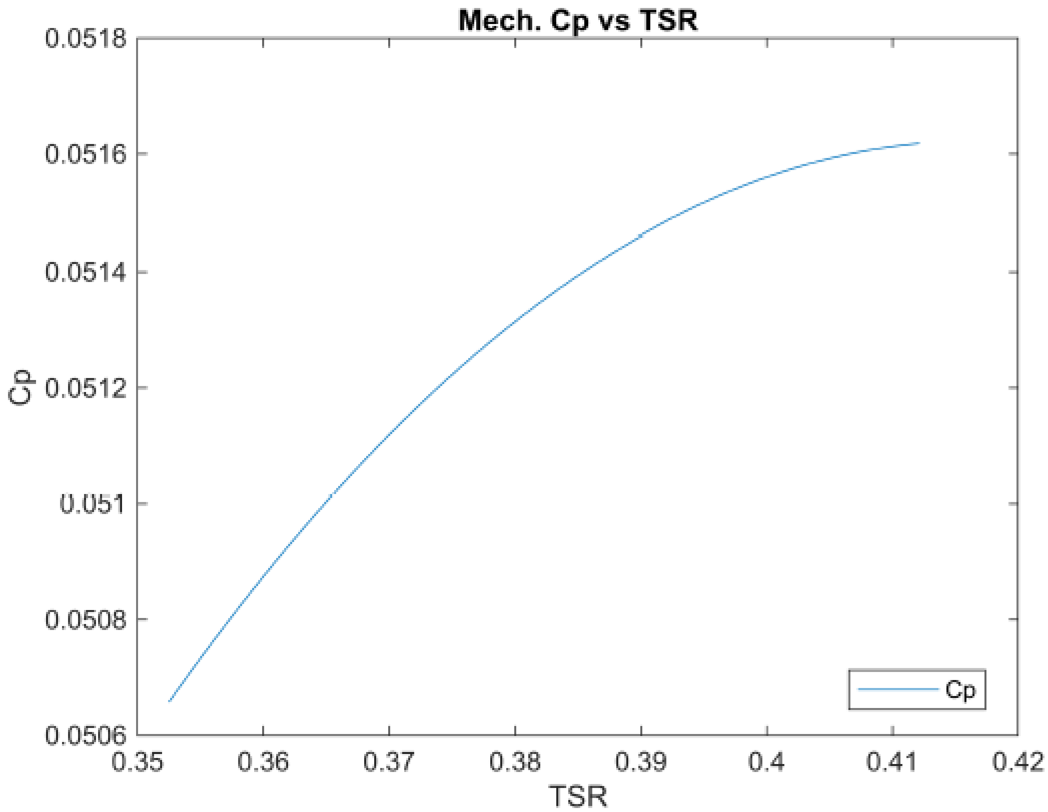


Figure 77: 1-31-24, Numerical Expression Power's C_P vs TSR

Figure 77 shows the C_P of the mechanical power produced versus the wheel's TSR for 1-31. It can be seen that C_P starts around 5% with a TSR of 0.35, and it peaks at around 5.2% with a TSR of 0.41.

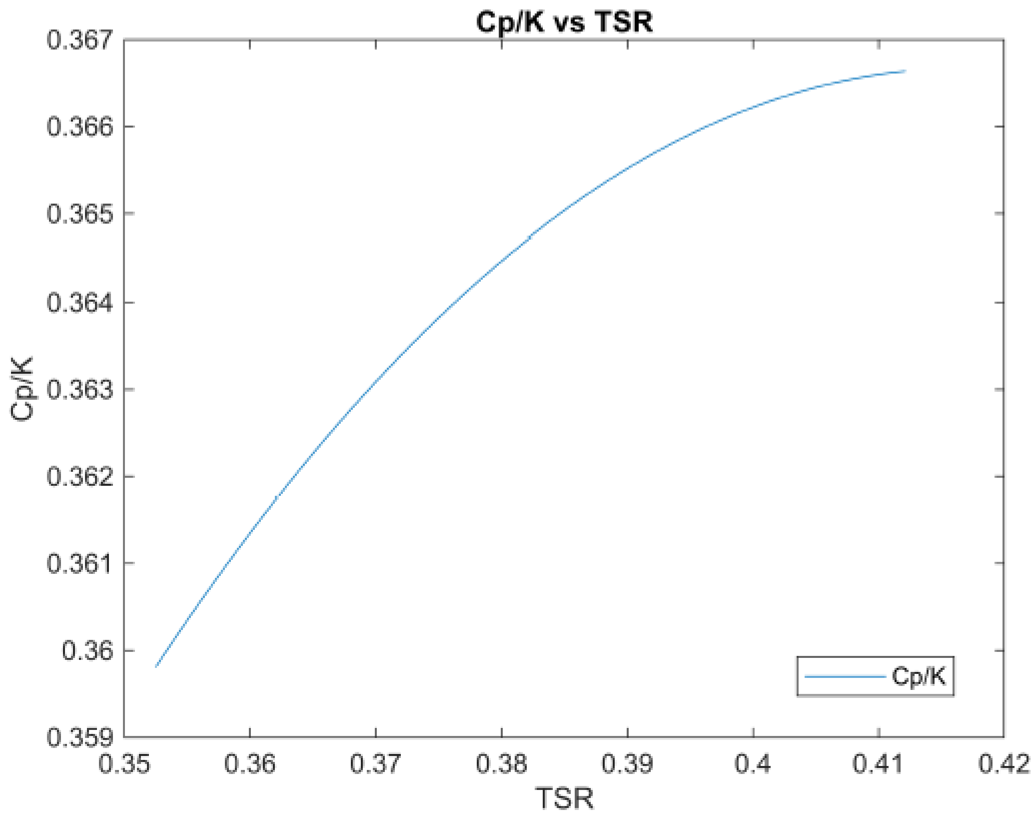


Figure 78: 1-31-24, Numerical Expression Power's C_P/K vs TSR

Figure 78 shows the mechanical power's C_P/K versus the wheel's TSR for 1-31. It shows that the C_P/K starts at around 36% with a TSR value of 0.35 and peaks at the value of around 36.7% with a TSR of 0.41.

Now Table 14, will display the values of K and that dataset's corresponding average flow speed.

Table 14: Results for K and Average Flow Speeds

Test Date	Average Flow Speed [m/s]	K Value
1/10/2024	0.8109	0.7037
1/16/2024	1.0767	0.4818
1/17/2024	0.9781	0.7127

1/19/2024	0.8054	0.8207
1/24/2024	0.9356	0.6184
1/31/2024	0.7039	0.1408

The plot showing this information visually follows.

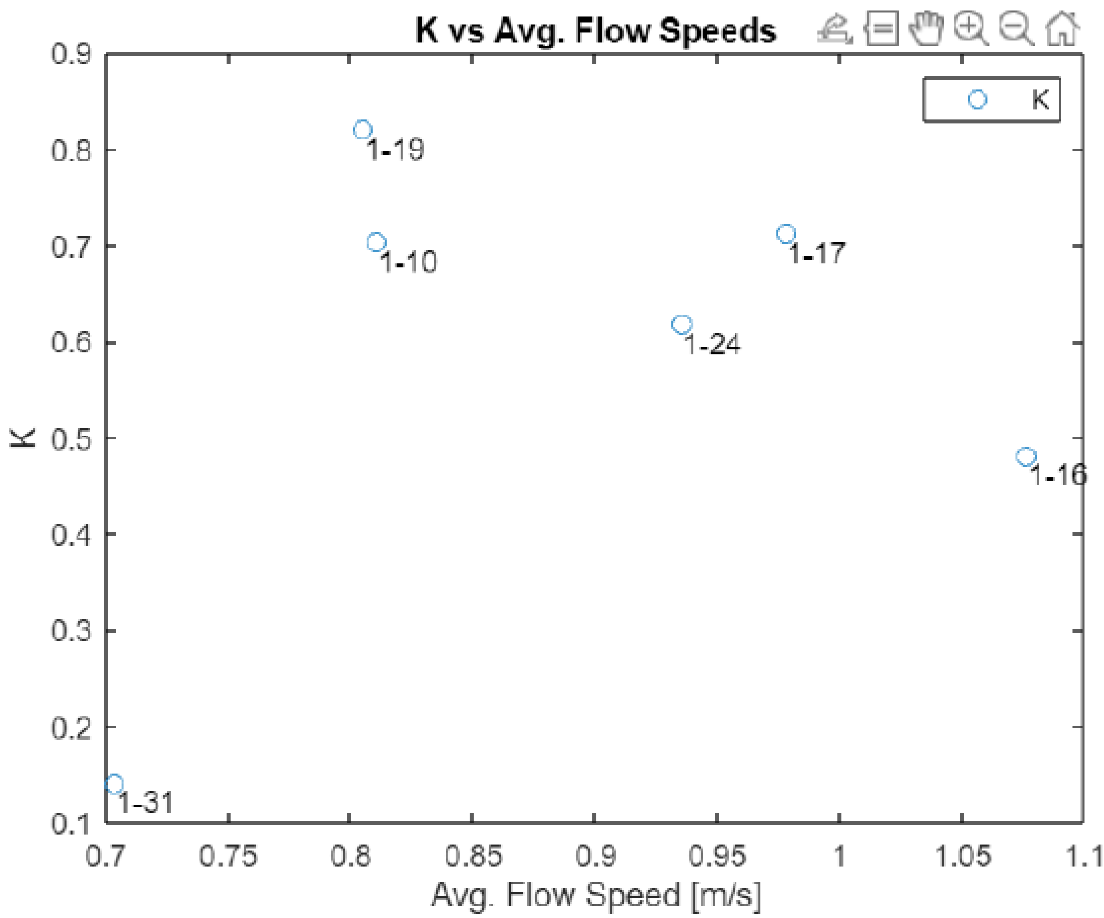


Figure 79: K vs Average Flow Speed for each dataset

Figure 79 suggests that higher flow speeds have higher K values. A comparison between the mechanical performance efficiency and each FSWW configuration was conducted. The average mechanical efficiency comparison can be seen in Figure 80.

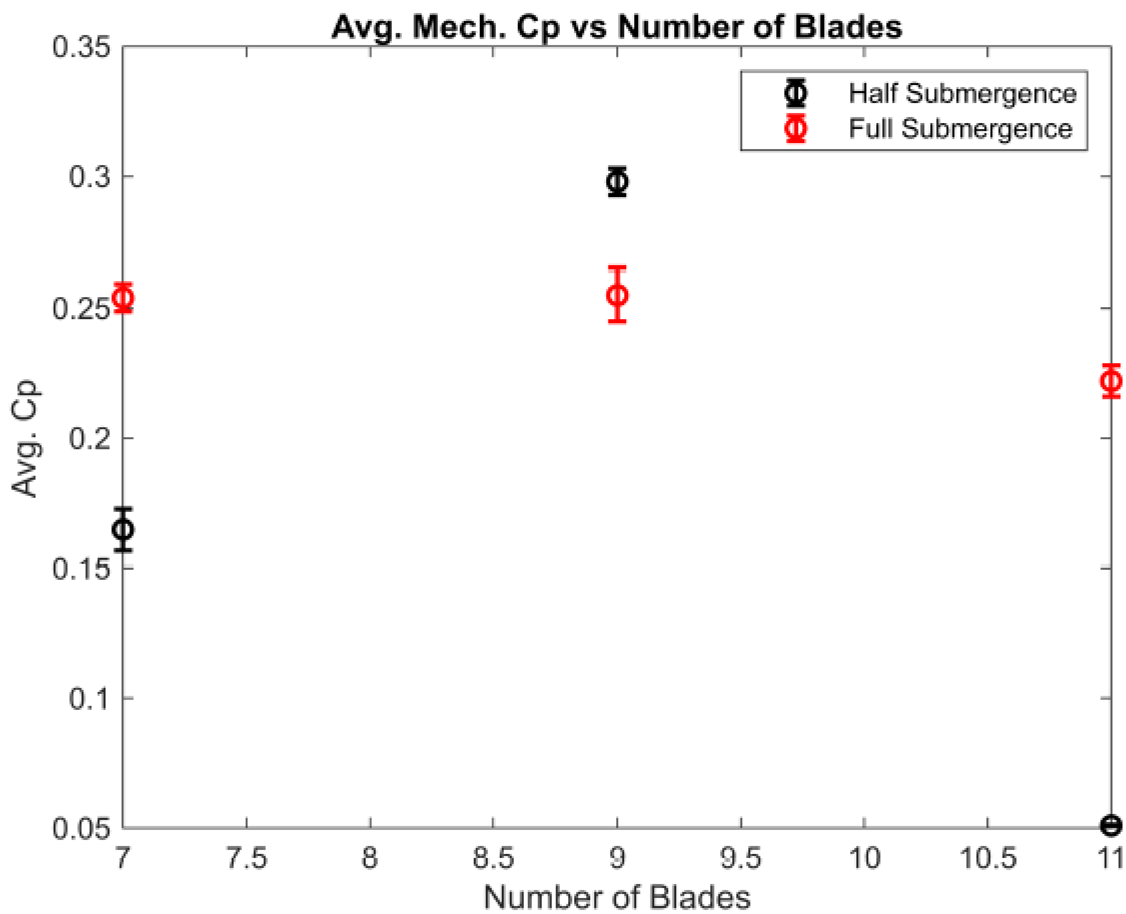


Figure 80: Avg. Mech. C_P vs FSWW Configuration based on empirical expression (16)

The maximum mechanical efficiency comparison can be seen in Figure 81.

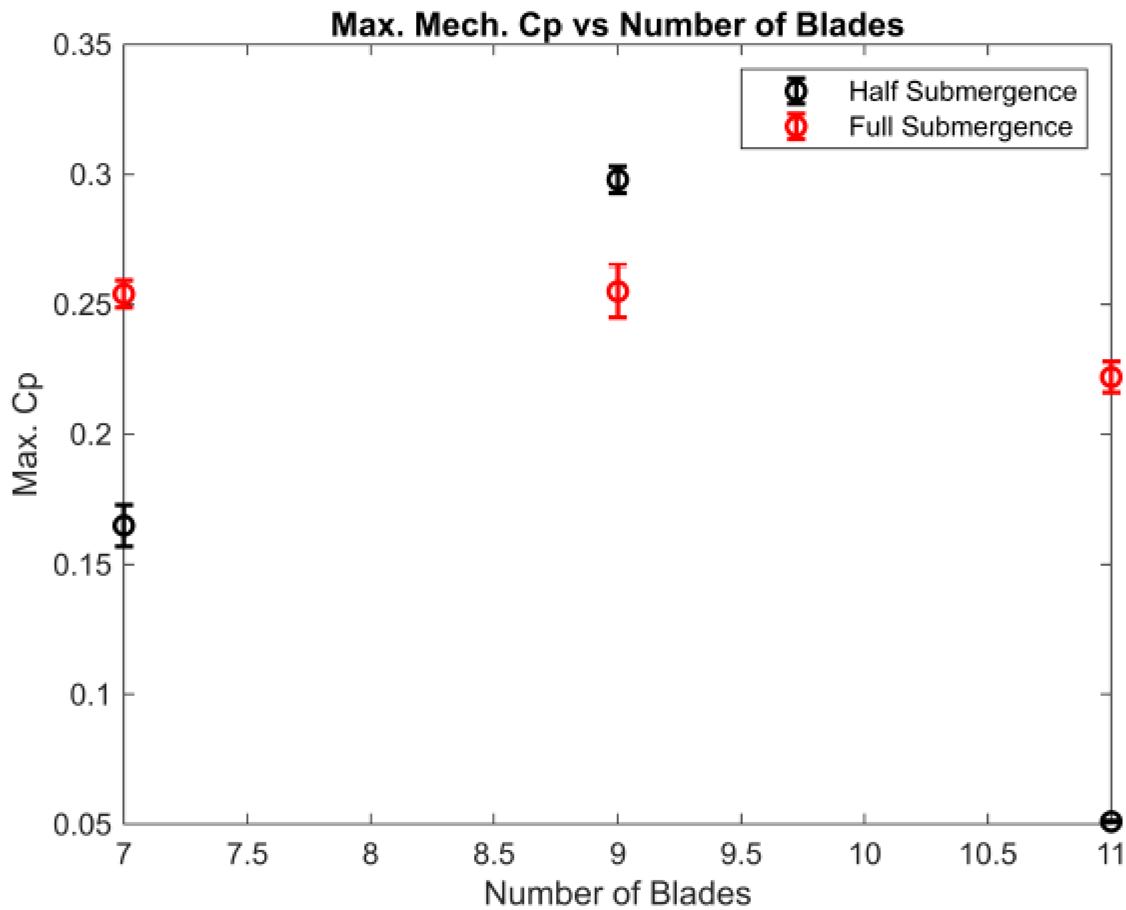


Figure 81: Max. Mech. C_P vs FSWW Configuration based on empirical expression (16)

Figure 82, shows the percent decrease between the average mechanical power produced and the average electrical power produced by each FSWW configuration, showing the PTO efficiency.

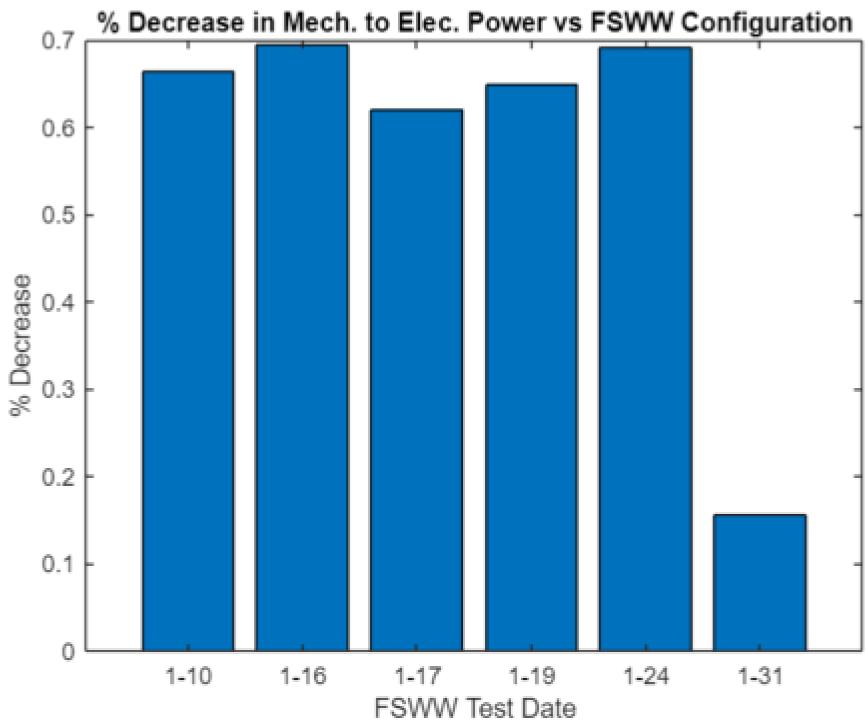


Figure 82: Percent Decrease in Mech. to Elec. Power vs FSWW Configuration

Table 15 shows each dataset's average and max mechanical power produced, average and max electrical power produced, the average and max mechanical C_P, and the average and max electrical C_P.

Table 15: FSWW Configuration Power & C_P Results

Date	Mech. Power [W]		Elec. Power [W]		Mech. C_P		Elec. C_P	
	Average	Max	Average	Max	Average	Max	Average	Max
1/10/24	25.1	46.6	8.4	17.0	25.4%	25.8%	8.5%	17.1%
1/16/24	18.7	28.1	5.7	8.8	16.5%	17.7%	5.0%	7.5%
1/17/24	44.9	108.9	17.0	33.4	25.5%	26.1%	10.2%	20.3%
1/19/24	14.3	26.1	5.0	8.9	29.8%	30.0%	10.4%	18.5%
1/24/24	34.1	69.3	10.5	26.6	22.2%	22.7%	6.7%	14.5%
1/31/24	3.2	3.8	2.7	3.2	5.1%	5.2%	4.4%	5.0%

The MHK platform's autonomy demonstration took place on February 16^{th}, 2024, and the vessel completed all tasks as scripted.

8.0 DISCUSSION

In this section, a description is provided for the implications of the results obtained here, the opportunities to improve the performance of the MHK turbine and the unmanned platform, recommendations for preventative maintenance and standardized operations and an outline for the scalability of this system.

8.1 Discussion of Results

Using Pimentel's empirical torque model-based determination of power "Ph" to compare with the power prediction "Pa", based on the curve fit, given by equation (11), allowed the choice of α in (11) to be set as α = 0.8. Hence,

$$P_M = \frac{1}{2}\rho AKU^3\left(1-\frac{4}{5}\lambda\right)^2\lambda \tag{16}$$

is established as the empirically fitted curve for estimating the power produced by a FSWW mounted on an unmanned platform. The magnitude P for each dataset is dependent on the value K, which likely depends on the flow speed. equation (16) was used to calculate the mechanical power produced by the FSWW during each test. The configuration ranking of highest to lowest mechanical and electrical power production is as follows, 9-blade full submergence, 11-blade full submergence, 7-blade full submergence, 7-blade half submergence, 9-blade half submergence, and finally the 11-blade half submergence. The configuration ranking of highest to lowest mechanical power efficiencies, based on equation (16), is as follows, 9-blade half submergence, 9-blade full submergence, 7-blade full submergence, 11-blade full submergence, 7-blade half submergence, and finally the 11-blade half submergence. The configuration ranking of highest to lowest electrical power efficiencies is the same as the mechanical power efficiencies ranking. According to these tabulations the 9-blade full submergence wheel configuration made the most power across the board with an average mechanical power of 44.9W and a maximum production of 108.9W, with an average electrical power generation of 17W and a maximum of 33.4W. The FSWW also reached the second highest efficiency while under this configuration. With mechanical efficiency reaching an average of 25.5%, and a maximum of 26.1%, while the electrical power generation had an average efficiency of 10.2% and a maximum of 20.3%, respectively when compared to the power available in the flow. These efficiencies are second only to those achieved by the 9-blade wheel at half submergence, which has an average of 29.8% and a maximum of 30% for the mechanical power and an average of 10.4% and a maximum of 18.5% for the electrical power generated. This reveals a 15.6% difference between the average mechanical power's efficiency and a 14% between the maximum mechanical power's efficiency between the two configurations. These percentage differences are notable. While the average electrical power efficiency had a 1.9% difference, and the maximum electrical power efficiency had a 9.3% difference between the second highest and highest measured efficiencies. These results could mean that even though the 9-blade wheel at full submergence made the most power, it may have better efficiency at half blade submergence levels. This would likely be due to the full blade having more complex interactions with the flow as it passes the full curvature of the blade. Overall, it seems as though the 9-blade FSWW configuration had the best power production and highest efficiencies. Followed by the 11-blade full submergence, the 7-blade full submergence, the 7-blade half submergence, and then the 11-blade half submergence. It is worth pointing out that the 11-blade half submergence configuration was tested on the day with the lowest average flow speed of 0.7039m/s, which would certainly affect the wheel's power production. These results also show a higher wet surface area does indeed lead to higher power production levels, as theory suggests. The 9-blade full submergence configuration and the 11-blade full submergence configuration had a 27.3% difference and 47.3% difference in average mechanical and electrical power produced respectively. While the 9-blade full submergence configuration and the 7-blade full submergence configuration had a 56.6% difference and a 67.7% difference in average mechanical and electrical power produced respectively. The 11-blade full submergence configuration and the 7-blade full submergence configuration have a 30.4% difference and a 22.2% difference in average mechanical and electrical power produced respectively. With these margins of performance differences, it is reasonable to say that in this case study the 9-blade full submergence configuration had the highest power production.

8.2 Discussion of Optimization Recommendations

After completing the extensive testing campaign and analyzing the resulting data it is imperative to reflect on both operations and system design that could be optimized for better power production outcomes. It is also important to acknowledge the MHK platform's autonomy demonstration. Operations with the two-vessel system and the davit were the most advantageous as compared to operations with the trailer. Given the nearby ICW, in situ testing was readily available for this proof-of-concept study, however testing while systematically controlling flow speeds and wave heights available to the FSWW would allow an even more detailed systems configuration analysis. As far as optimizing operations at the local site is concerned, it is recommended to avoid testing on Fridays due to increased boat traffic. Running tests during the high to low tide cycles is ideal due to anchor placement in the ICW relative to boat traffic. It is also recommended to create a fully encompassing testing exclusion zone rather than a singular boundary in the channel, to prevent boats from passing the MHK Platform between the seawall and the deployed vessel. It would also be beneficial to have a bullhorn available to communicate with passing boaters. Discharging the onboard battery bank to a consistent voltage level between tests may provide more constant charging behavior between tests, as the charge controller behaves differently as the battery becomes more and more charged. Potential system optimizations include an optimal control algorithm, as the proprietary charge controller within the PTO had certain power requirements that the end user could not bypass. A study investigating the power production of the FSWW after removing the CVT from the PTO and replacing it with a 1 to 85 planetary gearbox (the gear ratio achieved when the CVT is placed at its highest setting) would highlight the performance implications of the CVT. The introduction of a flow concentrator just before the waterwheel may also increase power production. The MHK's autonomy demonstration met all previously identified tasks, however continued improvement of the path-planning controller would allow for a smoother course taken by the vessel as it navigates to its destination. Development of a controller that utilizes the system's built in lidar would also allow the vessel to avoid obstacles and become more sophisticated.

8.3 Discussion of Maintenance & Standardized Operational Procedures

The procedures followed for field-testing were ideal for operations at the ICW Dockside location. Incorporating the above optimizations would make repeated testing more manageable for the testing team and safer for the MHK Platform. However, as testing continued a layer of salt formed on many of the MHK platform's surfaces, even with a freshwater rinse following each deployment. If this layer is allowed to thicken or remain on the vessel it will lead to corrosion and premature failure of various components used on the MHK platform. It is advised to wash the vessel with soapy water following each deployment, and it is imperative to scrub each surface except for the payload trays. It is recommended that prior to long-term storage or at the end of each testing campaign the electronics boxes be removed from the vessel to allow both payload trays to be fully cleansed with soapy water. At this time, it would also be advised that each electronic connector be cleaned with isopropyl alcohol and be evaluated for signs of corrosion. Should any corrosion be detected the connector should be replaced. Also, during this phase, the thrusters power cables should be inspected for cuts or points of moister intrusion. If any are detected the cables should be replaced for continued functionality and safety of the testing crew. A bolt and plastic components check should be conducted during this time as well. Should any bolts be accumulating rust, have suffered damage, or appear missing they should be replaced. As plastic components do not offer the same strength and resilience as some metals it is important to survey these parts on the boat. Should they exhibit any signs of failure, such as cracking or stripped threading, they should be repaired or replaced. The MHK platform is a great resource for the FAU research community and can be used for many years to come if properly cared for. These steps should be implemented by the team to ensure the vessels' longevity and to benefit the FAU Ocean engineering research community.

8.4 Discussion of MHK Turbine & Platform Scalability

After the development of the empirically tuned numerical expression for the power produced by the FSWW a brief study into the expected power production of scaled waterwheels was conducted, see Appendix L for the MATLAB script used for this study. The expression allowed for a stepwise analysis of how the blade length, width, and wheel radius stand to affect the power production of these variously scaled wheels. These results are interesting because the MHK platform could be deployed in arrays of its current size, or even in arrays with wheels of larger scales for more industrialized operations. The MHK turbine could also be scaled to larger sizes and implemented on other floating bodies. From an economic standpoint, larger deployments often mean reduced operations and management costs per unit, which could make this technology a competitive option for some applications. Table 16 shows the results from the scaling investigation.

Table 16: MHK Turbine Scaling Analysis

Power Predicted [W]	Area of the Blade [m^2]	Quantity Varied
33.10	0.349	Control, used to show what the wheel produced under established testing conditions
49.65	0.525	b=0.372 d=1.41 (A=b*d) *1.5X wide blades
66.20	0.6985	b=0.2477 d=2.82 *2X length blades
26.19	0.349	*The same blades with 1.5X the R
13.55	0.349	*The same blades with 2X the R
54.20	1.39	*2X blades with 2X the R
8.09	3.14	*3X blades with 3X the R

These results suggest that increasing the radius of the wheel without also increasing the area of the blades leads to a decrease in predicted power production. They also indicate that doubling the scale of the waterwheel leads to a 63.7% increase in predicted power production. Tripling the scale of the waterwheel leads to a drastic decrease in predicted power production from the current size of the wheel. Experimental verification of these predictions may prove that larger configurations have potential value for larger floating recharge stations.

9.0 CONCLUSIONS & FUTURE WORK

A perceived need for fully autonomous floating recharge stations for autonomous marine vehicles and UAVs motivated this case study-based investigation of the feasibility and optimization of small unmanned mobile MHK platforms serving as potential recharge stations for such vehicles in coastal and tidal waters. The case study involved undertaking a campaign for systematically field-testing various FSWW configurations to identify the optimal configuration for maximum power production. From these field-tests an empirical expression was developed to estimate the mechanical power produced by each configuration. The predictions using this expression were then compared with the actual electrical power produced by each configuration to draw conclusions about the efficacy of the PTO system. The empirical expression was also used to predict the power production of scaled-up waterwheels. A full demonstration of the MHK platform's autonomous behavior shows a novel system with great potential in the maritime domain. With improved vision-based navigation capabilities and a fully integrated COLREGS system, the MHK platform could offer many capabilities for sustainable energy solutions to the public. Data analysis of the empirical data gathered from testing of six different FSWW configurations identified the 9-blade fully submerged FSWW as providing maximum power between the various configurations. This was followed by the 11-blade full submergence and 7-blade full submergence configurations. On average there was approximately a 60% decrease in efficiency through the system as power was transformed from mechanical to electrical power, which highlights a need for improved manufacturing tolerances and techniques as these are a potential cause of high losses. Small additions can be made to improve the ICW Dockside wheel configuration testing procedures. Steps can be taken to ensure the longevity of the MHK platform. A brief look into the scalability of the FSWW shows that when doubled in scale the FSWW is predicted to produce a 63.7% increase in the power it produces at its original scale, which is 33.1W of power. Future experimental field-testing studies investigating these scaled power predictions could help determine a wider spread of applications for these floating recharge stations. As always, repeated testing of the same configurations to verify system behavior and repeatable power production is recommended. Investigations including a flow concentrator on the FSWW and separately a 1 to 85 ratio gearbox within the PTO would also provide important feedback on power optimization for this system. Further development and testing of waterwheel's speed control algorithms could also maximize efficiency.

List of Publications

McKinney, A., et al. "A Low-Flow Marine Hydrokinetic Turbine for a Floating Unmanned Mobile Platform", Oceans 2022, IEEE/MTS Conference. Hampton Roads VA. October 2022.

A. L. McKinney, et al., "Site-selection for Field-testing of a Marine Hydrokinetic Turbine Platform to Serve as a Floating Unmanned Mobile Recharging Station for Aerial Drones." Offshore Technology Conference, Huston Texas, 1- 4 May 2023.

Dhanak, M. R., Beaujean, P.-P., Frankenfield, J., Hall, A., Henderson, E., McKinney, A., Pimentel, H., and Tran, T. T.. *Development of an Unmanned Mobile Current*

Turbine Platform: Preprint. United States: N. p., 2023. Web. doi:10.36688/ewtec-2023-402.

H. Pimentel, et al., “A Power Takeoff Device for a Small Marine Hydrokinetic Turbine Deployed from an Unmanned Floating Platform.” Oceans 2023, IEEE/MTS Conference. Biloxi MS. September 2023.

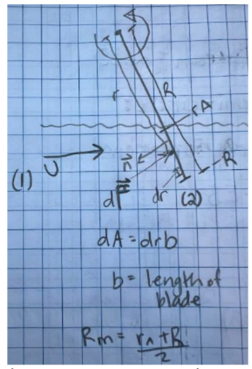
Acknowledgement

The work was supported by the US Department of Energy under award DE-EE0008636. The development of the USV was supported by the Office of Naval Research under grant N000141812212.

10.0 APPENDIX

Appendix A: Numerical Expression Derivation

<u>Derivations</u>



$$P_1 + \frac{1}{2}\rho U_1^2 + gz = P_2 + \frac{1}{2}\rho U_2^2 + gz$$

$$U_1 = U$$

$$U_2 = \Omega r$$

$$P_2 - P_1 = \frac{1}{2}\rho(U_1^2 - U_2^2$$

$$\overline{dF} = -pdA\vec{n}$$

$$= -(P_2 - P_1)dA\vec{n}$$

$$= -\frac{1}{2}\rho(U_1^2 - U_2^2)dA\vec{n}$$

$$\left|\overline{dF}\right| = \frac{1}{2}\,\rho[U^2 - (\Omega r)^2]dA$$

$$= \frac{1}{2}\,\rho[U^2 - (\Omega r)^2]bdr$$

$$dM = \frac{1}{2}\,\rho[U^2 - (\Omega r)^2]brdr$$

$$M = \frac{1}{2}\rho\int_{r_a}^{R}(U^2 - (\Omega r)^2)\Omega rdr = \text{Torque} = \text{T}$$

$$P = T\Omega = \frac{1}{2}\,\rho b\int_{r_a}^{R}(U^2 - (\Omega r)^2)\Omega rdr$$

$$P = \frac{1}{2}\rho bU^3\int_{r_a}^{R}\left(1 - (\frac{\Omega r}{U})^2\right)\left(\frac{\Omega r}{U}\right)dr$$

$$\text{Where } \left(\frac{\Omega r}{U}\right) = \lambda r_1 \text{ and } \lambda = \left(\frac{\Omega r}{U}\right)$$

$$dr = \frac{U\lambda}{\Omega} dr_1 = R dr_1$$

$$\frac{U\lambda}{\Omega} = \frac{U}{\Omega} * \frac{\Omega R}{U} = R$$

$$P = \frac{1}{2}\rho b U^3 \int_{\frac{\Omega r_a}{\lambda U}}^{1} (1 - \lambda^2 r_1^2)\lambda r_1 \left(\frac{U\lambda}{\Omega}\right) dr_1$$

$$P = \frac{1}{2}\rho b U^3 \int_{\frac{\Omega r_A}{\lambda U}}^{1} (1 - \lambda^2 r_1^2)\lambda r_1 r dr_1$$

$$P = \frac{1}{2}\rho b U^3 \lambda R \int_{\frac{r_a}{R}}^{1} (1 - \lambda^2 r_1^2) r_1 dr_1$$

$$= \frac{1}{2}\rho b U^3 \lambda R \left[\frac{r_1^2}{2} - \lambda^2 \frac{r_1^4}{4}\right]_{\frac{r_a}{R}}^{1}$$

…

$$P = \frac{1}{4}\rho U^2\, \Omega A(R + r_a)\left\{1 - \frac{\lambda^2}{2}(1 + \frac{1}{(R + r_a)}\left(\frac{r_a^2}{R} + \frac{r_a^3}{R^2}\right))\right\}$$

$$P = \frac{1}{2}\rho U^2\, A(\frac{R + r_a}{2})\Omega\left\{1 - \frac{\lambda^2}{2}(1 + \frac{1}{(R + r_a)}\left(\frac{r_a^2}{R} + \frac{r_a^3}{R^2}\right))\right\}$$

$$P = \frac{1}{2}\rho U^2\, A(\frac{R + r_a}{2})\Omega\{1 - \alpha\lambda^2\}$$

$$\text{When } \alpha = \frac{1}{2}(1 + \frac{1}{(R+r_a)}\left(\frac{r_a^2}{R} + \frac{r_a^3}{R^2}\right))$$

$$P = \frac{1}{2}\rho U^2\, A R_m \Omega\{1 - \alpha\lambda^2\} \text{ when } \lambda = \frac{\Omega R}{U} \text{ and } \Omega = \frac{U\lambda}{R}$$

$$P = \frac{1}{2}\rho U^3\, A\left(\frac{R_m}{R}\right)\lambda\{1 - \alpha\lambda^2\}$$

$$b = 1.41m$$

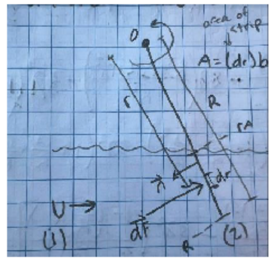
$$R = 0.5m$$

$$l = 0.238m = R - r_a$$

$$r_a = 0.5 - 0.238 = 0.262$$

$$\alpha = \frac{1}{2}(1 + \frac{1}{.762}\left(\frac{.262^2}{.5} + \frac{.262^3}{.5^2}\right))$$

one way to at it…



A drag method…

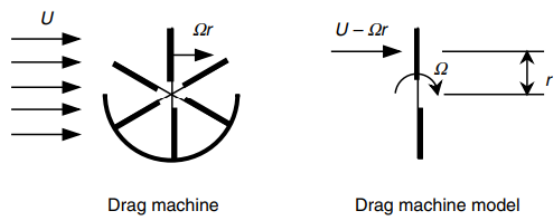


Figure 3.19 Simple drag machine and model; *U*, velocity of the undisturbed air flow; Ω, angular velocity of wind turbine rotor; *r*, radius

Drag Machine Diagram (Manwell, 2009)

Drag on strip:

Drxb: $D=\frac{1}{2}\rho C_D(U-\Omega R)^2 bdr$

Moment about O is:

$$T = D * r$$

$$T = \frac{1}{2}\rho C_D U^2 (U-\Omega r)^2 brdr$$

$$dP = (dT\Omega) = \frac{1}{2}\rho C_D (U-\Omega r)^2 b\Omega rdr$$

$$P = \frac{1}{2}\rho C_D b\int_{r_a}^{R}(U-\Omega r)^2 \Omega rdr$$

$$r = Rr_1$$

$$dr = Rdr_1$$

$$P = \frac{1}{2}\rho C_D b U^3 R \int_{\frac{r_a}{R}}^{1} (U - \Omega R r_1)^2 \Omega R r_1 (R dr_1)$$

$$P = \frac{1}{2}\rho C_D b U^3 R \int_{\frac{r_a}{R}}^{1} (1 - \lambda r_1)^2 \lambda r_1 dr_1$$

$$P = \frac{1}{2}\rho C_D b U^3 R\lambda \int_{\frac{r_a}{R}}^{1} (1 - \lambda r_1)^2 r_1 dr_1$$

$$P = \frac{1}{2}\rho C_D b U^3 R\lambda \int_{\frac{r_a}{R}}^{1} (1 - 2\lambda r_1 + \lambda^2 r_1^2) r_1 dr_1$$

$$P = \frac{1}{2}\rho C_D b U^3 R\lambda \left[\frac{r_1^3}{2} - \frac{2\lambda r_1^3}{3} + \frac{\lambda^2 r_1^2}{4}\right]_{\frac{r_a}{R}}^{1}$$

…

$$P = \frac{1}{24}\rho C_D U^3 A\lambda \left[6\left(1 + \frac{r_a}{R}\right) + 8\lambda \frac{1-(\frac{r_a}{R})^3}{1-\frac{r_a}{R}} - 3\lambda^2 \left(\frac{1-(\frac{r_a}{R})^4}{1-(\frac{r_a}{R})}\right)\right] \text{ when } x = \frac{r_a}{R}$$

$$\frac{r_a}{R} = \frac{0.262}{.5} = 0.524$$

$$P = \frac{1}{2}\rho C_D U^3 A\lambda \left[b(1.524) + 8\lambda \frac{0.856}{0.476} - 3\lambda^2 \left(\frac{0.925}{0.476}\right)\right]$$

$$P = \frac{1}{2}\rho C_D U^3 A\lambda [9.144 + 14.38\lambda - 5.83\lambda^2]$$

$$P = \frac{1}{2}\rho C_D U^3 A(9.144)\lambda [1 + 1.57\lambda - 0.638\lambda^2]$$

Appendix B: OrcaFlex Simulations for Anchor Line Tension & Vertical Downward Force Report Summary

OrcaFlex Simulations for Anchor Line Tension & Vertical Downward Force Report Summary

Introduction:

OrcaFlex simulations were conducted to verify that the anchor line specified for this project can withstand the tensions expected while the vehicle is anchored under various environmental conditions. These studies also showed the relative stability of the vessel at various sea state conditions. During design, the anchoring system and its components were specified to tolerate an estimated max tension of 7.2 kN on the line. A secondary threshold was implemented to cap the downward force on the nose of the vessel to a maximum of 222 N (50 lbf). This threshold was selected due to the easy mitigation of the additional force with added buoyancy on the vessel.

The simulation allows the user to specify their desired anchor line length, current speed, wave height, wind speed, anchor depth and wave type. Once these have been selected OrcaFlex first completes static calculations then runs the dynamic calculations. During the simulation, the tension experienced at each end of the line and along the line is monitored and can be reported if the use requests. Once the simulation is started the current and wave features ramp up from zero to the selected value and then the simulation collects the information for the dynamic calculations while the system is operating at these parameters. Throughout the simulation, the model can be observed from any view the user defines as seen below in Figure 1.

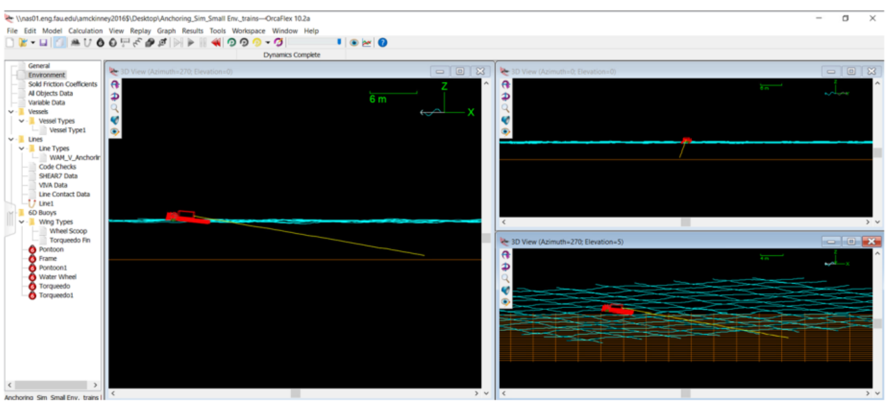


Figure 1: OrcaFlex user interface, three different orthogonal views to observe simulations with.

These simulations were conducted with "SPAR" and "Lumped" buoy elements constructed to model the WAM-V and freestream waterwheel (FSWW). The dynamic motion of the WAM-V and FSWW (heave, pitch, roll & yaw) was replicated with volume, mass, and inertial properties from the SolidWorks model of the complete system. Direct testing of the vessel's capabilities will take place at Zero Sea State conditions, zero-meter wave height, but the vessel is expected to safely operate at Sea State 2 conditions, half a meter wave height. During testing the vessel will encounter currents of up to 3 knots (1.54 m/s) while at anchor and will be anchored at a maximum depth of 5 m. The approach to these simulations was as follows. Measurements for the maximum effective tension, (Max Tension) at end A (the connection at the WAM-V) and end B (the connection at the anchor) were taken, along with the maximum tension values along the x, y, and z axis. Measurements for the maximum global tension in the z direction, (Max Gz Tension) were also collected.

Summary of Results:

In the graph, Figure 1, below Max GZ Tension is displayed for each current at each of the depths.

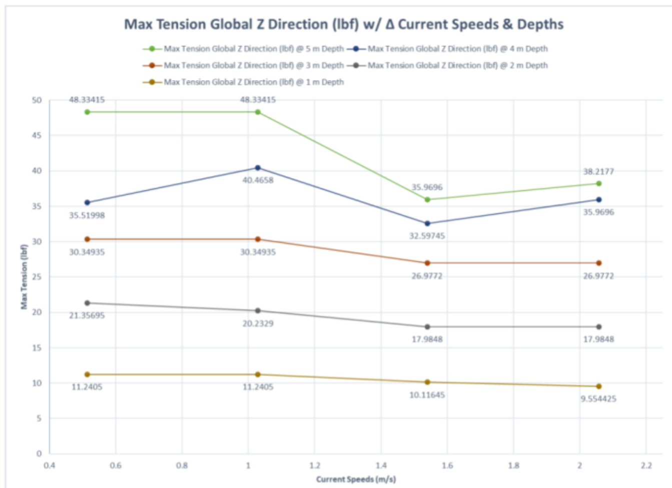


Figure 1: Shows Max Gz Tension in lbf for easy interpretation. The lowest force 9.554 lbf, being at 1 m depth and 4 kt current speed and the highest force 48.33 lbf, being at 5 m depth and 1 kt & 2 kt current speeds.

The 48.33 lbf high was reached at 5 m depth and 1 knot current speed. However, the 50 lbf was not breached with any of the tested conditions. With expected operation to take place at 1 m depth and 3 kt, the system will undergo approximately 10 lbf downward force.

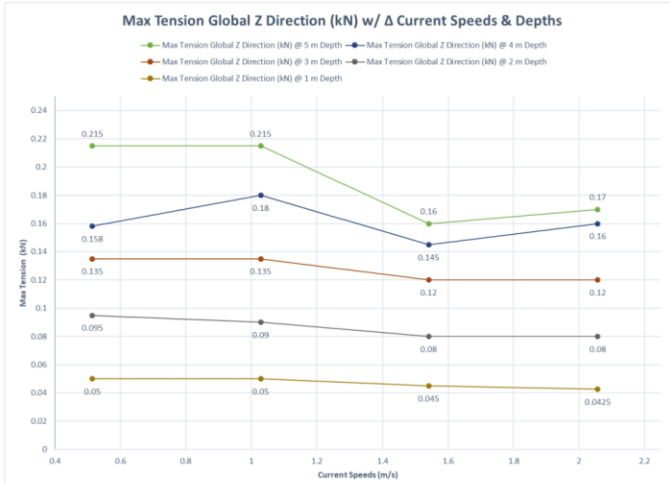


Figure 2: Shows Max Gz Tension in kN. Lowest force 0.0425 kN, being at 1 m depth with 4 kt and the highest force 0.215 kN, being at 5 m depth at 1 & 2 kt current speeds.

The vessel will undergo a downward force of around 0.045 kN at 1 m depth and 3 kt current speeds, Figure 2. This is well within the 222 N limit the system components are built to withstand. The graph below, Figure 3, shows the maximum effective tension, Max Tension, with each current speed at each depth.

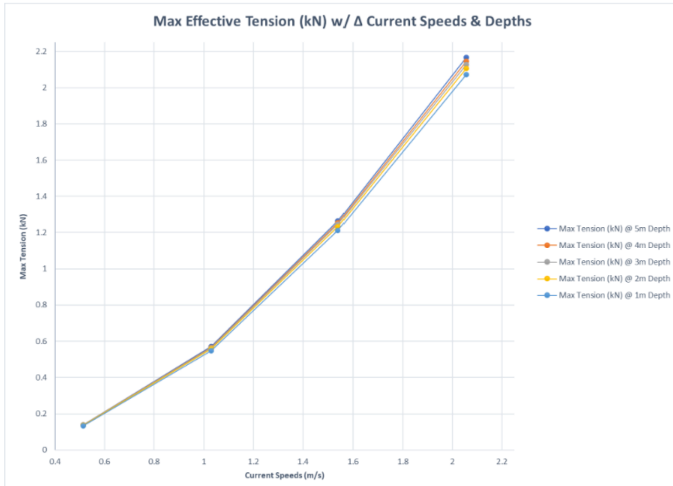


Figure 3: Shows maximum effective tension at end A of the line. The highest tension 2.16 kN, being reached at 5 m depth at 4 kt.

The highest tension remains below 2.2 kN, which is far below the 7.2 kN limit set for the maximum effective tension. Figure 4, shows both Figure 2 and Figure 3 on the same graph to visualize them on the same scale.

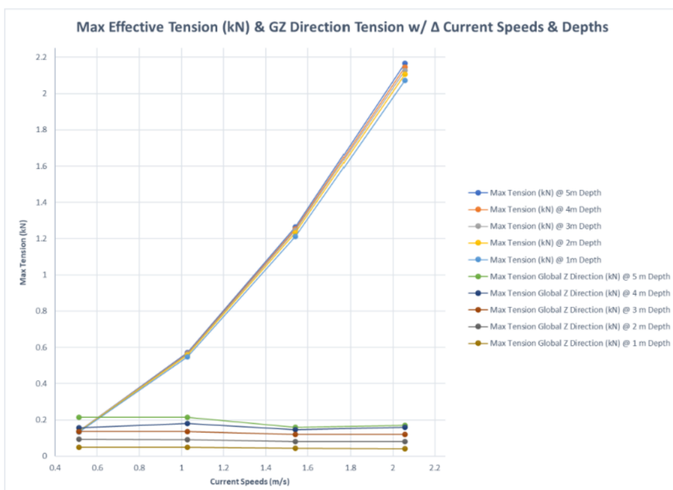


Figure 4: Shows both the Max Tension and the Max Gz Tension in one visual, both in kN.

The graph below Figure 5, show all five current speeds on a single graph. This is useful in comparing the magnitude of the tension expected at each current speed.

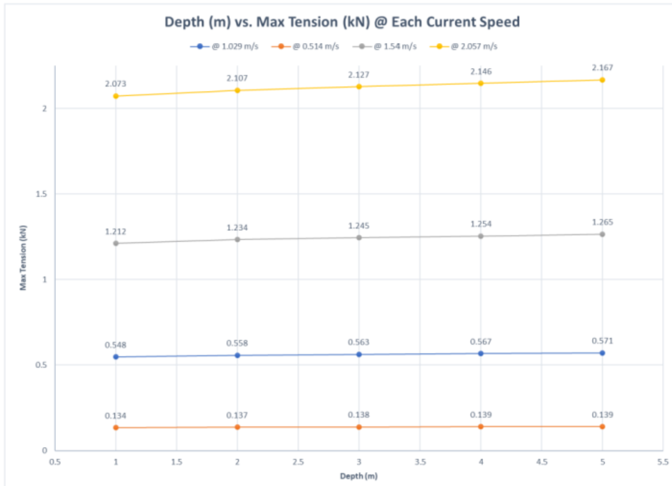


Figure 5: Shows all five Max Tensions lines at each current speed and each depth. The Max Tension ranges from to 0.134 kN at 1 m depth and 1 kt current speed to 2.167 kN at 5 m depth and 4 kt current speed.

This series of visuals shows that the Max Tension expected on the vessel, even under the relatively most rigorous conditions at Zero Sea State, do not exceed the 7.2 kN effective tension limit set for the system.

The graph below, Figure 6, shows a visual for the wind speed effects on the maximum tension.

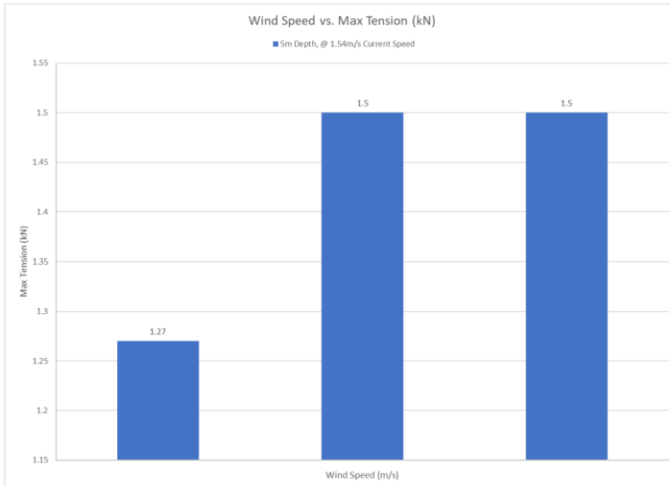


Figure 6: Wind Study at Zero Sea State conditions, Max Tension 1.5 kN, is reached at both wind speeds of 5 m/s and 10 m/s.

The above graph shows an insignificant increase in the maximum tension experienced by the line at end A with added winds. However, after doubling the wind speed from 5 m/s to 10 m/s no increase in the maximum tension was observed.

The graph below, Figure 7, shows a visual for the wind speed effects on the maximum tension at 0.5 wave height.

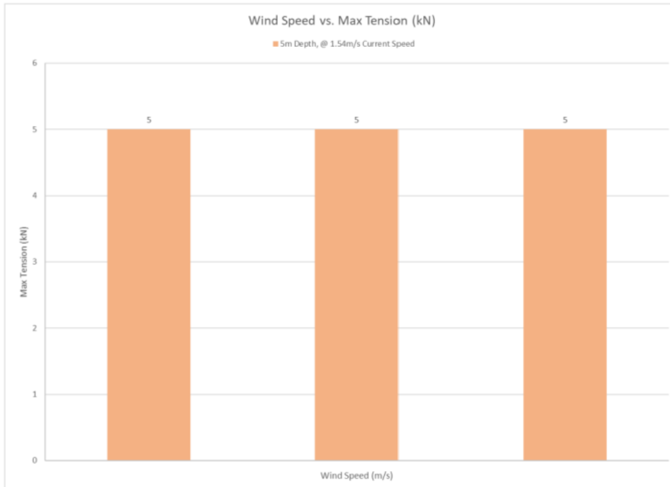


Figure 7: Wind Study at Sea State 2 conditions, Max Tension 5 kN, shows no change from wind speeds at 0 m/s, 5 m/s, and 10 m/s.

The graph below, Figure 8, compares the two wind studies.

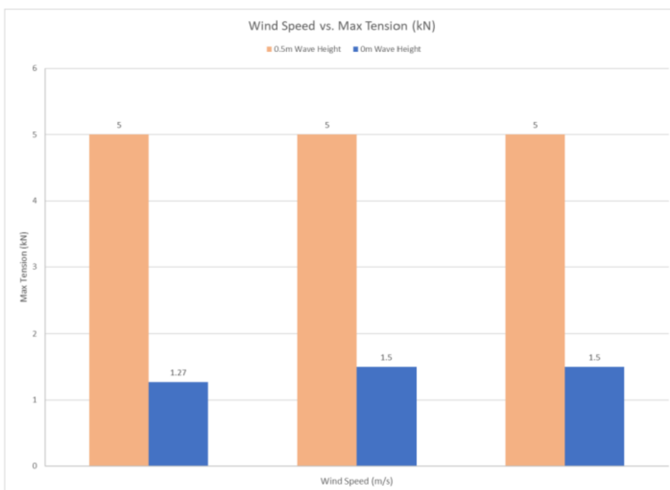


Figure 8: Both wind studies compared side by side, Max Tension of 5 kN, was reached with wind speeds of 5 m/s and 10 m/s with 0.5 m wave height.

As seen above the Sea State 2 conditions produced a significantly higher Max Tension about 4.5 kN larger than the Zero Sea State conditions wind study. But what is important to note in these studies is that adding wind to the other environmental conditions did not create a significant increase in the maximum tensions observed throughout the simulation. With these results it is safe to assume additional winds will not jeopardize the vessel while at anchor.

The graph below, Figure 9, shows that the maximum tension on the line reached its highest value of 5 kN at 0.5 m wave height. However, this 5 kN is still 2 kN under the 7.2 kN system limit. Thus, the vessel's anchoring system is not expected to suffer damage at ideal operating conditions (Zero to 2 Sea State, 5 m depth, & 3 kts current speed).

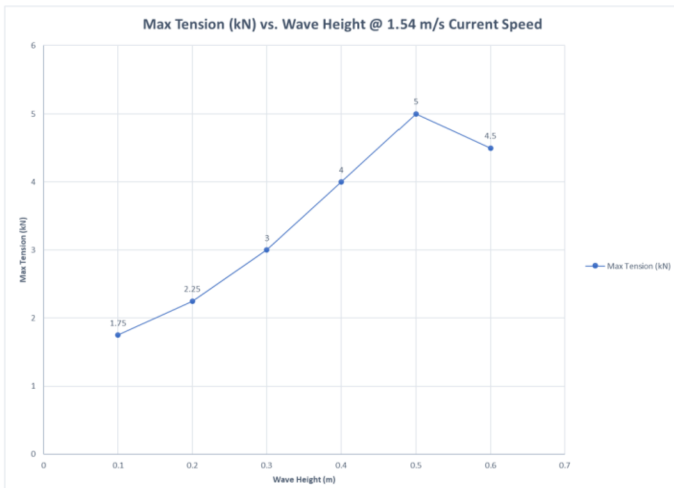


Figure 2: Max Tension simulation visualization, max tensions ranging from 1.75 kN at 0.1 m wave height to 5 kN at 0.5 m wave height.

The graph below, Figure 10, shows the maximum downward force on the line reached its highest value of 56.2 lbf at 0.6 m wave height. This is above the 50 lbf limit, however, it is also at an anchor depth that the vessel should never be operating under. The next highest downward force is 47.21 lbf at 0.3 m wave height and this value is below the system's limit. These findings mean that the vessel can safely anchor at any of the ideal operating conditions (Zero to 2 Sea State, 5 m depth, & 3 kts current speed).

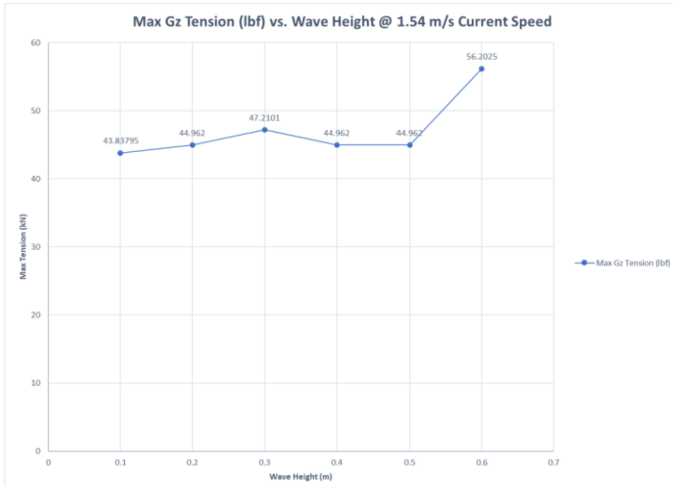


Figure 10: Max Gz Tension simulation visualization, max downward forces ranging from 56.2 lbf at 0.6 m wave height to 43.9 lbf at 0.1 m wave height.

Conclusion:

Several sets of simulations were conducted throughout this study. Each to investigate how differing environmental conditions and their combinations would affect the Max Tensions and the Max Gz Tensions experienced by the anchor line at end A. The first being a Zero Sea State conditions set of simulations. In which, each current speed and anchoring depth was tested with one wave height or wind speed. These simulations showed that under the ideal operating conditions none of the Max Tension or Max Gz Tension would exceed the 7.2 kN and 222 N or 50 lbf system limitations, respectively. They also indicated, although left un-visualized, at no point did the axial max tensions at end A surpass the 7.2 kN limit set for the anchoring system. The next set of simulations studied the effect of wind on the line tensions. This set of simulations showed that wind had little to no effect on the maximum tensions experienced by the line. It was also observed that there was no difference in the maximum tensions on the line with the WAM-V placed out of line with the anchor in the areas to the left or the right of the anchor. The next set of simulations studied the effects of incrementally larger wave heights on the tension observed at on the anchor line at end A. This set of simulations also concluded that between Zero Sea State conditions and Sea State 2 conditions and at ideal current speeds of 3 kt and maximum anchoring depth of 5 m the maximum tensions and the maximum downward forces on the line at end A do not surpass the anchoring system's design loads. The last set of simulations investigates the effects of sending two unique wave trains at the vessel at the same time. This set of simulations showed the maximum tension experienced by the vessel is not likely to surpass the system's limitation while undergoing two wave trains. However, the anchoring system is likely to suffer damage from downward forces on the line when encountering two wave trains. To avoid this damage, it is recommended to avoid anchoring in areas with high boat traffic. All results considered the WAM-V's anchoring system is in no danger of damage while operating under and from Zero Sea State to Sea State 2 conditions with ideal current speeds and maximum anchoring depths.

Site 1.3

Boat Traffic Survey Sheet

Name: Adriana M. & Hayley R. **Date:** 8 /12 /11

Field Information

Temperature (°F): 86 **Wind Speed (mph):** 12 **Wind Direction:** W

Current Direction: north... **Sea State:** Zero, high tide @ 9:30 am

Sky/Sun Conditions: sunny, no clouds, started vid. @ 8:01am

Time	Boats Passing	Time	Boats Passing
8:05am	1	10:20 am	1
8:20 am	1	10:21 am	1
8:25am	1	10:28 am	1
8:40am	1	10:29am	1
8:44am	1	10: 37am	1
9:08am	1	10: 37 am	1
9:15am	1	10:39am	1
9:27am	1	10:41 am	1
9:30 am	1	10:48 am	1
9:38am	1	11:01 am	1
9:42am	1	11:07 am	1
9:43am	1	11:11am	2
9:49am	1	11:20am	1
9:53am	1	11:24am	1
9:55am	1	11:35am	2
10:02 am	1	11:37am	1
10:06am	1	11:42am	1
10:07am	1	11:47am	2
10:14am	1	11:51am	1

11:54 am 1
11:55 am 1

12:03pm 2
12:04pm 2
12:11pm 1
12:12pm 1
12:15pm 1
12:17pm 1
12:21pm 2
12:22pm 2
12:23pm 2
12:32pm 2
12:35pm 2
12:37pm 1
12:40 pm 1
12:51pm 2
12:54pm 1
12:56pm 1
12:57pm 1
1:04pm 1
1:07pm 2
1:09pm 1
1:11pm 1
1:12pm 1
1:16pm 2
1:19pm 1
1:23pm 1
1:24pm 1

Site 1.3

Flow Speed & Water Depth Survey Sheet

Name: Adriana M. & Hayley R. Date: 8/11/22

Field Information

Temperature (°F): 85 Wind Speed (mph): 13 Wind Direction: W

Current Direction: S Sea State: zero

Sky/Sun Conditions: sunny, no clouds, see a sea turtle often

Time – Sensors "On": 8:48 am Time – Beginning of readings: 8:51 am

Time – End of readings: 2:17 pm

Miscellaneous Observations: - High tide @ 8:38 am

1 boat @ 9:09 am *platform did 1/4 turn @ 9:30 am, fixing itself

1 boat @ 9:13 am * flipped @ 9:33 am current now

2 boats @ 9:25 am going N.

2 boat @ 9:46 am

Water-taxi 9:47 am

1 boat @ 9:47 am
1 boat @ 9:50 am
1 boat @ 10:10 am
1 boat @ 10:20 am
1 boat @ 10:27 am
1 boat @ 10:30 am
water taxi 10:39 am
boat @ 10:46 am
boat @ 10:00 am
boat @ 11:04 am
boat @ 11:12 am
boat @ 11:20 am
boat @ 11:24
&
water taxi
boat @ 11:32 am
boat @ 11:42 am
boat @ 11:45 am
boat @ 11:44 am
boat @ 11:47 am

boat @ 11:51 am
boat @ 11:54 am
boat @ 12:07 pm
boat @ 12:08 pm
boat @ 12:18 pm
2 boats @ 12:23 pm
2 boats @ 12:32 pm
~~+ boat @~~
3 ~~boats @~~ boats @ 12:35 pm
1 boat @ 12:50 pm
1 boat @ 1:07 pm
1 boat @ 1:14 pm
1 boat @ 1:18 pm
1 boat @ 1:20 pm
1 boat @ 1:25 pm
1 boat @ 1:31 pm
1 boat @ 1:32 pm

1 boat @ 1:34 pm
1 boat @ 1:39 pm
5 boats @ 1:46 pm
2 boat @ 1:51 pm
boat @ 2:13 pm

55 boats

(79)

1:37pm	1	4:23pm	2
1:39pm	1	4:25pm	1
1:46pm	3	4:37pm	2
1:51pm	2	4:39pm	1
2:01pm	1	4:43pm	1 tot 131
2:09pm	1	4:47pm	1
2:11pm	2	4:48pm	1
2:13pm	1	4:50pm	1
2:21pm	1	4:58pm	4
2:36pm	1	5:13pm	1
2:38pm	1	5:15pm	1
2:45pm	1	5:21pm	1
2:47pm	4	5:23pm	1
2:52pm	2	5:25pm	1
2:53pm	2	5:26pm	1
3:00pm	1	5:28pm	4
3:02pm	1	5:47pm	1
3:04pm	1	5:50pm	2
3:10pm	2	5:54pm	2
3:21pm	1	5:59pm	1
3:23pm	1	6:04pm	1
3:25pm	1	6:06pm	1
3:35pm	1		
3:36pm	1		
3:41pm	1		
3:43pm	2		
3:50pm	1		
3:56pm	1		
3:58pm	2		
4:08pm	2		
4:16pm	2		

156 boats

End @ 6:15pm

Inlet

Flow Speed & Water Depth Survey Sheet

Name: Adriana M. & Hayley R. **Date:** 8/19/22

Field Information

Temperature (°F): 84 high 89 **Wind Speed (mph):** 3 **Wind Direction:** E

Current Direction: south **Sea State:** zero, low tide

Sky/Sun Conditions: sunny, no clouds, low tide @ 9:24 am
high tide @ 3:31 pm

Time – Sensors "On": 8:36 am **Time – Beginning of readings:** 8:40 am

Time – End of readings: ______

Miscellaneous Observations: ______

Current & Depth @ Inlet site. ~~Boat Traffic Survey Sheet~~

Name: ______________________ Date: __/__/__

Field Information

Temperature (°F): ______ Wind Speed (mph): ______ Wind Direction: ______

Current Direction: ______ Sea State: ______

Sky/Sun Conditions: ______

*platform @ 45°∠ @ 10:07 am, moved 180° pivot @ 10:24am (going N)

Time	Boats Passing	Time	Boats Passing
4	8:48am	9:45am	2
8:54am	2	9:47am	1
8:55am	1	9:51am	1
8:58am	1	10:01am	1
9:00am	1	10:04am	~~3~~ 4
9:05am	1	10:07am	1
9:08am	1	10:08am	2
9:16am	1	10:10am	1
9:17am	1	10:11am	1
9:25am	1	10:12am	1
9:27am	~~2~~ 1	10:19am	1
9:28am	2	10:21am	2
9:29am	1	10:22am	1
9:31am	2	10:25am	2
9:33am	1	10:27am	1
9:35am	2	10:31am	2
9:39am	4	10:34am	2
9:41am	2	10:35am	1
9:43am	1	10:36am	1

10:37am 1
10:43am 2
10:46am 2
10:47am 1
10:49am 1
10:50am 3
10:53am 1
10:56am 1
10:59am 3
11:01am 1
11:07am 2
11:11am 1
11:12am 3
11:14am 2
11:17am 1
11:18am 2
11:19am 1
11:25am 1
11:31am 4
11:32am 1
11:43am 1
11:46am 2

11:48am 1
11:50 am 4 → 101
11:55am 2
11:58am 1
11:59am 2
12:00pm 1
12:01pm 24
12:04pm 1
12:05pm 1
12:08pm 2
12:10pm 1
12:18pm 1
12:19pm 1
12:20pm 2
12:22pm 4

124 boats

183 boats

total = 257

Inlet

Flow Speed & Water Depth Survey Sheet

Name: Adriana M. & Hayley R. **Date:** 8/22/22

Field Information

Temperature (°F): 90 **Wind Speed (mph):** 9 **Wind Direction:** W

Current Direction: S **Sea State:** Zero

Sky/Sun Conditions: sunny, partly cloudy

Time – Sensors "On": 11:54am **Time – Beginning of readings:** 12:13pm

Time – End of readings: 6:02pm

Miscellaneous Observations:

Current & Flow Depth

~~Boat Traffic Survey Sheet~~

Name: ______________________ Date: __/__/__

Field Information

Temperature (°F): __________ Wind Speed (mph): __________ Wind Direction: __________

Current Direction: __________ Sea State: __________

Sky/Sun Conditions: flipped current from S to N @ 3:35pm

Time	Boats Passing	Time	Boats Passing
12:32pm	1	1:23pm	1
12:33pm	1	1:25pm	2
12:34pm	1	1:35pm	3
12:39 pm	2	1:37pm	1
12:40pm	1	1:45pm	1
12:44pm	1	1:46pm	2
12:46pm	2	1:49pm	1
12:48pm	3	1:51pm	1
12:50pm	1	1:54pm	1
12:51pm	1	1:58 pm	4
12:54pm	1	2:00pm	1
12:55pm	1	2:03pm	1
12:57pm	1	2:07pm	1
1:02pm	2	2:08pm	2
1:09pm	1	2:15 pm	1
1:12pm	1	2:23pm	1
1:17pm	3	2:32pm	1
1:20pm	3	2:36pm	1
1:22pm	2	2:38pm	2

2:42pm	1
2:44pm	3
2:46pm	2
2:49pm	2
2:53pm	1
2:56pm	2
3:11pm	2
3:12pm	1
3:14pm	1
3:15pm	2
3:16pm	1
3:21pm	1
3:24pm	1
3:30pm	2
3:31pm	2
3:32pm	1
3:35pm	1
3:37pm	1
3:39pm	1
3:43pm	1
3:44pm	2

3:48 pm 1 → 89 boats
3:51 pm 1
3:55 pm 3
3:58 pm 1
4:00 pm 1
4:04 pm 1
4:06 pm 2
4:09 pm 3
4:12 pm 2
4:15 pm 1
4:24 pm 1
4:25 pm 1
4:28 pm 2
4:38 pm 1
4:42 pm 1
4:43 pm 2
4:45 pm 1
4:47 pm 1
4:48 pm 2
4:49 pm 1
4:50 pm 1
4:52 pm 3 (bargel + tow)
4:55 pm 1
4:59 pm 1
5:00 pm 2
501 2
5:05 pm 1
5:10 pm 1
5:15 pm 1

5:20 pm 1
5:22 pm 1
5:28 pm 1
5:37 pm 1
5:38 pm 2

147 boats

off @ 6:02

Site Location: Inlet

Flow Speed & Water Depth Survey Sheet

Name(s): Adriana M. & Hayley R. Date: 8 / 15 / 22

Field Information

Temperature (°F): 85 Wind Speed (mph): 6 Wind Direction: NW

Current Direction: North Sea State: zero

Sky/Sun Conditions: partly cloudy

Time – Sensors "On": 8:09 am Time – Beginning of readings: 8:11 am

Time – End of readings: 6:20 pm

Miscellaneous Observations: → 45° pivot @10:19 am, → 45° pivot @ 12:32 pm
→ 45° pivot @ 12:50
high tide: 7:43 am
low tide: 1:49 pm

Time	# of Boats	Time	# of Boats
8:22 am	2	10:30 am	1
8:30 am	1	10:31 am	1
8:32 am	3	10:33 am	1
8:40 am	4	10:34 am	1
8:46 am	2	10:45 am	1
8:50 am	1	10:49 am	1
8:52 am	1	10:57 am	1
9:07 am	1	11:00 am	1
9:16 am	1	11:03 am	1
9:26 am	1	11:04 am	2
9:35 am	2	11:06 am	1
9:37 am	1	11:07 am	1
9:40 am	2	11:16 am	1
9:44 am	2	11:19 am	1
9:46 am	1	11:23 am	1
9:48 am	1	11:25 am	1
9:49 am	1	11:27 am	2
9:54 am	1	11:32 am	1
9:55 am	1	11:35 am	1
10:00 am	1	11:36 am	2
10:01 am	1	11:37 am	2
10:13 am	1	11:42 am	1
10:17 am	3	11:48 am	1
10:23 am	1	11:49 am	1
10:29 am	1	11:54 am	1

sub tot: 66

Site Location: ______________

11:58 am	2	2:54pm	3
12:07 pm	2	2:55pm	1
12:14 pm	1	2:58 pm	2
12:15 pm	1	2:59 pm	1
12:19pm	3	3:00pm	1
12:21 pm	1	3:02pm	1
12:22 pm	2	3:05pm	3
12:27 pm	2	3:06 pm	1
12:28 pm	1	3:11 pm	2
12:32 pm	1	3:18 pm	1
12:38 pm	1	3:19 pm	~~2~~ 3
12:41pm	2	3:24pm	1
12:47 pm	1	3:27 pm	2
12:52pm	2	3:33 pm	1
12:55 pm	2	3:34 pm	3
12:57 pm	1	3:43 pm	1
1:04 pm	1	3:45 pm	1
1:13 pm	1	3:47 pm	1
1:16 pm	3	3:49 pm	1
1:17pm	2	3:50 pm	1
1:22 pm	1	3:54 pm	1
1:23 pm	1	3:55 pm	1
1:26pm	2	3:56 pm	1
1:27 pm	1	3:58 pm	1
1:31 pm	5	3:59 pm	1
1:35pm	1	4:03 pm	2
1:39 pm	1	4:06 pm	1
1:42 pm	1	4:12pm	1
1:44pm	2	4:13 pm	1
1:53pm	1	4:20 pm	1
1:55pm	1	4:26 pm	1
2:00 pm	1	4:28 pm	1
2:05pm	5	4:31 pm	1
2:08 pm	1	4:33pm	2
2:09 pm	1	4:34pm	1
2:11 pm	2	4:37 pm	2
2:23 pm	1	4:42 pm	1
2:26 pm	2	4:44 pm	1
2:28 pm	1	4:48 pm	1
2:32 pm	1	4:55 pm	2
2:36 pm	1	4:56 pm	1
2:39 pm	1	4:59 pm	1
2:43 pm	1	5:01 pm	2
2:47pm	3	5:04 pm	1
2:49 pm	1	5:09 pm	2
		5:10pm	1

5:12	2
5:13	1
5:14	1
5:15	1
5:19	1
5:27	1
5:28	2
5:37	1
5:38	4
5:41	1
5:43	1
5:47	1
5:52	1
5:55	1
6:02	1
6:08	1
6:12	1
6:16	1

223 boats

108

Site 1.1: → little bit of grass in NW region
→ all of pass (2-3) was grassy
→ ~~from~~ sand bag wall ~~to NE portion of~~ pass (3-4) is sandy
around and slightly N in
was grass @ (4)
→ (4-5) grassy in N portion clearer is SE portion
→ pass 5 from [illegible] N to S

V#1 { pull up @ 5:20 } pass 1 from (1-2) S-N
{ pull up @ 10:09 }
V#2 { pull up @ 4:59 (facing S) → pass 2 from (2-3) N-S
{ pull up @ 11:03 → pass 3 from (3-4) S-N
V#3 pull up @ 5:20 (facing S) → pass 4 from (4-5) N-S

- pass 1 all grass, questionable baby grass in S portion
- pass 2 sand in S portion @ pull up grassy
- pass 3 grassy
- pass 4 grassy

site 1.1 is a no go... :(

Port Site:

V#1 no pull up } pass 1 from 1-2 N-S
V#2 pullup @ 0:20 rest of vid. nothing underwater
V#3 no pull up → last pass @ 20-30% stop

V#1 → @ (1) very grassy
→ @ 50% of pass 1 BEST SAND EVER → large expanse
seems near 2nd rock pile @ 70%
50% - 70% pass 1 absolutely perfect
@ 80% of pass 1 more sand
80-85%
@ 90-98% more sand
V#3 @ 2 mins forest
@ 3 min clif way deep → rest of vid. green deep clif

... so far BEST site!!!

Inlet Site:

V#1 pull up @ 4:28 → pass 1 (1–2) N-S

pull up @ 8:11 → pass 2 (3–4) S-N

V#2 no pull up → 1 drop → pass 3 (5–6) N-S

- @ (1) weird moss, the rest of pass (before) sandy, mostly sand
- pass 2 ALL SAND!
- pass 3 near (6) to S portion theres grass / clif

Tiki Tiki:

V#1 → Rocky / hard bottom

CB:

V#1: pull up 1 → pass 1 → (1–2) — N-S

pass 1 grassy

down 2 → deep and grassy

CB is a no gotoo grassy ...

Map:

* maybe best to be on the right side of ICW
* put diver down flag in MHK platform
peeps have to keep 500 ft radius

Potential Options for Intracoastal Waterway Site: Adjacent to the FAU - SeaTech Campus at: 26.055193° N, 80.112879° W, Distances from launch point: Dockside 200-220m. Site 1.1: Distances from launch point: 262-503m, support vessel: kayak.

* start @ 1 then go 2 then 3 then 4 then 5 (following shore line)
- 2nd pull up for start of path 2 to 3
- 3rd ~~path~~ pull up for pass 3 to 4 @ (3) we are 40ft from shore
- 4th pull up for 4 to 5, pile of rocks to 1st gap in bridge, @ (4) 50 ft from shore, just out of channel ~50ft from ~~ten~~ channel → @ end see grass

* also did Garmin map for all the passes

@ CB → pass (1→2) started @ seawall
↳ 12" from shore
→ 1st pull up marks start of (2) to (4), 25"–16" deep
30" offshore
@ 1:50–2:05pm

Potential New Sites:

Port Site: * will be more -wakes here than @ 1.1

(4/10)

* start @ (1), 20 ft from shore
9" deep @ 20"
* pass 1 in front of wall
15" from seawall
20-30 % from sign
all SAND!
* no wind
* 1st pull up marks start of 3-4 pass
→ mark @ 20-30 % down
@ 11"

2nd rock pile good
to southern jetty @ 70%
Zig pattern
* bottom : garmin

Inlet Site: @1 → ask permisson if deck look good

→ rocks to pier 66 1st pass
30" from shore

- start NW to S the turn in and go N to NE corner
- 3rd pass w/ garmin (5 to 6)

~~* current measurement @ inlet site @ 10:15am~~

Bottom Type Survey Sheet

Name: Adriana N., Hayley R., Hugo P

Date: 8/3/22

Field Information

Temperature (°F): 83 Wind Speed (mph): 8mph Wind Direction: S W

Current Direction: slack @ low tide Sea State: zero

Sky/Sun Conditions:

· clear skies

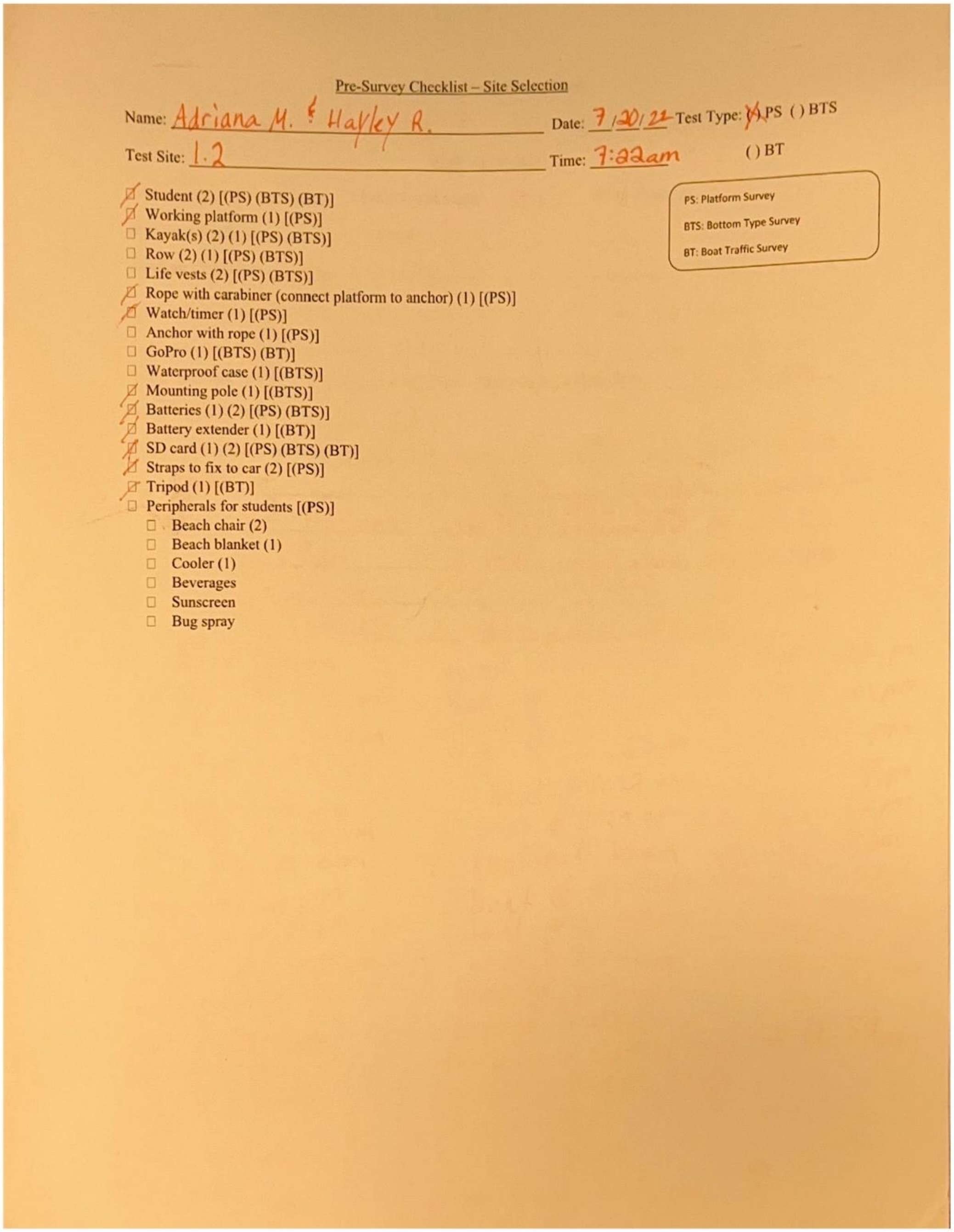
Miscellaneous Observations:

* platform on @ 11:31am @ Tiki Tiki Dock
in place @ 11:~~36~~ am @ 11:36am
boat @ 11:38
2@ boat @ 11:40 factor in 2° tilt
boat @ 11:49
boat @ 11:55
pulled in @ 12:00pm
** current @ 1.1.%

platform was off

Platform on @ 12:27
in place @ 12:36
12:36 adjustment
12:43 2 boats
12:47 2 boats
12:51 boat
12:56 2 boats
1:00 boat
1:03 boat
off @ 1:06 pm
1.1 N Current
* platform on 4:16 pm
platform in place @ 4:23 pm
2 boats @ 4:27pm
boat @ 4:30 pm
4 boats @ 4:37 pm
boats @ 4:44pm
house boat @ 4:52 pm
boat @ 4:54 pm
barge 4:56 pm
3 boats 4:59pm
kill @ 5:00pm

on @ 5:23pm
@ CB @ 5:25 platform in place
boat @ 5:25
5:27 pm behind boat
5:30 boat
5:30 getting closer to channel
5:31 poop done



<u>Pre-Survey Checklist – Site Selection</u>

Name: Adriana M. & Hayley R. Date: 7/20/22 Test Type: (X) PS ( ) BTS ( ) BT

Test Site: 1.2 Time: 7:22am

PS: Platform Survey
BTS: Bottom Type Survey
BT: Boat Traffic Survey

- [x] Student (2) [(PS) (BTS) (BT)]
- [x] Working platform (1) [(PS)]
- [ ] Kayak(s) (2) (1) [(PS) (BTS)]
- [ ] Row (2) (1) [(PS) (BTS)]
- [ ] Life vests (2) [(PS) (BTS)]
- [x] Rope with carabiner (connect platform to anchor) (1) [(PS)]
- [x] Watch/timer (1) [(PS)]
- [ ] Anchor with rope (1) [(PS)]
- [ ] GoPro (1) [(BTS) (BT)]
- [ ] Waterproof case (1) [(BTS)]
- [x] Mounting pole (1) [(BTS)]
- [x] Batteries (1) (2) [(PS) (BTS)]
- [x] Battery extender (1) [(BT)]
- [x] SD card (1) (2) [(PS) (BTS) (BT)]
- [x] Straps to fix to car (2) [(PS)]
- [x] Tripod (1) [(BT)]
- [ ] Peripherals for students [(PS)]
  - [ ] Beach chair (2)
  - [ ] Beach blanket (1)
  - [ ] Cooler (1)
  - [ ] Beverages
  - [ ] Sunscreen
  - [ ] Bug spray

Flow Speed & Water Depth Survey Sheet

Name: Adriana M. & Hayley R. **Date:** 7/20/22

Field Information

Temperature (°F): 86 **Wind Speed (mph):** 4 mph **Wind Direction:** W

Current Direction: ______ **Sea State:** zero

Sky/Sun Conditions: Partly cloudy/w

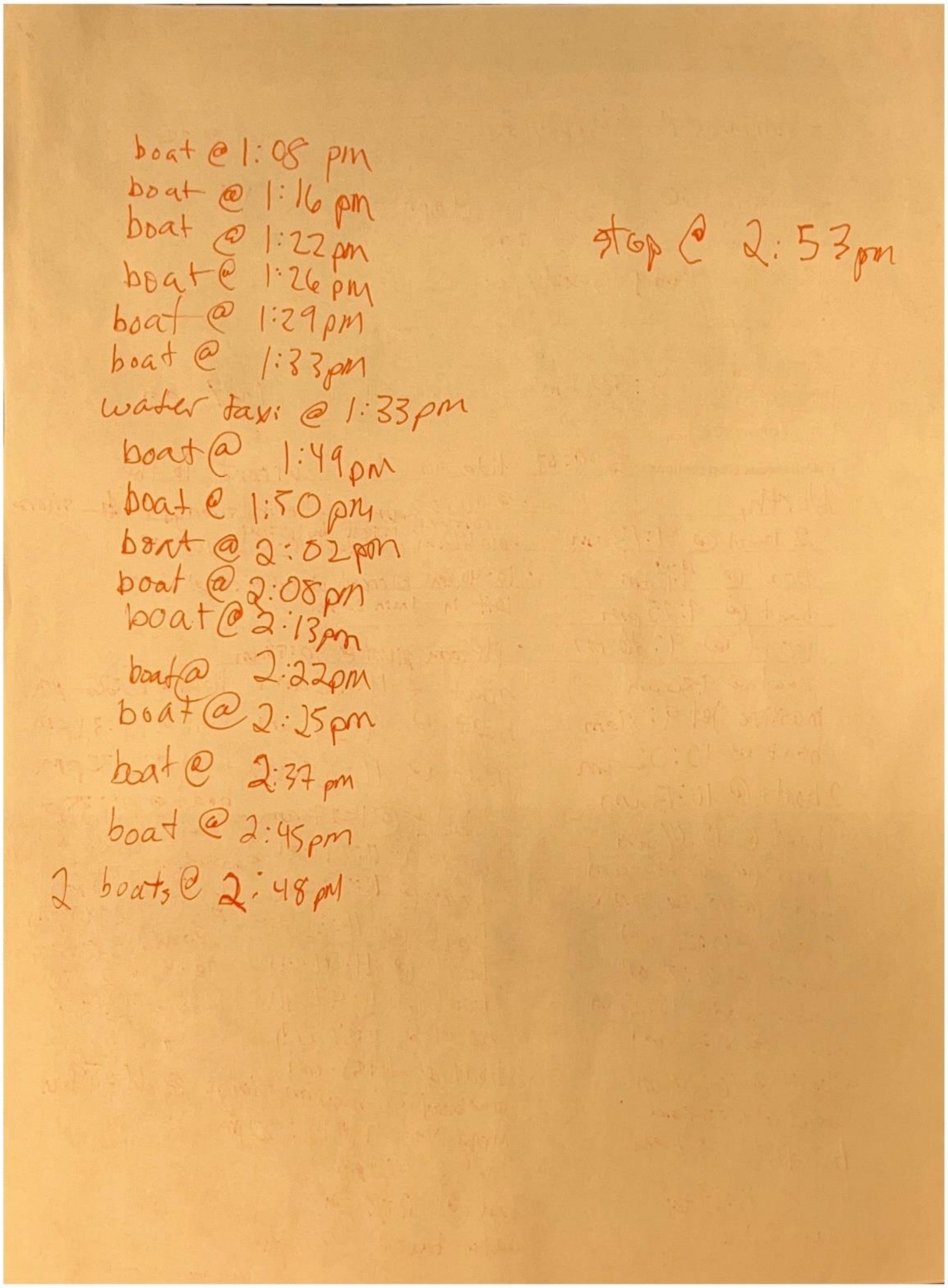
Time – Sensors "On": 8:30 am **Time – Platform Set and Running:** 9:07 am

Time – Sensors "Off": ______

Miscellaneous Observations: @ 9:07 tide is low, current to the North,

- @ 10:03 am platform sways to shore, corrects itself by 10:04
- platform rotated 180° @ 10:18
- 10:40am current visual test @ shore 10ft in 1min 20sec
- platform pivot @ 10:53am

2 boat @ 9:13am
boat @ 9:19am
boat @ 9:25 am
boat @ 9:26 am
boat @ 9:30 am
massive jet 9:39am
boat @ 10:02am
2 boats @ 10:13am
boat @ 10:14 am
boat @ 10:15 am
boat @ 10:16 am
2 boats @ 10:21 am
boat @ 10:22am
water taxi @ 10:25am
boat @ 10:30am
boat @ 10:34am
boat @ 10:39am
boat @ 10:57am
boat @ 11:13am
boat @ 11:14am
boat @ 11:20am
boat @ 11:21 am
boat @ 11:25am
boat @ 11:27 am
boat @ 11:29 am
boat @ 11:30 am
boat @ 11:36am
boat @ 11:41am
boat @ 11:47am
boat @ 11:51 am
boat @ 11:56am
tow boat w/ boat and dingy @ 11:59am
mega yatch @ 12:00pm
boat @ 12:20 pm
boat @ 12:22 pm
water taxi @ 12:26pm
boat @ 12:27 pm
boat @ 12:31pm
boat @ 12:32pm
boat @ 12:35pm
boat @ 12:37pm
2 boats @ 12:45pm
boat @ 12:48pm
3 boats @ 12:50pm
boat @ 12:58pm
boat @ 12:59pm


boat @ 1:08 pm
boat @ 1:16 pm
boat @ 1:22 pm
boat @ 1:26 pm
boat @ 1:29 pm
boat @ 1:33 pm
water taxi @ 1:33 pm
boat @ 1:49 pm
boat @ 1:50 pm
boat @ 2:02 pm
boat @ 2:08 pm
boat @ 2:13 pm
boat @ 2:22 pm
boat @ 2:25 pm
boat @ 2:37 pm
boat @ 2:45 pm
2 boats @ 2:48 pm

stop @ 2:53 pm

Figure 10. Potential Options for Intracoastal Waterway Sites: Adjacent to the FAU - Sea Tech Campus at: 26.055193^0 N, 80.112879^0 W Distances from launch point: Dockside 200-220m. Site 1.1: Distances from launch point: 262-503m, support vessel: kayak. Site 1.2: Distances from launch point: 620-715m, support vessel: kayak. Shore support team.

2

Site Selection Survey Procedure

Summary

Goals and Objectives

The MHK team would like to select a proper site to deploy the MHK FSWW for open water testing. For that, it is necessary to conduct a site selection survey, which involves:

- Acquiring data (flow speed, water depth, bottom type, boat traffic) from several different locations using a data acquisition floating platform equipped with a depth sensor and a flow speed sensor.
- Obtaining information about the sea floor type using a GoPro.
- Quantifying boat traffic using a GoPro to record local flux of vessels.

The primary goal is to successfully run the abovementioned tests, and thus select the appropriate location for deployment of the FSWW. The procedures detailed in this document serve to standardize the work involved in accomplishing that objective. Details about the survey steps as well as the time, materials and personnel needed are written in the following pages.

Description of Tasks and Activities

There are four main activities, each one requiring allocated time, materials, and personnel. The main activities can be broken down as:

- Flow Speed Measurements
    - Sensor Platform deployment
    - Sensor Platform retrieval, storage, and maintenance
- Bottom type survey
- Boat traffic survey

Flow Speed Measuremts

Sensor Platform Deployment

1. Make sure all sensors are properly positioned (and connected) and the battery is fully charged
2. Make sure SD card is empty and in the Teensy
3. Have all items on the pre-survey checklist checked
4. Have personnel on standby and make sure kayaks are ready
5. Bring platform and kayaks to water (*through the back end of the McAlister)*
   5.1 Turn Teensy on before taking platform into the water – start a dedicated timer to time how long it will take from turning the system on to fully deploying the platform in its final spot.
6. Take platform to anchoring point and tie it down to anchor point. Start timer.
   6.1 One kayak tows the platform while the other follows, while carrying the anchor.
   6.2 Drop the anchor and tie the platform to the anchor's rope. Start timer.
   6.3 Stop the dedicated timer – write down how long it took from turning the board on to deploying the platform. That time will be used to exclude the inaccurate data acquired before final anchoring of platform.
7. Have student(s) take place and watch the platform during the whole duration of the survey.

Sensor Platform Retrieval, Storage and Maintenance

1. Kayaks approach platform. Stop timer.
2. Disconnect platform from anchor rope and connect it to leading kayak.
3. Back-up kayak retrieves the anchor and follows the leading kayak back to McAlister, where the platform and kayaks will be taken out of the water.
4. Rinse equipment with fresh water.
5. Bring platform to lab. Take SD card out and check readings, making sure they are ok.
6. Check battery charge with multimeter and charge it if needed (below 12.4V).

Bottom Type Survey

1. Make sure SD card is clear and in the GoPro.
2. Make sure batteries are charged
3. Have all items on pre-survey checklist checked.
4. Have personnel on standby
5. Make sure waterproof housing is watertight
6. Reach surveying site, (university rented a boat with a captain as the chase boat was not ready for this portion of site selection)
7. Power on GoPro, start recording & submerge.
8. Poke sea floor with 10" measuring stick; pull back two inches

9. Record video at a standstill for 2-3 minutes
10. Pull up GoPro and review visibility of the video
11. If water is clear, see 11.1. If water is muddy, see 11.2
    11.1 Conduct 15 passes within the desired testing area
    11.2 If visibility is under 2', conduct 26 passes within the desired testing area
12. Start new video and submerge GoPro on the side of the boat
13. Conduct a sweeping pattern over the entire test site (S to N)
14. Pull up the GoPro, check video length
15. Head back to shore, unload boat and pack up testing supplies
16. Head back to Sea Tech, unload equipment.
17. Download data and clear SD card
18. Charge battery

Boat Traffic Survey

1. Transport equipment from pre-checklist to the transport vehicle
2. Load equipment in car
3. Ensure staff have arrived
4. Depart for testing site
5. Unload vehicle
6. Mount GoPro to tripod
7. Place the tripod in clear view of the water way
8. Ensure GoPro battery extender is on
9. Power on GoPro
10. Begin recording, students will mark each boat as it passes on the Boat Traffic Survey Sheet
11. Monitor the GoPro throughout the day
12. 30 min. before sundown end the recording
13. Power down GoPro
14. Load equipment into car
15. Drive back to SeaTech
16. Unload equipment
17. Upload data to MHK Drive
18. Clear SD card
19. Recharge batteries

Pre-Survey Checklist – Site Selection

Name: ____ Date: ___/___/___ Test Type: ( ) PS ( ) BTS

Test Site: ____ Time: _________ ( ) BT

PS: Platform Survey

BTS: Bottom Type Survey

BT: Boat Traffic Survey

- ☐ Student (2) [(PS) (BTS) (BT)]
- ☐ Working platform (1) [(PS)]
- ☐ Kayak(s) (2) (1) [(PS)]
- ☐ Row (2) (1) [(PS)]
- ☐ Life vests (2) [(PS) (BTS)]
- ☐ Rope with carabiner (connect platform to anchor) (1) [(PS)]
- ☐ Watch/timer (1) [(PS)]
- ☐ Anchor with rope (1) [(PS)]
- ☐ GoPro (1) [(BTS) (BT)]
- ☐ Waterproof case (1) [(BTS)]
- ☐ Mounting pole (1) [(BTS)]
- ☐ Tripod (1) [(BT)]
- ☐ Batteries (1) (2) [(PS) (BTS) (BT)]
- ☐ SD card (1) (2) [(PS) (BTS) (BT)]
- ☐ Straps to fix to car (2) [(PS)]
- ☐ Peripherals for students [(PS)]
  - ☐ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☐ Cooler (1)
  - ☐ Beverages
  - ☐ Sunscreen
  - ☐ Bug spray

Flow Speed & Water Depth Survey Sheet

Name: ____ **Date**: ___/___/___

Field Information

Temperature (°F): ____________ **Wind Speed (mph)**: ____________ **Wind Direction**: ______________

Current Direction: ____________ **Sea State**: ____

Sky/Sun Conditions: ____

____

____

Time – Sensors "On": __________________ **Time – Platform Set and Running**: _______________________

Time – Sensors "Off": _________________

Miscellaneous Observations: ____

____

____

____

____

____

Boat Traffic Survey Sheet

Name: ____ **Date**: ___/___/___

Field Information

Temperature (°F): ____________ **Wind Speed (mph)**: ____________ **Wind Direction**: ______________

Current Direction: ____________ **Sea State**: ____

Sky/Sun Conditions: ____

____

____

Time	Boats Passing	Time	Boats Passing

Miscellaneous Observations:

Bottom Type Survey Sheet

Name: ____ **Date**: ___/___/___

Field Information

Temperature (°F): ____________ **Wind Speed (mph)**: ____________ **Wind Direction**: ______________

Current Direction: ____________ **Sea State**: ____

Sky/Sun Conditions: ____

____

____

Miscellaneous Observations: ____

____

____

____

____

____

____

____

____

____

____

____

____

____

Appendix D: Testing Checklist

Pre-Testing Checklist

Name: ____ Date: ___/___/___ Test Type: ( ) AS ( ) WW

Test Site: ____ Time: __________ ( ) C&N ( ) D

AS: Anchoring System

C&N: Controls & Navigation Test

WW: Water Wheel Test

D: Demo

- ☐ Students (3) [(AS) (C&N) (WW) (D)]
- ☐ Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - ☐ USWW and PTO are installed and operational
  - ☐ Inflate pontoons
  - ☐ Check all cables and connections
  - ☐ Charge controller switch on (turn switch up on PTO box)
  - ☐ PTO battery on (turn black box switch up)
  - ☐ Control box on
  - ☐ Check if Wi-Fi connection is enabled
  - ☐ Check if propellers are working fine
  - ☐ Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- ☐ Drone [(D)]
- ☐ Environmental checklist [(AS) (C&N) (WW) (D)]
- ☐ Kayak(s) (2) (1) [(AS) (C&N) (D)]
- ☐ Row (2) (1) [(AS) (C&N) (D)]
- ☐ Watch/timer (1) [(AS) (WW)]
- ☐ Anchor with rope (1) [(AS) (WW) (D)]
- ☐ GoPro (1) [(AS) (WW) (D)]
- ☐ Waterproof case (1) [(AS) (WW) (D)]
- ☐ Peripherals for students [(AS) (C&N) (WW) (D)]
  - ☐ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☐ Cooler (1)
  - ☐ Beverages
  - ☐ Sunscreen
  - ☐ Bug spray

Wheel/Blade #: ____________________

Sub. Level: ________________________

Time Data Saving Started: ___________

Environmental Data Sheet

Name: ______________________________ **Date:** ___/___/___

Field Information

Temperature (°F): __________ **Wind Speed (mph):** __________ **Wind Direction:** __________

Current Direction: __________ **Sea State:** ______________________________

Sky/Sun Conditions: ______________________________

Miscellaneous Observations: ______________________________

Appendix E: Autonomy Testing Procedure

Autonomy Field Testing Procedure

Table of Contents

Goals and Objectives

In-water autonomy testing of the WAMV will allow the software team the ability to implement code and verify results. With the ability to receive real-time feedback, the software team can identify inefficiencies and streamline the development of various controllers required for autonomous navigation. The software team has been tasked to program the MHK Platform where it can perform all scripted tasks without human intervention, effectively making the MHK Platform fully autonomous. To do this, the vessel must complete various tasks as programmed by the software team. These tasks shall include navigation and transportation to and from the testing site via the onboard GPS and vision system, automatic deployment and retraction of the FSWW, and shall be able to deploy and retract the anchor, without assistance. To achieve this, several navigational controllers must be developed. These controllers include a path planning controller, a station keeping controller, and a waypoint following controller. The AAS requires all the WAMV's electronic systems to be integrated, and for all functional protocols to be programmed and scripted through ROS. Thus, the primary objective is to verify that the code programmed by the software team effectively performs all the required tasks, as previously mentioned.

Testing Sites

Due to a davit failure at SeaTech two sites were used for autonomy testing. Initial tests in Summer of 2023 were conducted in North Lake at Holland Park in Hollywood FL.

Figure 1: Boat ramps at Holland Park

Figure 1, shows the boat ramps used to access the water. Once in the water, the vessels navigated to North Lake for testing, as it had larger areas of open water and lower boat traffic, Figure 2.

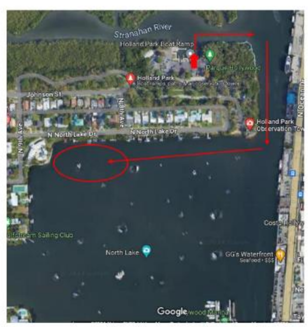


Figure 2: North Lake Testing Area

2

The testing area shown by the red oval in Figure 2. This test site was used throughout summer testing. The second site for autonomy testing was the marina and Whiskey Creek near SeaTech, Figure 3.

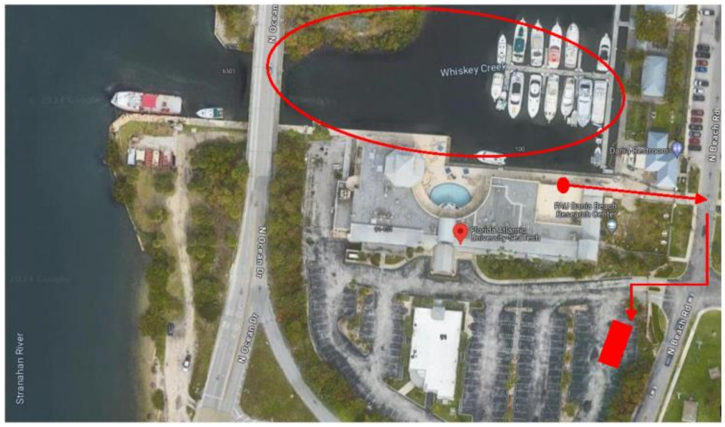


Figure 3: FAU SeaTech Testing Area

Figure 3 shows the SeaTech testing area with a red oval outline. The red arrows leading from the rollup door in room 117 through east property into the parking lot to the red rectangle show the route that the chase boat and the WAMV had to be pushed (on their cats) to be trailered for testing at Holland Park.

<u>Description of Tests</u>

Holland Park

The tests at this site were in development of the three controllers listed above (a path planning controller, a station keeping controller, and a way point following controller). A summary of what this entails is as follows. First the autonomy checklist was used to ensure everything was gathered and ready to be taken to the truck prior to leaving the lab. After the supplemental equipment like tools, laptops, a battery and inverter, chargers, sunscreen and bug spray were collected, the WAMV and chase boat were prepared for departure. Once ready for departure, both vessels were pushed to the ramp at east property. The ramp was adjusted depending on which vessel would be descending it, then the vessel was guided down the ramp by at least three people. The vessel was then pushed out the gate and into the SeaTech parking lot where it would be trailered. After the vessel was trailered it would be taken to the boat ramp at Holland Park, approximately a fifteen-minute drive one way. At the boat ramp the team would launch the first vessel and tie it off at the dock. A team member would remain with the vessel to ensure its safe keeping and the rest of the team would return to campus to pick up the second vessel. The second vessel would be pushed the remainder of the way to the staging area, loaded, and driven to Holland Park. Once it arrived and was tied off to the dock, the truck would be parked, and all axillary equipment would be moved from the truck onto the chase boat. After loading and boarding, the chase boat would then follow the WAMV to the designated testing area, the route shown in Figure 2 (the WAMV would be driven via remote control from the chase boat). Once in the testing area, around three hours were spent testing code on the vessel (or as long as the weather permitted). This consists of the software team making changes to the code on their laptops aboard the chase boat (while one person remote controlled the WAMV to ensure it was nearby and safe) and sending the adjusted code to the WAMV via Wi-Fi communications and watching the WAMV demonstrate whatever the new code told it to do. After testing was completed, the vessels navigated back to the boat ramps and the first vessel was extracted. Once trailered the first vessel was taken back to SeaTech, while one team member stayed with the second vessel at the park. The first vessel was then replaced back on its cart at SeaTech and pushed back into the lab while the truck went back to the park and trailered the second vessel. When the second vessel arrived back to campus, it was placed back on its cart and pushed back to a secured location. The entire deployment and retrieval process generally takes anywhere from an hour and a half to two hours. This process, done twice in one day, led to significant amounts of time being spent on operations rather than testing, which is not standard considering the davit can deploy a vessel within ten minutes when functioning properly.

SeaTech Marina

Testing at SeaTech required much less deployment and retrieval time as opposed to Holland Park. A few missions were run in November, however a manufacturing error on the davit's motor, gearbox, and power switch required maintenance work and put the team completely out of commission. Once the davit was fully operational, the testing process went as follows. The WAMV was prepared for deployment and then pushed out of the lab directly to the davit staging area (approximately ten feet from the lab). The WAMV would then be rigged up and hoisted into the water directly off the deck. The WAMV was then tied off to the dock while the team set up the working area (a folding table with chairs near the west side of campus). After the work area was set up the WAMV would be remote controlled out of the area directly in front of the lab and into the larger marina area where it would be tested. Testing in this area was mainly AAS related. This meant that the vessel would face up current, be told to drop and retrieve the anchor and its behavior monitored and adjusted until it consistently operated as intended. After the days' testing was complete the WAMV would be remote controlled back to the area near the lab, retrieved with the davit, and pushed back into the lab. With this deployment method taking approximately thirty minutes much more time could be spent testing per designated testing day. While the WAMV was deployed in the marina one team member was to be on kayak duty. In the event that the WAMV lost communication with the shore-based team or failed to respond, becoming stranded in the marina, the team member would deploy the kayak from the floating dock and retrieve the WAMV. This never happened, but the precaution was still in place.

<u>Holland Park Testing Procedure</u>

1. Approximately five days prior to testing a float plan must be submitted to the university to ensure the vessels' safe keeping and to reserve the time of a university employed boat captain (for operations of the chase boat). During this step the full day of operations should be planned, outline the crew's arrival time to campus, the vessels deployment time, the vessels retrieval time, and the return to campus for testing cleanup time.

2. Ensure that all batteries have been properly charged, this includes the main system battery, the thruster batteries, the RC remote batteries, and the programing power station battery.
3. Remount any batteries that were removed from the WAMV for charging.
4. Have two people double check every electrical connection and connector on the WAMV systems.
5. Ensure there are no unsecured items resting/sitting on the WAMV.
6. Ensure all electronics boxes and batteries are mounted and secured properly.
7. Perform systems check prior to leaving the lab, check communications, the GPS and the IMU.
8. Ensure the pontoons have sufficient air pressure.
9. Next ensure the chase boat is ready for deployment. Check the fuel tank level and the inflation level of the boat.
10. Ensure the safety chest is in the chase boat and properly loaded. Ensure there are enough life jackets on board for the entire crew that day.
11. Gather all auxiliary equipment and load it into the truck.
12. Move the truck and trailer to the staging area.
13. Return to the lab, open the rollup door, and push the chase boat out and to the ramp. Ensure that the ramp is configured for the chase boat's wheel width. And make sure the lifeguard's ATV and the marina's golf cart are not in the path of the boat.
14. With at least three people, guide the chase boat down the ramp.
15. Push the chase boat out the gate through Dania Beach parking lot and into the SeaTech parking lot. Make sure to place the steel plates over the gate's track upon entering the parking lot or the chase boat cart could lose a wheel.
16. Stop the cart directly behind the trailer.
17. Run ratchet straps (at least four sets) across the width of the trailer creating a cradle to support the bottom of the chase boat (the trailer had 2 pontoon rails and did not have a flat surface to rest the chase boat on).
18. Allow an FAU forklift certified employee to forklift the chase boat from its cart and place it on the trailer.
19. Once the chase boat is on the trailer ratchet, strap the vessel to the trailer (using at least 3 rachet straps).
20. Have one team member push the cart under the car cover by the lobby, so that it is protected from the rain while the team is out testing.
21. Have two team members remain at SeaTech to push the WAMV out of the lab and to the ramp while the truck takes the chase boat to Holland Park. Once the WAMV has been pushed to the ramp, move the ramps so that they accommodate the wheel width of the WAMV. Wait for the truck and the driver to return prior to pushing the WAMV down the ramp.
22. Once the truck has arrived with the chase boat at Holland Park, and has been backed into a ramp stall, the ratch straps securing the boat to the trailer must be removed. Once the straps are removed the boat's bow and stern lines should be held from shore while the boat is reversed into the water. Once the boat is tied off to the dock a team member needs

to remove the ratchet straps that span the cross section of the trailer, so that the WAMV may sit in the pontoon rails once loaded onto the trailer. One team member must remain with the vessel while the truck returns to SeaTech to pick up the WAMV.

23. Once the truck has returned to SeaTech, the WAMV would be guided down the ramp by at least three people. Once down the ramp the WAMV would be pushed the remainder of the way to the staging area.
24. The WAMV would be placed directly behind the trailer, so that it could be lifted onto the trailer by the forklift.
25. After the FAU forklift certified employee has lifted the chase boat from its cart and placed it on the trailer (with the forklift) the team then rachet straps the WAMV (in four places) onto the trailer.
26. Next the WAMV and the rest of the team are driven to Holland Park.
27. Once at Holland Park and reversed into the ramp stall, the straps holding the WAMV to the trailer must be removed.
28. Once the WAMV is free from the trailer, the bow and stern lines should be held from shore as the vessel is reversed into the water, then the vessel should be tied off to the dock.
29. Now that both vessels are deployed and tied off to the dock, the auxiliary equipment for testing should be loaded into the chase boat.
30. Now the WAMV electronic systems should be powered on and checked for proper functionality prior to leaving the dock.
31. After the systems have been verified at the dock the crew may don their life jackets, untie the vessels, and board the chase boat for departure.
32. Now the WAMV is driven via remote control (from the chase boat) as both vessels navigate to the testing location in North Lake.
33. Once in the testing location, the software team begins their work, one person monitors the WAMV's position relative to the chase boat with the RC remote, and the chase boat's captain manages the situation in accordance with safe maritime practices.
34. After testing has been completed for the day, both vessels have been navigated back to the docks at the boat ramps, and tied off, the retrieval processes begin.
35. Power down the WAMV's electrical systems and place all auxiliary equipment back in the truck and reverse the truck into the ramp stall with the chase boat in it.
36. The team should then replace the ratchet straps across the trailer's pontoon rails, ensuring the chase boat has the proper cradle to rest in. Reverse the trailer into the water to retrieve the vessel.
37. Next negotiate the chase boat back onto the trailer using the lines and by pulling it from the front bow ring.
38. Once the chase boat is back on the trailer, ratchet strap it in place, securing it back to the trailer.
39. After the chase boat is secured, two team members should return to SeaTech with the truck. While one team member remains with the WAMV at the park.

40. After reaching SeaTech and parking in the staging area, the ratchet straps securing the chase boat to the trailer should be removed. And the chase boat's cart should be pushed back into place behind trailer.
41. The FAU forklift certified employee should then lift the chase boat from the trailer (with the forklift) and place it back into its cart.
42. The chase boat should then be pushed (by at least 3 people) back into the lab, through the same route taken to reach the staging area. Again, make sure to place the small steel plates over the gate's tracks prior to pushing the WAMV over them to ensure the wheels and the cart are not damaged.
43. The team should then return to Holland Park to retrieve the WAMV.
44. When back at Holland Park and reversed into the boat ramp with the WAMV in it, negotiate the WAMV back onto the trailer using the lines and by pulling it from the front support structure.
45. Once the WAMV is on the trailer and pulled out of the water, secure it to the trailer in four places with rachet straps. Return to SeaTech with the truck.
46. Upon arrival to SeaTech if there is more testing to be conducted that week see step 37.a. If that is the last outing of the week see step 37.b.
    a. The WAMV may be parked on the trailer in the gated area on the west side of campus. Here the trailer can be chained to the building and the gate closed for security of the vessel. Next the vessel and trailer are rinsed with fresh water, the batteries are removed for charging, and the vessel is covered with tarps.
    b. Should that be the final testing trip of the work week follow steps 47-51 for final vessel stowing instructions.
47. The WAMV's carts should be pushed back to the staging area (stopping directly behind the trailer). The ratchet straps should also be removed, freeing the WAMV from the trailer.
48. The FAU forklift certified employee should then lift the WAMV from the trailer (with the forklift) and place it back into its carts.
49. The WAMV should then be pushed (by at least 3 people) back to the lab, through the same route taken to reach the staging area. Again, ensure to place the small steel plates over the gate's tracks prior to pushing the WAMV over them to ensure the wheels and the cart are not damaged.
50. Prior to pushing the WAMV back into the lab, ensure it is thoroughly rinsed with fresh water to remove the salt for that day's operations.
51. After allowing the WAMV to air dry and the carts to drain, push the WAMV back into the lab and charge the batteries.

SeaTech Marina Testing

Figure 4: Testing in the Marina

1. Approximately five days prior to testing, a float plan must be submitted to the university to ensure complete adherence to FAU's boating policies. Even though no human manned vessels are anticipated to enter the water, it is best practice to submit a float plan for the kayak, should it be necessary to rescue the WAMV in the marina. During this step the full day of operations should be planned, outline the crew's arrival time to campus, the vessels deployment time, the vessels retrieval time. Outline how and where the kayak will be staged, who will be operating it, and clearly state that the kayak is being staged simply as an emergency precaution.
2. Conduct steps 2-8 in the above procedure to ensure the WAMV is ready to deploy.
3. Next, open the rollup door and push the WAMV out of the lab, to the davit staging area, approximately ten feet.
4. Properly rig the WAMV and hoist it into the water with davit. This is a two-person job. One person should be operating the davit, and the second person should be operating the lines on the WAMV to prevent it from swinging or hitting the rails or dock.
5. Once the WAMV is in the water it should be tied off to the dock.
6. Once tied off, a systems check should be run to verify proper functionality prior to leaving the dock.
7. After the systems check, the team should set up the working area on the deck near the west side of campus. This includes, setting up a folder table, placing chairs, laptops, and the programing power station.
8. After the dock-based work area is set up, the kayak should be staged on the floating dock in front of the McAllister.
9. Next the WAMV should be untied from the dock and driven via remote control out of the small area near the davit, into the larger marina area.
10. Testing shall then be conducted.
11. Once testing is completed for the day, the WAMV should be driven back into the area near the davit for retrieval.

12. Properly rig the WAMV and hoist it back into its carts on the upper deck. Follow the same personnel requirements as outlined in step 4.
13. Once the WAMV is in its carts, detach the rigging, power down the WAMV's electronics, and rinse the vessel with fresh water.
14. Next conduct steps 50-51 from the procedure above.

Appendix F: Original Testing Schedule

Phase One End Date	KEY
11/30/2023	Tide times need to be confirmed in Nov.

Date	Task	Tide/Time	Boat	Staff/Crew	Location	PTO	Code	Drone	Anchoring sys.	Electronics
Oct. 20	DAVIT IS INSTALLED	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Oct. 23	*Tentative* WAMV Controller Tunning (WAMV Nav. Testing)	Low to High 9:50A to 4:20P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed on WMAV	Installed on WAMV
Oct. 24	Anchor Sys. Testing	Low to High 10:55A to 5:20P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed on WMAV	Installed on WAMV
Oct. 25	Anchor Sys. Testing	Low to High 11:55A to 6:20P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed on WMAV	Installed on WAMV
Oct. 26	WAMV Controller Tunning (WAMV Nav. Testing) (Vision & Obstacle Avoidance)	Low to High 12:50A to 7:05P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed on WMAV	Installed on WAMV
Oct. 27	WAMV Controller Tunning (WAMV Nav. Testing) (Vision & Obstacle Avoidance)	High to Low 7:40A to 1:50P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed on WMAV	Installed on WAMV
Oct. 30	WAMV Controller Tunning (WAMV Nav. Testing) (Vision & Obstacle Avoidance)	High to Low 10:10A to 4:15P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed on WMAV	Installed on WAMV
Oct. 31	WAMV Controller Tunning (WAMV Nav. Testing) (Vision & Obstacle Avoidance)	High to Low 10:50A to 4:55P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed on WMAV	Installed on WAMV
Nov. 1	WAMV Controller Tunning (WAMV Nav. Testing) (Vision & Obstacle Avoidance)	High to Low 11:40A to 5:45P	kayak	Caleb, RC Person, Deployment Help	Marina	n/a		n/a	Installed & Functional	Installed on WAMV
Nov. 2	Autonomous Anchor Sys. Testing Mission	High to Low 12:30P to 6:35P	Chase Boat	Caleb, RC Person, Deployment Help	1.3	n/a		n/a	Installed & Functional	Installed on WAMV
Nov. 3	Autonomous Anchor Sys. Testing Mission	High to Low 1:20P to 7:30P	Chase Boat	Caleb, RC Person, Deployment Help	1.3	n/a		n/a	Installed & Functional	Installed on WAMV
Nov. 6	Autonomous Anchor Sys. Testing Mission	Low to High 8:40A to 3:10P	Chase Boat	Caleb, RC Person, Deployment Help	1.3	n/a		n/a	Installed & Functional	Installed on WAMV
Nov. 7	PTO Integration	Low to High 9:40A to 4:00P		Caleb, RC Person, Deployment Help	LAB 117	n/a		n/a	Installed on WMAV	Installed on WAMV
Nov. 8	PTO Integration	Low to High 10:30A to 4:45P		Caleb, RC Person, Deployment Help	LAB 118	n/a		n/a	Installed on WMAV	Installed on WAMV
Nov. 9	PTO Integration	Low to High 11:15A to 5:25P		Caleb, RC Person, Deployment Help	LAB 119	n/a		n/a	Installed on WMAV	Installed on WAMV
Nov. 10	VETERAN'S DAY									
Nov. 13	7 blade Sub. 1 Test	High to Low 8:00A to 2:00P	Chase Boat	Adriana, Hugo, John	Dockside	Installed on WAMV		n/a	Installed on WMAV	Installed on WAMV
Nov. 14	7 blade Sub. 2 Test	High to Low 8:40A to 2:40P	Chase Boat	Adriana, Hugo, John	Dockside	Installed on WAMV		n/a	Installed on WMAV	Installed on WAMV
Nov. 15	USWW Transition	High to Low 9:20A to 3:20P			LAB 117			n/a	Installed on WMAV	Installed on WAMV
Nov. 16	9 blade Sub. 1 Test	High to Low 10:10A to 4:05P	Chase Boat	Adriana, Hugo, John	Dockside	Installed on WAMV		n/a	Installed on WMAV	Installed on WAMV
Nov. 17	9 blade Sub. 2 Test	High to Low 11:00A to 5:00P	Chase Boat	Adriana, Hugo, John	Dockside	Installed on WAMV		n/a	Installed on WMAV	Installed on WAMV
Nov. 20	USWW Transition	Low to High 7:30A to 2:00P			LAB 117			n/a	Installed on WMAV	Installed on WAMV
Nov. 21	11 blade Sub. 1 Test	Low to High 8:35A to 3:00P	Chase Boat	Adriana, Hugo, John	Dockside	Installed on WAMV		n/a	Installed on WMAV	Installed on WAMV
Nov. 22	THANKSGIVING BREAK									
Nov. 23	THANKSGIVING BREAK									
Nov. 24	THANKSGIVING BREAK									
Nov. 27	11 blade Sub. 2 Test	High to Low 8:00A to 2:00P	Chase Boat	Adriana, Hugo, John	Dockside	Installed on WAMV		n/a	Installed on WMAV	Installed on WAMV
Nov. 28								n/a	Installed on WMAV	Installed on WAMV
Nov. 29	Full DEMO	High to Low 9:30A to 3:30P	McAlister	Adriana, Hugo, John, Dhanak & DOE People	1.3	Installed on WAMV		Present for DEMO	Installed & Functional for DEMO	Installed & Functional for DEMO
Nov. 30	Full DEMO	High to Low 10:15A to 4:15P	McAlister	Adriana, Hugo, John, Dhanak & DOE People	1.3	Installed on WAMV		Present for DEMO	Installed & Functional for DEMO	Installed & Functional for DEMO

*times are straight up
*need to add 40 min for USWW deployment days (don't want to snag slack tide)

Appendix G: MHK Field-testing Procedure

MHK Turbine & Platform Field Testing Procedure

Table of Contents

Goals and Objectives

The primary objective is to verify the MHK Platform's power production from the MHK turbine in open water, and to create a standardized operational procedure. To verify the optimal power production, the turbine will be tested in three different blade configurations which are the 7-blade, 9-blade, and 11-blade configurations. Furthermore, each blade configuration will be tested at two submergence levels. These two levels will consist of a full blade submergence and half blade submergence. An analysis will be conducted on the systemic configurations to determine their effects on the platform's performance. This analysis will then be used to generate a system configuration that produces maximum power. The autonomous behavior of the MHK Platform must be fully demonstrated and perform the following tasks. The vessel shall perform a fully autonomous demonstration and must navigate to a predetermined location, anchor itself, drop the FSWW, harvest energy, stow the FSWW, un-anchor itself, and navigate back to its home position.

Testing Sites

The MHK Turbine will be tested at the ICW Dockside testing location, Figure 1.

Figure 1: ICW Dockside (left) water depth contour map (right)

The WAMV will be deployed using the davit at SeaTech and the WAMV will be driven via remote control to the final testing location shown within the red rectangle in Figure 1. The MHK Platform autonomy demonstration will take place at test site 1.3, illustrated in Figure 2.

2

Figure 2: Site 1.3 (left & middle) water depth contour map (right)

Description of Tests

Several sets of tests will be conducted to verify the power production of the MHK turbine. These include 7, 9, and 11 blade wheel configurations at full and half blade submergence in the ICW. It shall also include the MHK Platform completing the autonomous mission as outlined in Goals and Objectives. The chase boat will first be deployed with the davit, so that anchor lines can be deployed for the MHK platform and the buoy testing exclusion zone. Then the WAMV shall be prepared for deployment and pushed out of the lab directly to the davit staging area (approximately ten feet from the lab). The WAMV will then be rigged up and hoisted into the water directly from the deck. The WAMV will then be tied off to the dock while the team runs system checks. System checks shall be completed prior to leaving the dock. After verification, the team will set up the shore-based watch location near the tow boat all the way on west property, right by the testing location, as illustrated in Figure 1. Next the MHK Platform will be deployed and attached to the previously set anchor line. Once the MHK Platform is attached to the anchor line, the FSWW will be deployed and allowed to harvest the current's hydrokinetic energy for the full length of a high to low tide cycle or low to high tide cycle. At the end of the cycle, the MHK Platform will be unhooked from the anchor line and returned to the davit for retrieval. Exact procedures for the tests are outlined in the following segment. The autonomous navigation mission will run in the exact same manner except the MHK Platform will demonstrate its autonomous mission and return to the initial place it was anchored for MHK turbine testing. The MHK Platform will be escorted by the chase boat as it demonstrates it autonomy to ensure safety and allow observation.

Supporting Equipment

A BlueRobotics sonar pinger was used to determine the depth of the water that the vessel was in. An AIRMAR UST800 Ultrasonic Speed sensor was used to determine the speed of the flow when the boat was at anchor.

MHK Turbine Field Testing Procedure

1. Approximately five days prior to testing, a float plan must be submitted to the university to ensure the vessels' safe keeping and to reserve the time of a university employed boat captain (for operations of the chase boat). During this step the full day of operations

should be planned, outline the crew's arrival time to campus, the vessels deployment time and the vessels retrieval time.

2. Ensure that all batteries have been properly charged. This includes the main system battery, the thruster batteries, the RC remote batteries, and the programing power station battery.
3. Remount any batteries that were removed from the WAMV.
4. Have two people double-check every electrical connection and connector on the WAMV systems.
5. Ensure there are no unsecured items resting/sitting on the WAMV.
6. Ensure all electronic boxes and batteries are mounted and secured properly.
7. Preform systems check prior to leaving the lab, check communications, the GPS and the IMU.
8. Ensure the pontoons have sufficient air pressure.
9. Verify the chase boat is ready for deployment by checking the fuel tank level and the inflation level of the boat.
10. Ensure the safety chest is in the chase boat and properly loaded. Ensure there are enough life jackets on board for the entire crew that day.
11. Gather all auxiliary equipment and load it onto a cart and push it to the shore-based watch location near the tow boat. Setup the folding table, chairs, and programing power station.
12. Return to the lab, open the rollup door, and push the chase boat out and to the davit staging area, approximately ten feet.
13. Properly rig the chase boat and hoist it into the water with davit. This is a two-person job. One person should be operating the davit, and a second person should be operating the lines on the chase boat to prevent it from swinging or hitting the rails or dock.
14. Once the chase boat is in the water it should be pulled towards the McAlister and tied off to the dock. At this point the captain should arrive and conduct pre-launch protocols. The main MHK Platform anchor and its line and the exclusion zone buoy line and anchor should be loaded into the chase boat at this time.
15. Once ready for launch, both anchor lines must be deployed in the ICW Dockside testing location in accordance with the tide conditions. In a high to low tide cycle, the tide would be flowing north, so the anchor would need to be placed south of the testing zone so that the MHK Platform would position itself in the flow within the testing zone. For a low to high tide cycle, the flow would be heading south, so the anchor would need to be placed north of the testing zone so that the MHK Platform would position itself in the flow within the testing zone.

Figure 3: Current flowing south, low to high tide cycle

Figure 4: Current flowing north, high to low tide cycle

The buoy exclusion zone is to be dropped fifty feet west of the MHK anchor line to establish the permit required 50ft testing radius around the vessel.

16. After setting the anchor lines the chase boat and her crew are to return to the davit staging area for the testing briefing.
17. During the testing briefing ensure all testing personnel have been informed on how to detect wildlife that may approach or enter the testing area. If any animals enter the testing radius all testing is to halt until the animals exit the testing site on their own accord. If the spotters lose sight of the animal testing may resume after not having seen the creature within the testing area for 30 minutes.
18. Next, push the MHK Platform out of the lab, to the davit staging area.

19. Properly rig the MHK Platform and hoist it into the water with davit. This is a two-person job, a person should be operating the davit, and a second person should be operating the lines on the MHK Platform to prevent it from swinging or hitting the rails or dock.

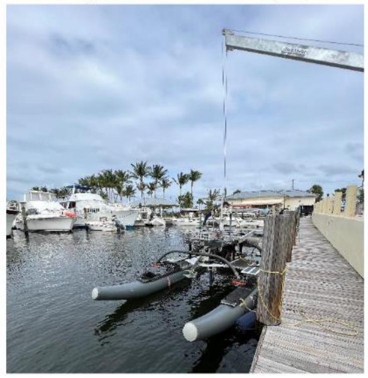


Figure 5: WAMV just lowered by davit, tied off for safety

20. Once the MHK Platform is in the water it should be tied off to the dock.
21. Once tied off, a systems check should be run to verify proper functionality prior to leaving the dock. At this time the proper submergence rod should be installed and verified as well, Figure 3. The photo shows the half blade submergence rod, a shorter rod was used for full blade submergence.

Figure 6: Submergence Rods

22. After verification, the MHK Platform should be driven via remote control to the testing area and near the attachment point on the anchor line. The chase boat will follow the MHK Platform out to the testing location.
23. After arriving at the testing location, a team member aboard the chase boat will hook the MHK Platform to the anchor line and allow the current to position the MHK Platform. Should the platform swing too far into the channel the lines were adjusted to keep the vessel out of the channel.

24. Next the chase boat returned to shore and the team took their places to monitor the MHK Platform for the duration of the testing period. The FSWW would be lowered to the deployed position via wireless communication with the MHK Platform from shore and data measurements and recording would begin the moment the FSWW begins turning.
25. After the testing period had concluded the data recording was stopped, the FSWW was stowed, and the chase boat would return to the MHK Platform and unhook it, so that it could be driven via remote control back into the area near the davit for retrieval.
26. Properly rig the MHK Platform and hoist it back into its carts on the upper deck. Follow the same personnel requirements as outlined in step 19. As the MHK Platform is being hoisted back into its cart the chase boat and an additional team member shall retrieve the anchor lines from the ICW and return for retrieval itself.
27. Once the MHK Platform is in its carts, detach the rigging, power down the electronics, and rinse the vessel with fresh water.
28. After allowing the MHK Platform to air dry and the carts to drain, push the WAMV back into the lab and charge the batteries.
29. Next position the chase boat in the within the davit's reach, rig, and hoist it into the air.
30. Prior to moving the chase boat over the cart, rinse it with fresh water.
31. After rinsing the chase boat, lower it back onto its cart and push it back into the lab.

MHK Autonomous Mission Demonstration Procedure

1. Conduct steps 1-23, of the above testing procedure excluding step 11. This establishes the MHK Platform at the testing site and shows it demonstrating the functional FSWW. The team is also still in the chase boat near where the MHK Platform is deployed.
2. After the team is satisfied with the demonstration of the FSWW, the FSWW should be moved to the stowed position and any data recording should be ended.
3. Next a team member on the chase boat should unhook the MHK Platform from the anchor line and hold it until the software team instructs them that the MHK Platform has been place in "Auto Mode," at which point the MHK Platform should be released, and it should begin its autonomous mission.
4. The chase boat should flow the MHK Platform as it navigates to the predetermined location and observe its behavior ensuring the programmed tasks are completed as expected.
5. After the MHK Platform returns to its home location at the ICW Dockside "Auto Mode" will be switched back to "Manual Mode" and the MHK Platform should be driven via remote control back into the marina and to the davit for retrieval.
6. Next conduct steps 26-31 from the procedure above.

Appendix H: Testing Schedules

Date:	11-Dec
Test:	USWW Wheel - 9 Blade
Wheel Submergence (in)	Full Blade
Location:	ICW Dockside

Time	Tides	Task	Personnel	Notes
6:00am				
6:30am				
7:00am				
7:30am	High tide 7:20	Arrive @ SeaTech	Caleb, Adriana, Hugo, John	Begin preparations for blade testing, see pre-testing checklist
8:00am	(factor in tide change)	DEPLOY - Launch WAMV	Caleb, Adriana, Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
8:30am		Start Measurements	Caleb, Adriana, Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
9:00am		Cont. testing	Caleb, Adriana, Hugo	Start logging measurements from shore
9:30am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
10:00am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
10:30am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
11:00am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
11:30am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
1:30pm	Low Tide 1:25	Retrieve WAMV	Caleb, Adriana, Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
2:00pm				
2:30pm				
3:00pm				
3:30pm				
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Date:	12-Dec
Test:	USWW Wheel - 9 Blade
Wheel Submergence (in)	1/2 Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am	High tide 8:00	Arrive @ SeaTech	Adriana, Hugo, John	Begin preparations for blade testing, see pre-testing checklist
8:30am	(factor in tide change)	DEPLOY - Launch WAMV	Adriana, Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
9:00am		Start Measurements	Adriana, Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
9:30am		Cont. testing	Adriana, Hugo	Start logging measurements from shore
10:00am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
10:30am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
11:00am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
11:30am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
1:30pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
2:00pm	Low Tide 2:00	Retrieve WAMV	Adriana, Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
2:30pm		Transition to the 7 Blade Wheel	Adriana, Hugo, John	Switch from 9 to the 7 blade wheel configuration
3:00pm		Transition to the 7 Blade Wheel	Adriana, Hugo, John	Switch from 9 to the 7 blade wheel configuration
3:30pm		Transition to the 7 Blade Wheel	Adriana, Hugo, John	Switch from 9 to the 7 blade wheel configuration
4:00pm		Transition to the 7 Blade Wheel	Adriana, Hugo, John	Switch from 9 to the 7 blade wheel configuration
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Date:	10-Jan
Test:	USWW Wheel -7 Blade
Wheel Submergence (in)	Full Blade
Location:	ICW Dockside

GOOD DATA
*had to tow WAMV into Place

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am	High tide 7:45	Arrive @ SeaTech	Caleb, Adriana, Hugo, John	Begin preparations for blade testing, see pre-testing checklist
8:30am	(factor in tide change)	DEPLOY - Launch WAMV	Caleb, Adriana, Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
9:00am		Start Measurements	Caleb, Adriana, Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
9:30am		Cont. testing	Caleb, Adriana, Hugo	Start logging measurements from shore
10:00am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
10:30am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
11:00am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
11:30am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
1:30pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
2:00pm	Low Tide 1:45	Retrieve WAMV	Caleb, Adriana, Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
2:30pm				
3:00pm				
3:30pm				
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Date:	11-Jan	
Test:	USWW Wheel - 7 Blade	BAD DATA REDO
Wheel Submergence (in)	1/2 Blade	*had to tow WAMV into Place
Location:	ICW Dockside	

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am				
8:30am	High tide 8:30	Arrive @ SeaTech	Caleb, Adriana, Hugo, John	Begin preparations for blade testing, see pre-testing checklist
9:00am	(factor in tide change)	DEPLOY - Launch WAMV	Caleb, Adriana, Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
9:30am		Start Measurements	Caleb, Adriana, Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
10:00am		Cont. testing	Caleb, Adriana, Hugo	Start logging measurements from shore
10:30am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
11:00am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
11:30am		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
1:30pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
2:00pm		Cont. testing	Caleb, Adriana, Hugo	Monitor measurements and wheel from shore
2:30pm	Low Tide 2:30	Retrieve WAMV	Caleb, Adriana, Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
3:00pm		~*May need to change wheel to a more ideal configeration for the DEMO*~		
3:30pm		~*May need to change wheel to a more ideal configeration for the DEMO*~		
4:00pm		~*May need to change wheel to a more ideal configeration for the DEMO*~		
4:30pm		~*May need to change wheel to a more ideal configeration for the DEMO*~		
5:00pm		~*May need to change wheel to a more ideal configeration for the DEMO*~		
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Date:	16-Jan
Test:	USWW Test 7 Blade
Wheel Submergence (in)	1/2 Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am	Low tide 6:30			
7:00am	(factor in tide change)	Arrive @ SeaTech	Adriana, Hugo, John	Begin preparations for blade testing, see pre-testing checklist
7:30am		DEPLOY - Launch WAMV	Adriana, Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
8:00am		Start Measurements	Adriana, Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
8:30am		Cont. testing	Adriana, Hugo	Start logging measurements from shore
9:00am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
9:30am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
10:00am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
10:30am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
11:00am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
11:30am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
12:30pm	High Tide 12:30	Retrieve WAMV	Adriana, Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
1:00pm				
1:30pm				
2:00pm				
2:30pm				
3:00pm				
3:30pm				
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Date:	17-Jan
Test:	USWW Test 9 Blade
Wheel Submergence (in)	Full Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am	Low tide 7:30	Arrive @ SeaTech	Adriana, Hugo, Xavi, John	Begin preparations for blade testing, see pre-testing checklist
8:00am	(factor in tide change)	DEPLOY - Launch WAMV	Adriana, Hugo, Xavi, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
8:30am		Start Measurements	Adriana, Hugo, Xavi, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
9:00am		Cont. testing	Adriana, Hugo, Xavi	Start logging measurements from shore
9:30am		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
10:00am		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
10:30am		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
11:00am		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
11:30am		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
1:30pm	Low Tide 1:30	Retrieve WAMV	Adriana, Hugo, Xavi, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
2:00pm				
2:30pm				
3:00pm				
3:30pm				
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Date:	18-Jan
Test:	USWW Test 9 Blade
Wheel Submergence (in)	1/2 Blade
Location:	ICW Dockside

~charge contoller didn't start had to reschedule testing~

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am				
8:30am	Low tide 8:30	Arrive @ SeaTech	Adriana, Hugo, John	Begin preparations for blade testing, see pre-testing checklist
9:00am	(factor in tide change)	DEPLOY - Launch WAMV	Adriana, Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
9:30am		Start Measurements	Adriana, Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
10:00am		Cont. testing	Adriana, Hugo	Start logging measurements from shore
10:30am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
11:00am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
11:30am		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
1:30pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
2:00pm		Cont. testing	Adriana, Hugo	Monitor measurements and wheel from shore
2:30pm	High Tide 2:20	Retrieve WAMV	Adriana, Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
3:00pm				
3:30pm				
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Date:	19-Jan
Test:	USWW Test 9 Blade
Wheel Submergence (in)	1/2 Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am				
8:30am				
9:00am				
9:30am	Low tide 9:30	Arrive @ SeaTech	Adriana, Hugo, Xavi, John	Begin preparations for blade testing, see pre-testing checklist
10:00am	(factor in tide change)	DEPLOY - Launch WAMV	Adriana, Hugo, Xavi, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
10:30am		Start Measurements	Adriana, Hugo, Xavi, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
11:00am		Cont. testing	Adriana, Hugo, Xavi	Start logging measurements from shore
11:30am		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
1:30pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
2:00pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
2:30pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
3:00pm		Cont. testing	Adriana, Hugo, Xavi	Monitor measurements and wheel from shore
3:30pm	Low Tide 3:20	Retrieve WAMV	Adriana, Hugo, Xavi, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Tides Near Me: https://tidesnear.me/tide_stations/2022
Longer outlook: https://marineweather.net/tide/whiskey-creek-south-entrance-icww-fl-tides

Date:	24-Jan
Test:	USWW Test 11 Blade
Wheel Submergence (in)	Full Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am	High tide 8:00	Arrive @ SeaTech	Hugo, Xavi, John	Begin preparations for blade testing, see pre-testing checklist
8:30am	(factor in tide change)	DEPLOY - Launch WAMV	Hugo, Xavi, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
9:00am		Start Measurements	Hugo, Xavi, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
9:30am		Cont. testing	Hugo, Xavi	Start logging measurements from shore
10:00am		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
10:30am		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
11:00am		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
11:30am		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
1:30pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
2:00pm	Low tide 2:00	Retrieve WAMV	Hugo, Xavi, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
2:30pm				
3:00pm				
3:30pm				
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

Tides Near Me: https://tidesnear.me/tide_stations/2022
Longer outlook: https://marineweather.net/tide/whiskey-creek-south-entrance-icww-fl-tides

Date:	31-Jan
Test:	USWW Test 11 Blade
Wheel Submergence (in)	1/2 Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am				
8:30am				
9:00am				
9:30am				
10:00am				
10:30am				
11:00am				
11:30am		Arrive @ SeaTech	Hugo, Xavi, John	Begin preparations for blade testing, see pre-testing checklist
12:00pm	High tide 12:00			
12:30pm	(factor in tide change)	DEPLOY - Launch WAMV	Hugo, Xavi, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
1:00pm		Start Measurements	Hugo, Xavi, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
1:30pm		Cont. testing	Hugo, Xavi	Start logging measurements from shore
2:00pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
2:30pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
3:00pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
3:30pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
4:00pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
4:30pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
5:00pm		Cont. testing	Hugo, Xavi	Monitor measurements and wheel from shore
5:30pm		Retrieve WAMV	Hugo, Xavi, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
6:00pm	SUNSET			
6:30pm	Low tide 6:30			
7:00pm				

Tides Near Me: https://tidesnear.me/tide_stations/2022
Longer outlook: https://marineweather.net/tide/whiskey-creek-south-entrance-icww-fl-tides

Date:	27-Feb
Test:	USWW Test - 7 Blade
Wheel Submergence (in)	Full Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am		Arrive @ SeaTech	Hugo, John	Begin preparations for blade testing, see pre-testing checklist
7:30am	High tide 12:00			
8:00am	(factor in tide change)	DEPLOY - Launch WAMV	Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
8:30am		Start Measurements	Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
9:00am		Cont. testing	Hugo,	Start logging measurements from shore
9:30am		Cont. testing	Hugo,	Monitor measurements and wheel from shore
10:00am		Cont. testing	Hugo,	Monitor measurements and wheel from shore
10:30am		Cont. testing	Hugo,	Monitor measurements and wheel from shore
11:00am		Cont. testing	Hugo,	Monitor measurements and wheel from shore
11:30am		Cont. testing	Hugo,	Monitor measurements and wheel from shore
12:00pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
12:30pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
1:00pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
1:30pm	Low tide 1:34	Retrieve WAMV	Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
2:00pm				
2:30pm				
3:00pm				
3:30pm				
4:00pm				
4:30pm				
5:00pm				
5:30pm				
6:00pm				
6:30pm				
7:00pm				

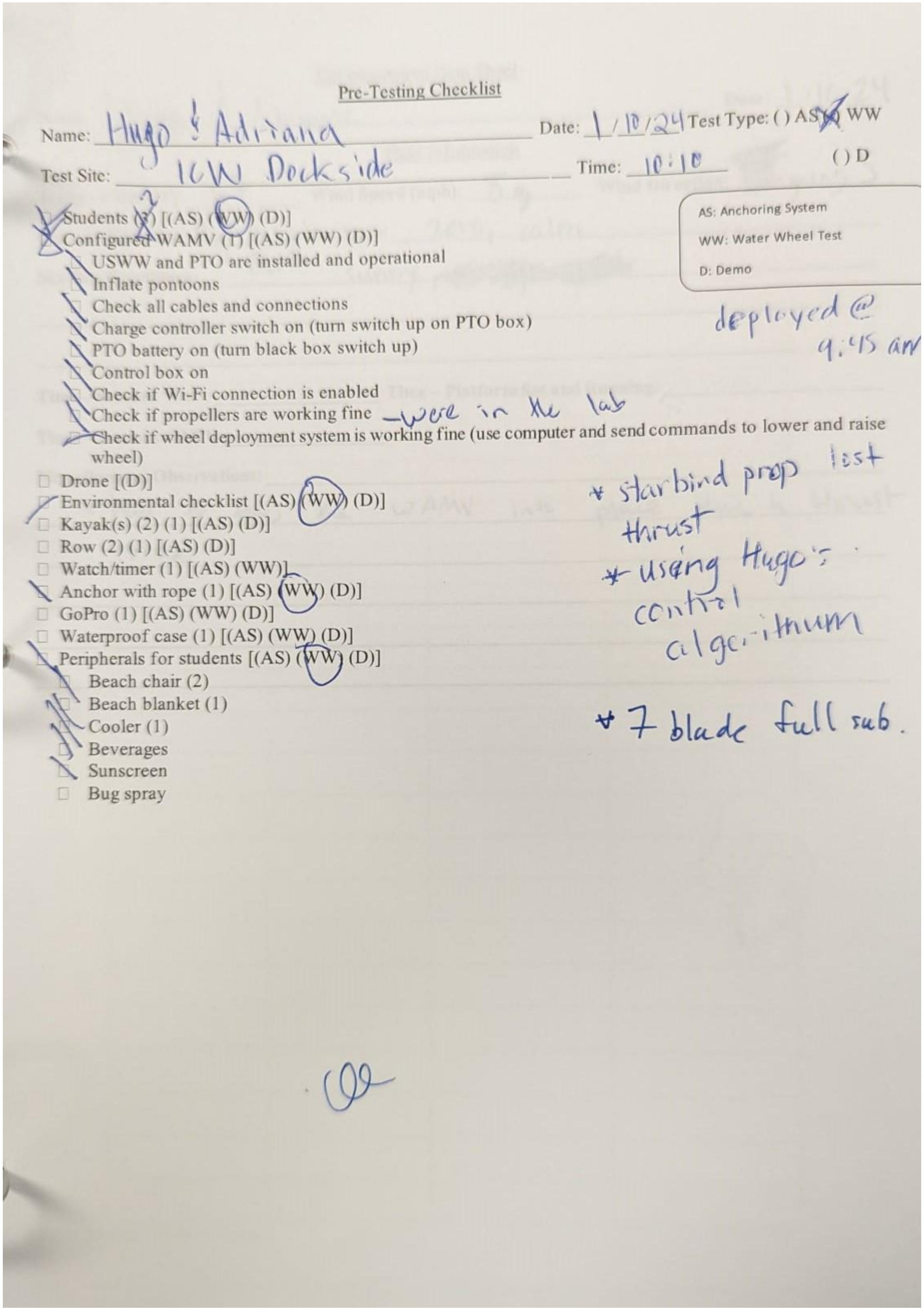
Tides Near Me: https://tidesnear.me/tide_stations/2022
Longer outlook: https://marineweather.net/tide/whiskey-creek-south-entrance-icww-fl-tides

Date:	29-Feb
Test:	USWW Test - 9 Blade
Wheel Submergence (in)	Full Blade
Location:	ICW Dockside

Time	**Tides**	**Task**	**Personnel**	**Notes**
6:00am				
6:30am				
7:00am				
7:30am				
8:00am				
8:30am				
9:00am				
9:30am				
10:00am				
10:30am				
11:00am	High tide 11:20	Arrive @ SeaTech	Hugo, John	Begin preparations for blade testing, see pre-testing checklist
11:30am	(factor in tide change)			
12:00pm		DEPLOY - Launch WAMV	Hugo, John	Launch Chase Boat, tie off to dock allow captain to do pre trip checks
12:30pm		Start Measurements	Hugo, John	Lauch WAMV with davit, RC to mooring line at ICW Dockside, attach to line, deploy wheel
1:00pm		Cont. testing	Hugo,	Start logging measurements from shore
1:30pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
2:00pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
2:30pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
3:00pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
3:30pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
4:00pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
4:30pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
5:00pm		Cont. testing	Hugo,	Monitor measurements and wheel from shore
5:30pm	Low tide 5:40	Retrieve WAMV	Hugo, John	End data logging, RC back to SeaTech, Recover w/ davit, rinse w/ fresh water, store in lab, charge batteries
6:00pm				
6:30pm				
7:00pm				

Tides Near Me: https://tidesnear.me/tide_stations/2022
Longer outlook: https://marineweather.net/tide/whiskey-creek-south-entrance-icww-fl-tides

Appendix I: Environmental Test Sheets



Pre-Testing Checklist

Name: Hugo & Adriana Date: 1/10/24 Test Type: ( ) AS (X) WW ( ) D

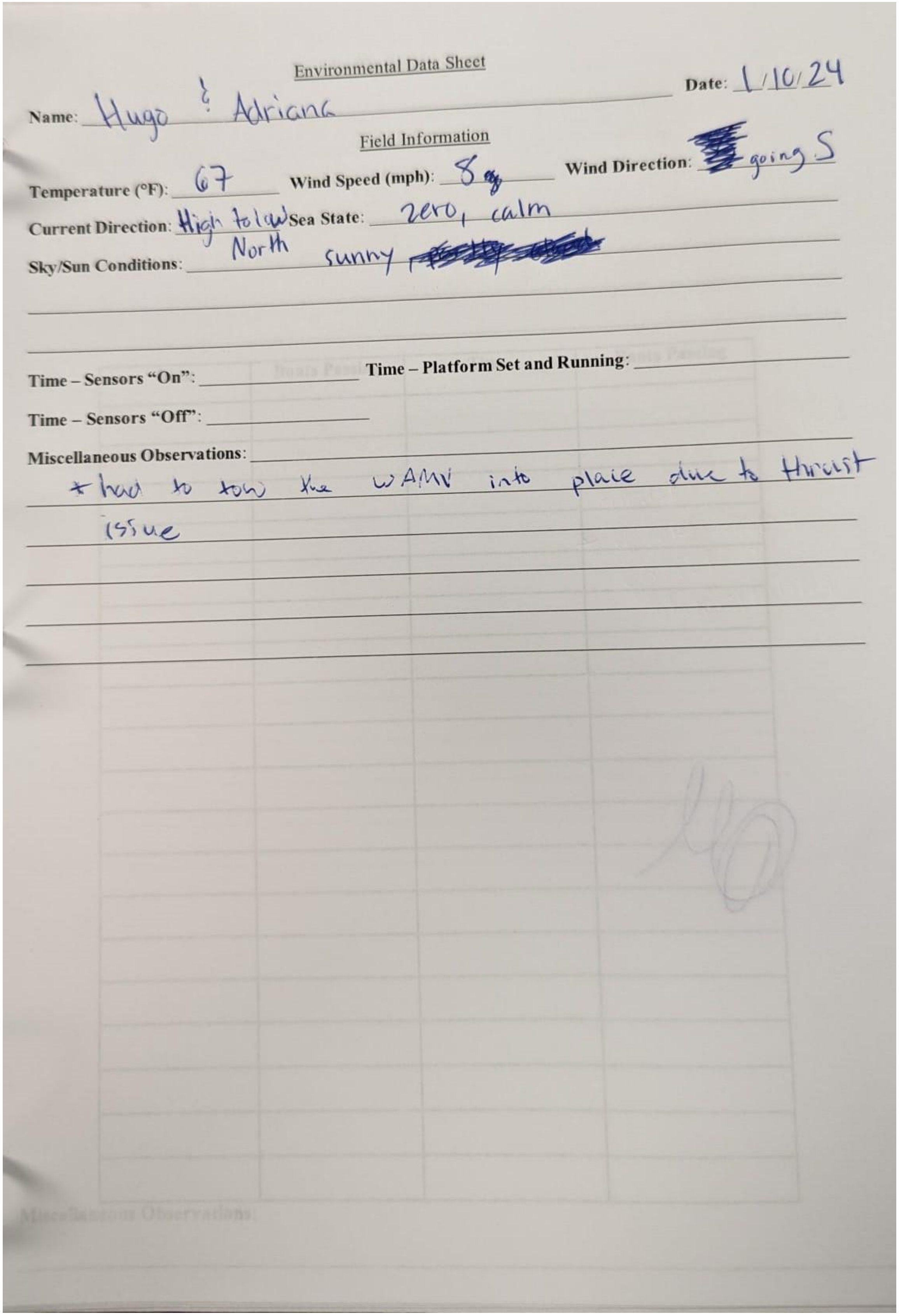
Test Site: ICW Dockside Time: 10:10

AS: Anchoring System
WW: Water Wheel Test
D: Demo

- [x] Students (2) [(AS) (WW) (D)]
- [x] Configured WAMV (1) [(AS) (WW) (D)]
  - [x] USWW and PTO are installed and operational
  - [x] Inflate pontoons
  - [x] Check all cables and connections
  - [x] Charge controller switch on (turn switch up on PTO box)
  - [x] PTO battery on (turn black box switch up)
  - [x] Control box on
  - [x] Check if Wi-Fi connection is enabled
  - [x] Check if propellers are working fine — were in the lab
  - [x] Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- [ ] Drone [(D)]
- [x] Environmental checklist [(AS) (WW) (D)]
- [ ] Kayak(s) (2) (1) [(AS) (D)]
- [ ] Row (2) (1) [(AS) (D)]
- [ ] Watch/timer (1) [(AS) (WW)]
- [x] Anchor with rope (1) [(AS) (WW) (D)]
- [ ] GoPro (1) [(AS) (WW) (D)]
- [ ] Waterproof case (1) [(AS) (WW) (D)]
- [x] Peripherals for students [(AS) (WW) (D)]
  - [x] Beach chair (2)
  - [x] Beach blanket (1)
  - [x] Cooler (1)
  - [x] Beverages
  - [x] Sunscreen
  - [ ] Bug spray

deployed @ 9:45 am

* starbird prop lost thrust
* using Hugo's control algorithum
* 7 blade full sub.



Environmental Data Sheet

Date: 1/10/24

Name: Hugo & Adriana

Field Information

Temperature (°F): 67 Wind Speed (mph): 8 Wind Direction: going S

Current Direction: High to low North Sea State: zero, calm

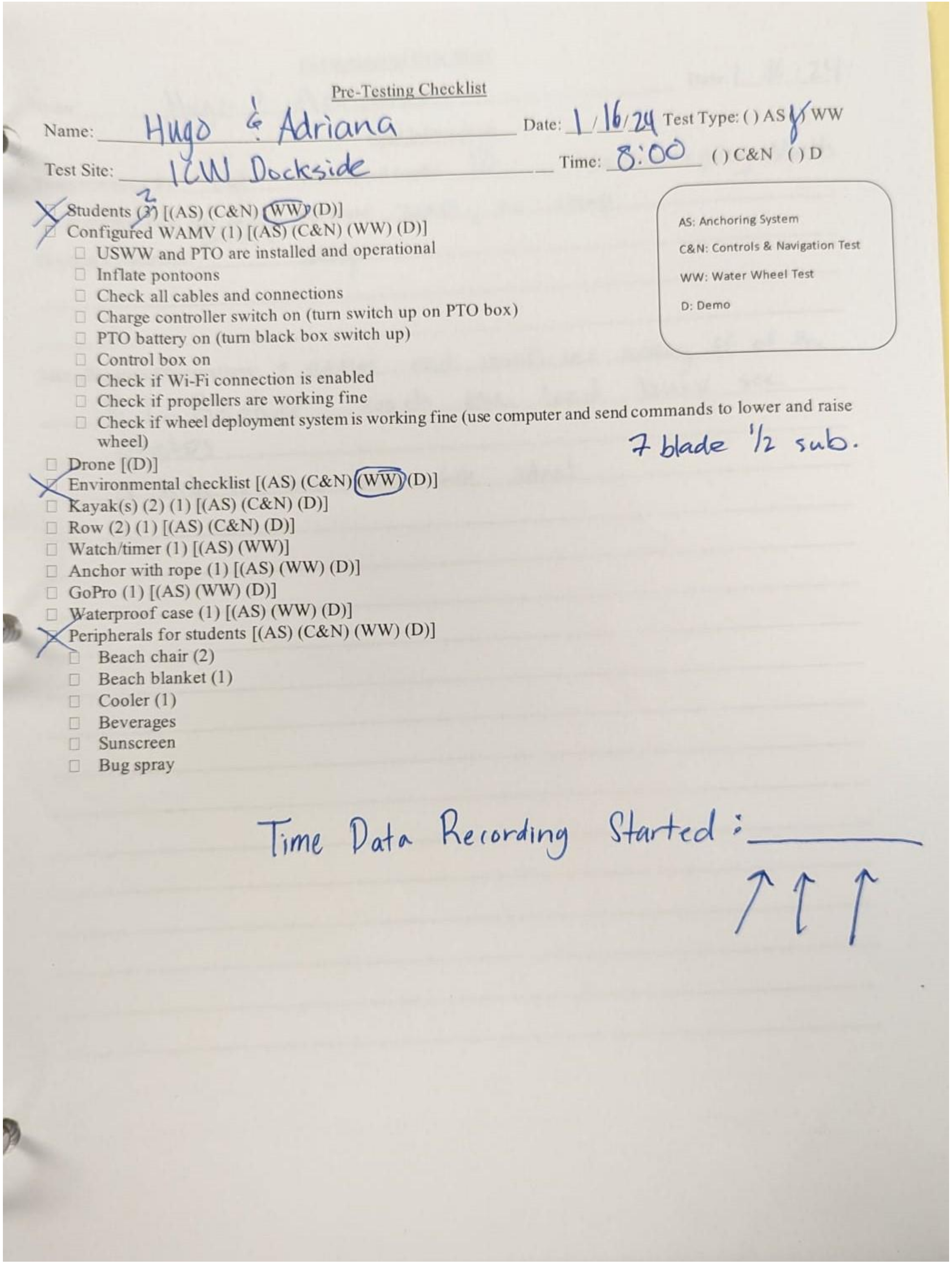
Sky/Sun Conditions: sunny

Time – Sensors "On": ______ Time – Platform Set and Running: ______

Time – Sensors "Off": ______

Miscellaneous Observations:

* had to tow the WAMV into place due to thrust issue



Pre-Testing Checklist

Name: Hugo & Adriana Date: 1/16/24 Test Type: ( ) AS (✓) WW

Test Site: ICW Dockside Time: 8:00 ( ) C&N ( ) D

AS: Anchoring System
C&N: Controls & Navigation Test
WW: Water Wheel Test
D: Demo

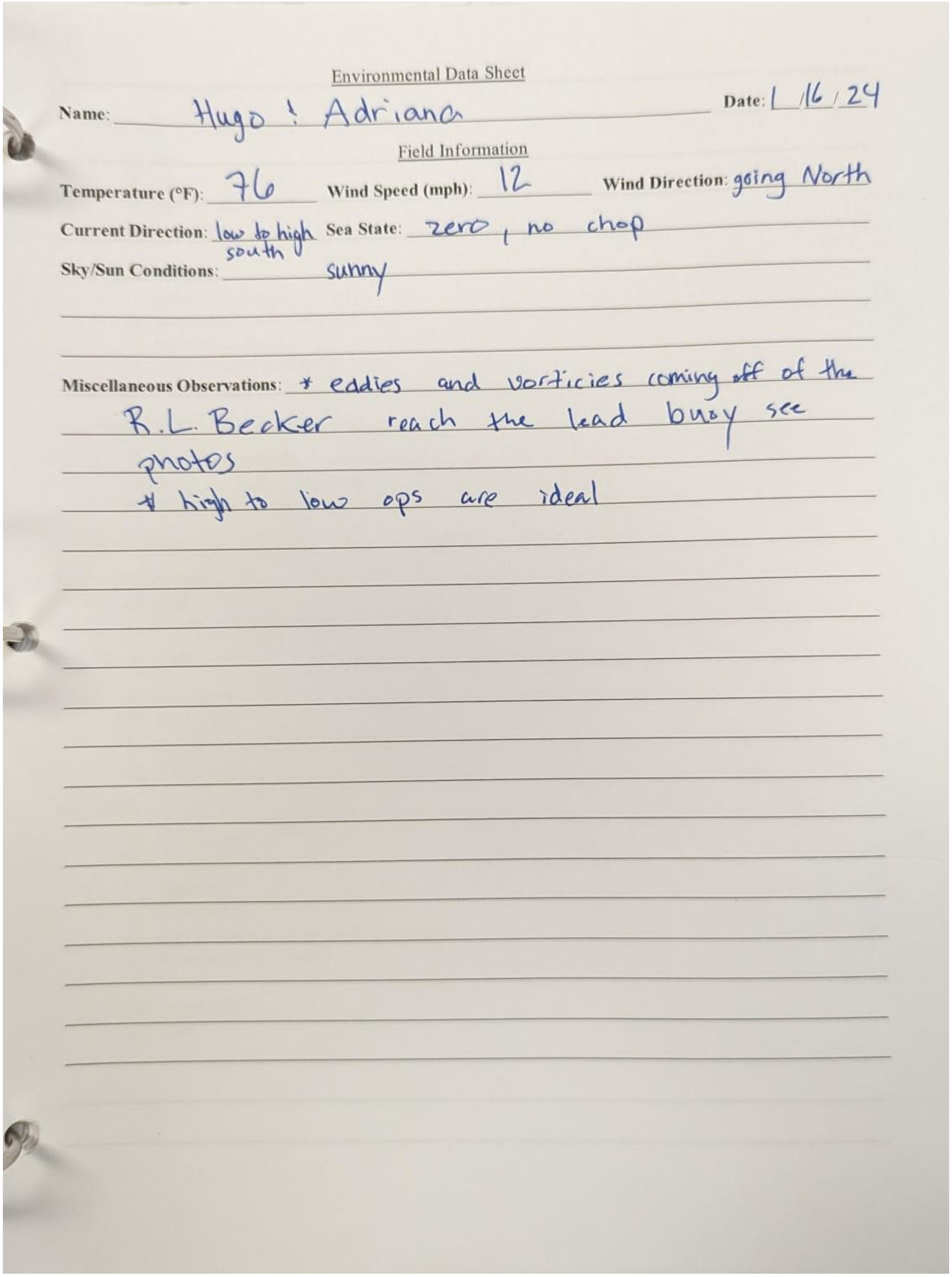
- [x] Students (3) 2 [(AS) (C&N) (WW) (D)]
- [x] Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - [ ] USWW and PTO are installed and operational
  - [ ] Inflate pontoons
  - [ ] Check all cables and connections
  - [ ] Charge controller switch on (turn switch up on PTO box)
  - [ ] PTO battery on (turn black box switch up)
  - [ ] Control box on
  - [ ] Check if Wi-Fi connection is enabled
  - [ ] Check if propellers are working fine
  - [ ] Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)

7 blade 1/2 sub.

- [ ] Drone [(D)]
- [x] Environmental checklist [(AS) (C&N) (WW) (D)]
- [ ] Kayak(s) (2) (1) [(AS) (C&N) (D)]
- [ ] Row (2) (1) [(AS) (C&N) (D)]
- [ ] Watch/timer (1) [(AS) (WW)]
- [ ] Anchor with rope (1) [(AS) (WW) (D)]
- [ ] GoPro (1) [(AS) (WW) (D)]
- [ ] Waterproof case (1) [(AS) (WW) (D)]
- [x] Peripherals for students [(AS) (C&N) (WW) (D)]
  - [ ] Beach chair (2)
  - [ ] Beach blanket (1)
  - [ ] Cooler (1)
  - [ ] Beverages
  - [ ] Sunscreen
  - [ ] Bug spray

Time Data Recording Started: ________

↑ ↑ ↑



Environmental Data Sheet

Name: Hugo & Adriana Date: 1/16/24

Field Information

Temperature (°F): 76 Wind Speed (mph): 12 Wind Direction: going North

Current Direction: low to high south Sea State: zero, no chop

Sky/Sun Conditions: sunny

Miscellaneous Observations: * eddies and vorticies coming off of the R.L. Becker reach the lead buoy see photos

* high to low ops are ideal

Pre-Testing Checklist

Name: Hugo, Xavi, Adriana Date: 1/17/24 Test Type: ( ) AS (X) WW

Test Site: ICW Dockside Time: ________ ( ) C&N ( ) D

AS: Anchoring System

C&N: Controls & Navigation Test

WW: Water Wheel Test

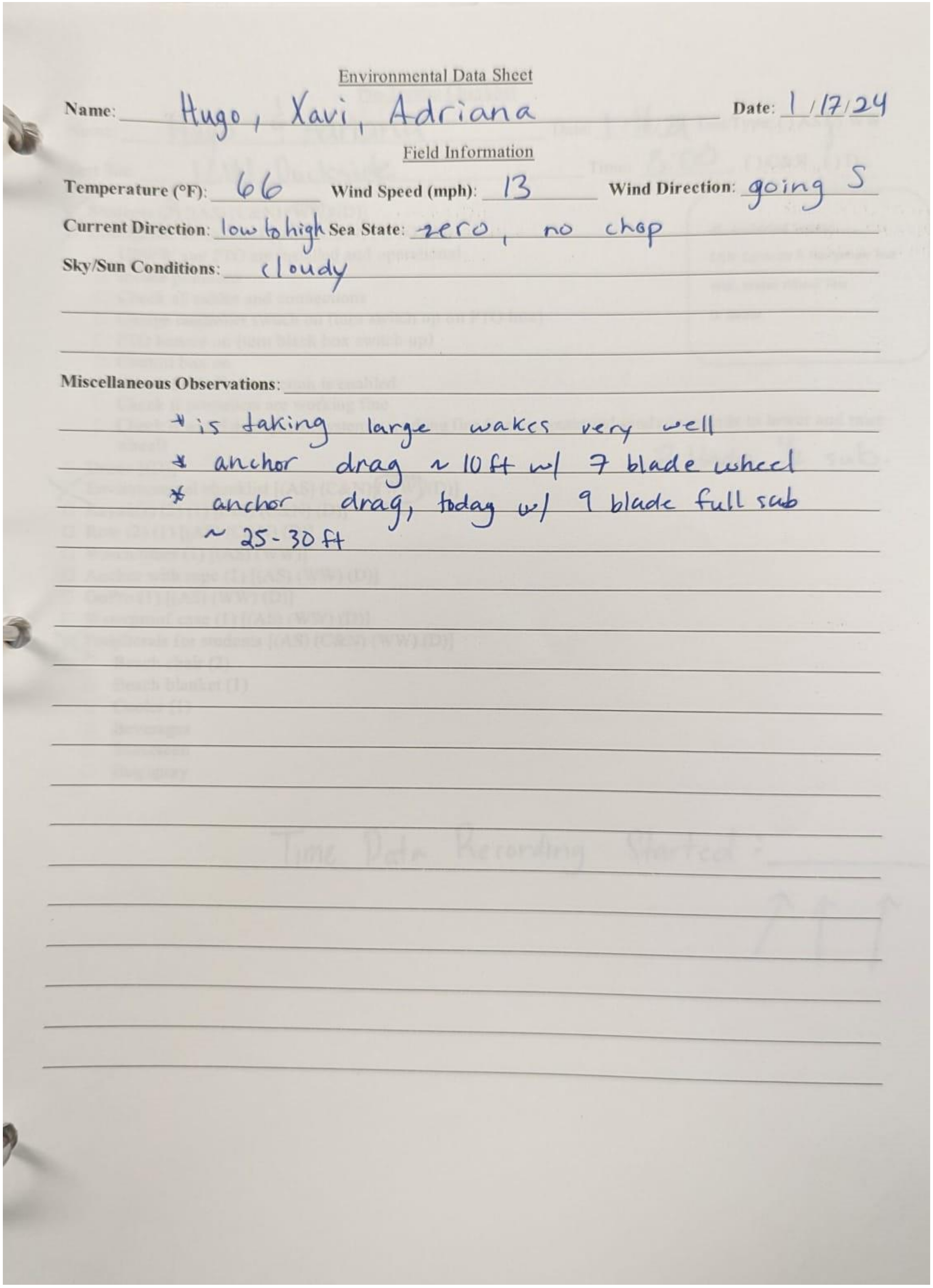
D: Demo

- ☒ Students (3) [(AS) (C&N) (WW) (D)]
- ☒ Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - ☐ USWW and PTO are installed and operational
  - ☐ Inflate pontoons
  - ☐ Check all cables and connections
  - ☐ Charge controller switch on (turn switch up on PTO box)
  - ☐ PTO battery on (turn black box switch up)
  - ☐ Control box on
  - ☐ Check if Wi-Fi connection is enabled
  - ☐ Check if propellers are working fine
  - ☐ Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- ☐ Drone [(D)]
- ☒ Environmental checklist [(AS) (C&N) (WW) (D)]
- ☐ Kayak(s) (2) (1) [(AS) (C&N) (D)]
- ☐ Row (2) (1) [(AS) (C&N) (D)]
- ☐ Watch/timer (1) [(AS) (WW)]
- ☑ Anchor with rope (1) [(AS) (WW) (D)]
- ☐ GoPro (1) [(AS) (WW) (D)]
- ☐ Waterproof case (1) [(AS) (WW) (D)]
- ☑ Peripherals for students [(AS) (C&N) (WW) (D)]
  - ☐ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☐ Cooler (1)
  - ☐ Beverages
  - ☐ Sunscreen
  - ☐ Bug spray

9 blade full sub.

Time data recording started: 8:41

In future work, implement accelerometer on WAM-V to tell when a wake is occurring so the system can take the load off the WW



Environmental Data Sheet

Name: Hugo, Xavi, Adriana Date: 1/17/24

Field Information

Temperature (°F): 66 Wind Speed (mph): 13 Wind Direction: going S

Current Direction: low to high Sea State: zero, no chop

Sky/Sun Conditions: cloudy

Miscellaneous Observations:

* is taking large wakes very well
* anchor drag ~ 10 ft w/ 7 blade wheel
* anchor drag, today w/ 9 blade full sub ~ 25-30 ft

Pre-Testing Checklist

Name: Hugo & Adriana Date: 1/19/24 Test Type: ( ) AS (X) WW

Test Site: ICW Dockside Time: 10:30 ( ) C&N ( ) D

AS: Anchoring System

C&N: Controls & Navigation Test

WW: Water Wheel Test

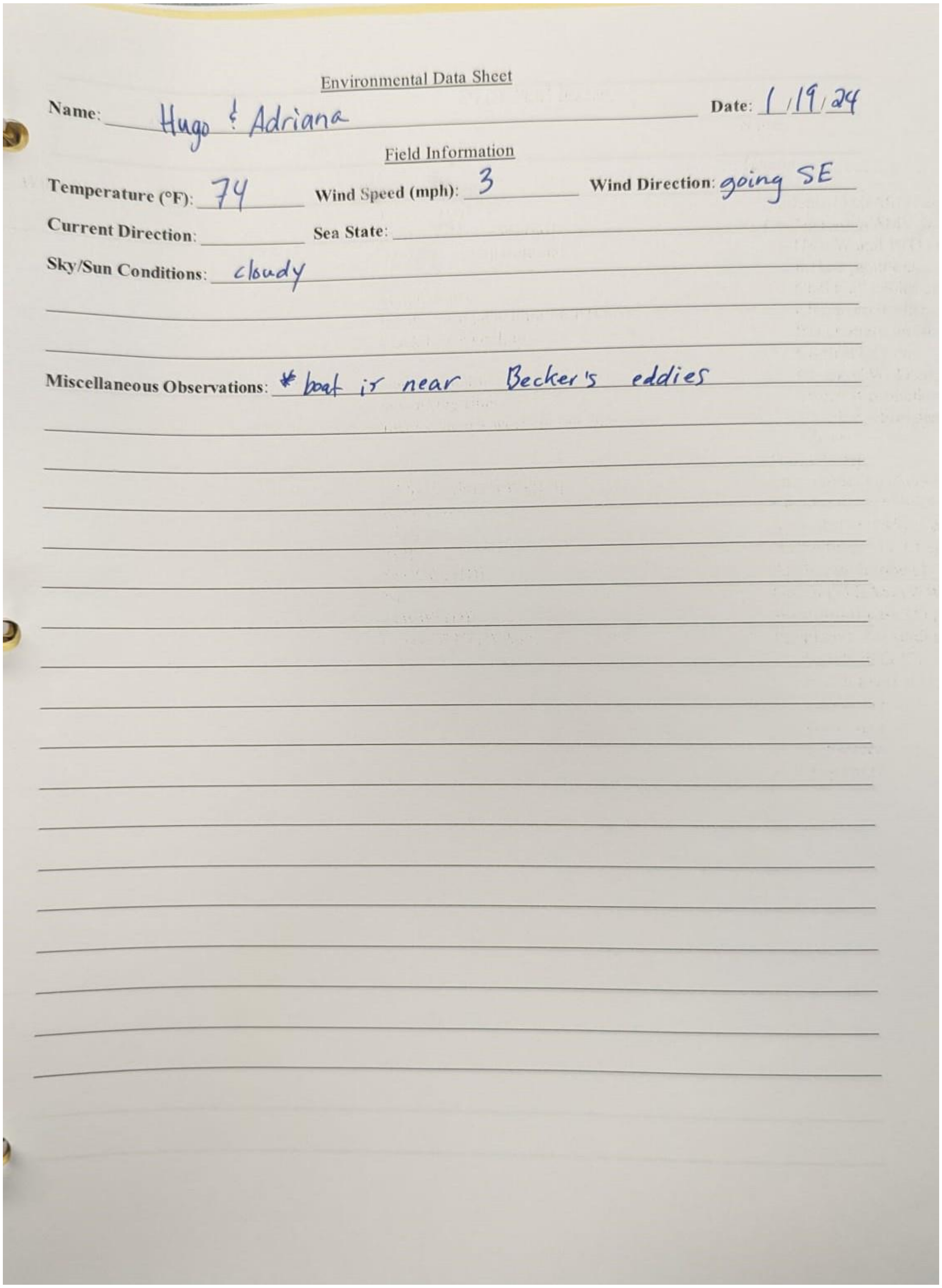
D: Demo

- ☐ Students (3) [(AS) (C&N) (WW) (D)]
- ☐ Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - ☐ USWW and PTO are installed and operational
  - ☐ Inflate pontoons
  - ☐ Check all cables and connections
  - ☐ Charge controller switch on (turn switch up on PTO box)
  - ☐ PTO battery on (turn black box switch up)
  - ☐ Control box on
  - ☐ Check if Wi-Fi connection is enabled
  - ☐ Check if propellers are working fine
  - ☐ Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- ☐ Drone [(D)]
- ☐ Environmental checklist [(AS) (C&N) (WW) (D)]
- ☐ Kayak(s) (2) (1) [(AS) (C&N) (D)]
- ☐ Row (2) (1) [(AS) (C&N) (D)]
- ☐ Watch/timer (1) [(AS) (WW)]
- ☐ Anchor with rope (1) [(AS) (WW) (D)]
- ☐ GoPro (1) [(AS) (WW) (D)]
- ☐ Waterproof case (1) [(AS) (WW) (D)]
- ☐ Peripherals for students [(AS) (C&N) (WW) (D)]
  - ☐ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☐ Cooler (1)
  - ☐ Beverages
  - ☐ Sunscreen
  - ☐ Bug spray

wheel/blade # 9

Sub. level: 1/2

Time data saving started: 11:10 am


Environmental Data Sheet

Name: Hugo & Adriana Date: 1/19/24

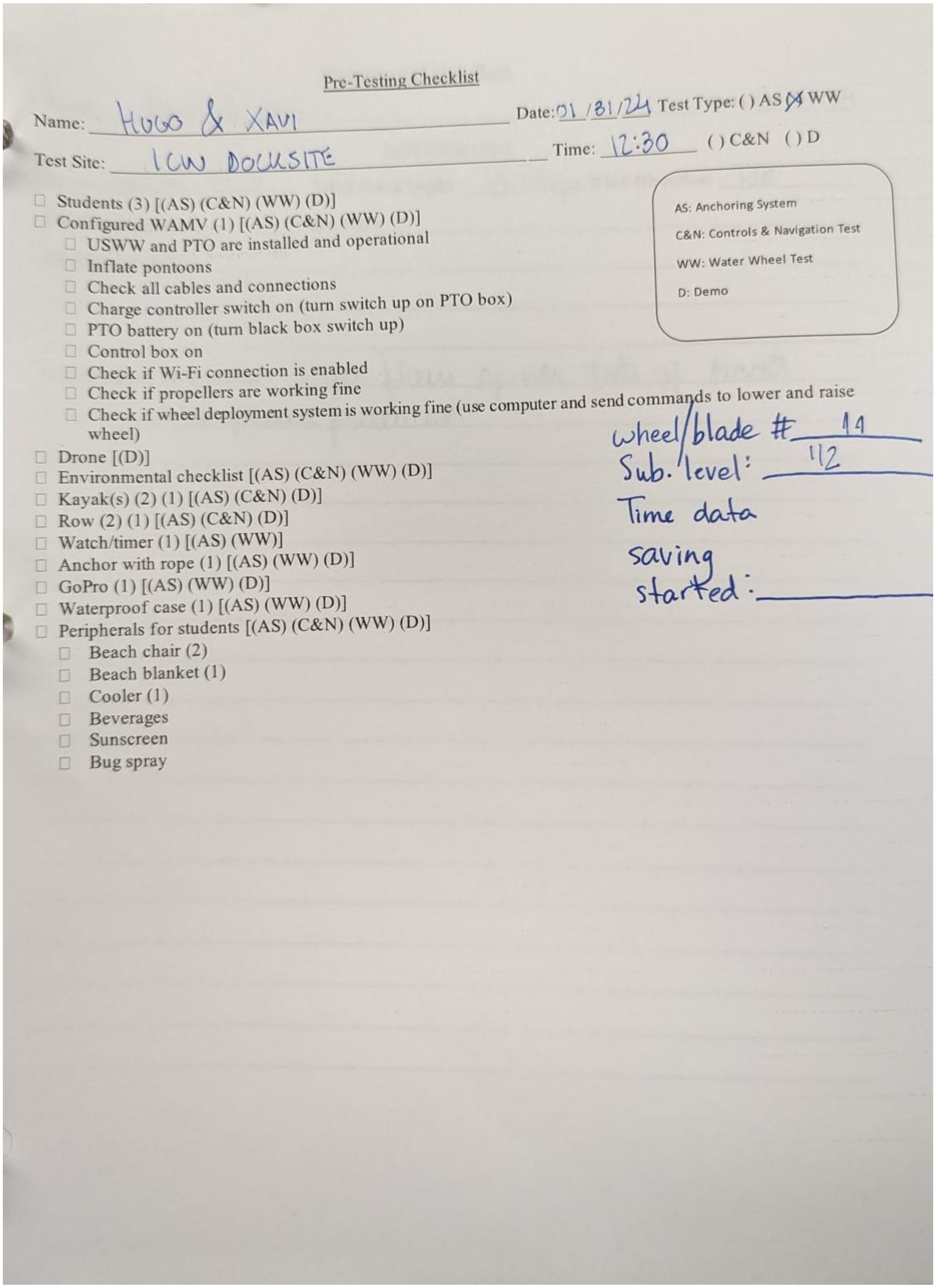
Field Information

Temperature (°F): 74 Wind Speed (mph): 3 Wind Direction: going SE

Current Direction: ______ Sea State: ______

Sky/Sun Conditions: cloudy

Miscellaneous Observations: * boat is near Becker's eddies



Pre-Testing Checklist

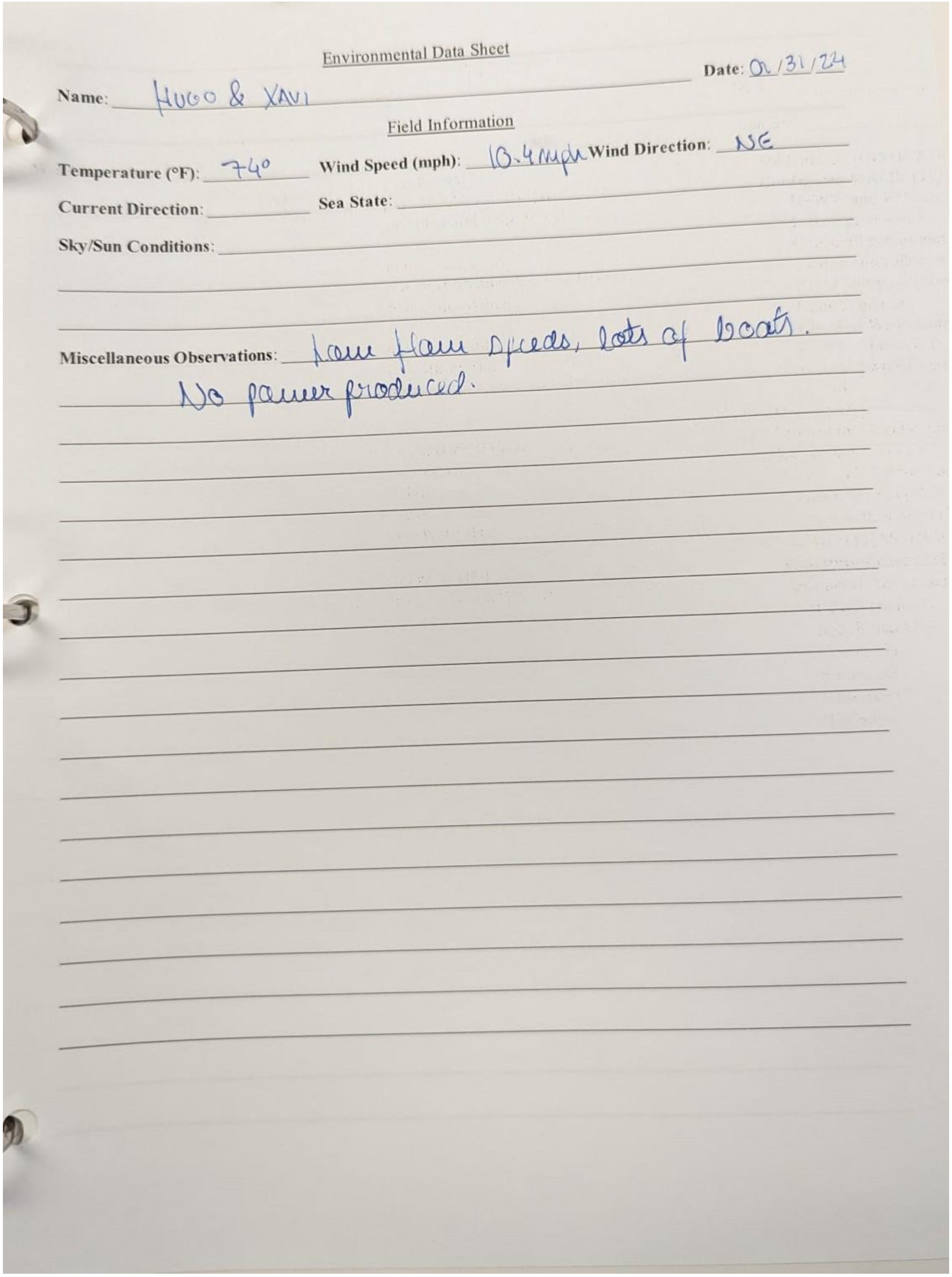
Name: Hugo & Xavi Date: 01/31/24 Test Type: ( ) AS (X) WW ( ) C&N ( ) D

Test Site: ICW Docksite Time: 12:30

AS: Anchoring System
C&N: Controls & Navigation Test
WW: Water Wheel Test
D: Demo

- ☐ Students (3) [(AS) (C&N) (WW) (D)]
- ☐ Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - ☐ USWW and PTO are installed and operational
  - ☐ Inflate pontoons
  - ☐ Check all cables and connections
  - ☐ Charge controller switch on (turn switch up on PTO box)
  - ☐ PTO battery on (turn black box switch up)
  - ☐ Control box on
  - ☐ Check if Wi-Fi connection is enabled
  - ☐ Check if propellers are working fine
  - ☐ Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- ☐ Drone [(D)]
- ☐ Environmental checklist [(AS) (C&N) (WW) (D)]
- ☐ Kayak(s) (2) (1) [(AS) (C&N) (D)]
- ☐ Row (2) (1) [(AS) (C&N) (D)]
- ☐ Watch/timer (1) [(AS) (WW)]
- ☐ Anchor with rope (1) [(AS) (WW) (D)]
- ☐ GoPro (1) [(AS) (WW) (D)]
- ☐ Waterproof case (1) [(AS) (WW) (D)]
- ☐ Peripherals for students [(AS) (C&N) (WW) (D)]
  - ☐ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☐ Cooler (1)
  - ☐ Beverages
  - ☐ Sunscreen
  - ☐ Bug spray

wheel/blade #: 14
Sub. level: 1/2
Time data saving started: ______



Environmental Data Sheet

Name: Hugo & Xavi

Date: 01/31/24

Field Information

Temperature (°F): 74°

Wind Speed (mph): 10.4mph

Wind Direction: NE

Current Direction:

Sea State:

Sky/Sun Conditions:

Miscellaneous Observations: Low flow speeds, lots of boats. No power produced.

Pre-Testing Checklist

Name: Caleb & Adriana Date: 11 / 3 /23 Test Type: (X) AS ( ) WW ( ) D

Test Site: Dockside @ SeaTech Time: 3:45pm

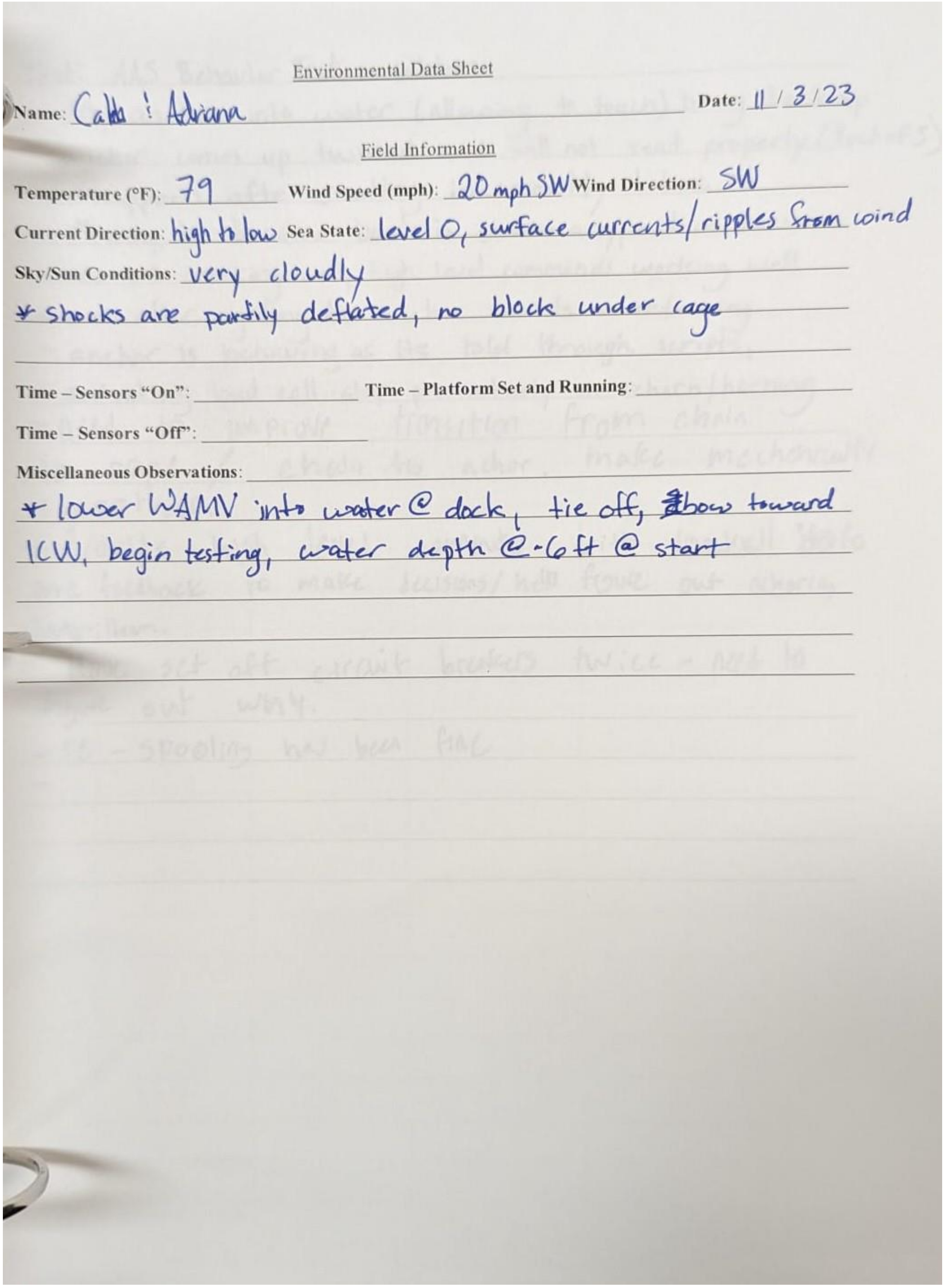
AS: Anchoring System

WW: Water Wheel Test

D: Demo

- ☐ Students (3) [(AS) (WW) (D)]
- ☐ Configured WAMV (1) [(AS) (WW) (D)]
  - ☐ USWW and PTO are installed and operational
  - ☐ Inflate pontoons
  - ☐ Check all cables and connections
  - ☐ Charge controller switch on (turn switch up on PTO box)
  - ☐ PTO battery on (turn black box switch up)
  - ☐ Control box on
  - ☐ Check if Wi-Fi connection is enabled
  - ☐ Check if propellers are working fine
  - ☐ Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- ☐ Drone [(D)]
- ☐ Environmental checklist [(AS) (WW) (D)]
- ☐ Kayak(s) (2) (1) [(AS) (D)]
- ☐ Row (2) (1) [(AS) (D)]
- ☐ Watch/timer (1) [(AS) (WW)]
- ☐ Anchor with rope (1) [(AS) (WW) (D)]
- ☐ GoPro (1) [(AS) (WW) (D)]
- ☐ Waterproof case (1) [(AS) (WW) (D)]
- ☐ Peripherals for students [(AS) (WW) (D)]
  - ☐ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☐ Cooler (1)
  - ☐ Beverages
  - ☐ Sunscreen
  - ☐ Bug spray

* pulled WAMV out of water @ 4:50



Environmental Data Sheet

Name: Calla & Adriana Date: 11 / 3 / 23

Field Information

Temperature (°F): 79 Wind Speed (mph): 20 mph SW Wind Direction: SW

Current Direction: high to low Sea State: level 0, surface currents/ripples from wind

Sky/Sun Conditions: very cloudly

* shocks are partily deflated, no block under cage

Time – Sensors "On": Time – Platform Set and Running:

Time – Sensors "Off":

Miscellaneous Observations:

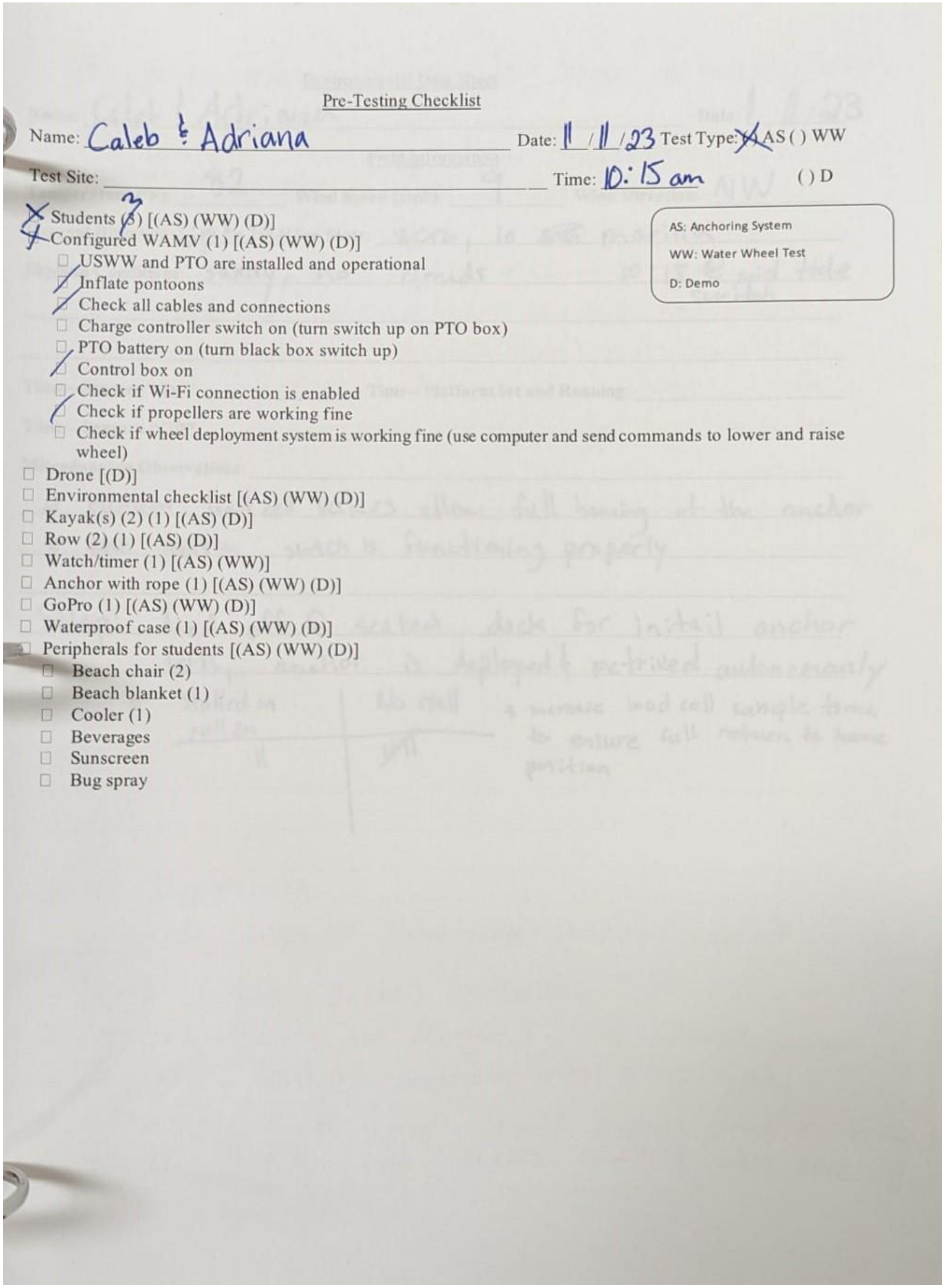
* lower WAMV into water @ dock, tie off, bow toward ICW, begin testing, water depth @ ~6 ft @ start

Test: AAS Behavior Test in Water

- drop anchor into water (allowing to touch) bring back up
- anchor comes up twisted and will not seat properly (4 out of 5)
  - ↗ happens after seating incorrectly 1 time **
  - * may be because boat is stationary, not in reverse
- coms are working well, high level commands working well

** even after righting the anchor twists on returning

- anchor is behaving as its told through scripts,
- activating load cell stop prematurly on return/homing
- need to improve transition from chain to rope / chain to achor. make mechanically smoother.
- Provide high level computer with loadcell info and feedback to make decisions/help figure out achoring algorithm.
- Have set off circuit breakers twice - need to figure out why.
- re-spooling has been fine
-



Pre-Testing Checklist

Name: Caleb & Adriana Date: 1 / 1 / 23 Test Type: (X) AS ( ) WW

Test Site: ______________ Time: 10:15 am ( ) D

AS: Anchoring System
WW: Water Wheel Test
D: Demo

- ☒ Students (3) [(AS) (WW) (D)]
- ☒ Configured WAMV (1) [(AS) (WW) (D)]
  - ☐ USWW and PTO are installed and operational
  - ☑ Inflate pontoons
  - ☑ Check all cables and connections
  - ☐ Charge controller switch on (turn switch up on PTO box)
  - ☐ PTO battery on (turn black box switch up)
  - ☑ Control box on
  - ☐ Check if Wi-Fi connection is enabled
  - ☑ Check if propellers are working fine
  - ☐ Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- ☐ Drone [(D)]
- ☐ Environmental checklist [(AS) (WW) (D)]
- ☐ Kayak(s) (2) (1) [(AS) (D)]
- ☐ Row (2) (1) [(AS) (D)]
- ☐ Watch/timer (1) [(AS) (WW)]
- ☐ Anchor with rope (1) [(AS) (WW) (D)]
- ☐ GoPro (1) [(AS) (WW) (D)]
- ☐ Waterproof case (1) [(AS) (WW) (D)]
- ☐ Peripherals for students [(AS) (WW) (D)]
  - ☐ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☐ Cooler (1)
  - ☐ Beverages
  - ☐ Sunscreen
  - ☐ Bug spray

Environmental Data Sheet

Name: Caleb & Adriana **Date:** 1/11/23

Field Information

Temperature (°F): 82 **Wind Speed (mph):** 9 **Wind Direction:** NW

Current Direction: high to low **Sea State:** zero, in marina

Sky/Sun Conditions: sunny, no clouds 10:15 @ mid tide switch

Time – Sensors "On": **Time – Platform Set and Running:**

Time – Sensors "Off":

Miscellaneous Observations:

* current load cell values allow full homing of the anchor
* the tension swich is functioning properly

Setup: tied off @ seatech dock for initail anchor tests, anchor is deployed & retrived autonomausly

* Stalled on pull on	No stall
II	~~IIII~~ I

* increase load cell sample time to ensure full return to home position

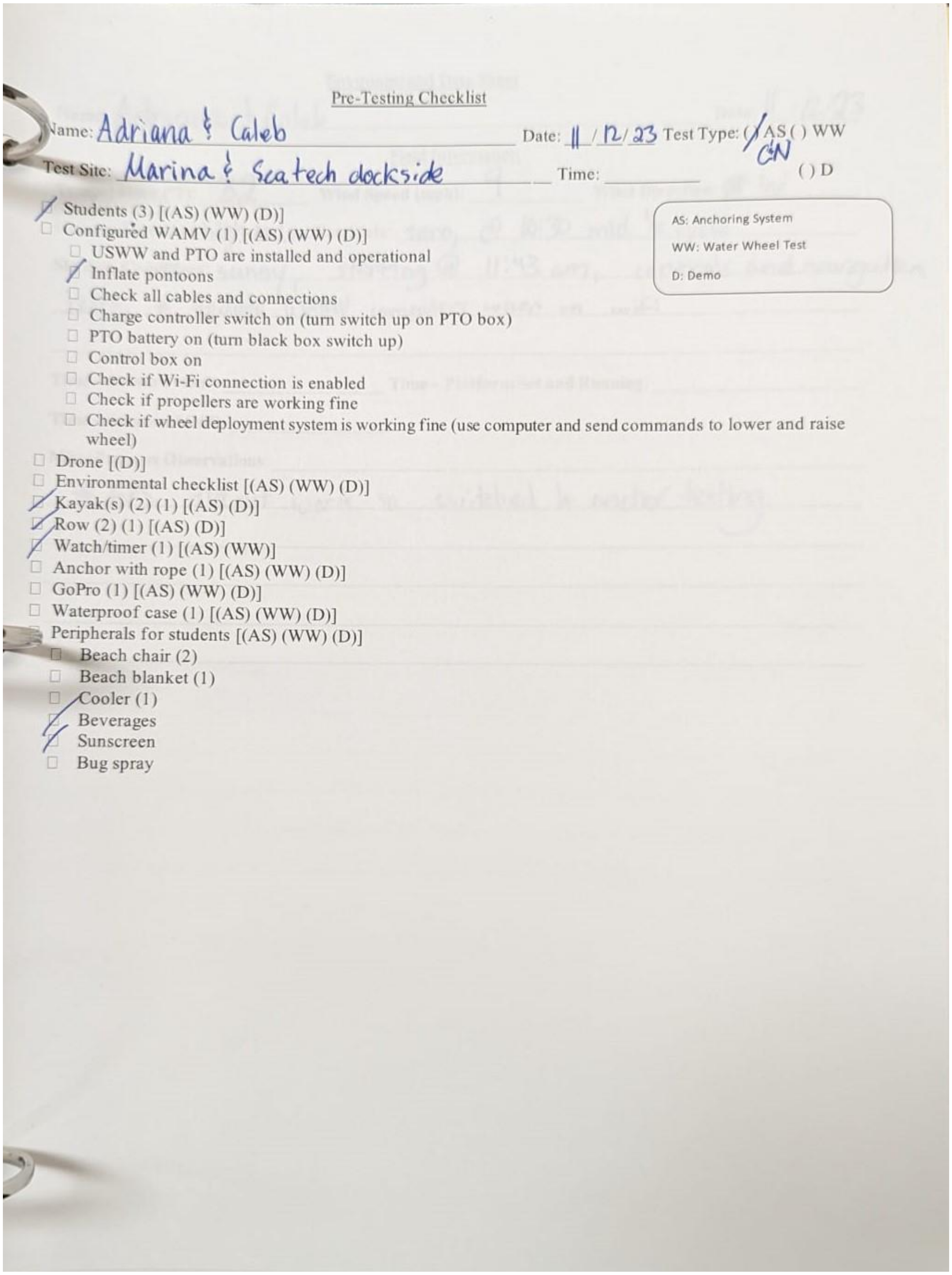
@11:02 anchoring algerithum test began in marina near bridge.

- determine anchoring behaviors needed
- drop anchor, rc to set, let out scope
- start w/ 5to1 scope → 15m currently

* 1st run: anchor set, tip way in mud, anchor took a 45°
dropped anchor and rced back @ slow speed then let thee winch pull the WAMV in as it brought the line in, unset the anchor well and pulled back almost completly to home, anchor spun backwards and did not seat properly in the home position

-Notes Programming

- Entertain Idea of Go up - Stop - Go out a bit - Go up
- 5-1 scope seems reasonable
- Overide Going out / Going in w standby a_stop
- Increase load cell sample avg time maybe
- allowing it to pull itself seems good on retrieval
- reverse thrust with heading control when anchoring



Pre-Testing Checklist

Name: Adriana & Caleb ______ Date: 11 / 12 / 23 Test Type: (✓) AS ( ) WW CN ( ) D

Test Site: Marina & Seatech dockside ______ Time: ________

AS: Anchoring System
WW: Water Wheel Test
D: Demo

- [x] Students (3) [(AS) (WW) (D)]
- [ ] Configured WAMV (1) [(AS) (WW) (D)]
  - [ ] USWW and PTO are installed and operational
  - [x] Inflate pontoons
  - [ ] Check all cables and connections
  - [ ] Charge controller switch on (turn switch up on PTO box)
  - [ ] PTO battery on (turn black box switch up)
  - [ ] Control box on
  - [ ] Check if Wi-Fi connection is enabled
  - [ ] Check if propellers are working fine
  - [ ] Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- [ ] Drone [(D)]
- [ ] Environmental checklist [(AS) (WW) (D)]
- [x] Kayak(s) (2) (1) [(AS) (D)]
- [x] Row (2) (1) [(AS) (D)]
- [x] Watch/timer (1) [(AS) (WW)]
- [ ] Anchor with rope (1) [(AS) (WW) (D)]
- [ ] GoPro (1) [(AS) (WW) (D)]
- [ ] Waterproof case (1) [(AS) (WW) (D)]
- [ ] Peripherals for students [(AS) (WW) (D)]
  - [ ] Beach chair (2)
  - [ ] Beach blanket (1)
  - [x] Cooler (1)
  - [x] Beverages
  - [x] Sunscreen
  - [ ] Bug spray

Environmental Data Sheet

Name: Adriana & Caleb Date: 11/12/23

Field Information

Temperature (°F): 82 Wind Speed (mph): 9 Wind Direction: W

Current Direction: high to low Sea State: zero, @ 10:30 mid 1/2 cycle

Sky/Sun Conditions: sunny, starting @ 11:43 am, controls and navigation tests, * update WAMV computers when on wifi

Time – Sensors "On": Time – Platform Set and Running:

Time – Sensors "Off":

Miscellaneous Observations:

* GPS did not work so switched to anchor testing

Pre-Testing Checklist

Name: Hugo, Caleb, Adriana Date: 12/5/23 Test Type: ( ) AS (X) WW

Test Site: ICW Dockside Time: 8:00 am ( ) C&N ( ) D

- [x] Students (3) [(AS) (C&N) (WW) (D)]
- [ ] Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - [ ] USWW and PTO are installed and operational
  - [x] Inflate pontoons
  - [x] Check all cables and connections
  - [ ] Charge controller switch on (turn switch up on PTO box)
  - [ ] PTO battery on (turn black box switch up)
  - [x] Control box on
  - [x] Check if Wi-Fi connection is enabled
  - [x] Check if propellers are working fine
  - [ ] Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- [ ] Drone [(D)]
- [x] Environmental checklist [(AS) (C&N) (WW) (D)]
- [ ] Kayak(s) (2) (1) [(AS) (C&N) (D)]
- [ ] Row (2) (1) [(AS) (C&N) (D)]
- [ ] Watch/timer (1) [(AS) (WW)]
- [ ] Anchor with rope (1) [(AS) (WW) (D)]
- [ ] GoPro (1) [(AS) (WW) (D)]
- [ ] Waterproof case (1) [(AS) (WW) (D)]
- [ ] Peripherals for students [(AS) (C&N) (WW) (D)]
  - [ ] Beach chair (2)
  - [ ] Beach blanket (1)
  - [ ] Cooler (1)
  - [ ] Beverages
  - [ ] Sunscreen
  - [ ] Bug spray

AS: Anchoring System
C&N: Controls & Navigation Test
WW: Water Wheel Test
D: Demo

Pre-Testing Checklist

Name: Hugo, Caleb, Adriana Date: 12/5/23 Test Type: ( ) AS (X) WW

Test Site: ICW Dockside Time: 8:00 am ( ) C&N ( ) D

AS: Anchoring System
C&N: Controls & Navigation Test
WW: Water Wheel Test
D: Demo

- [x] Students (3) [(AS) (C&N) (WW) (D)]
- [ ] Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - [ ] USWW and PTO are installed and operational
  - [x] Inflate pontoons
  - [x] Check all cables and connections
  - [ ] Charge controller switch on (turn switch up on PTO box)
  - [x] PTO battery on (turn black box switch up)
  - [x] Control box on
  - [x] Check if Wi-Fi connection is enabled
  - [x] Check if propellers are working fine
  - [ ] Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- [ ] Drone [(D)]
- [x] Environmental checklist [(AS) (C&N) (WW) (D)]
- [ ] Kayak(s) (2) (1) [(AS) (C&N) (D)]
- [ ] Row (2) (1) [(AS) (C&N) (D)]
- [ ] Watch/timer (1) [(AS) (WW)]
- [ ] Anchor with rope (1) [(AS) (WW) (D)]
- [ ] GoPro (1) [(AS) (WW) (D)]
- [ ] Waterproof case (1) [(AS) (WW) (D)]
- [ ] Peripherals for students [(AS) (C&N) (WW) (D)]
  - [ ] Beach chair (2)
  - [ ] Beach blanket (1)
  - [ ] Cooler (1)
  - [ ] Beverages
  - [ ] Sunscreen
  - [ ] Bug spray

Environmental Data Sheet

ame: ______________________ Date: 12/05/2023

Field Information

emperature (°F): 73 Wind Speed (mph): 8 Wind Direction: S

urrent Direction: S Sea State: 0

ky/Sun Conditions: SUNNY

ime – Sensors "On": ______ Time – Platform Set and Running: ______

ime – Sensors "Off": ______

iscellaneous Observations: ______

Environmental Data Sheet

Name: Hugo F. Pimentel Date: 12/06/2023

Field Information

Temperature (°F): 68 Wind Speed (mph): 15 Wind Direction: South (going)

Current Direction: low to high Sea State: zero, slight wind chop

Sky/Sun Conditions: sunny

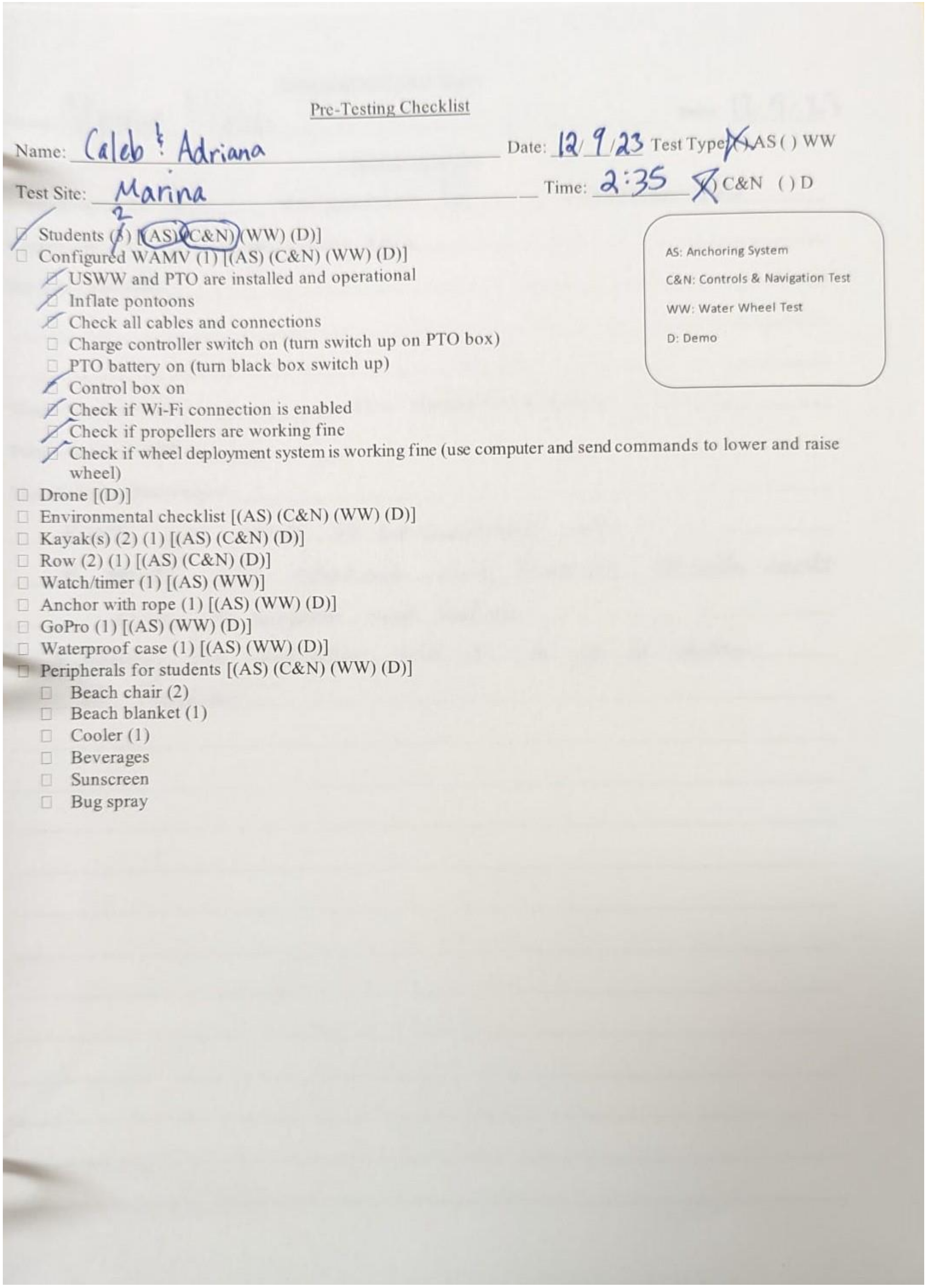
Time – Sensors "On": Time – Platform Set and Running:

Time – Sensors "Off":

Miscellaneous Observations:

* 7900 sec runtime starting anchor move ended @ 8040 sec
* Deployed ~ 11:45 am
* look into when the PWM is changed via terminal why we have to send another command to start the seirial coms again?
* 12650 s → BEGIN change to half submergence
* 12775 s → completed change to half submergence
* x = 869, y = 34 anchor spot @ 1.3
* points in the ICW:
  - x = 775 y = 25
  - x = 620 y 9.5
  - x = 490 y = 0 → by no wake sign
  - x = 400 y = −12
  - x = 170 y = −22
  - x = 30 y = −32 → @ tow boat
  - x = 7 y = 8 → under the bridge
  - x = −6 y = 80 in mariena

see back



Pre-Testing Checklist

Name: Caleb & Adriana Date: 12/9/23 Test Type: (X) AS ( ) WW

Test Site: Marina Time: 2:35 (X) C&N ( ) D

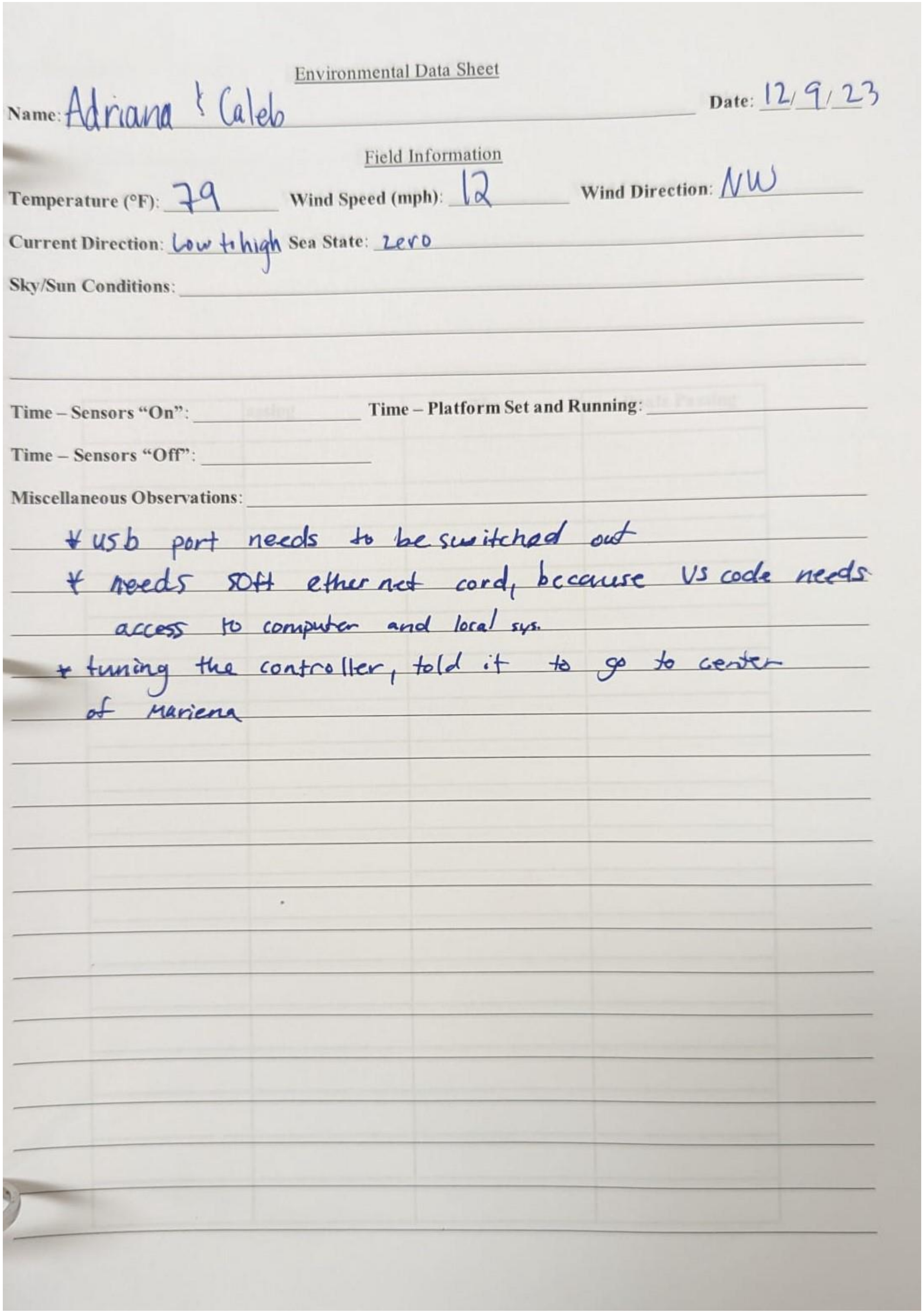
- [x] Students (2) [(AS) (C&N) (WW) (D)]
- [ ] Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - [x] USWW and PTO are installed and operational
  - [x] Inflate pontoons
  - [x] Check all cables and connections
  - [ ] Charge controller switch on (turn switch up on PTO box)
  - [ ] PTO battery on (turn black box switch up)
  - [x] Control box on
  - [x] Check if Wi-Fi connection is enabled
  - [x] Check if propellers are working fine
  - [x] Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- [ ] Drone [(D)]
- [ ] Environmental checklist [(AS) (C&N) (WW) (D)]
- [ ] Kayak(s) (2) (1) [(AS) (C&N) (D)]
- [ ] Row (2) (1) [(AS) (C&N) (D)]
- [ ] Watch/timer (1) [(AS) (WW)]
- [ ] Anchor with rope (1) [(AS) (WW) (D)]
- [ ] GoPro (1) [(AS) (WW) (D)]
- [ ] Waterproof case (1) [(AS) (WW) (D)]
- [ ] Peripherals for students [(AS) (C&N) (WW) (D)]
  - [ ] Beach chair (2)
  - [ ] Beach blanket (1)
  - [ ] Cooler (1)
  - [ ] Beverages
  - [ ] Sunscreen
  - [ ] Bug spray

AS: Anchoring System

C&N: Controls & Navigation Test

WW: Water Wheel Test

D: Demo



Environmental Data Sheet

Name: Adriana & Caleb Date: 12/9/23

Field Information

Temperature (°F): 79 Wind Speed (mph): 12 Wind Direction: NW

Current Direction: Low to high Sea State: zero

Sky/Sun Conditions: ______

Time – Sensors "On": ______ Time – Platform Set and Running: ______

Time – Sensors "Off": ______

Miscellaneous Observations:

* usb port needs to be switched out
* needs 50ft ethernet cord, because VS code needs access to computer and local sys.
* tuning the controller, told it to go to center of Mariena

Pre-Testing Checklist

Name: Adriana, Caleb, Hugo Date: 12 / 11 / 23 Test Type: ( ) AS (X) WW

Test Site: ICW Dockside Time: 8:15 am ( ) C&N ( ) D

AS: Anchoring System
C&N: Controls & Navigation Test
WW: Water Wheel Test
D: Demo

- [x] Students (3) [(AS) (C&N) (WW) (D)]
- [ ] Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - [x] USWW and PTO are installed and operational
  - [x] Inflate pontoons
  - [x] Check all cables and connections
  - [x] Charge controller switch on (turn switch up on PTO box)
  - [x] PTO battery on (turn black box switch up)
  - [x] Control box on
  - [x] Check if Wi-Fi connection is enabled
  - [x] Check if propellers are working fine
  - [x] Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- [ ] Drone [(D)]
- [x] Environmental checklist [(AS) (C&N) (WW) (D)]
- [ ] Kayak(s) (2) (1) [(AS) (C&N) (D)]
- [ ] Row (2) (1) [(AS) (C&N) (D)]
- [ ] Watch/timer (1) [(AS) (WW)]
- [ ] Anchor with rope (1) [(AS) (WW) (D)]
- [ ] GoPro (1) [(AS) (WW) (D)]
- [ ] Waterproof case (1) [(AS) (WW) (D)]
- [ ] Peripherals for students [(AS) (C&N) (WW) (D)]
  - [x] Beach chair (2)
  - [x] Beach blanket (1)
  - [x] Cooler (1)
  - [x] Beverages
  - [x] Sunscreen
  - [x] Bug spray

9 blade full sub.

Environmental Data Sheet

Name: Adriana, Hugo, Caleb Date: 12/11/23

Field Information

Temperature (°F): 67 Wind Speed (mph): 14 Wind Direction: going south

Current Direction: High to low Sea State: zero

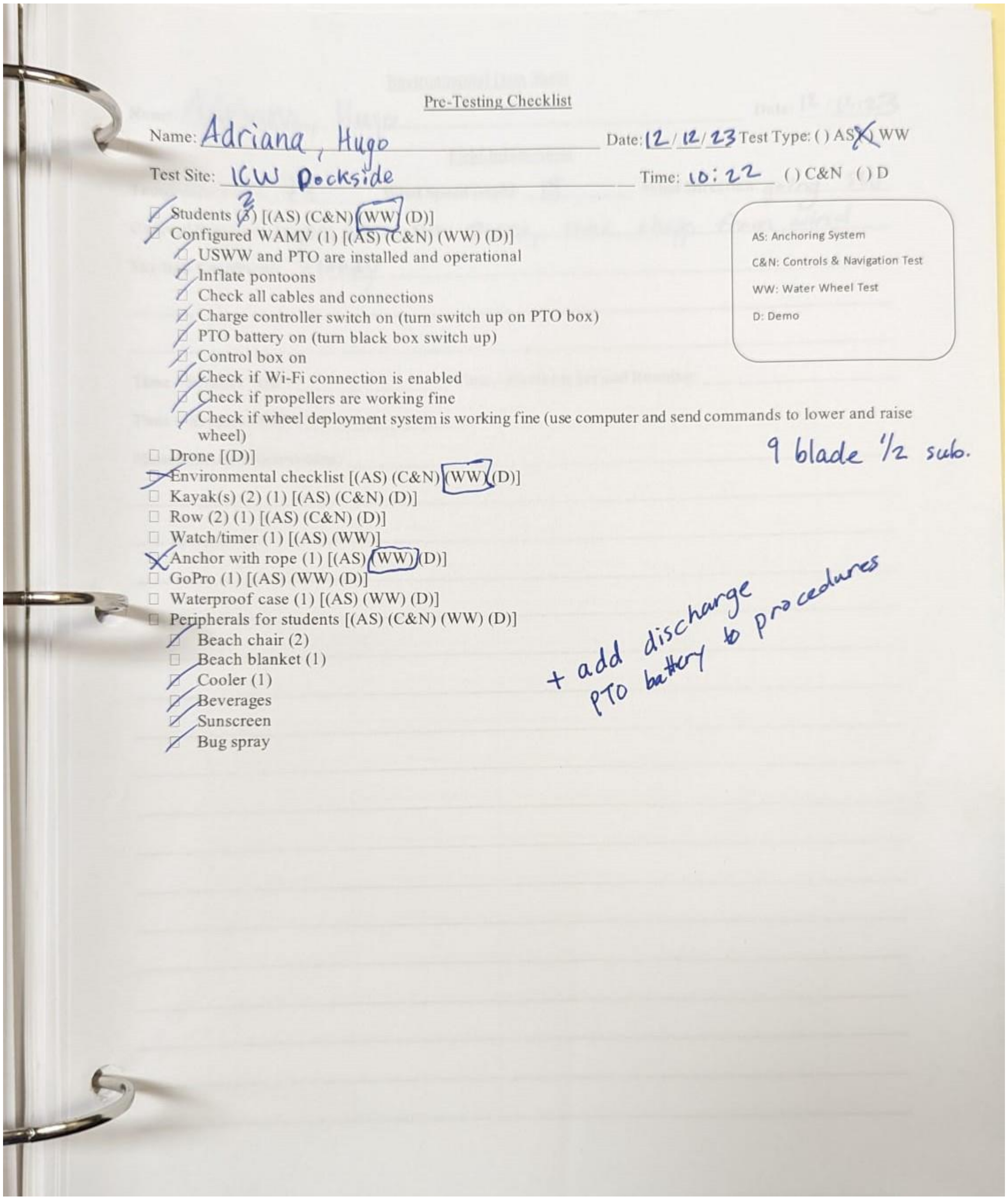
Sky/Sun Conditions: Sunny

Time – Sensors "On": ______ Time – Platform Set and Running: ______

Time – Sensors "Off": ______

Miscellaneous Observations:

- When nearing full charge, battery voltage oscillates 13.7V → 12.3V → 13.7V



Pre-Testing Checklist

Name: Adriana, Hugo Date: 12/12/23 Test Type: ( ) AS (X) WW

Test Site: ICW Dockside Time: 10:22 ( ) C&N ( ) D

- ☑ Students (3 → 2) [(AS) (C&N) (WW) (D)]
- ☑ Configured WAMV (1) [(AS) (C&N) (WW) (D)]
  - ☑ USWW and PTO are installed and operational
  - ☑ Inflate pontoons
  - ☑ Check all cables and connections
  - ☑ Charge controller switch on (turn switch up on PTO box)
  - ☑ PTO battery on (turn black box switch up)
  - ☑ Control box on
  - ☑ Check if Wi-Fi connection is enabled
  - ☑ Check if propellers are working fine
  - ☑ Check if wheel deployment system is working fine (use computer and send commands to lower and raise wheel)
- ☐ Drone [(D)]
- ☑ Environmental checklist [(AS) (C&N) (WW) (D)]
- ☐ Kayak(s) (2) (1) [(AS) (C&N) (D)]
- ☐ Row (2) (1) [(AS) (C&N) (D)]
- ☐ Watch/timer (1) [(AS) (WW)]
- ☒ Anchor with rope (1) [(AS) (WW) (D)]
- ☐ GoPro (1) [(AS) (WW) (D)]
- ☐ Waterproof case (1) [(AS) (WW) (D)]
- ☐ Peripherals for students [(AS) (C&N) (WW) (D)]
  - ☑ Beach chair (2)
  - ☐ Beach blanket (1)
  - ☑ Cooler (1)
  - ☑ Beverages
  - ☑ Sunscreen
  - ☑ Bug spray

AS: Anchoring System
C&N: Controls & Navigation Test
WW: Water Wheel Test
D: Demo

9 blade 1/2 sub.

+ add discharge PTO battery to procedures

Environmental Data Sheet

Name: Adriana, Hugo   Date: 12/12/23

Field Information

Temperature (°F): 74   Wind Speed (mph): 18   Wind Direction: going SW

Current Direction: high to Low   Sea State: zero, some chopp from wind

Sky/Sun Conditions: cloudy

Time – Sensors "On": ____   Time – Platform Set and Running: ____

Time – Sensors "Off": ____

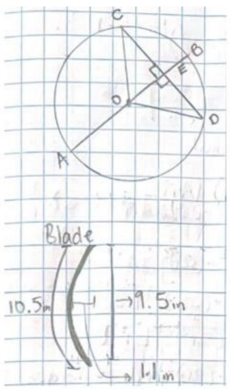
Miscellaneous Observations: ____

C_D Estimation

C_D Flat Plate = 1.98

C_D Hollow Semi-cylinder facing stream = 2.30

But our blade is not flat or a semi-cylinder:



Intersecting Chords Theorem

$$CE * ED = AE * EB$$

$$AE = \frac{CE * ED}{EB}$$

Radius$=\frac{(AE+EB)}{2}$

$$AE = \frac{4.75 * 4.75}{1.1} = 20.5114$$

$$r = \frac{20.5114 + 1.1}{2} = 10.801in$$

Curvature

Shape	C_D	Curvature
Flat	1.98	0.00
¼ Cylinder	2.14	0.0925
Semi-Cylinder	2.30	0.2105

$$\frac{1}{10.8} = 0.09$$

$$2.3 - 1.98 = 0.32$$

$$0.32 * (0.44) = 0.14$$

$$1.98 + 0.14 = 2.12$$

C_D for our blade is 2.12

Appendix K: MATLAB Scripts

```
% Load Data & Set Names
data = readtable("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed
1-10\NW2\rd110.csv");
%disp(data)

datast.time = rd110.time_elapsed;
datast.values = table2array(data(:,2:6));
%disp(datast.time)
%disp(datast.values)

% Checking that all FS values have a proper time stamp
freq = 0.1;
results = check_timestamp(datast,freq);
%disp(results.values)

% Checking the Data Range
bounds = [0.001,60];
results = check_range(results,bounds);
%disp(results.values)

% %Checking for Stagnant Data
% bound = {0.00001, py.None};
% window1 = 0.01;
% results = check_delta(results, bound, window1);
% disp(results.values)

% Make CSV
h = {'Time' 'FS' 'Wrmp' 'Vg' 'Ig' 'Tww'};
body = [datast.time, results.values];
tabel = [h; num2cell(body)];
%disp(tabel)

% writecell(tabel, "qc110.csv")
% type qc110.csv
```

1

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-10\NW2\qc110.mat");
tqc = qc110.Time;
FSqc = qc110.FS;
Wrpmqc = qc110.Wrmp;
Vgqc = qc110.Vg;
Igqc = qc110.Ig;
Twwqc = qc110.Tww;

window = 1000;

% Remove Outliers
FSrm = rmoutliers(FSqc);
Wrpmrm = rmoutliers(Wrpmqc);
Vgrm = rmoutliers(Vgqc);
Igrm = rmoutliers(Igqc);
Twwrm = rmoutliers(Twwqc);

size(tqc)
```

```
ans = 1×2
      125257           1
```

```
size(FSrm)
```

```
ans = 1×2
      124916           1
```

```
size(Wrpmrm)
```

```
ans = 1×2
      124083           1
```

```
size(Vgrm)
```

```
ans = 1×2
      118151           1
```

```
size(Igrm)
```

```
ans = 1×2
      122998           1
```

```
size(Twwrm)
```

```
ans = 1×2
      125257           1
```

```

% Trim FSrm to match the length of Vgrm
FSrm = FSrm(1:length(Vgrm));
% Trim Wrpmrm to match the length of Vgrm
Wrpmrm = Wrpmrm(1:length(Vgrm));
% Trim Igrm to match the length of Vgrm
```

```
Igrm = Igrm(1:length(Vgrm));
% Trim Twwrm to match the length of Vgrm
Twwrm = Twwrm(1:length(Vgrm));

% Now they all should have the same length
disp(size(FSrm))
```

```
      118151           1
```

```
disp(size(Wrpmrm))
```

```
      118151           1
```

```
disp(size(Vgrm))
```

```
      118151           1
```

```
disp(size(Igrm))
```

```
      118151           1
```

```
disp(size(Twwrm))
```

```
      118151           1
```

```

% Ensure that the time vector has the same length as the other data vectors after
removing outliers
FSrm_valid = ~isnan(FSrm);  % Find valid indices for FSrm
Wrpmrm_valid = ~isnan(Wrpmrm);  % Find valid indices for Wrpmrm
Vgrm_valid = ~isnan(Vgrm);  % Find valid indices for Vgrm
Igrm_valid = ~isnan(Igrm);  % Find valid indices for Igrm
Twwrm_valid = ~isnan(Twwrm);  % Find valid indices for Twwrm
valid_indices = FSrm_valid & Wrpmrm_valid & Vgrm_valid & Igrm_valid & Twwrm_valid;
% Combine valid indices

tqc = tqc(valid_indices);  % Filter the time vector to match the lengths of FSrm,
Wrpmrm, Vgrm and Igrm
FSrm = FSrm(valid_indices); %Filter FSrm
Wrpmrm = Wrpmrm(valid_indices); %Filter Wrpmrm
Vgrm = Vgrm(valid_indices);  % Filter Vgrm
Igrm = Igrm(valid_indices);  % Filter Igrm
Twwrm = Twwrm(valid_indices);  % Filter Twwrm

% Now, FSrm, Wrpmrm, Vgrm, Igrm, and tqc should have the same length
disp(length(tqc)); % Display the length to verify
```

```
      108973
```

```
disp(length(FSrm));
```

```
      108973
```

```
disp(length(Wrpmrm));
```

```
108973
```

```
disp(length(Vgrm));
```

```
108973
```

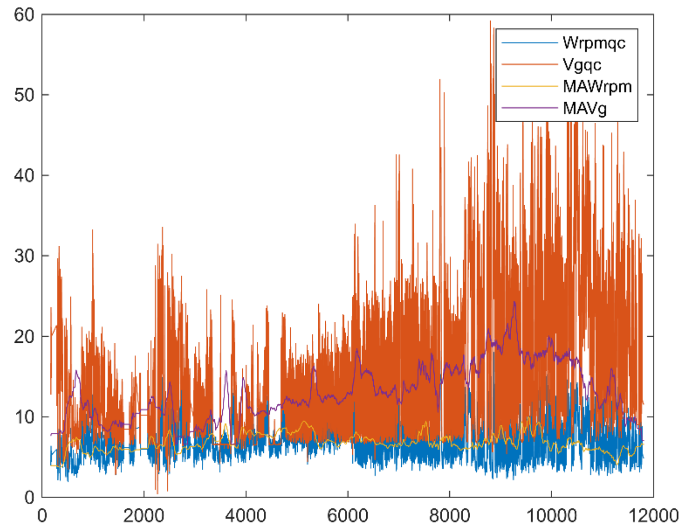
```
disp(length(Igrm));
```

```
108973
```

```
disp(length(Twwrm));
```

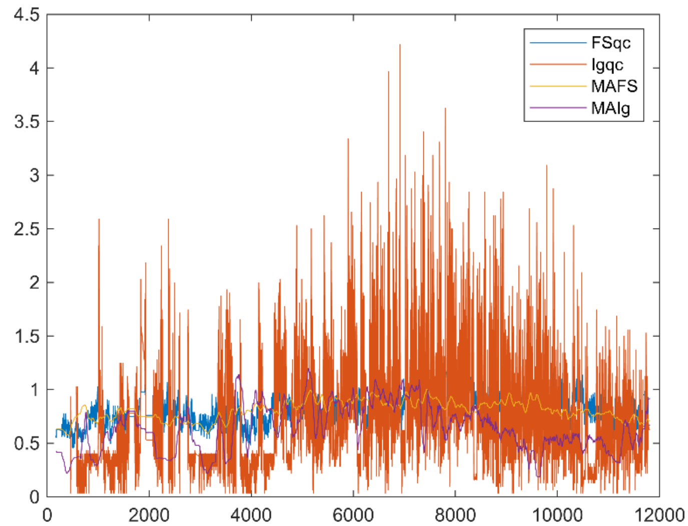
```
108973
```

```
% Smoothing the Data
MAFS = movmean(FSrm, window);
MAWrpm = movmean(Wrpmrm, window);
MAVg = movmean(Vgrm, window);
MAIg = movmean(Igrm, window);
MATww = movmean(Twwrm, window);

% Plotting
figure
plot( tqc, Wrpmqc(1:length(tqc)), tqc, Vgqc(1:length(tqc)))
hold on
plot( tqc,MAWrpm, tqc,MAVg)
legend('Wrpmqc','Vgqc','MAWrpm','MAVg')
hold off
```




```
figure
plot(tqc, FSqc(1:length(tqc)), tqc, Igqc(1:length(tqc)))
hold on
plot(tqc,MAFS, tqc,MAIg)
legend('FSqc', 'Igqc','MAFS', 'MAIg')
hold off
```

4




```
% Make CSV
h = {'Time' 'MAFS' 'MAWrpm' 'MAVg' 'MAIg' 'MATww'};
body = [tqc, MAFS, MAWrpm, MAVg, MAIg, MATww];
tabel = [h; num2cell(body)];
%disp(tabel)
```

```
% writecell(tabel, "MA110.csv")
% type MA110.csv
```

5

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-10\NW2\MA110.mat");
MAtp = MA110.Time;
MAfsp = MA110.MAFS;
MAWrpmp = MA110.MAWrpm;
MAVgp = MA110.MAVg;
MAIgp = MA110.MAIg;
MATwwp = MA110.MATww;

Wrs = ((MAWrpmp.*2.*pi)./60);

% Constants
A = 0.349;
Cd = 1.98;
R = 0.4858;
p = 1023.6;
a = 0.80; %Ph/Pa = 25.08/35.64
a1=0.8;
a2=0.85;
a3=0.9;
a4=0.95;
a5=0.33;
a6=0.5; %Ph/Pa = 24.01/51.25
a7=0.98;
a8=0.9;
g1=0.8907;

K=(25.08/35.64)
```

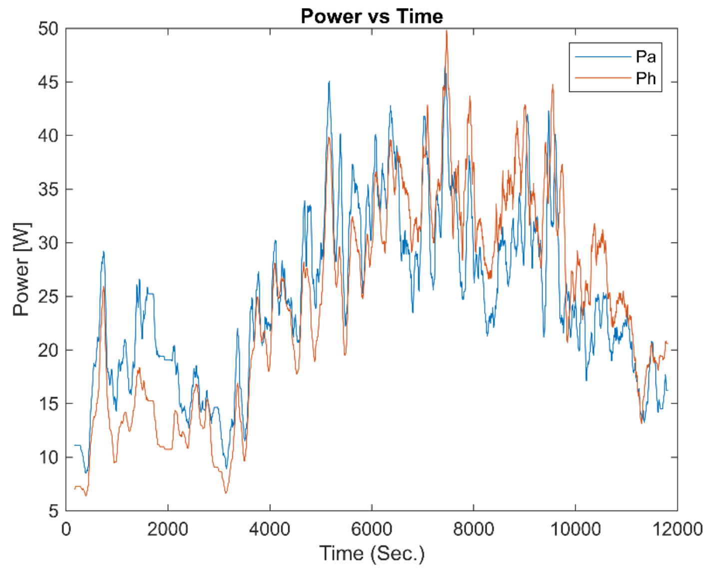
```
K = 0.7037
```

```
AVGFS=mean(MAfsp)
```

```
AVGFS = 0.8109
```

```
window = 1000;

l = ((Wrs.*R)./MAfsp);
Pa = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l.*(K);


% Theoretical
Ph = MATwwp.*Wrs;
figure
plot(MAtp,Pa, MAtp, Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa','Ph')
```

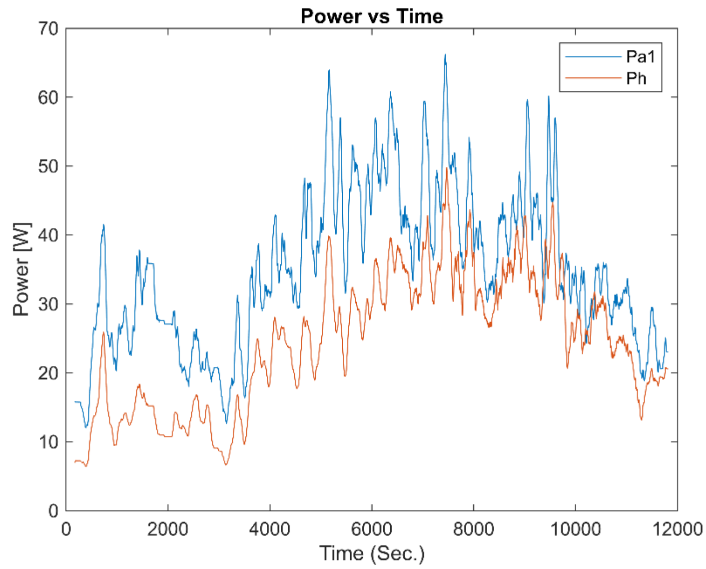
1




```
c = corrcoef(Pa,Ph)
```

```
c = 2×2
    1.0000    0.8609
    0.8609    1.0000
```

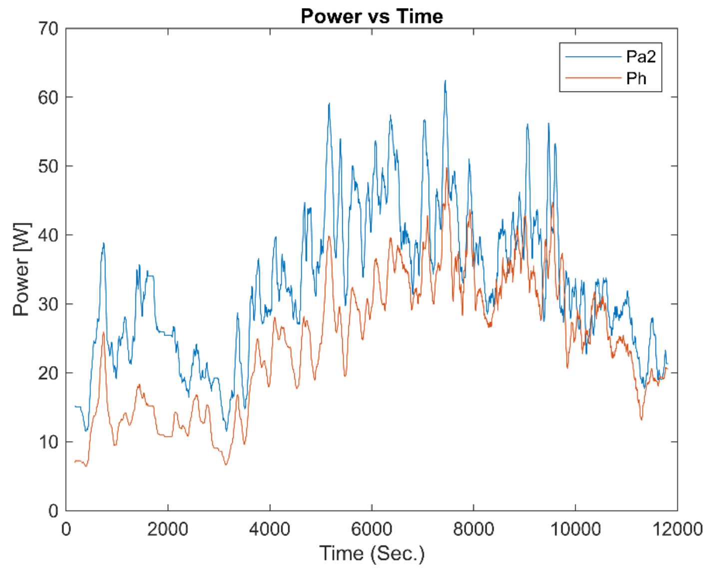
```
Pa1 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a1.*l).^2).*l;
figure
plot(MAtp,Pa1, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa1','Ph')
```




```
c1 = corrcoef(Pa1,Ph)
```

```
c1 = 2×2
    1.0000    0.8609
    0.8609    1.0000
```

```
Pa2 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a2.*l).^2).*l;
figure
plot(MAtp,Pa2, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa2','Ph')
```

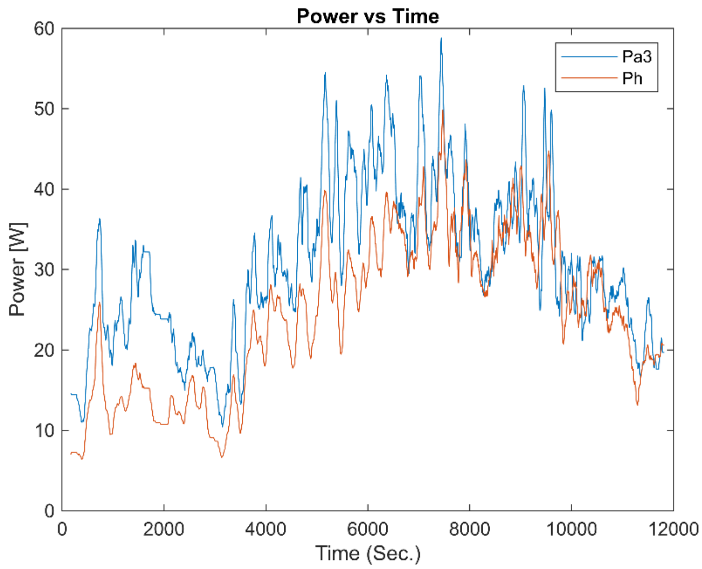



```
c2 = corrcoef(Pa2,Ph)
```

```
c2 = 2×2
    1.0000    0.8585
    0.8585    1.0000
```

```
Pa3 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a3.*l).^2).*l;
figure
plot(MAtp,Pa3, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa3','Ph')
```

4

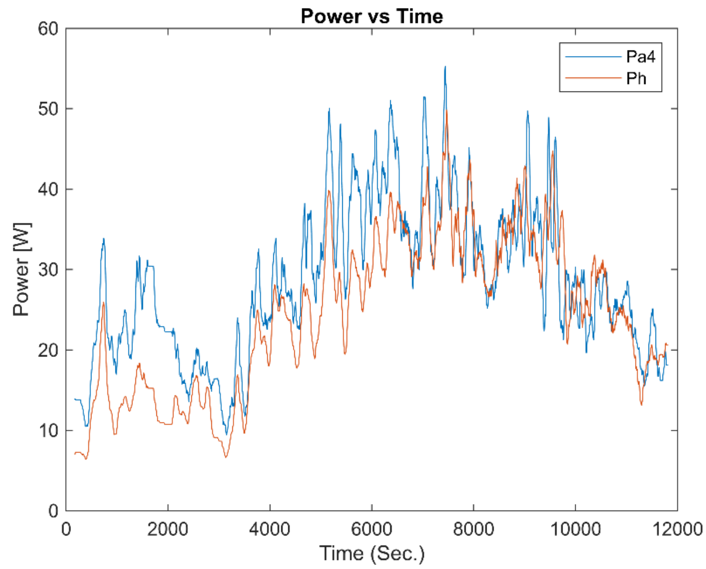



```
c3 = corrcoef(Pa3,Ph)
```

```
c3 = 2×2
    1.0000    0.8543
    0.8543    1.0000
```

```
Pa4 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a4.*l).^2).*l;
figure
plot(MAtp,Pa4, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa4','Ph')
```

5

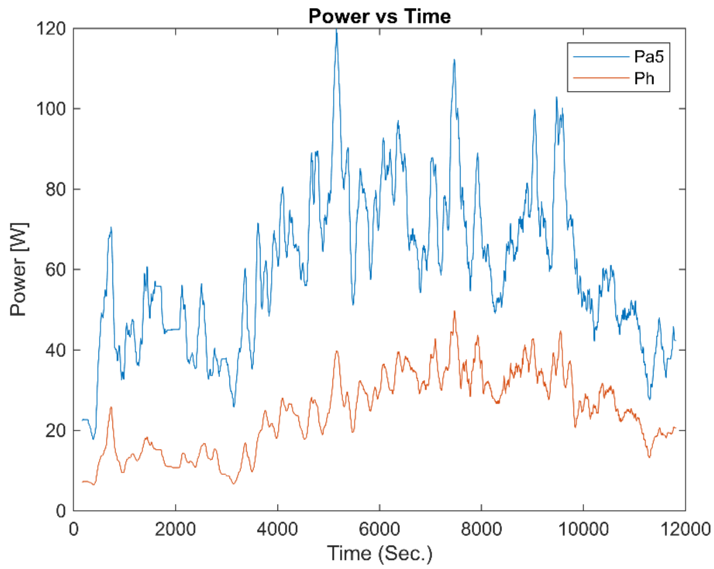



```
c4 = corrcoef(Pa4,Ph)
```

```
c4 = 2×2
    1.0000    0.8481
    0.8481    1.0000
```

```
Pa5 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a5.*l).^2).*l;
figure
plot(MAtp,Pa5, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa5','Ph')
```

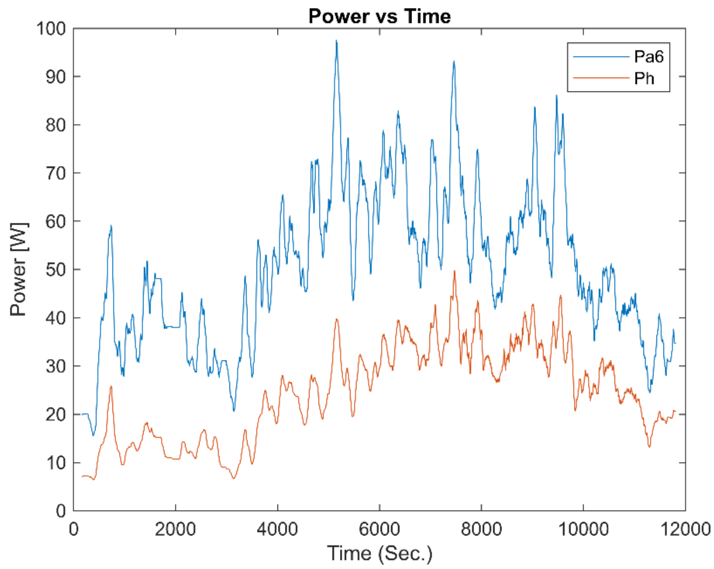
6




```
c5 = corrcoef(Pa5,Ph)
```

```
c5 = 2×2
    1.0000    0.8319
    0.8319    1.0000
```

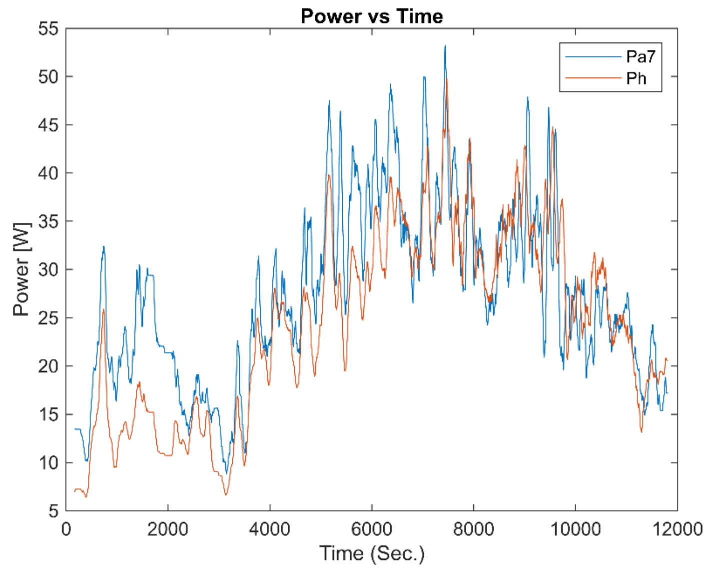
```
Pa6 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a6.*l).^2).*l;
figure
plot(MAtp,Pa6, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa6','Ph')
```




```
c6 = corrcoef(Pa6,Ph)
```

```
c6 = 2×2
    1.0000    0.8495
    0.8495    1.0000
```

```
Pa7 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a7.*l).^2).*l;
figure
plot(MAtp,Pa7, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa7','Ph')
```




```
c7 = corrcoef(Pa7,Ph)
```

```
c7 = 2×2
    1.0000    0.8434
    0.8434    1.0000
```

```
g = Ph./Pa7;
AVGPh=mean(Ph)
```

```
AVGPh = 25.0790
```

```
AVGPa=mean(Pa)
```

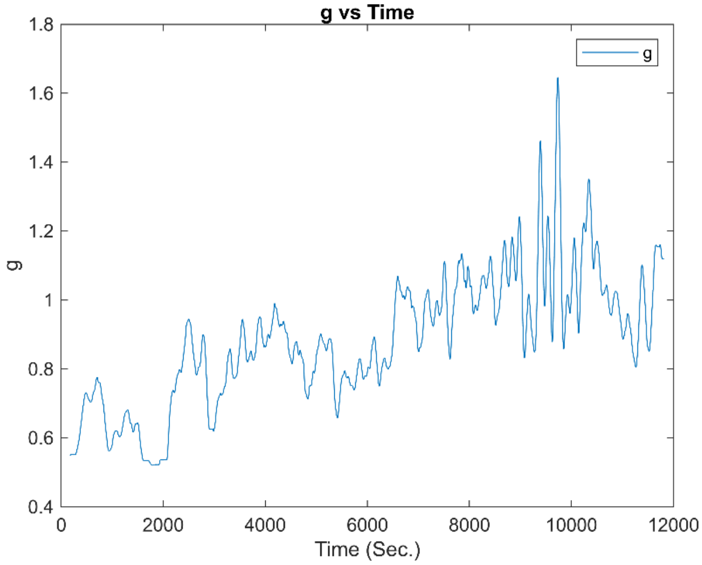
```
AVGPa = 25.0796
```

```
AVGg=mean(g)
```

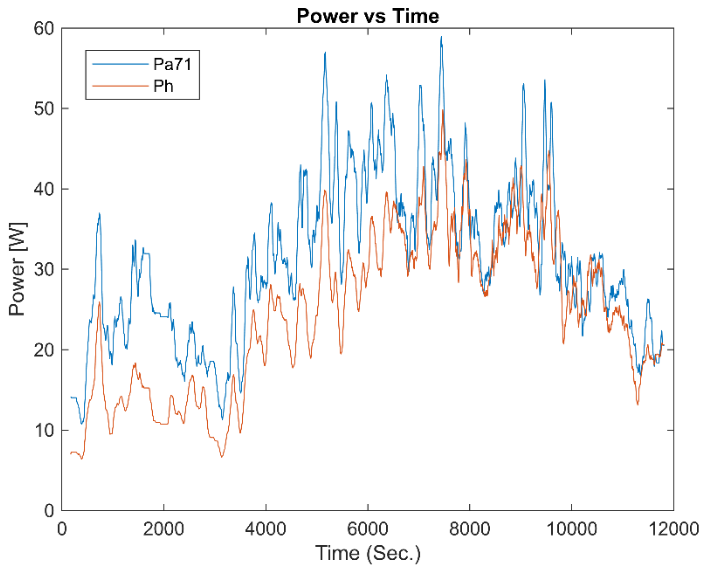
```
AVGg = 0.9004
```

```
MAg = movmean(g, window);

figure
plot(MAtp,MAg)
title("g vs Time");
xlabel("Time (Sec.)");
ylabel("g");
legend('g')
```

9



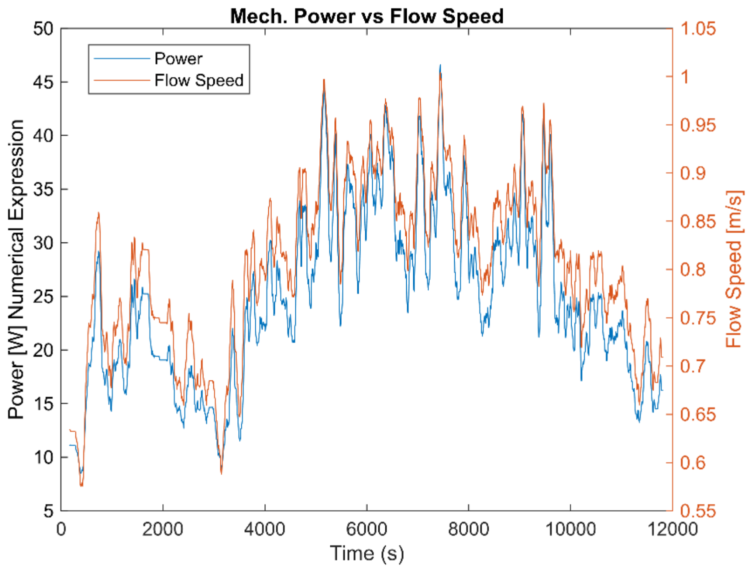

```
Pa71 = (1/2).*p.*A.*g1.*Cd.*(MAfsp.^3).*((1-a.*1).^2).*1;
figure
plot(MAtp,Pa71, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa71','Ph')

legend("Position", [0.15169,0.79933,0.16086,0.092742])
```




```
c71 = corrcoef(Pa71,Ph)
```

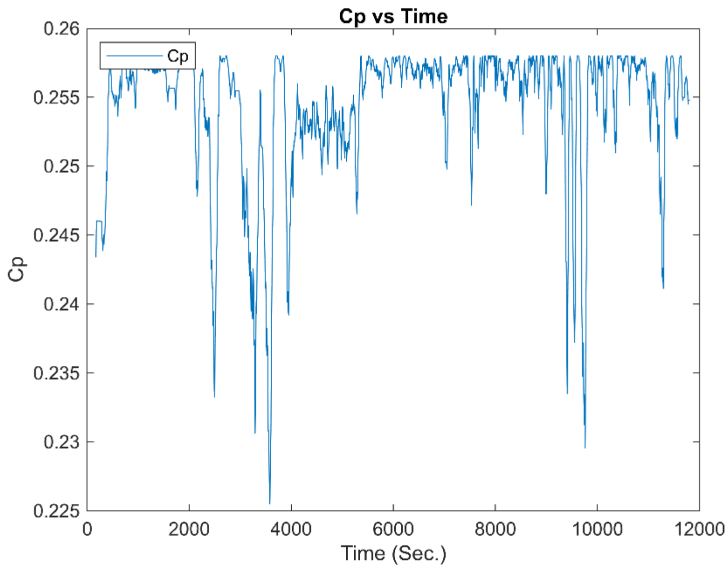
```
c71 = 2×2
    1.0000    0.8609
    0.8609    1.0000
```

```
figure
plot(MAtp,Pa);
ylabel('Power [W] Numerical Expression');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Mech. Power vs Flow Speed');

legend("Position", [0.15122,0.80929,0.23123,0.092742])
```



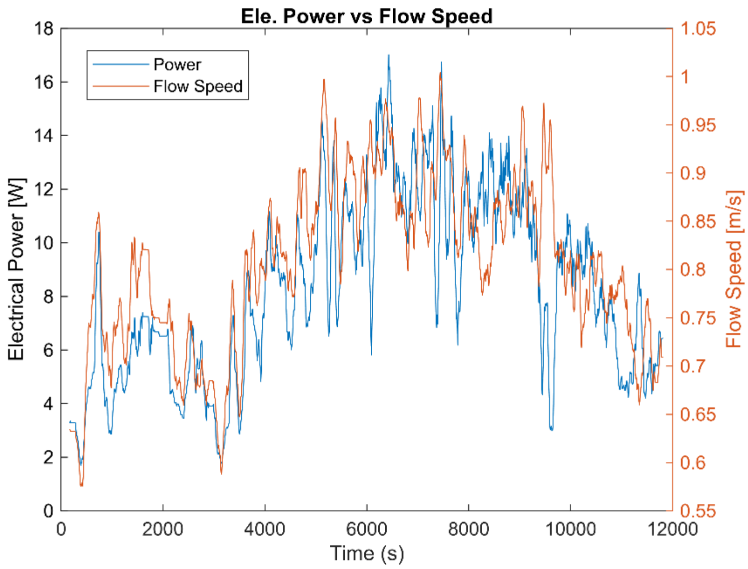

```
Pe = MAVgp.*MAIgp;

figure
plot(MAtp,Pe);
ylabel('Electrical Power [W]');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Ele. Power vs Flow Speed');

legend("Position", [0.14973,0.79933,0.23123,0.092742])
```

12




```
figure
plot(MAtp,Cp);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('CP vs Flow Speed');

legend("Position", [0.58941,0.14621,0.23123,0.092742])
```

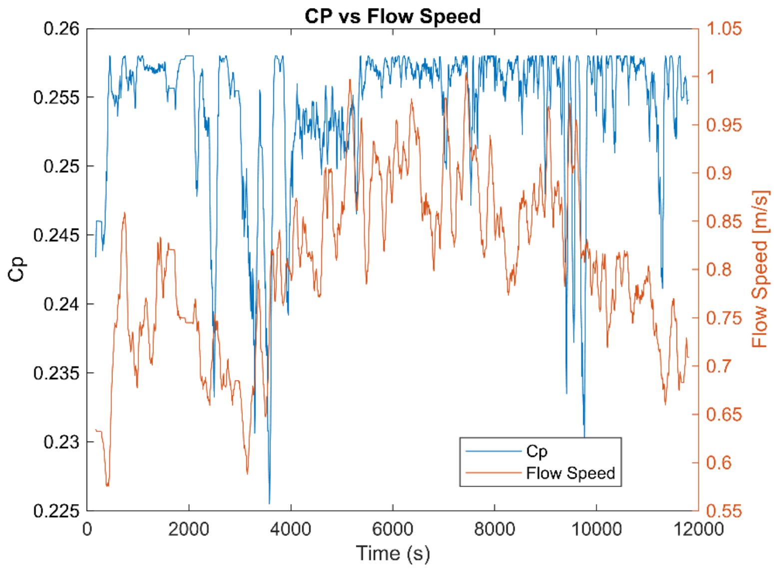
14




```
% Cp of Numerical Expression
Cp = Pa./((1/2).*p.*A.*(MAfsp.^3));
Cpsdt = std(Cp)
```

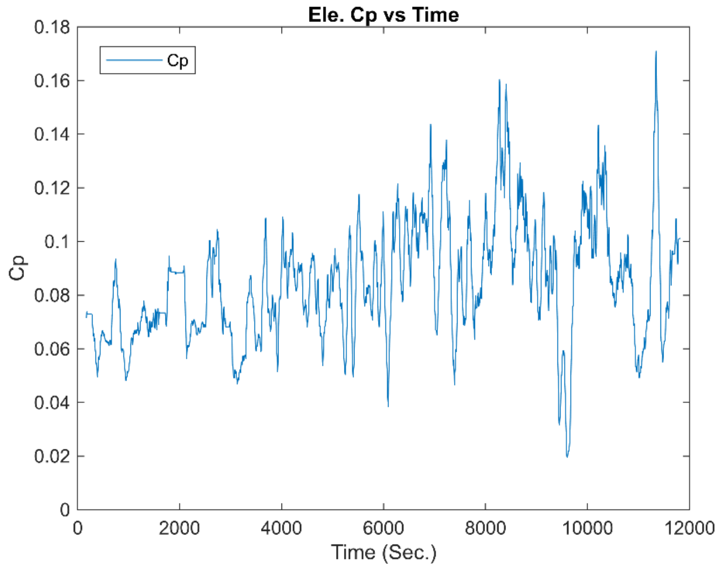
```
Cpsdt = 0.0052
```

```
figure
plot(MAtp,Cp)
title("Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')

legend("Position", [0.13908,0.85295,0.13472,0.051075])
```

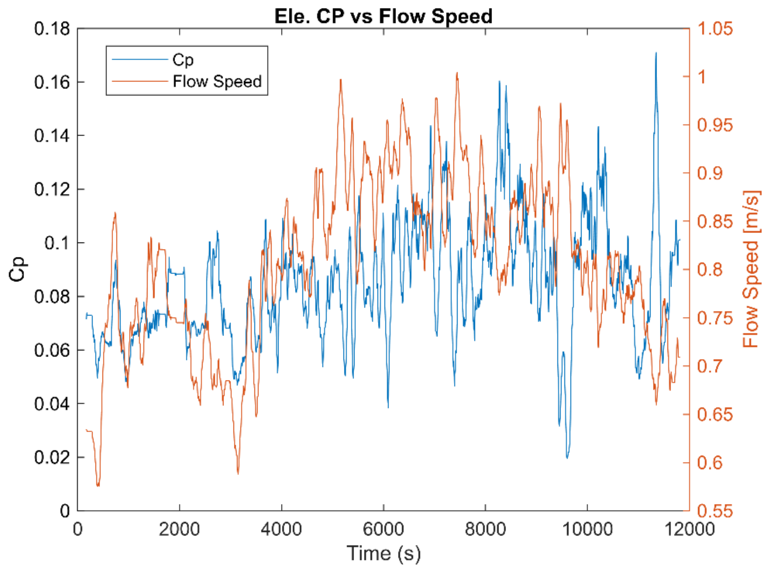



```
% Cp of the Pe
Cpe = Pe./((1/2).*p.*A.*(MAfsp.^3));

figure
plot(MAtp,Cpe)
title("Ele. Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')

legend("Position", [0.151,0.84299,0.13472,0.051075])
```

15

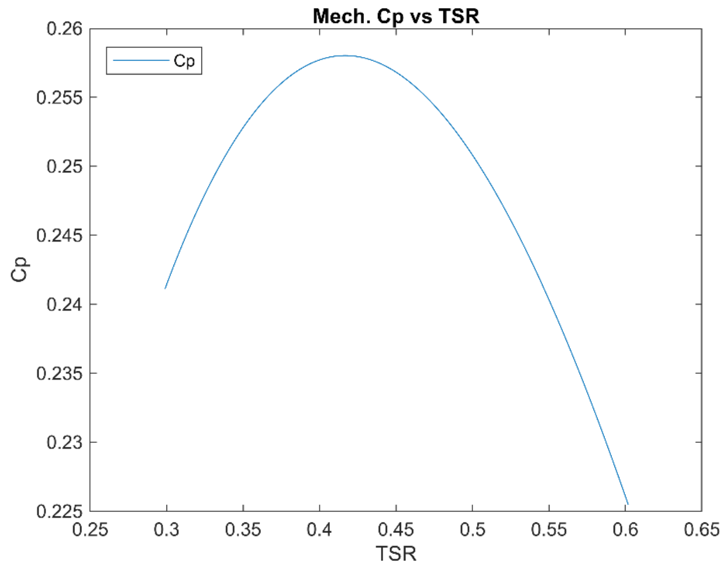



```
figure
plot(MAtp,Cpe);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('Ele. CP vs Flow Speed');

legend("Position", [0.15271,0.8073,0.23123,0.092742])
```

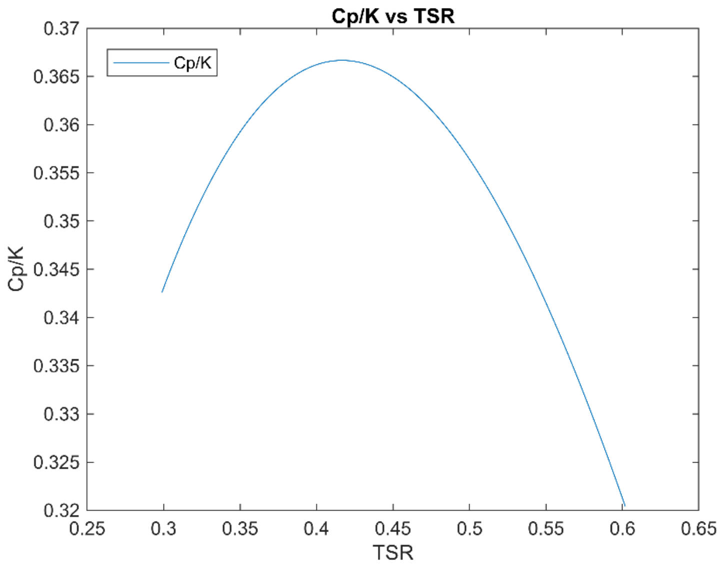



```
% Mech. Cp vs Lambda
figure
plot(l,Cp)
title("Mech. Cp vs TSR");
xlabel("TSR");
ylabel("Cp");
legend('Cp')

legend("Position", [0.14355,0.84498,0.13472,0.051075])
```

17




```
% Cp/K vs Lambda
CPk = Cp/K;
figure
plot(l,CPk)
title("Cp/K vs TSR");
xlabel("TSR");
ylabel("Cp/K");
legend('Cp/K')

legend("Position", [0.14677,0.841,0.15684,0.051075])
```




```
AVGPa=mean(Pa)
```

AVGPa = 25.0796

```
MAXPa=max(Pa)
```

MAXPa = 46.6252

```
AVGPe=mean(Pe)
```

AVGPe = 8.4169

```
MAXPe=max(Pe)
```

MAXPe = 17.0324

```
AVGCp=mean(Cp)
```

AVGCp = 0.2543

```
MaxCp=max(Cp)
```

MaxCp = 0.2580

```
AVGCpe=mean(Cpe)
```

AVGCpe = 0.0849

```
MAXCpe=max(Cpe)
```

```
MAXCpe = 0.1710
```

```
% Load Data & Set Names
data = readtable("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-16\New
Way\rd116.csv");
%disp(data)

datast.time = rd116.time_elapsed;
datast.values = table2array(data(:,2:6));
%disp(datast.time)
%disp(datast.values)

% Checking that all FS values have a proper time stamp
freq = 0.1;
results = check_timestamp(datast,freq);
%disp(results.values)

% Checking the Data Range
bounds = [0.001,35];
results = check_range(results,bounds);
%disp(results.values)

% Make CSV
h = {'Time' 'FS' 'Wrmp' 'Vg' 'Ig' 'Tww'};
body = [datast.time, results.values];
tabel = [h; num2cell(body)];
%disp(tabel)

% writecell(tabel, "qc116.csv")
% type qc116.csv
```

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-16\New
Way\qc116.mat");
tqc = qc116.Time;
FSqc = qc116.FS;
Wrpmqc = qc116.Wrmp;
Vgqc = qc116.Vg;
Igqc = qc116.Ig;
Twwqc = qc116.Tww;

window = 1000;

% Remove Outliers
FSrm = rmoutliers(FSqc);
Wrpmrm = rmoutliers(Wrpmqc);
Vgrm = rmoutliers(Vgqc);
Igrm = rmoutliers(Igqc);
Twwrm = rmoutliers(Twwqc);

size(tqc)
```

```
ans = 1×2
      106964           1
```

```
size(FSrm)
```

```
ans = 1×2
      106911           1
```

```
size(Wrpmrm)
```

```
ans = 1×2
      106948           1
```

```
size(Vgrm)
```

```
ans = 1×2
      106964           1
```

```
size(Igrm)
```

```
ans = 1×2
      103793           1
```

```
size(Twwrm)
```

```
ans = 1×2
       96014           1
```

```
% Trim FSrm to match the length of Twwrm
FSrm = FSrm(1:length(Twwrm));
% Trim Wrpmrm to match the length of Twwrm
Wrpmrm = Wrpmrm(1:length(Twwrm));
```

```
% Trim Vgrm to match the length of Twwrm
Vgrm = Vgrm(1:length(Twwrm));
% Trim Igrm to match the length of Twwrm
Igrm = Igrm(1:length(Twwrm));


% Now they all should have the same length
disp(size(FSrm))
```

```
       96014           1
```

```
disp(size(Wrpmrm))
```

```
       96014           1
```

```
disp(size(Vgrm))
```

```
       96014           1
```

```
disp(size(Igrm))
```

```
       96014           1
```

```
disp(size(Twwrm))
```

```
       96014           1
```

```

% Ensure that the time vector has the same length as the other data vectors after
removing outliers
FSrm_valid = ~isnan(FSrm);  % Find valid indices for FSrm
Wrpmrm_valid = ~isnan(Wrpmrm);  % Find valid indices for Wrpmrm
Vgrm_valid = ~isnan(Vgrm);  % Find valid indices for Vgrm
Igrm_valid = ~isnan(Igrm);  % Find valid indices for Igrm
Twwrm_valid = ~isnan(Twwrm);  % Find valid indices for Twwrm
valid_indices = FSrm_valid & Wrpmrm_valid & Vgrm_valid & Igrm_valid & Twwrm_valid;
% Combine valid indices

tqc = tqc(valid_indices);  % Filter the time vector to match the lengths of FSrm,
Wrpmrm, Vgrm and Igrm
FSrm = FSrm(valid_indices); %Filter FSrm
Wrpmrm = Wrpmrm(valid_indices); %Filter Wrpmrm
Vgrm = Vgrm(valid_indices);  % Filter Vgrm
Igrm = Igrm(valid_indices);  % Filter Igrm
Twwrm = Twwrm(valid_indices);  % Filter Twwrm

% Now, FSrm, Wrpmrm, Vgrm, Igrm, and tqc should have the same length
disp(length(tqc)); % Display the length to verify
```

```
       65778
```

```
disp(length(FSrm));
```

65778

```
disp(length(Wrpmrm));
```

65778

```
disp(length(Vgrm));
```

65778

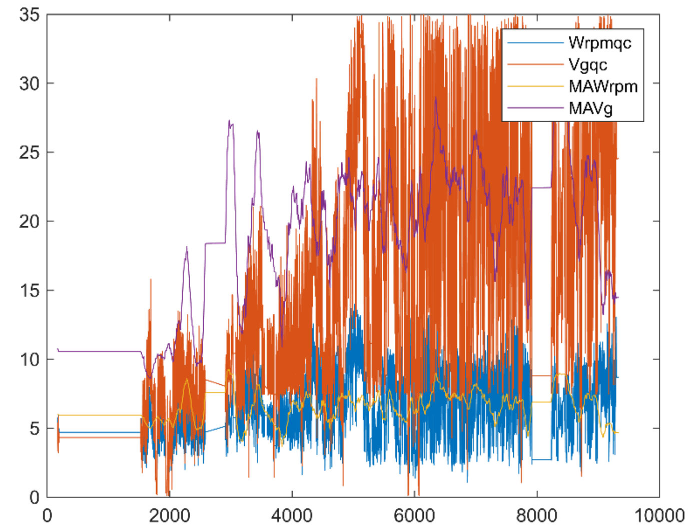
```
disp(length(Igrm));
```

65778

```
disp(length(Twwrm));
```

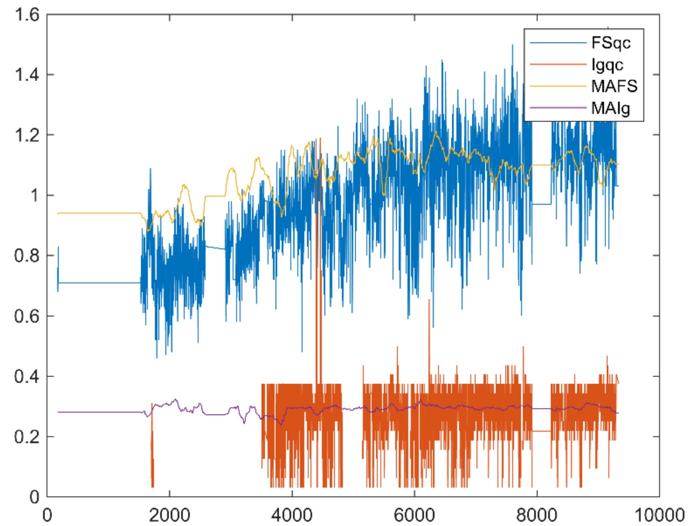
65778

```

% Down Sample the Data
% Dt = downsample(tqc, 10);
% DFS = downsample(FSrm, 10);
% DWrpm = downsample(Wrpmrm, 10);
% DVg = downsample(Vgrm, 10);
% DIg = downsample(Igrm, 10);
% DTww = downsample(Twwrm, 10);

% Smoothing the Data
MAFS = movmean(FSrm, window);
MAWrpm = movmean(Wrpmrm, window);
MAVg = movmean(Vgrm, window);
MAIg = movmean(Igrm, window);
MATww = movmean(Twwrm, window);

% Plotting
figure
plot( tqc, Wrpmqc(1:length(tqc)), tqc, Vgqc(1:length(tqc)))
hold on
plot( tqc,MAWrpm, tqc,MAVg)
legend('Wrpmqc','Vgqc','MAWrpm','MAVg')
hold off
```




```
figure
plot(tqc, FSqc(1:length(tqc)), tqc, Igqc(1:length(tqc)))
hold on
plot(tqc,MAFS, tqc,MAIg)
legend('FSqc', 'Igqc','MAFS', 'MAIg')
hold off
```

4




```
% Make CSV
h = {'Time' 'MAFS' 'MAWrpm' 'MAVg' 'MAIg' 'MATww'};
body = [tqc, MAFS, MAWrpm, MAVg, MAIg, MATww];
tabel = [h; num2cell(body)];
%disp(tabel)
```

```
% writecell(tabel, "MA116.csv")
% type MA116.csv
```

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-16\New
Way\MA116.mat");
MAtp = MA116.Time;
MAfsp = MA116.MAFS;
MAWrpmp = MA116.MAWrpm;
MAVgp = MA116.MAVg;
MAIgp = MA116.MAIg;
MATwwp = MA116.MATww;

Wrs = ((MAWrpmp.*2.*pi)./60);

% Constants
A = (0.349/2);
Cd = 1.98;
R = 0.4858;
p = 1023.6;
a = 0.8; %Ph/Pa = 18.71/38.83
a1=0.8;
a2=0.85;
a3=0.9;
a4=0.95;
a5=0.33;
a6=0.5; %Ph/Pa = 13.98/49.13
a7=0.98; %Ph/Pa = 13.98/33.24
a8=0.75;
g1=0.5572;

K=(18.71/38.83)
```

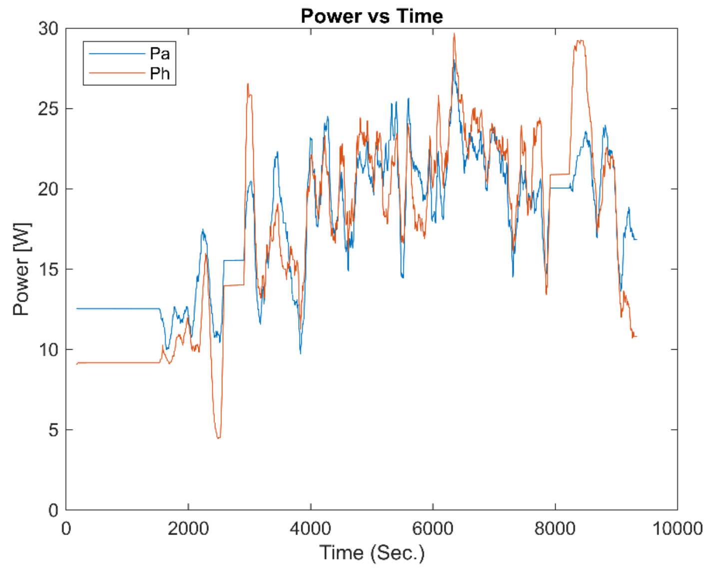
```
K = 0.4818
```

```
AVGFS =mean(MAfsp)  %1.08 m/s
```

```
AVGFS = 1.0767
```

```
window = 1000;

l = ((Wrs.*R)./MAfsp);
Pa = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l.*(K);

% Theoretical
Ph = MATwwp.*Wrs;

figure
plot(MAtp,Pa, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
```

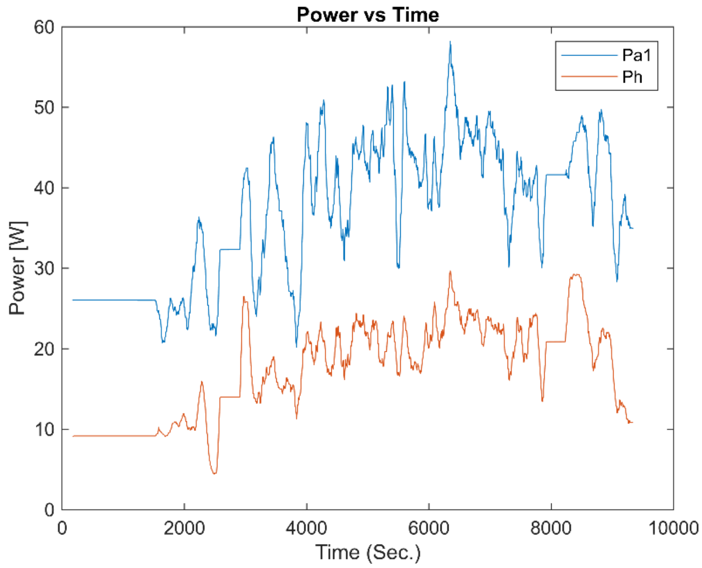
```
legend('Pa','Ph')

legend("Position", [0.14407,0.81925,0.13271,0.092742])
```




```
c = corrcoef(Pa,Ph)
```

```
c = 2×2
    1.0000    0.8831
    0.8831    1.0000
```

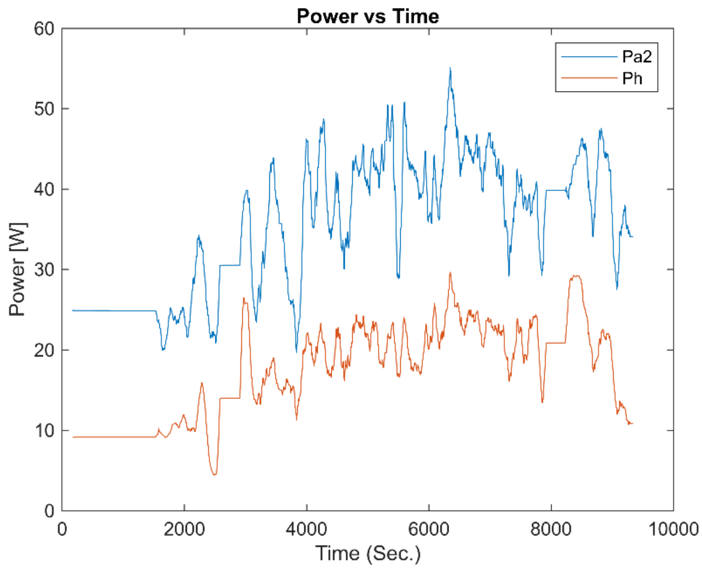
```
Pa1 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a1.*1).^2).*1;

figure
plot(MAtp,Pa1, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa1','Ph')
```




```
c1 = corrcoef(Pa1,Ph)
```

```
c1 = 2×2
    1.0000    0.8831
    0.8831    1.0000
```

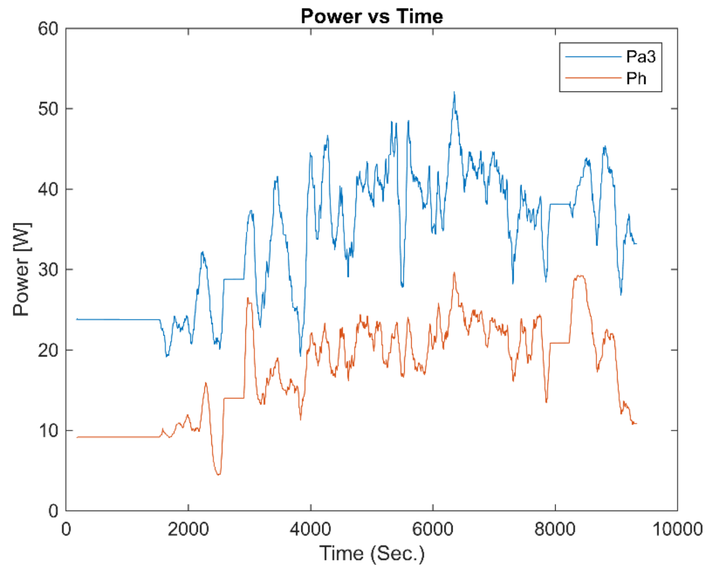
```
Pa2 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a2.*l).^2).*l;

figure
plot(MAtp,Pa2, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa2','Ph')
```




```
c2 = corrcoef(Pa2,Ph)
```

```
c2 = 2×2
    1.0000    0.8786
    0.8786    1.0000
```

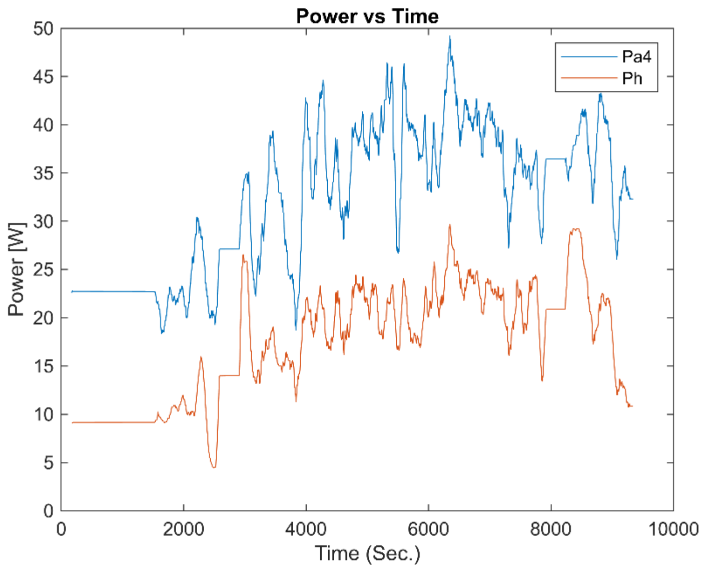
```
Pa3 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a3.*l).^2).*l;

figure
plot(MAtp,Pa3, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa3','Ph')
```




```
c3 = corrcoef(Pa3,Ph)
```

```
c3 = 2×2
    1.0000    0.8729
    0.8729    1.0000
```

```
Pa4 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a4.*l).^2).*l;

figure
plot(MAtp,Pa4, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa4','Ph')
```

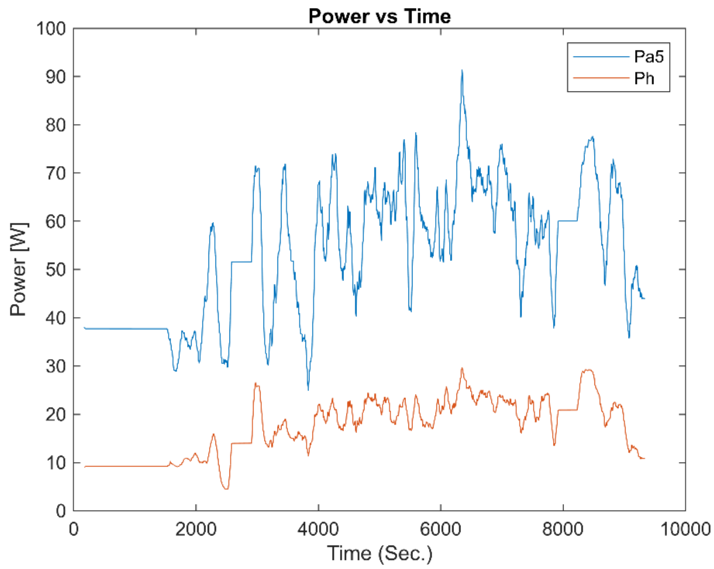



```
c4 = corrcoef(Pa4,Ph)
```

```
c4 = 2×2
    1.0000    0.8658
    0.8658    1.0000
```

```
Pa5 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a5.*1).^2).*1;

figure
plot(MAtp,Pa5, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa5','Ph')
```

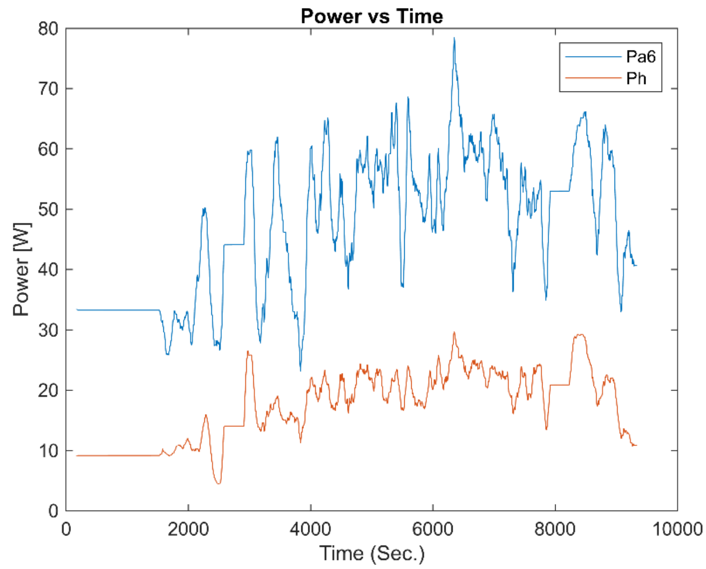
6




```
c5 = corrcoef(Pa5,Ph)
```

```
c5 = 2×2
    1.0000    0.8914
    0.8914    1.0000
```

```
Pa6 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a6.*l).^2).*l;

figure
plot(MAtp,Pa6, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa6','Ph')
```

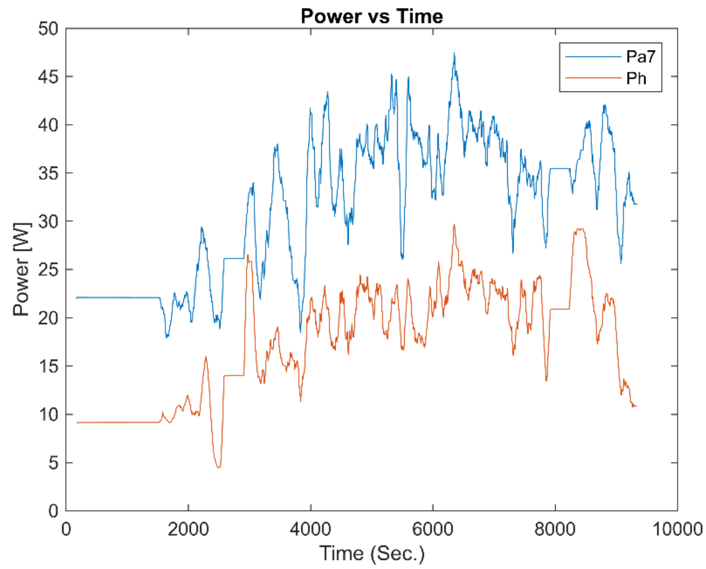



```
c6 = corrcoef(Pa6,Ph)
```

```
c6 = 2×2
    1.0000    0.8930
    0.8930    1.0000
```

```
Pa7 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a7.*l).^2).*l;

figure
plot(MAtp,Pa7, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa7','Ph')
```

8




```
c7 = corrcoef(Pa7,Ph)
```

```
c7 = 2×2
    1.0000    0.8608
    0.8608    1.0000
```

```
g = Ph./Pa7;
MAg = movmean(g, window);
AVGPh=mean(Ph)
```

```
AVGPh = 18.7106
```

```
AVGPa=mean(Pa)
```

```
AVGPa = 18.7081
```

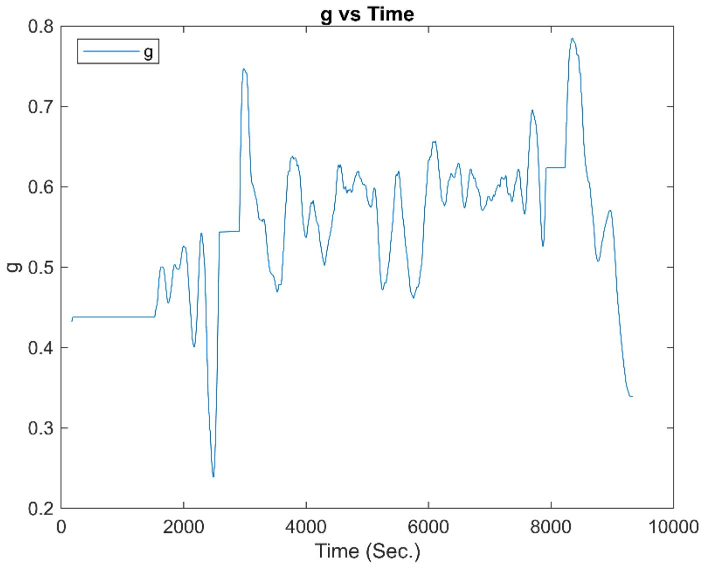
```
AVGg=mean(g)
```

```
AVGg = 0.5572
```

```
figure
plot(MAtp,MAg)
title("g vs Time");
xlabel("Time (Sec.)");
ylabel("g");
legend('g')
```

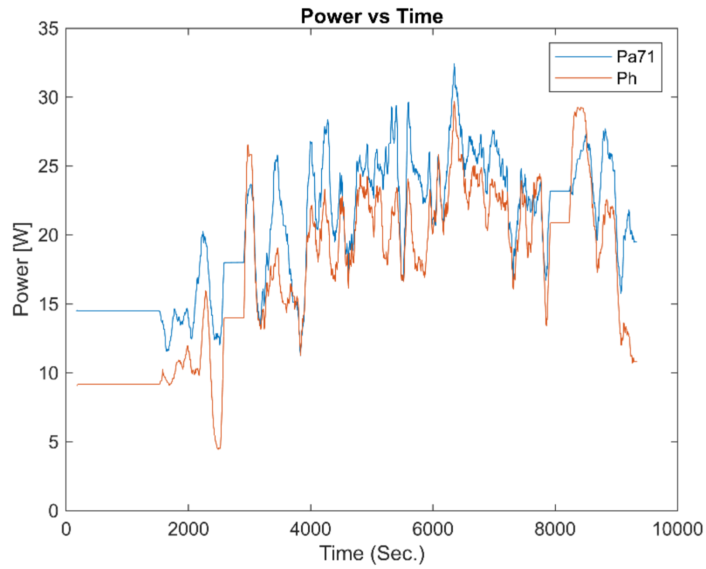
9

```
legend("Position", [0.14376,0.85693,0.11662,0.051075])
```




```
Pa71 = (1/2).*p.*A.*g1.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l;

figure
plot(MAtp,Pa71, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa71','Ph')
```

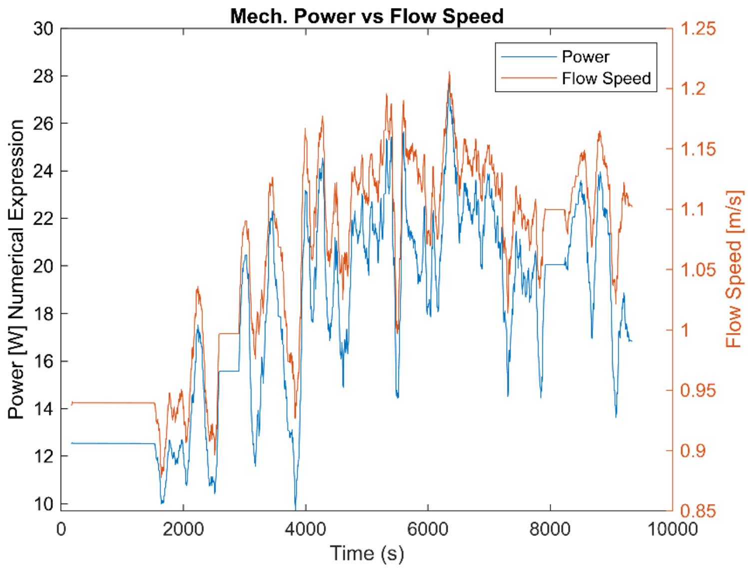
10




```
c71 = corrcoef(Pa71,Ph)
```

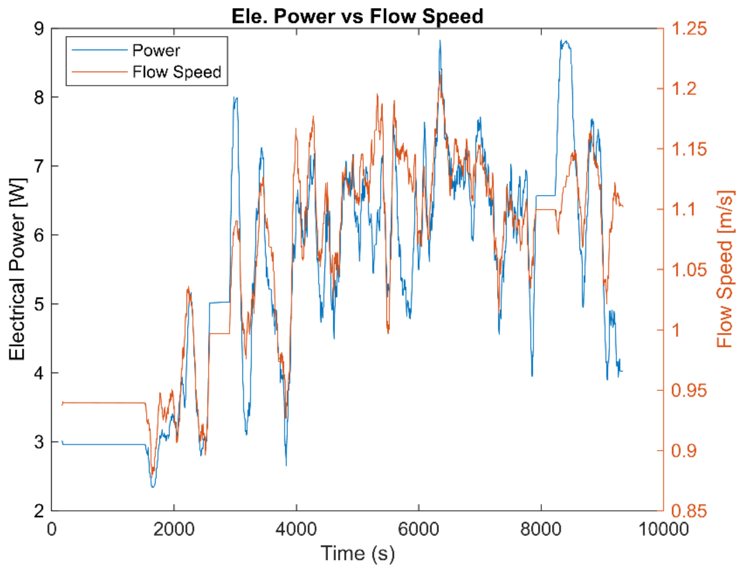
```
c71 = 2×2
    1.0000    0.8831
    0.8831    1.0000
```

```
figure
plot(MAtp,Pa);
ylabel('Power [W] Numerical Expression');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Mech. Power vs Flow Speed');
```




```
Pe = MAVgp.*MAIgp;

figure
plot(MAtp,Pe);
ylabel('Electrical Power [W]');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Ele. Power vs Flow Speed');

legend("Position", [0.13483,0.82323,0.23123,0.092742])
```

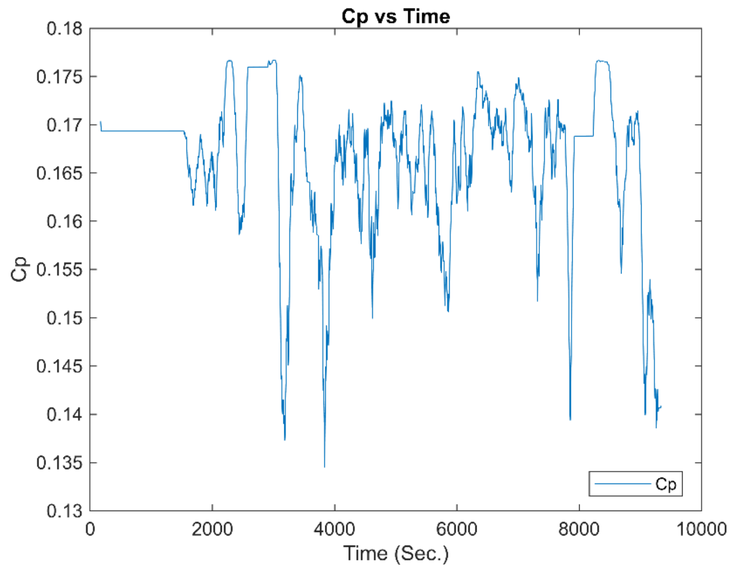
12




```
% Cp of Numerical Expression
Cp = Pa./((1/2).*p.*A.*(MAfsp.^3));
Cpsdt = std(Cp)
```

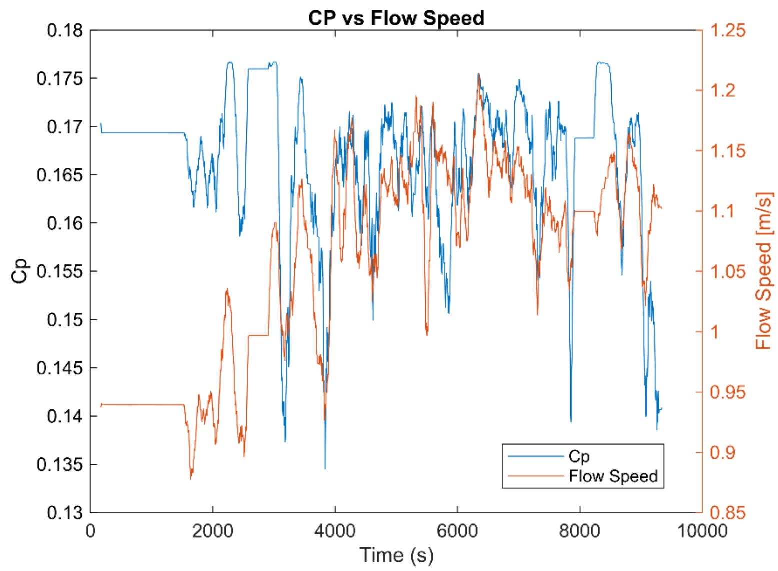
```
Cpsdt = 0.0080
```

```
figure
plot(MAtp,Cp)
title("Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')

legend("Position", [0.75462,0.13013,0.13472,0.051075])
```

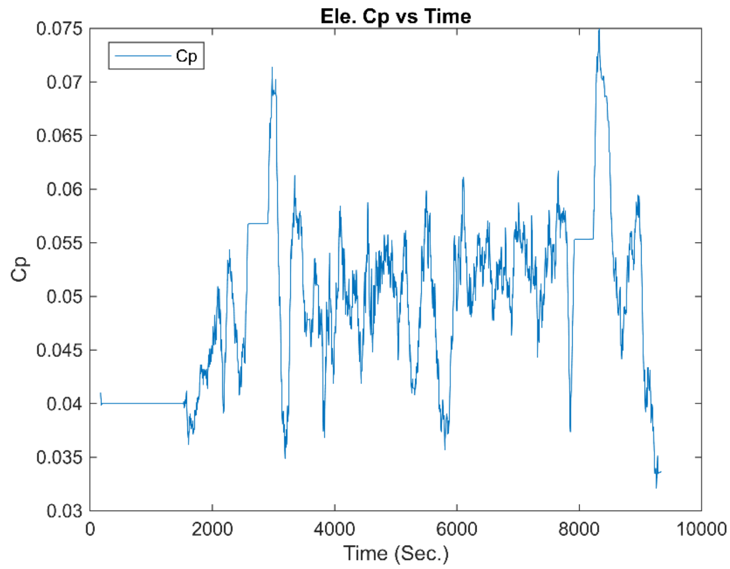



```
figure
plot(MAtp,Cp);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('CP vs Flow Speed');

legend("Position", [0.63859,0.14222,0.23123,0.092742])
```

14

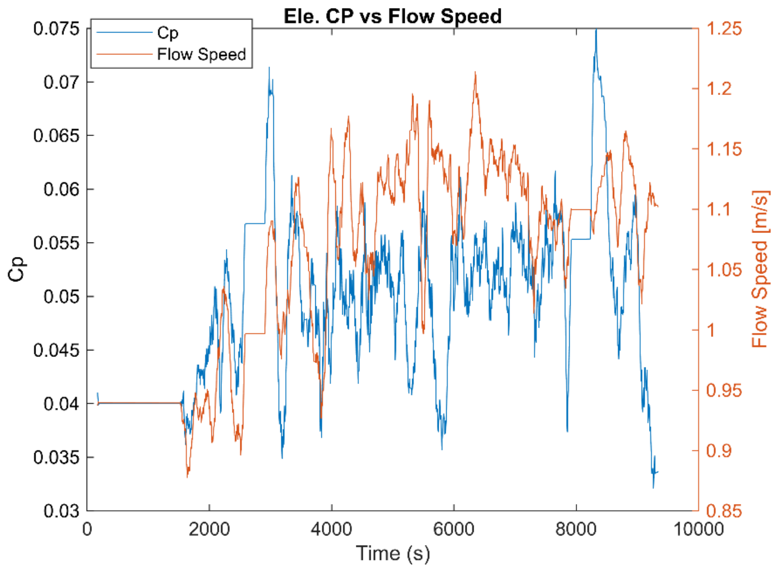



```
% Cp of the Pe
Cpe = Pe./((1/2).*p.*A.*(MAfsp.^3));

figure
plot(MAtp,Cpe)
title("Ele. Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')

legend("Position", [0.14653,0.85295,0.13472,0.051075])
```



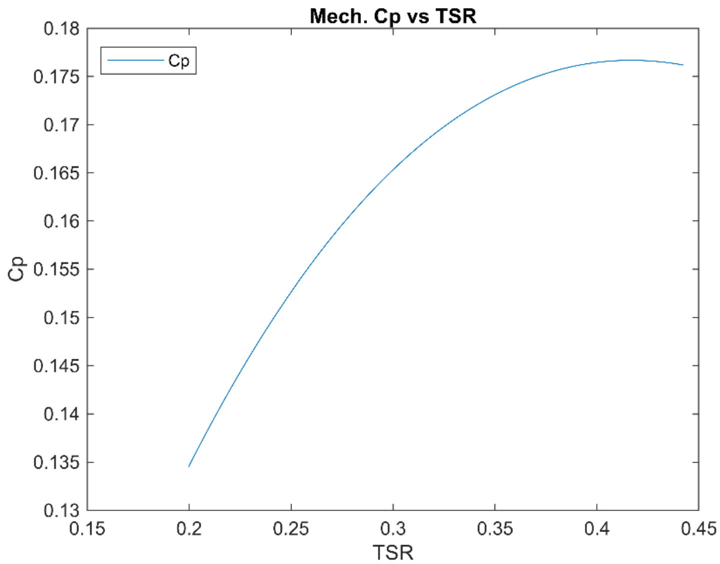

```
figure
plot(MAtp,Cpe);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('Ele. CP vs Flow Speed');

legend("Position", [0.14079,0.81128,0.23123,0.092742])

legend("Position", [0.12141,0.8526,0.23123,0.093739])
```

16

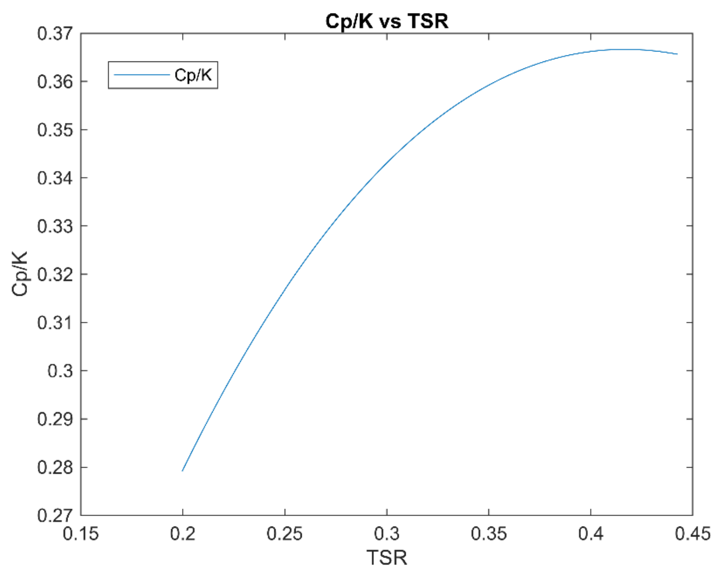



```
% Mech. Cp vs Lambda
figure
plot(l,Cp)
title("Mech. Cp vs TSR");
xlabel("TSR");
ylabel("Cp");
legend('Cp')

legend("Position", [0.14057,0.84498,0.13472,0.051075])
```

17




```
% Cp/K vs Lambda
CPk = Cp/K;
figure
plot(l,CPk)
title("Cp/K vs TSR");
xlabel("TSR");
ylabel("Cp/K");
legend('Cp/K')

legend("Position", [0.15571,0.82905,0.15684,0.051075])
```




```
AVGPa=mean(Pa)
```

AVGPa = 18.7081

```
MAXPa=max(Pa)
```

MAXPa = 28.0661

```
AVGPe=mean(Pe)
```

AVGPe = 5.6833

```
MAXPe=max(Pe)
```

MAXPe = 8.8395

```
AVGCp=mean(Cp)
```

AVGCp = 0.1650

```
MaxCp=max(Cp)
```

MaxCp = 0.1767

```
AVGCpe=mean(Cpe)
```

```
AVGCpe = 0.0498
```

```
MAXCpe=max(Cpe)
```

```
MAXCpe = 0.0750
```

```
% Load Data & Set Names
data = readtable("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\1-17\rd117.csv");
%disp(data)

datast.time = rd117.time_elapsed;
datast.values = table2array(data(:,2:6));
%disp(datast.time)
%disp(datast.values)

% Checking that all FS values have a proper time stamp
freq = 0.1;
results = check_timestamp(datast,freq);
%disp(results.values)

% Checking the Data Range
bounds = [0.001,90];
results = check_range(results,bounds);
%disp(results.values)

% %Checking for Stagnant Data
% bound = {0.00001, py.None};
% window1 = 0.01;
% results = check_delta(results, bound, window1);
% disp(results.values)

% Make CSV
h = {'Time' 'FS' 'Wrmp' 'Vg' 'Ig' 'Tww'};
body = [datast.time, results.values];
tabel = [h; num2cell(body)];
%disp(tabel)

% writecell(tabel, "qc117e.csv");
% type qc117e.csv;
```

1

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\1-17\qc117e.mat");
tqc = qc117e.Time;
FSqc = qc117e.FS;
Wrpmqc = qc117e.Wrmp;
Vgqc = qc117e.Vg;
Igqc = qc117e.Ig;
Twwqc = qc117e.Tww;
window = 1000;

% Remove Outliers
FSrm = rmoutliers(FSqc);
Wrpmrm = rmoutliers(Wrpmqc);
Vgrm = rmoutliers(Vgqc);
Igrm = rmoutliers(Igqc);
Twwrm = rmoutliers(Twwqc);

size(tqc)
```

```
ans = 1×2
      182405           1
```

```
size(FSrm)
```

```
ans = 1×2
      177120           1
```

```
size(Wrpmrm)
```

```
ans = 1×2
      181147           1
```

```
size(Vgrm)
```

```
ans = 1×2
      182037           1
```

```
size(Igrm)
```

```
ans = 1×2
      177080           1
```

```
size(Twwrm)
```

```
ans = 1×2
      171701           1
```

```
% Trim FSrm to match the length of Twwrm
FSrm = FSrm(1:length(Twwrm));
% Trim Wrpmrm to match the length of Twwrm
Wrpmrm = Wrpmrm(1:length(Twwrm));
% Trim Vgrm to match the length of Twwrm
Vgrm = Vgrm(1:length(Twwrm));
```

```
% Trim Igrm to match the length of Twwrm
Igrm = Igrm(1:length(Twwrm));


% Now they all should have the same length
disp(size(FSrm))
```

```
171701           1
```

```
disp(size(Wrpmrm))
```

```
171701           1
```

```
disp(size(Vgrm))
```

```
171701           1
```

```
disp(size(Igrm))
```

```
171701           1
```

```
disp(size(Twwrm))
```

```
171701           1
```

```

% Ensure that the time vector has the same length as the other data vectors after
removing outliers
FSrm_valid = ~isnan(FSrm);  % Find valid indices for FSrm
Wrpmrm_valid = ~isnan(Wrpmrm);  % Find valid indices for Wrpmrm
Vgrm_valid = ~isnan(Vgrm);  % Find valid indices for Vgrm
Igrm_valid = ~isnan(Igrm);  % Find valid indices for Igrm
Twwrm_valid = ~isnan(Twwrm);  % Find valid indices for Twwrm
valid_indices = FSrm_valid & Wrpmrm_valid & Vgrm_valid & Igrm_valid & Twwrm_valid;
% Combine valid indices

tqc = tqc(valid_indices);  % Filter the time vector to match the lengths of FSrm,
Wrpmrm, Vgrm and Igrm
FSrm = FSrm(valid_indices); %Filter FSrm
Wrpmrm = Wrpmrm(valid_indices); %Filter Wrpmrm
Vgrm = Vgrm(valid_indices);  % Filter Vgrm
Igrm = Igrm(valid_indices);  % Filter Igrm
Twwrm = Twwrm(valid_indices);  % Filter Twwrm

% Now, FSrm, Wrpmrm, Vgrm, Igrm, and tqc should have the same length
disp(length(tqc)); % Display the length to verify
```

```
162111
```

```
disp(length(FSrm));
```

```
162111
```

```
disp(length(Wrpmrm));
```

162111

```
disp(length(Vgrm));
```

162111

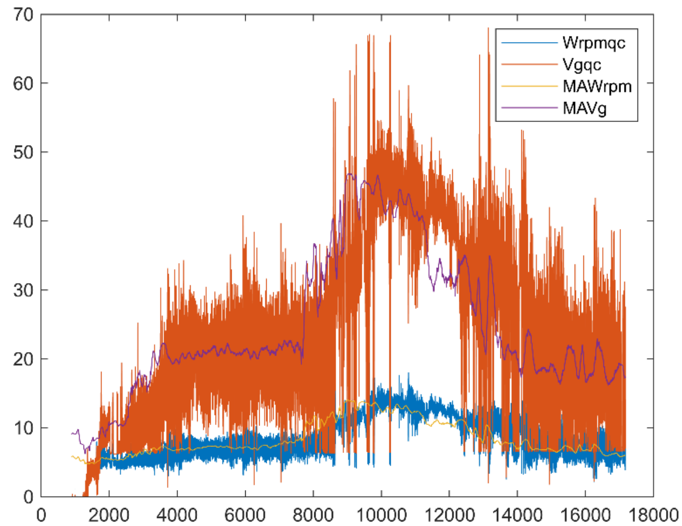
```
disp(length(Igrm));
```

162111

```
disp(length(Twwrm));
```

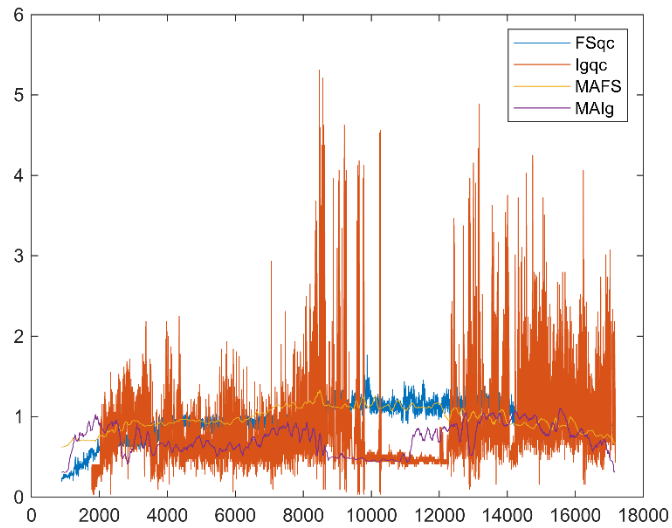
162111

```

% % Down Sample the Data
% Dt = downsample(tqc, 10);
% DFS = downsample(FSrm, 10);
% DWrpm = downsample(Wrpmrm, 10);
% DVg = downsample(Vgrm, 10);
% DIg = downsample(Igrm, 10);
% DTww = downsample(Twwrm, 10);

% Smoothing the Data
MAFS = movmean(FSrm, window);
MAWrpm = movmean(Wrpmrm, window);
MAVg = movmean(Vgrm, window);
MAIg = movmean(Igrm, window);
MATww = movmean(Twwrm, window);

% Plotting
figure
plot( tqc, Wrpmqc(1:length(tqc)), tqc, Vgqc(1:length(tqc)))
hold on
plot( tqc,MAWrpm, tqc,MAVg)
legend('Wrpmqc','Vgqc','MAWrpm','MAVg')
hold off
```




```
figure
plot(tqc, FSqc(1:length(tqc)), tqc, Igqc(1:length(tqc)))
hold on
plot(tqc,MAFS, tqc,MAIg)
legend('FSqc', 'Igqc','MAFS', 'MAIg')
hold off
```

4




```
% Make CSV
h = {'Time' 'MAFS' 'MAWrpm' 'MAVg' 'MAIg' 'MATww'};
body = [tqc, MAFS, MAWrpm, MAVg, MAIg, MATww];
tabel = [h; num2cell(body)];
%disp(tabel)
```

```
% writecell(tabel, "RmMA117e.csv");
% type RmMA117e.csv;
```

5

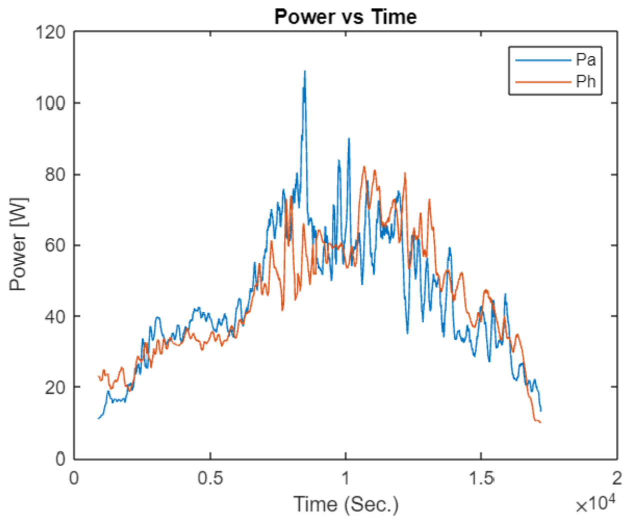
```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\1-17\RmMA117e.mat");
MAtp = RmMA117e.Time;
MAfsp = RmMA117e.MAFS;
MAWrpmp = RmMA117e.MAWrpm;
MAVgp = RmMA117e.MAVg;
MAIgp = RmMA117e.MAIg;
MATwwp = RmMA117e.MATww;

Wrs = ((MAWrpmp.*2.*pi)./60);

% Constants
A = 0.349;
Cd = 1.98;
R = 0.4858;
p = 1023.6;
a = 0.8; %Ph/Pa = 44.95/63.07
a1=0.8;
a2=0.85;
a3=0.9;
a4=0.95;
a5=0.33; %Ph/Pa = 43.37/112.05
a6=0.5; %Ph/Pa = 43.37/92.18
a7=0.98; %Ph/Pa = 43.37/47.12
a8=0.9;
g1=0.9790;

K=(44.95/63.07)
```

```
K = 0.7127
```

```
AVGFS=mean(MAfsp)
```

```
AVGFS = 0.9781
```

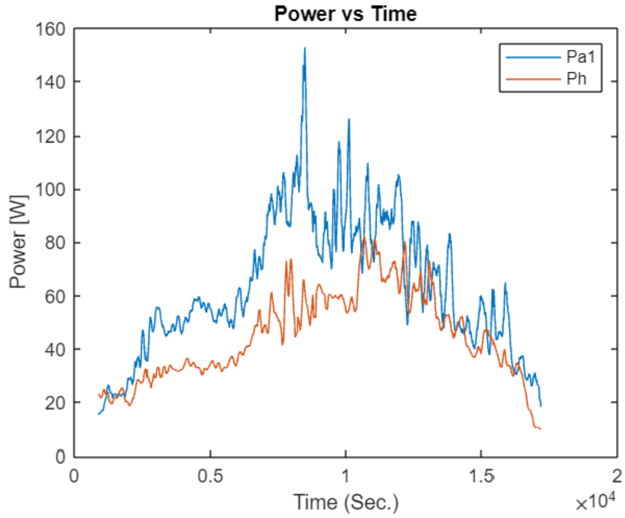
```
window = 1000;

l = ((Wrs.*R)./MAfsp);
Pa = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l.*(K);

% Theoretical
Ph = MATwwp.*Wrs;
figure
plot(MAtp,Pa, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa','Ph')
```




```
c = corrcoef(Pa,Ph)
```

```
c = 2×2
    1.0000    0.7882
    0.7882    1.0000
```

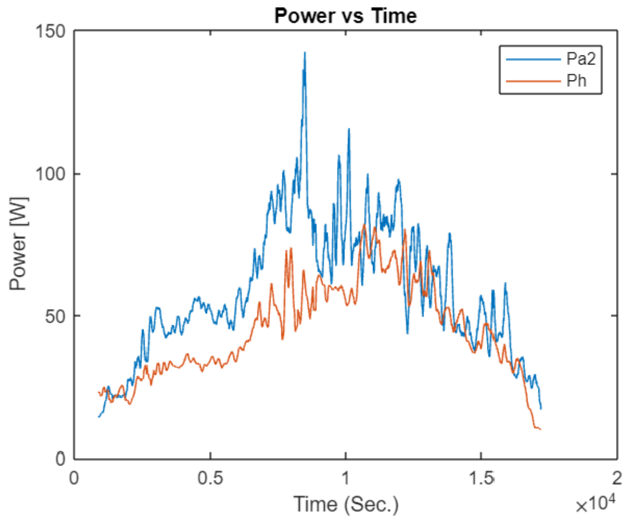
```
Pa1 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a1.*l).^2).*l;
figure
plot(MAtp,Pa1, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa1','Ph')
```




```
c1 = corrcoef(Pa1,Ph)
```

```
c1 = 2×2
    1.0000    0.7882
    0.7882    1.0000
```

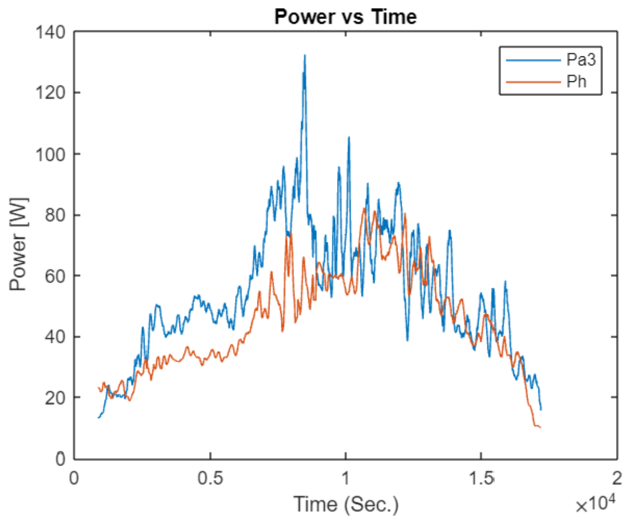
```
Pa2 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a2.*l).^2).*l;
figure
plot(MAtp,Pa2, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa2','Ph')
```




```
c2 = corrcoef(Pa2,Ph)
```

```
c2 = 2×2
    1.0000    0.7690
    0.7690    1.0000
```

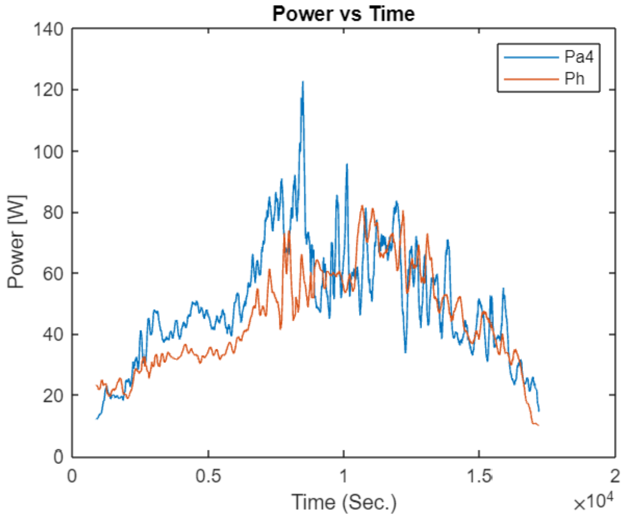
```
Pa3 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a3.*l).^2).*l;
figure
plot(MAtp,Pa3, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa3','Ph')
```




```
c3 = corrcoef(Pa3,Ph)
```

```
c3 = 2×2
    1.0000    0.7444
    0.7444    1.0000
```

```
Pa4 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a4.*l).^2).*l;
figure
plot(MAtp,Pa4, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa4','Ph')
```

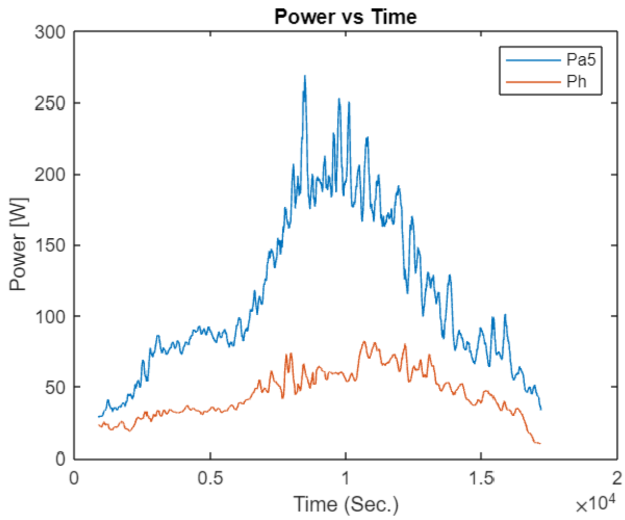



```
c4 = corrcoef(Pa4,Ph)
```

```
c4 = 2×2
    1.0000    0.7134
    0.7134    1.0000
```

```
Pa5 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a5.*l).^2).*l;
figure
plot(MAtp,Pa5, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa5','Ph')
```

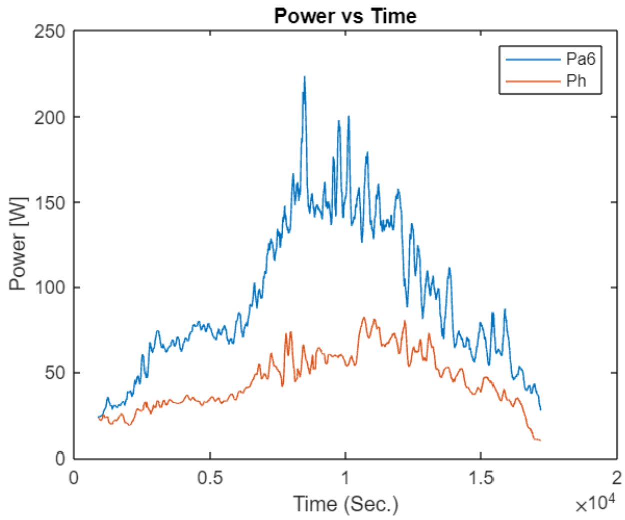
6




```
c5 = corrcoef(Pa5,Ph)
```

```
c5 = 2×2
    1.0000    0.8417
    0.8417    1.0000
```

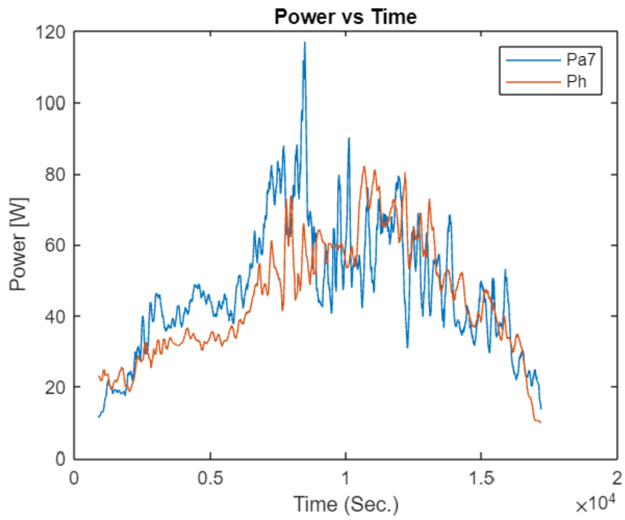
```
Pa6 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a6.*l).^2).*l;
figure
plot(MAtp,Pa6, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa6','Ph')
```




```
c6 = corrcoef(Pa6,Ph)
```

```
c6 = 2×2
    1.0000    0.8372
    0.8372    1.0000
```

```
Pa7 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a7.*l).^2).*l;
figure
plot(MAtp,Pa7, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa7','Ph')
```




```
c7 = corrcoef(Pa7,Ph)
```

```
c7 = 2×2
    1.0000    0.6913
    0.6913    1.0000
```

```
g = Ph./Pa7;
AVGg = mean(g)
```

```
AVGg = 0.9790
```

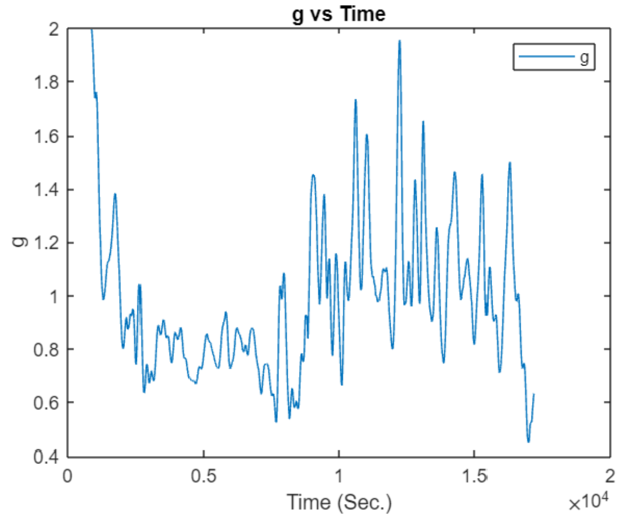
```
AVGPh=mean(Ph)
```

```
AVGPh = 44.9463
```

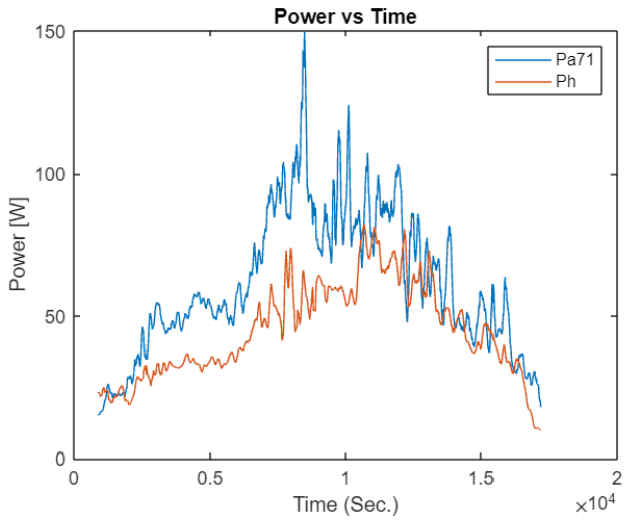
```
AVGPa=mean(Pa)
```

```
AVGPa = 44.9489
```

```
MAg = movmean(g, window);
figure
plot(MAtp,MAg)
title("g vs Time");
xlabel("Time (Sec.)");
ylabel("g");
legend('g')
```



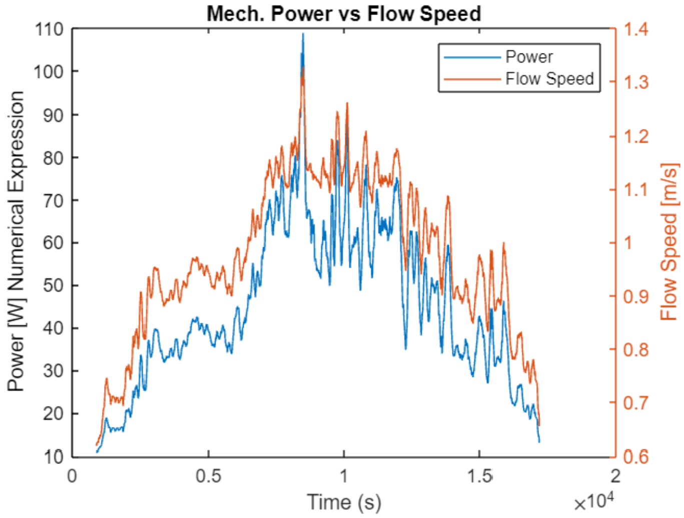

```
Pa71 = (1/2).*p.*A.*g1.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l;
figure
plot(MAtp,Pa71, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa71','Ph')
```




```
c71 = corrcoef(Pa71,Ph)
```

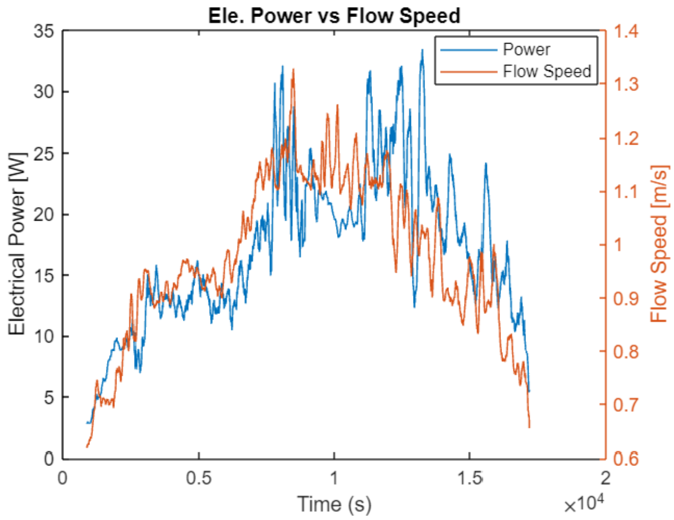
```
c71 = 2×2
    1.0000    0.7882
    0.7882    1.0000
```

```
figure
plot(MAtp,Pa);
ylabel('Power [W] Numerical Expression');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Mech. Power vs Flow Speed');
```




```
Pe = MAVgp.*MAIgp;

figure
plot(MAtp,Pe);
ylabel('Electrical Power [W]');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Ele. Power vs Flow Speed');

legend("Position", [0.66258,0.82124,0.23123,0.092742])
```

12

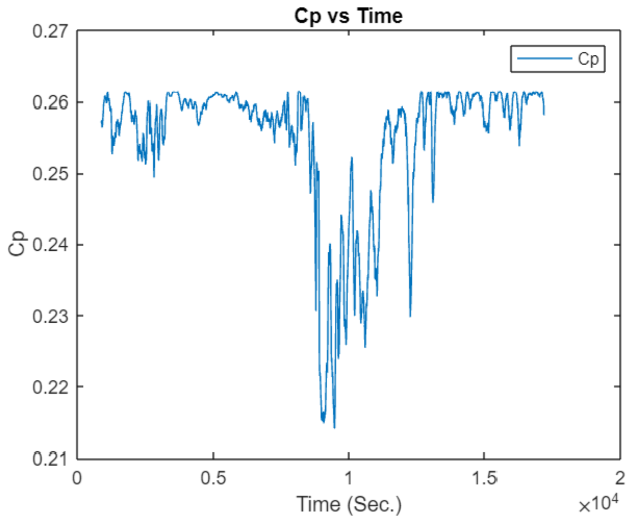



```
% Cp of the Numerical Expression
Cp = Pa./((1/2).*p.*A.*(MAfsp.^3));
Cpsdt = std(Cp)
```

```
Cpsdt = 0.0100
```

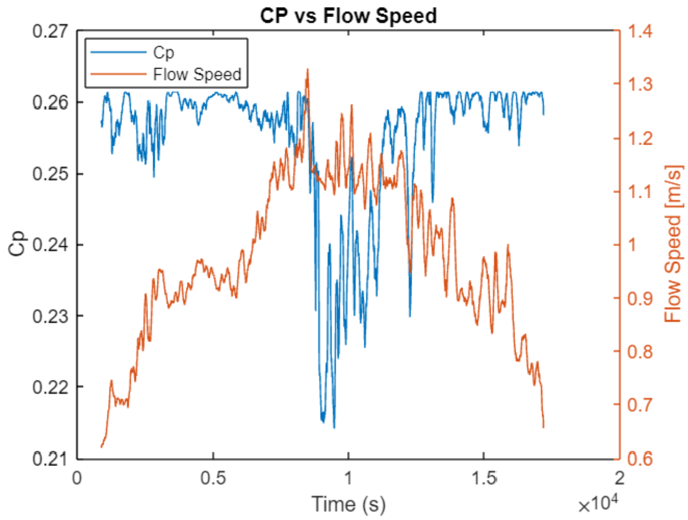
```
figure
plot(MAtp,Cp)
title("Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')
```

13



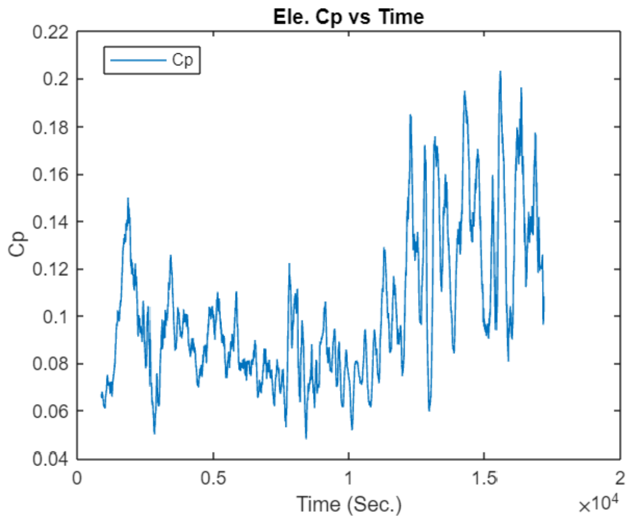

```
figure
plot(MAtp,Cp);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('CP vs Flow Speed');

legend("Position", [0.14242,0.81526,0.23123,0.092742])
```

14

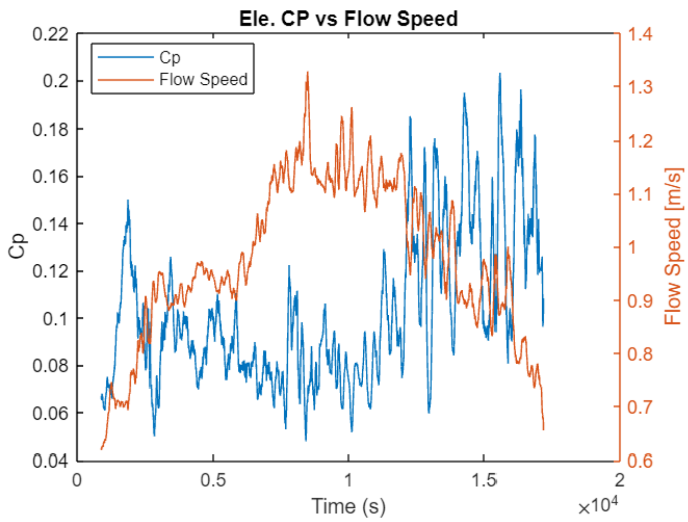



```
% Cp of the Pe
Cpe = Pe./((1/2).*p.*A.*(MAfsp.^3));

figure
plot(MAtp,Cpe)
title("Ele. Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')

legend("Position", [0.16888,0.84498,0.13472,0.051075])
```

15

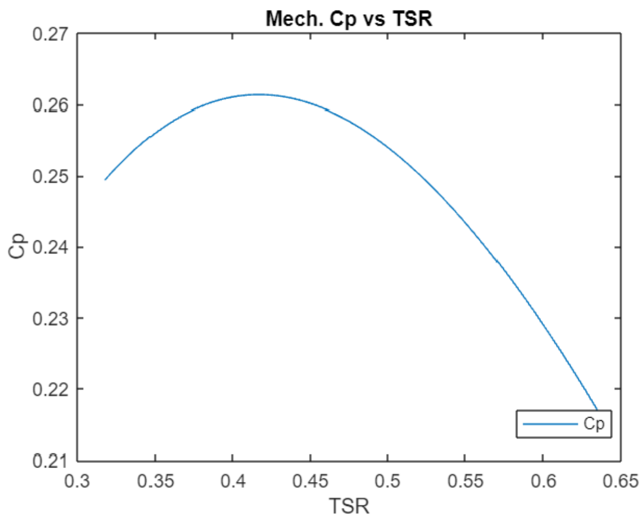



```
figure
plot(MAtp,Cpe);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('Ele. CP vs Flow Speed');

legend("Position", [0.15136,0.81128,0.23123,0.092742])
```



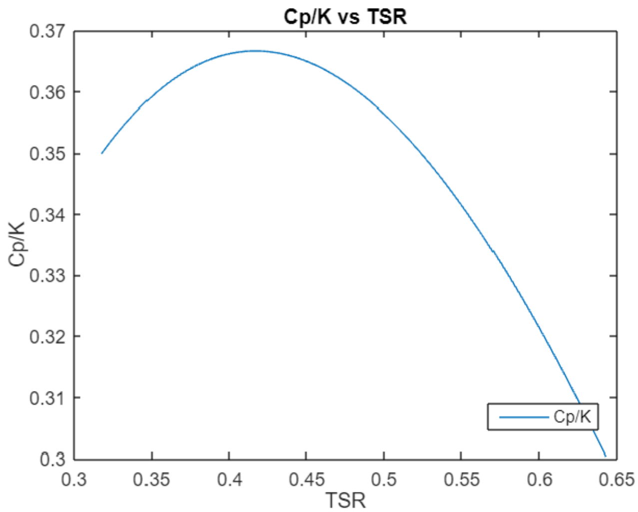

```
% Mech. Cp vs Lambda
figure
plot(l,Cp)
title("Mech. Cp vs TSR");
xlabel("TSR");
ylabel("Cp");
legend('Cp')

legend("Position", [0.75611,0.15203,0.13472,0.051075])
```

17




```
% Cp/K vs Lambda
CPk = Cp/K;
figure
plot(l,CPk)
title("Cp/K vs TSR");
xlabel("TSR");
ylabel("Cp/K");
legend('Cp/K')

legend("Position", [0.72207,0.16398,0.15684,0.051075])
```

18




```
AVGPa=mean(Pa)
```

AVGPa = 44.9489

```
MAXPa=max(Pa)
```

MAXPa = 108.8674

```
AVGPe=mean(Pe)
```

AVGPe = 17.0418

```
MAXPe=max(Pe)
```

MAXPe = 33.4328

```
AVGCp=mean(Cp)
```

AVGCp = 0.2546

```
MaxCp=max(Cp)
```

MaxCp = 0.2613

```
AVGCpe=mean(Cpe)
```

AVGCpe = 0.1016

```
MAXCpe=max(Cpe)
```

MAXCpe = 0.2032

```
% Load Data & Set Names
data = readtable("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-19\New
Way\rd119.csv");
%disp(data)

datast.time = rd119.time_elapsed;
datast.values = table2array(data(:,2:6));
%disp(datast.time)
%disp(datast.values)

% Checking that all FS values have a proper time stamp
freq = 0.1;
results = check_timestamp(datast,freq);
%disp(results.values)

% Checking the Data Range
bounds = [0.001,35];
results = check_range(results,bounds);
%disp(results.values)

% Make CSV
h = {'Time' 'FS' 'Wrmp' 'Vg' 'Ig' 'Tww'};
body = [datast.time, results.values];
tabel = [h; num2cell(body)];
%disp(tabel)

% writecell(tabel, "qc119.csv")
% type qc119.csv
```

1

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-19\New
Way\qc119.mat");
tqc = qc119.Time;
FSqc = qc119.FS;
Wrpmqc = qc119.Wrmp;
Vgqc = qc119.Vg;
Igqc = qc119.Ig;
Twwqc = qc119.Tww;
window = 1000;

% Remove Outliers
FSrm = rmoutliers(FSqc);
Wrpmrm = rmoutliers(Wrpmqc);
Vgrm = rmoutliers(Vgqc);
Igrm = rmoutliers(Igqc);
Twwrm = rmoutliers(Twwqc);

size(tqc)
```

```
ans = 1×2
      124329           1
```

```
size(FSrm)
```

```
ans = 1×2
      121794           1
```

```
size(Wrpmrm)
```

```
ans = 1×2
      122337           1
```

```
size(Vgrm)
```

```
ans = 1×2
      119382           1
```

```
size(Igrm)
```

```
ans = 1×2
      123890           1
```

```
size(Twwrm)
```

```
ans = 1×2
      124329           1
```

```

% Trim FSrm to match the length of Vgrm
FSrm = FSrm(1:length(Vgrm));
% Trim Wrpmrm to match the length of Vgrm
Wrpmrm = Wrpmrm(1:length(Vgrm));
% Trim Igrm to match the length of Vgrm
```

```
Igrm = Igrm(1:length(Vgrm));
% Trim Twwrm to match the length of Vgrm
Twwrm = Twwrm(1:length(Vgrm));

% Now they all should have the same length
disp(size(FSrm))
```

```
    119382           1
```

```
disp(size(Wrpmrm))
```

```
    119382           1
```

```
disp(size(Vgrm))
```

```
    119382           1
```

```
disp(size(Igrm))
```

```
    119382           1
```

```
disp(size(Twwrm))
```

```
    119382           1
```

```
% Ensure that the time vector has the same length as the other data vectors after
removing outliers
FSrm_valid = ~isnan(FSrm);  % Find valid indices for FSrm
Wrpmrm_valid = ~isnan(Wrpmrm);  % Find valid indices for Wrpmrm
Vgrm_valid = ~isnan(Vgrm);  % Find valid indices for Vgrm
Igrm_valid = ~isnan(Igrm);  % Find valid indices for Igrm
Twwrm_valid = ~isnan(Twwrm);  % Find valid indices for Twwrm
valid_indices = FSrm_valid & Wrpmrm_valid & Vgrm_valid & Igrm_valid & Twwrm_valid;
% Combine valid indices

tqc = tqc(valid_indices);  % Filter the time vector to match the lengths of FSrm,
Wrpmrm, Vgrm and Igrm
FSrm = FSrm(valid_indices); %Filter FSrm
Wrpmrm = Wrpmrm(valid_indices); %Filter Wrpmrm
Vgrm = Vgrm(valid_indices);  % Filter Vgrm
Igrm = Igrm(valid_indices);  % Filter Igrm
Twwrm = Twwrm(valid_indices);  % Filter Twwrm

% Now, FSrm, Wrpmrm, Vgrm, Igrm, and tqc should have the same length
disp(length(tqc)); % Display the length to verify
```

```
    110451
```

```
disp(length(FSrm));
```

```
    110451
```

2

```
disp(length(Wrpmrm));
```

```
110451
```

```
disp(length(Vgrm));
```

```
110451
```

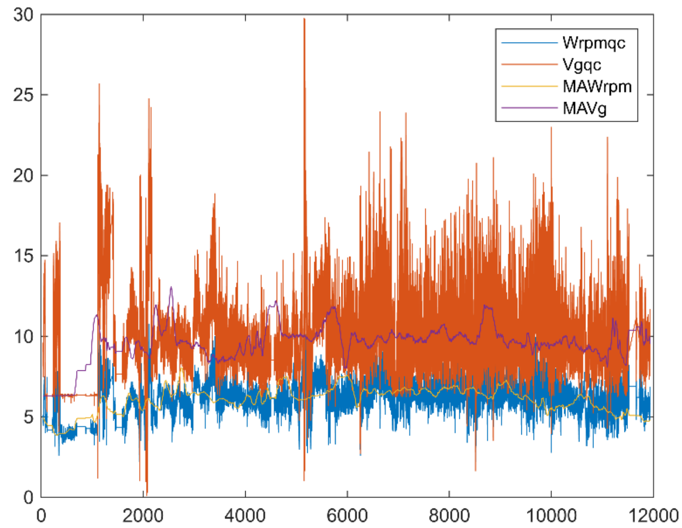
```
disp(length(Igrm));
```

```
110451
```

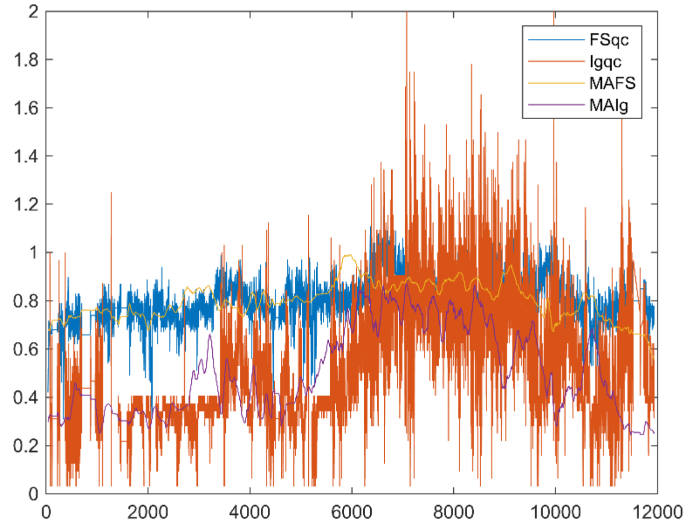
```
disp(length(Twwrm));
```

```
110451
```

```
% Smoothing the Data
MAFS = movmean(FSrm, window);
MAWrpm = movmean(Wrpmrm, window);
MAVg = movmean(Vgrm, window);
MAIg = movmean(Igrm, window);
MATww = movmean(Twwrm, window);

% Plotting
plot( tqc, Wrpmqc(1:length(tqc)), tqc, Vgqc(1:length(tqc)))
hold on
plot( tqc,MAWrpm, tqc,MAVg)
legend('Wrpmqc','Vgqc','MAWrpm','MAVg')
hold off
```




```
plot(tqc, FSqc(1:length(tqc)), tqc, Igqc(1:length(tqc)))
hold on
plot(tqc,MAFS, tqc,MAIg)
legend('FSqc', 'Igqc','MAFS', 'MAIg')
hold off
```




```
% Make CSV
h = {'Time' 'MAFS' 'MAWrpm' 'MAVg' 'MAIg' 'MATww'};
body = [tqc, MAFS, MAWrpm, MAVg, MAIg, MATww];
tabel = [h; num2cell(body)];
%disp(tabel)
```

```
% writecell(tabel, "MA119.csv")
% type MA119.csv
```

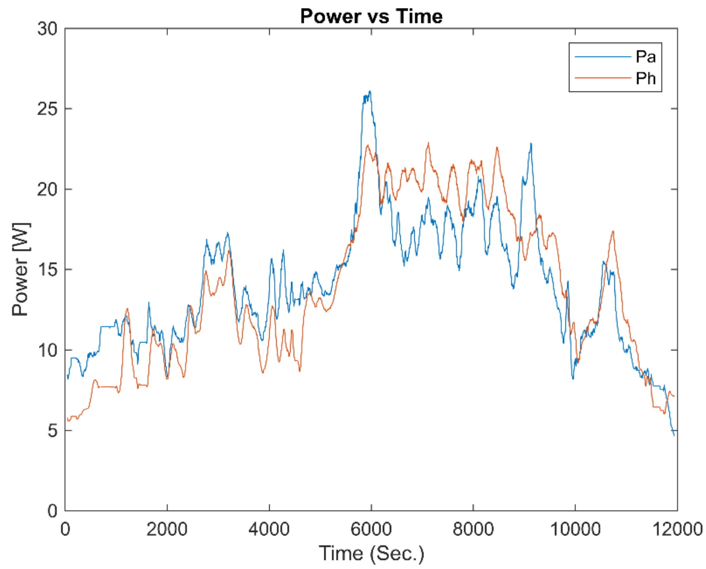
```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-19\New
Way\MA119.mat");
MAtp = MA119.Time;
MAfsp = MA119.MAFS;
MAWrpmp = MA119.MAWrpm;
MAVgp = MA119.MAVg;
MAIgp = MA119.MAIg;
MATwwp = MA119.MATww;

Wrs = ((MAWrpmp.*2.*pi)./60);

% Constants
A = (0.349/2);
Cd = 1.98;
R = 0.4858;
p = 1023.6;
a = 0.8;
a1=0.8; %Ph/Pa = 14.28/17.4
a2=0.85;
a3=0.9;
a4=0.95;
a5=0.33;
a6=0.5; %Ph/Pa = 13.99/23.78
a7=0.98; %Ph/Pa = 13.98/14.06
a8=0.9;
g1=1.01;

K=(14.28/17.4)
```

```
K = 0.8207
```

```
AVGFS=mean(MAfsp) %AVGFS=0.8054 w/ Ph/Pa = 13.99/23.78
```

```
AVGFS = 0.8054
```

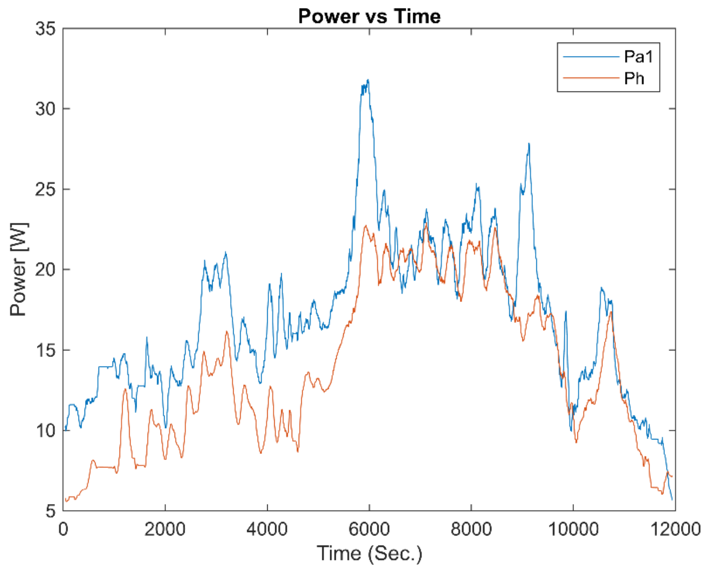
```
window = 1000;

l = ((Wrs.*R)./MAfsp);
Pa = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l.*(K);

% Theoretical
Ph = MATwwp.*Wrs;
figure
plot(MAtp,Pa, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa','Ph')
```




```
c = corrcoef(Pa,Ph)
```

```
c = 2×2
    1.0000    0.8630
    0.8630    1.0000
```

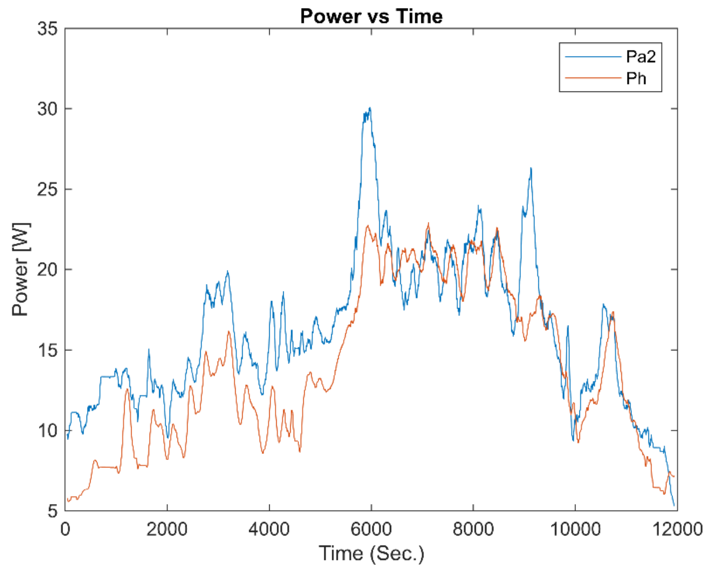
```
Pa1 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a1.*l).^2).*l;
figure
plot(MAtp,Pa1, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa1','Ph')
```




```
c1 = corrcoef(Pa1,Ph)
```

```
c1 = 2×2
    1.0000    0.8630
    0.8630    1.0000
```

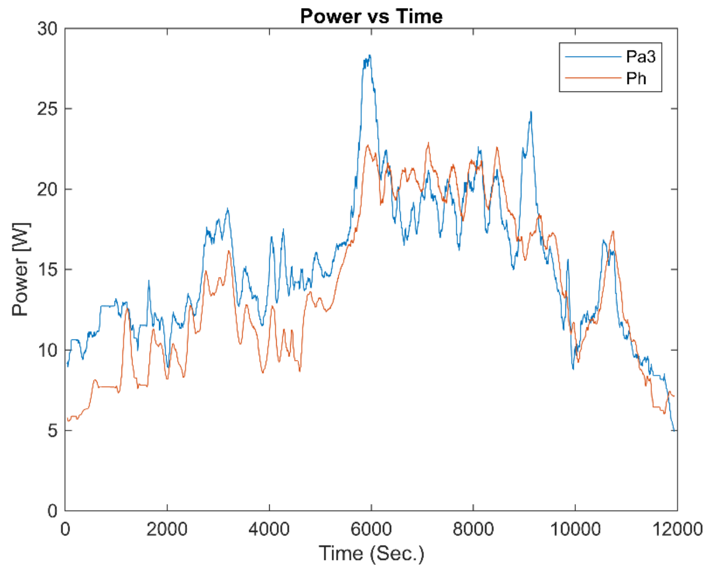
```
Pa2 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a2.*1).^2).*1;
figure
plot(MAtp,Pa2, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa2','Ph')
```




```
c2 = corrcoef(Pa2,Ph)
```

```
c2 = 2×2
    1.0000    0.8623
    0.8623    1.0000
```

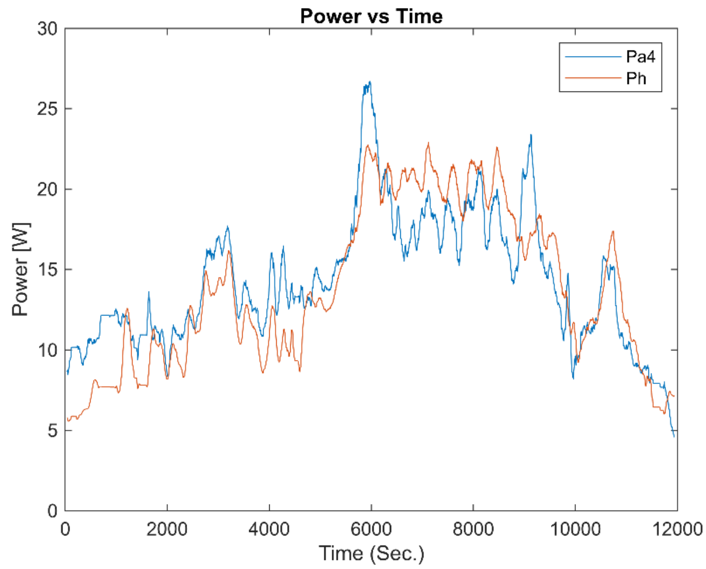
```
Pa3 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a3.*l).^2).*l;
figure
plot(MAtp,Pa3, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa3','Ph')
```




```
c3 = corrcoef(Pa3,Ph)
```

```
c3 = 2×2
    1.0000    0.8611
    0.8611    1.0000
```

```
Pa4 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a4.*1).^2).*1;
figure
plot(MAtp,Pa4, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa4','Ph')
```

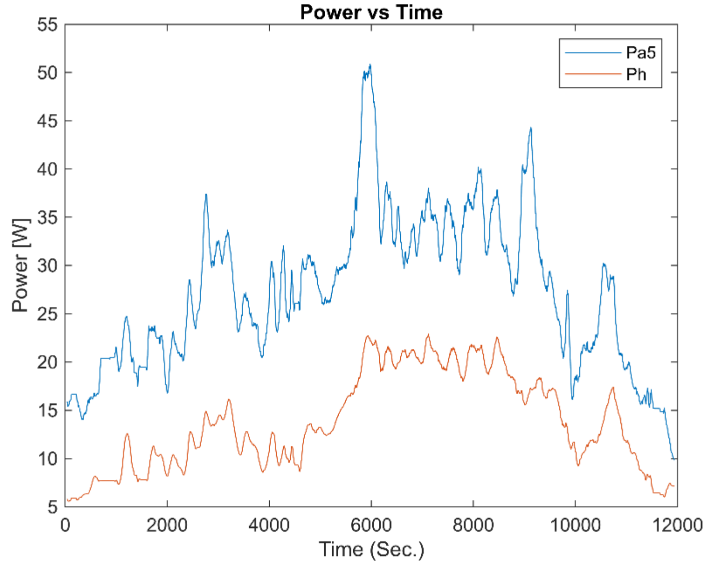



```
c4 = corrcoef(Pa4,Ph)
```

```
c4 = 2×2
    1.0000    0.8594
    0.8594    1.0000
```

```
Pa5 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a5.*l).^2).*l;
figure
plot(MAtp,Pa5, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa5','Ph')
```

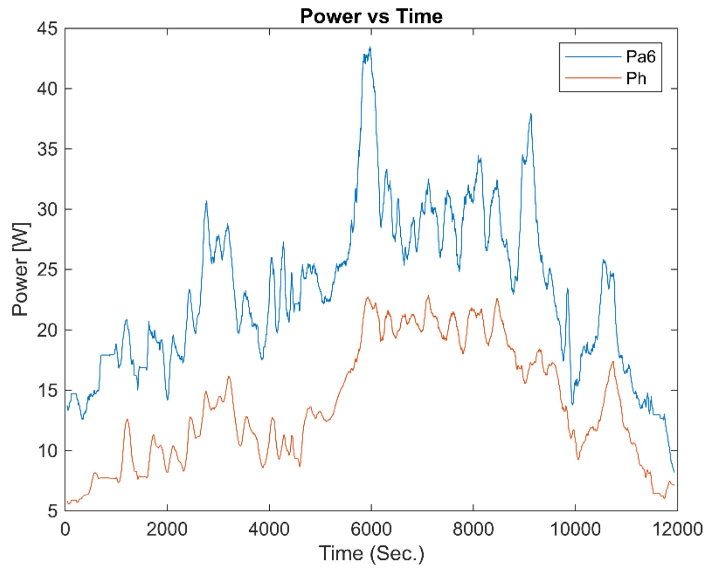
6




```
c5 = corrcoef(Pa5,Ph)
```

```
c5 = 2×2
    1.0000    0.8575
    0.8575    1.0000
```

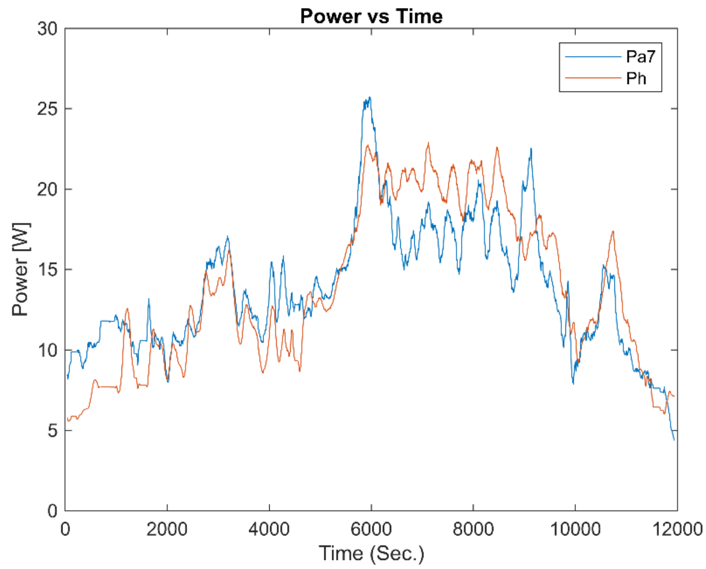
```
Pa6 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a6.*l).^2).*l;
figure
plot(MAtp,Pa6, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa6','Ph')
```




```
c6 = corrcoef(Pa6,Ph)
```

```
c6 = 2×2
    1.0000    0.8612
    0.8612    1.0000
```

```
Pa7 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a7.*l).^2).*l;
figure
plot(MAtp,Pa7, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa7','Ph')
```




```
c7 = corrcoef(Pa7,Ph)
```

```
c7 = 2×2
    1.0000    0.8581
    0.8581    1.0000
```

```
AVGPh=mean(Ph)
```

```
AVGPh = 14.2840
```

```
AVGPa=mean(Pa)
```

```
AVGPa = 14.2836
```

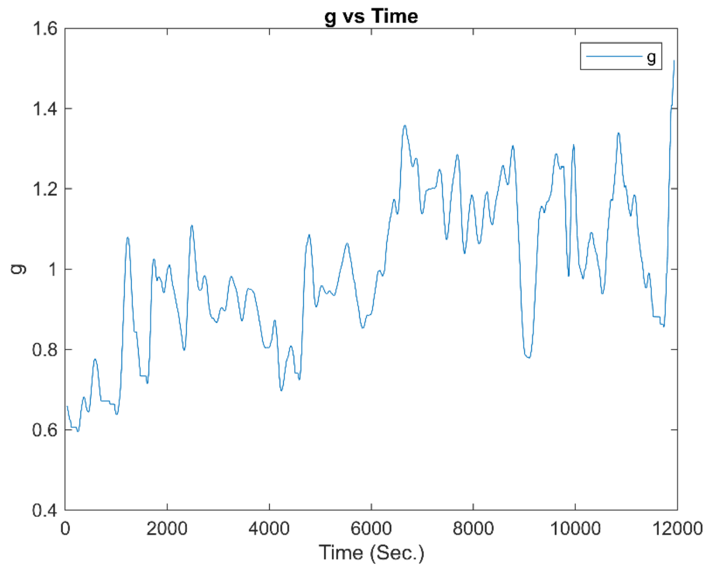
```
g = (MATwwp.*Wrs)./((1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a7.*1).^2).*1);
MAg = movmean(g, window);
AVGg = mean(g)
```

```
AVGg = 1.0109
```

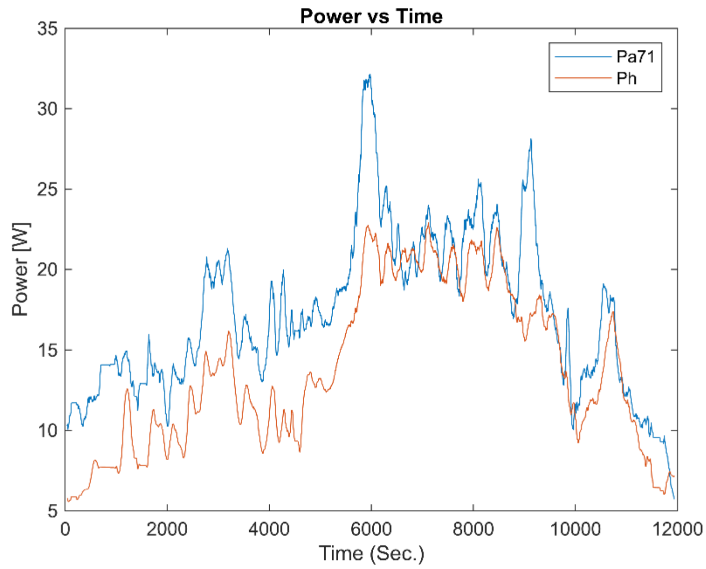
```
figure
plot(MAtp,MAg);
title("g vs Time");
xlabel("Time (Sec.)");
ylabel("g");
```

9

```
legend('g')
```



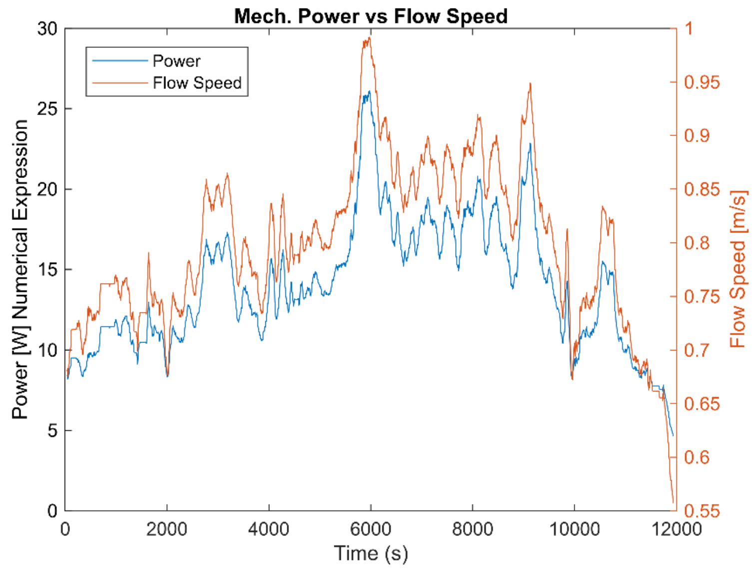

```
Pa71 = (1/2).*p.*A.*g1.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l;
figure
plot(MAtp,Pa71, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa71','Ph')
```




```
c71 = corrcoef(Pa71,Ph)
```

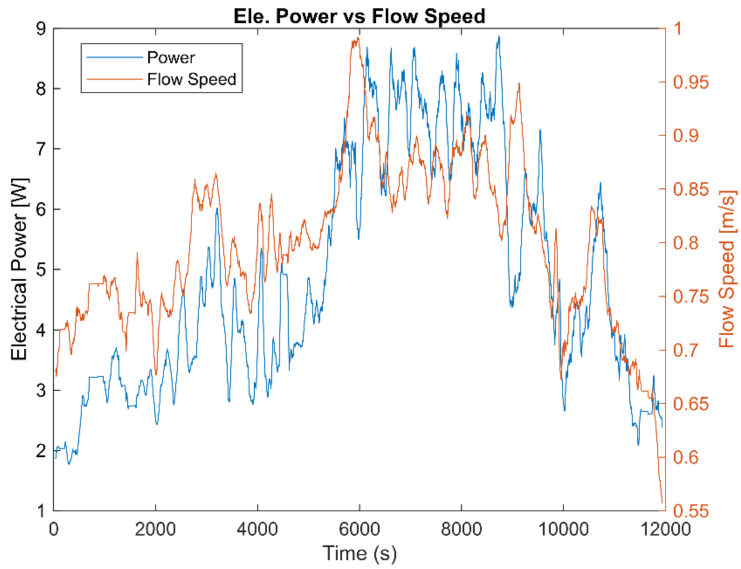
```
c71 = 2×2
    1.0000    0.8630
    0.8630    1.0000
```

```
figure
plot(MAtp,Pa);
ylabel('Power [W] Numerical Expression');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Mech. Power vs Flow Speed');

legend("Position", [0.14377,0.80531,0.23123,0.092742])
```




```
Pe = MAVgp.*MAIgp;

figure
plot(MAtp,Pe);
ylabel('Electrical Power [W]');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Ele. Power vs Flow Speed');

legend("Position", [0.15122,0.81128,0.23123,0.092742])
```

12

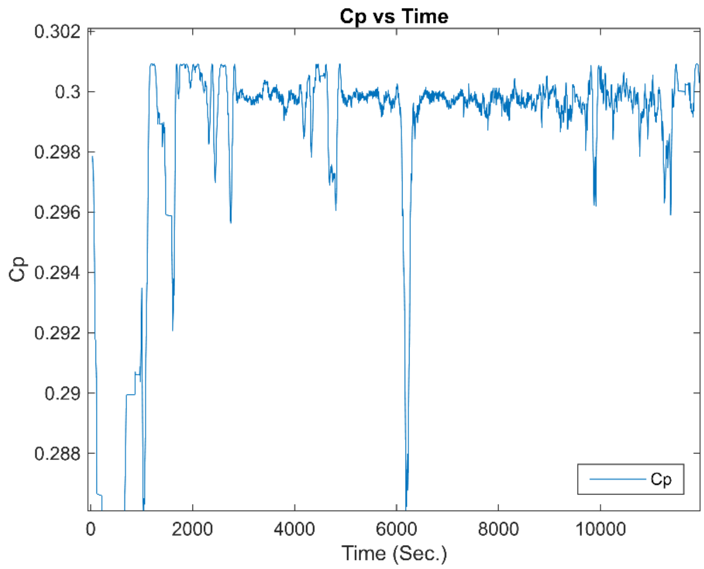



```
% Cp of Numerical Expression
Cp = Pa./((1/2).*p.*A.*(MAfsp.^3));
Cpsdt = std(Cp)
```

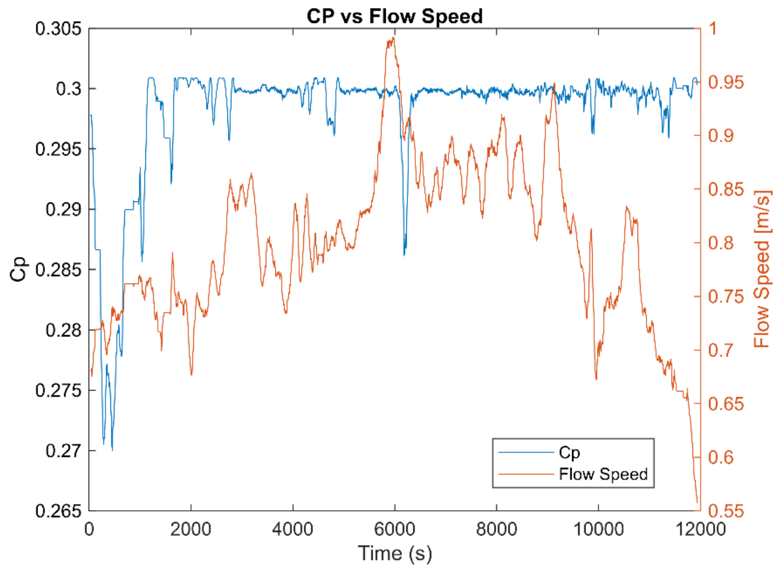
```
Cpsdt = 0.0051
```

```
figure
plot(MAtp,Cp)
title("Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')

xlim([23 12023])
ylim([0.1364 0.1524])
legend("Position", [0.75015,0.13809,0.13472,0.051075])

xlim([-49 11951])
ylim([0.2861 0.3021])
```

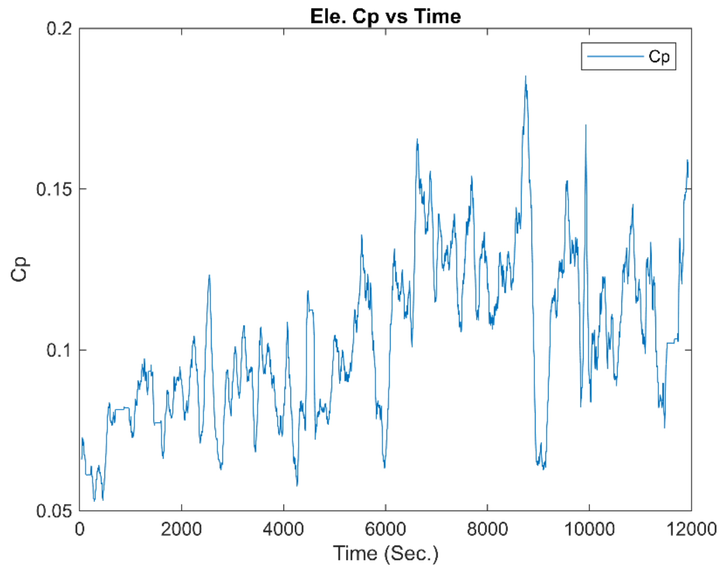
13



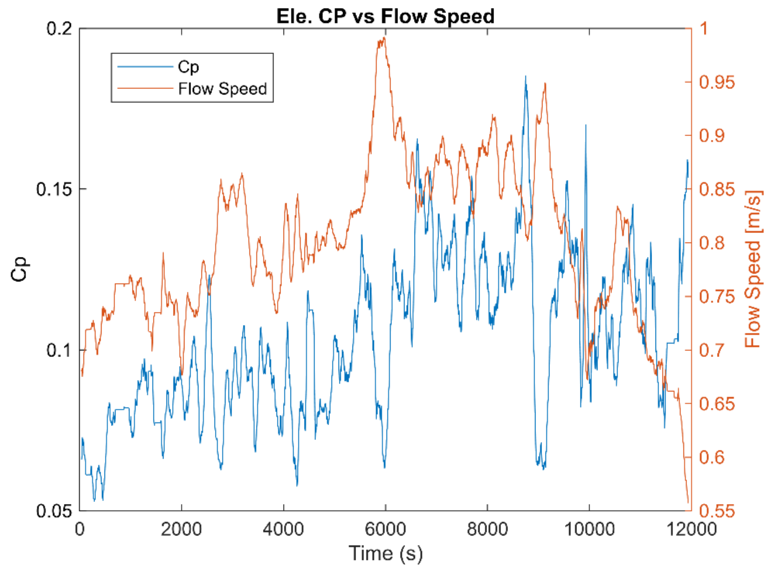

```
figure
plot(MAtp,Cp);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('CP vs Flow Speed');

legend("Position", [0.62816,0.14422,0.23123,0.092742])
```



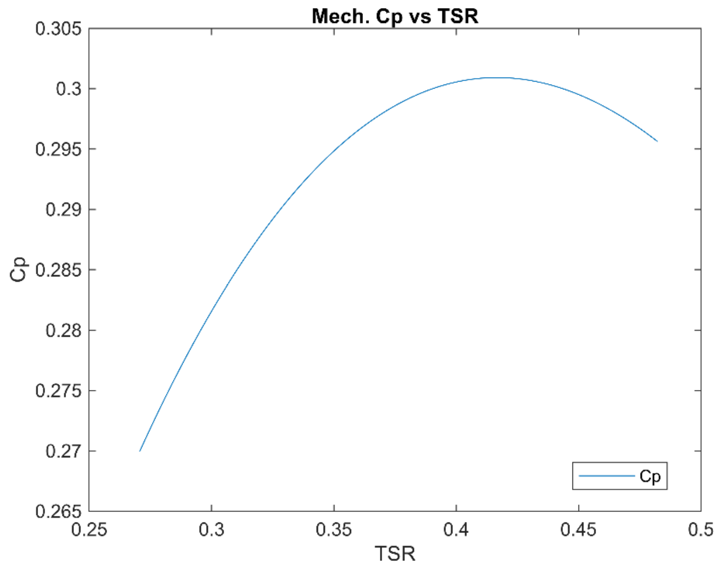

```
% Cp of the Pe
Cpe = Pe./((1/2).*p.*A.*(MAfsp.^3));

figure
plot(MAtp,Cpe)
title("Ele. Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')
```



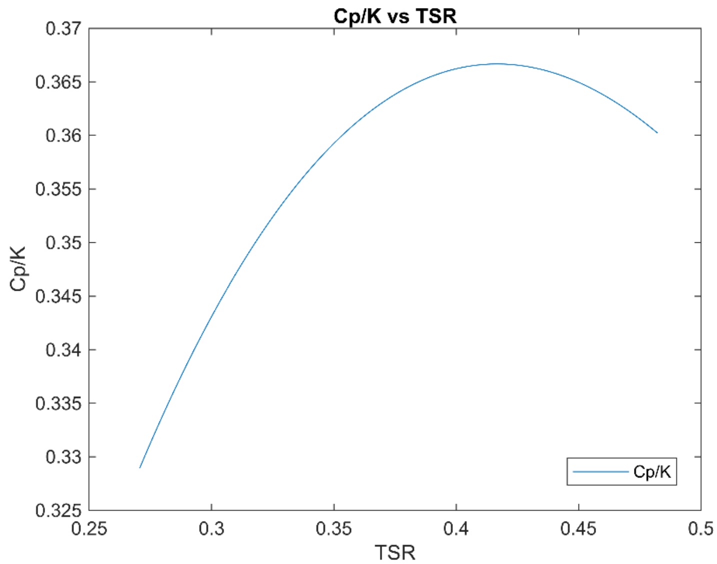

```
figure
plot(MAtp,Cpe);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('Ele. CP vs Flow Speed');

legend("Position", [0.15718,0.79535,0.23123,0.092742])
```




```
% Mech. Cp vs Lambda
figure
plot(l,Cp)
title("Mech. Cp vs TSR");
xlabel("TSR");
ylabel("Cp");
legend('Cp')

legend("Position", [0.73525,0.14407,0.13472,0.051075])
```




```
% Cp/K vs Lambda
CPk = Cp/K;
figure
plot(l,CPk)
title("Cp/K vs TSR");
xlabel("TSR");
ylabel("Cp/K");
legend('Cp/K')

legend("Position", [0.72654,0.15004,0.15684,0.051075])
```




```
AVGPa=mean(Pa)
```

AVGPa = 14.2836

```
MAXPa=max(Pa)
```

MAXPa = 26.1435

```
AVGPe=mean(Pe)
```

AVGPe = 5.0236

```
MAXPe=max(Pe)
```

MAXPe = 8.8759

```
AVGCp=mean(Cp)
```

AVGCp = 0.2984

```
MaxCp=max(Cp)
```

MaxCp = 0.3009

```
AVGCpe=mean(Cpe)
```

AVGCpe = 0.1041

```
MAXCpe=max(Cpe)
```

```
MAXCpe = 0.1854
```

```
% Load Data & Set Names
data = readtable("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed
1-24\rd124.csv");
%disp(data)

datast.time = rd124.time_elapsed;
datast.values = table2array(data(:,2:6));
%disp(datast.time)
%disp(datast.values)

% Checking that all FS values have a proper time stamp
freq = 0.1;
results = check_timestamp(datast,freq);
%disp(results.values)

% Checking the Data Range
bounds = [0.001,75];
results = check_range(results,bounds);
%disp(results.values)

% %Checking for Stagnant Data
% bound = {0.00001, py.None};
% window1 = 0.01;
% results = check_delta(results, bound, window1);
% disp(results.values)

% Make CSV
h = {'Time' 'FS' 'Wrmp' 'Vg' 'Ig' 'Tww'};
body = [datast.time, results.values];
tabel = [h; num2cell(body)];
%disp(tabel)

% writecell(tabel, "qc124.csv")
% type qc124.csv
```

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-24\New
Way\qc124.mat");
tqc = qc124.Time;
FSqc = qc124.FS;
Wrpmqc = qc124.Wrmp;
Vgqc = qc124.Vg;
Igqc = qc124.Ig;
Twwqc = qc124.Tww;

window = 1000;

% Remove Outliers
FSrm = rmoutliers(FSqc);
Wrpmrm = rmoutliers(Wrpmqc);
Vgrm = rmoutliers(Vgqc);
Igrm = rmoutliers(Igqc);
Twwrm = rmoutliers(Twwqc);

size(tqc)
```

```
ans = 1×2
      155985           1
```

```
size(FSrm)
```

```
ans = 1×2
      155965           1
```

```
size(Wrpmrm)
```

```
ans = 1×2
      154204           1
```

```
size(Vgrm)
```

```
ans = 1×2
      154978           1
```

```
size(Igrm)
```

```
ans = 1×2
      141773           1
```

```
size(Twwrm)
```

```
ans = 1×2
      155985           1
```

```
% Trim FSrm to match the length of Igrm
FSrm = FSrm(1:length(Igrm));
% Trim Wrpmrm to match the length of Igrm
Wrpmrm = Wrpmrm(1:length(Igrm));
```

1

```
% Trim Vgrm to match the length of Igrm
Vgrm = Vgrm(1:length(Igrm));
% Trim Twwrm to match the length of Igrm
Twwrm = Twwrm(1:length(Igrm));

% Now they all should have the same length
disp(size(FSrm))
```

```
141773          1
```

```
disp(size(Wrpmrm))
```

```
141773          1
```

```
disp(size(Vgrm))
```

```
141773          1
```

```
disp(size(Igrm))
```

```
141773          1
```

```
disp(size(Twwrm))
```

```
141773          1
```

```
% Ensure that the time vector has the same length as the other data vectors after
removing outliers
FSrm_valid = ~isnan(FSrm);  % Find valid indices for FSrm
Wrpmrm_valid = ~isnan(Wrpmrm);  % Find valid indices for Wrpmrm
Vgrm_valid = ~isnan(Vgrm);  % Find valid indices for Vgrm
Igrm_valid = ~isnan(Igrm);  % Find valid indices for Igrm
Twwrm_valid = ~isnan(Twwrm);  % Find valid indices for Twwrm
valid_indices = FSrm_valid & Wrpmrm_valid & Vgrm_valid & Igrm_valid & Twwrm_valid;
% Combine valid indices

tqc = tqc(valid_indices);  % Filter the time vector to match the lengths of FSrm,
Wrpmrm, Vgrm and Igrm
FSrm = FSrm(valid_indices); %Filter FSrm
Wrpmrm = Wrpmrm(valid_indices); %Filter Wrpmrm
Vgrm = Vgrm(valid_indices);  % Filter Vgrm
Igrm = Igrm(valid_indices);  % Filter Igrm
Twwrm = Twwrm(valid_indices);  % Filter Twwrm

% Now, FSrm, Wrpmrm, Vgrm, Igrm, and tqc should have the same length
disp(length(tqc)); % Display the length to verify
```

```
127317
```

```
disp(length(FSrm));
```

```
127317
```

```
disp(length(Wrpmrm));
```

```
127317
```

```
disp(length(Vgrm));
```

```
127317
```

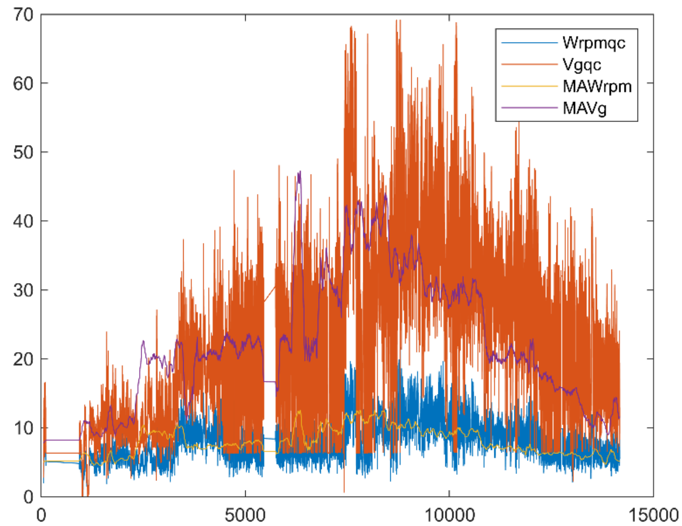
```
disp(length(Igrm));
```

```
127317
```

```
disp(length(Twwrm));
```

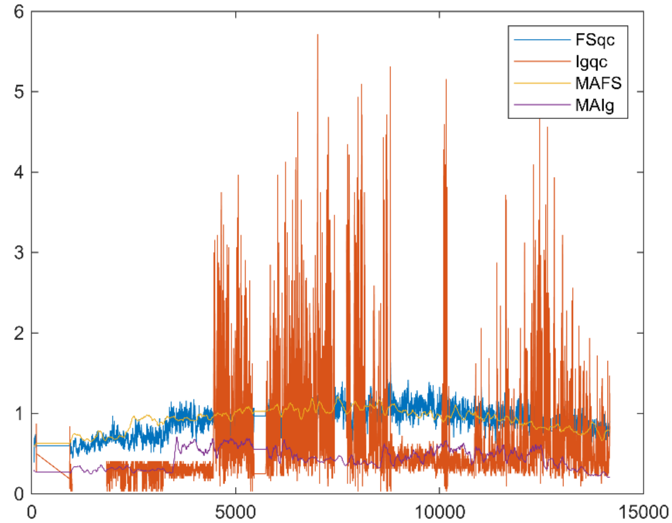
```
127317
```

```
% Smoothing the Data
MAFS = movmean(FSrm, window);
MAWrpm = movmean(Wrpmrm, window);
MAVg = movmean(Vgrm, window);
MAIg = movmean(Igrm, window);
MATww = movmean(Twwrm, window);

% Plotting
figure
plot( tqc, Wrpmqc(1:length(tqc)), tqc, Vgqc(1:length(tqc)))
hold on
plot( tqc,MAWrpm, tqc,MAVg)
legend('Wrpmqc','Vgqc','MAWrpm','MAVg')
hold off
```




```
figure
plot(tqc, FSqc(1:length(tqc)), tqc, Igqc(1:length(tqc)))
hold on
plot(tqc,MAFS, tqc,MAIg)
legend('FSqc', 'Igqc','MAFS', 'MAIg')
hold off
```

4




```
% Make CSV
h = {'Time' 'MAFS' 'MAWrpm' 'MAVg' 'MAIg' 'MATww'};
body = [tqc, MAFS, MAWrpm, MAVg, MAIg, MATww];
tabel = [h; num2cell(body)];
%disp(tabel)
```

```
% writecell(tabel, "MA124.csv")
% type MA124.csv
```

5

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-24\New
Way\MA124.mat");
MAtp = MA124.Time;
MAfsp = MA124.MAFS;
MAWrpmp = MA124.MAWrpm;
MAVgp = MA124.MAVg;
MAIgp = MA124.MAIg;
MATwwp = MA124.MATww;

Wrs = ((MAWrpmp.*2.*pi)./60);

% Constants
A = 0.349;
Cd = 1.98;
R = 0.4858;
p = 1023.6;
a = 0.8; %Ph/Pa = 34.14/55.21
a1=0.8;
a2=0.85;
a3=0.9;
a4=0.95;
a5=0.33; %Ph/Pa = 33.75/98.07
a6=0.5; %Ph/Pa = 33.75/80.98
a7=0.98; %Ph/Pa = 33.75/41.87
a8=0.9;
g1=0.7921;

K=(34.14/55.21)
```

```
K = 0.6184
```

```
AVGFS=mean(MAfsp)
```

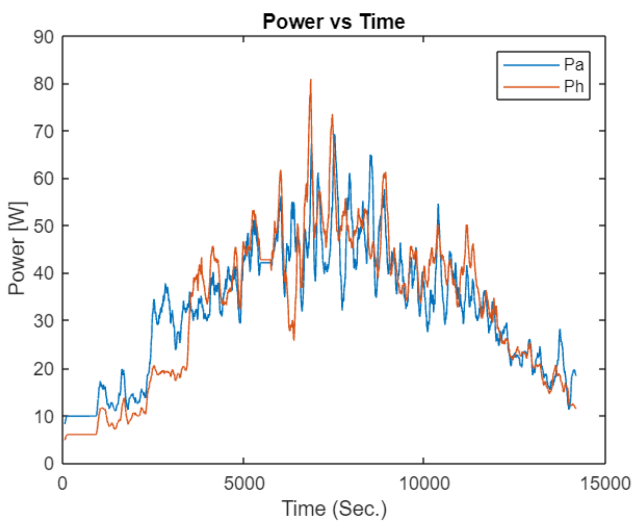
```
AVGFS = 0.9356
```

```
AVGWrs=mean(Wrs)
```

```
AVGWrs = 0.8518
```

```
window = 1000;

l = ((Wrs.*R)./MAfsp);
Pa = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l.*(K);

% Theoretical
Ph = MATwwp.*Wrs;
figure
plot(MAtp,Pa, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
```

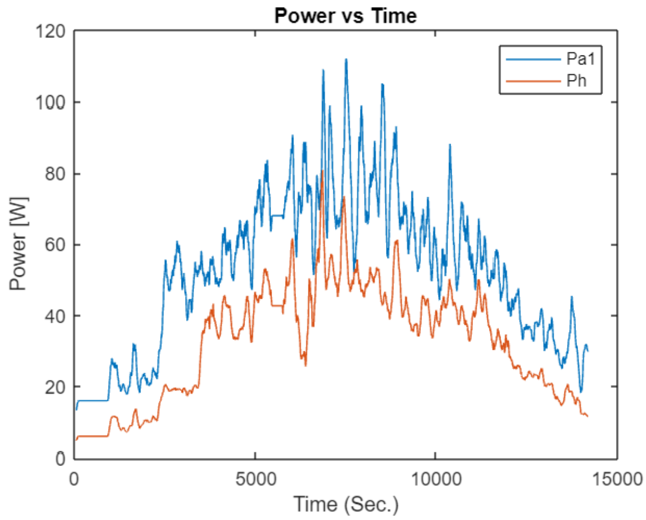
```
ylabel("Power [W]");
legend('Pa','Ph');
```




```
c = corrcoef(Pa,Ph)
```

```
c = 2×2
    1.0000    0.8734
    0.8734    1.0000
```

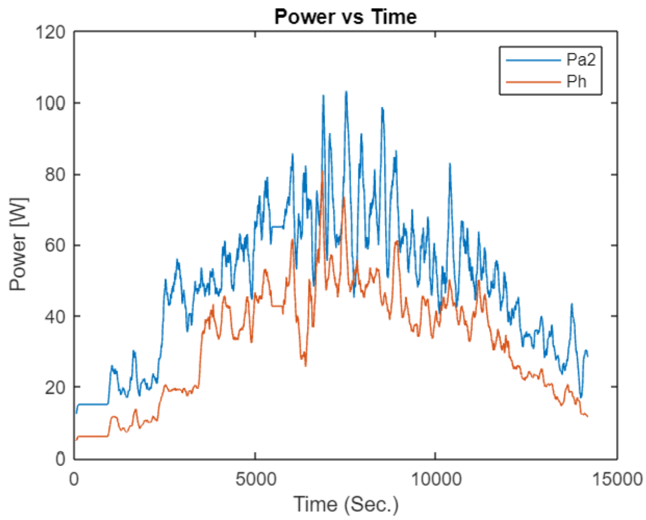
```
Pa1 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a1.*l).^2).*l;
figure
plot(MAtp,Pa1, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa1','Ph')
```




```
c1 = corrcoef(Pa1,Ph)
```

```
c1 = 2×2
    1.0000    0.8734
    0.8734    1.0000
```

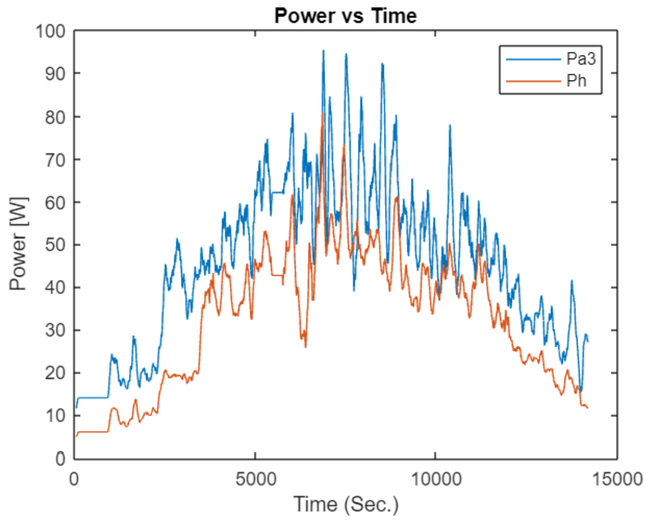
```
Pa2 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a2.*l).^2).*l;
figure
plot(MAtp,Pa2, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa2','Ph')
```




```
c2 = corrcoef(Pa2,Ph)
```

```
c2 = 2×2
    1.0000    0.8735
    0.8735    1.0000
```

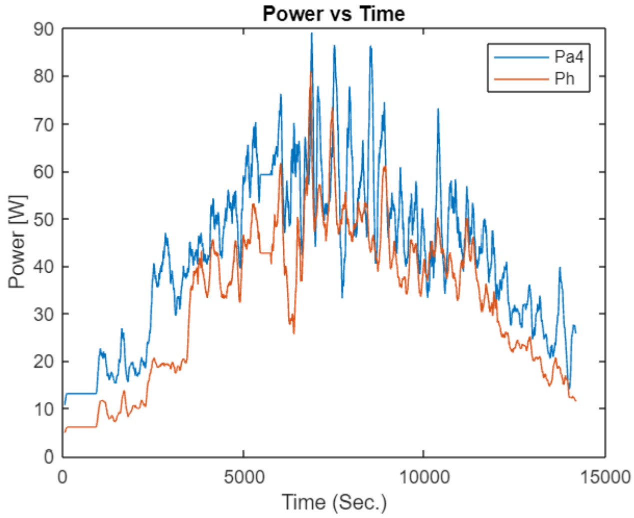
```
Pa3 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a3.*l).^2).*l;
figure
plot(MAtp,Pa3, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa3','Ph')
```




```
c3 = corrcoef(Pa3,Ph)
```

```
c3 = 2×2
    1.0000    0.8710
    0.8710    1.0000
```

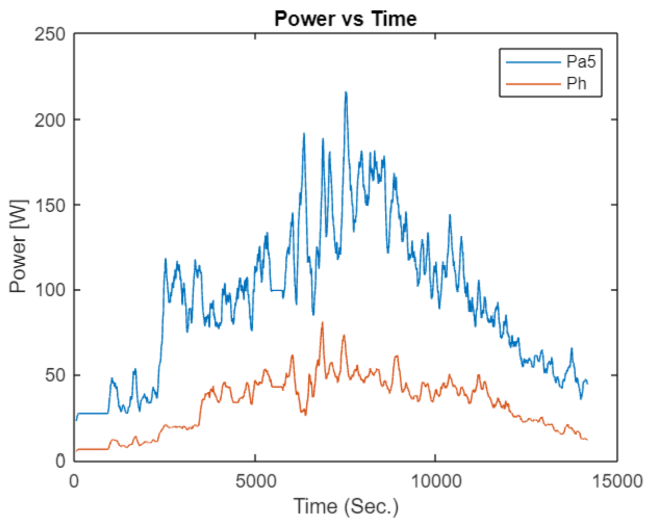
```
Pa4 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a4.*l).^2).*l;
figure
plot(MAtp,Pa4, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa4','Ph')
```




```
c4 = corrcoef(Pa4,Ph)
```

```
c4 = 2×2
    1.0000    0.8654
    0.8654    1.0000
```

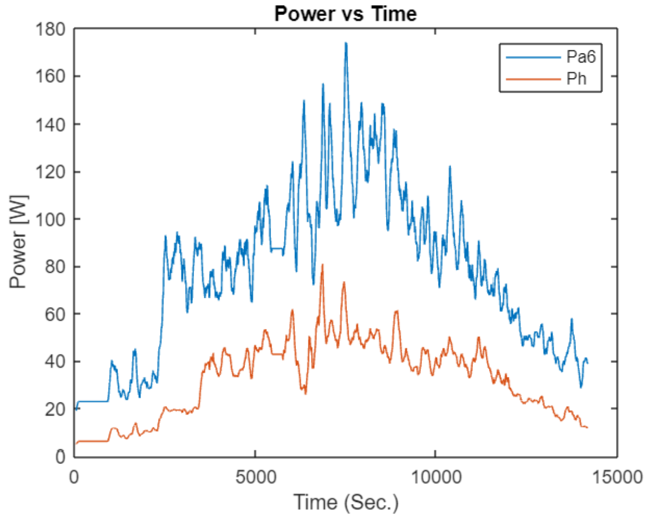
```
Pa5 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a5.*l).^2).*l;
figure
plot(MAtp,Pa5, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa5','Ph')
```




```
c5 = corrcoef(Pa5,Ph)
```

```
c5 = 2×2
    1.0000    0.8241
    0.8241    1.0000
```

```
Pa6 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a6.*l).^2).*l;
figure
plot(MAtp,Pa6, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa6','Ph')
```

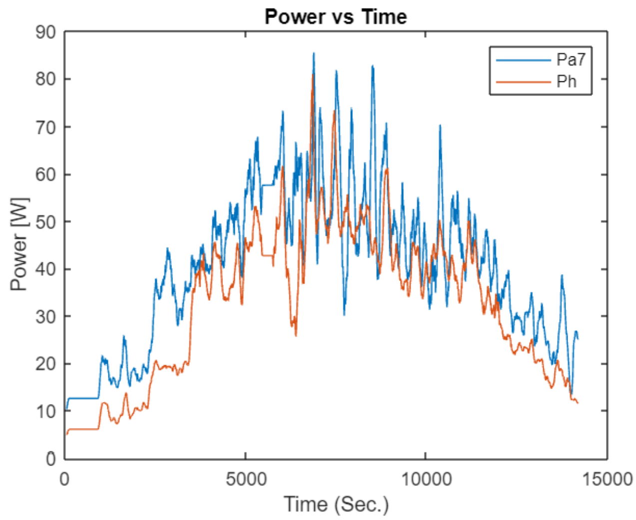



```
c6 = corrcoef(Pa6,Ph)
```

```
c6 = 2×2
    1.0000    0.8458
    0.8458    1.0000
```

```
Pa7 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a7.*l).^2).*l;
figure
plot(MAtp,Pa7, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa7','Ph')
```

8




```
c7 = corrcoef(Pa7,Ph)
```

```
c7 = 2×2
    1.0000    0.8601
    0.8601    1.0000
```

```
g = Ph./Pa7;
AVGg = mean(g)
```

```
AVGg = 0.7921
```

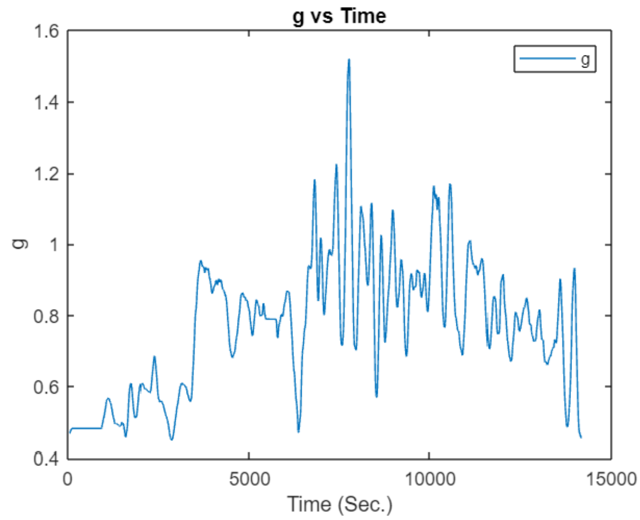
```
AVGPh=mean(Ph)
```

```
AVGPh = 34.1362
```

```
AVGPa=mean(Pa)
```

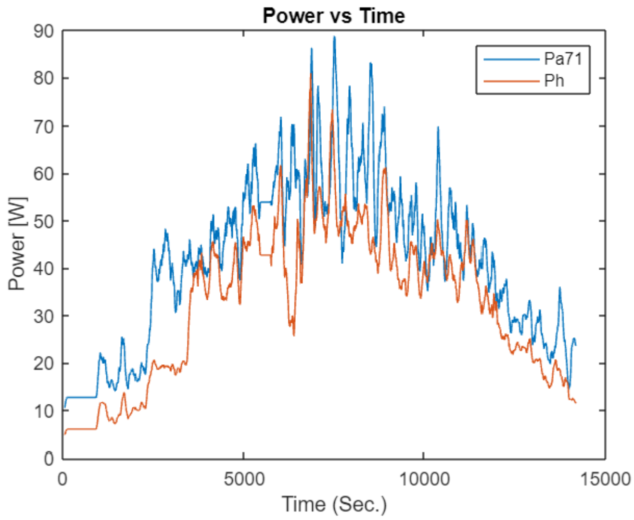
```
AVGPa = 34.1375
```

```
MAg = movmean(g, window);
figure
plot(MAtp,MAg)
title("g vs Time");
xlabel("Time (Sec.)");
ylabel("g");
legend('g')
```




```
Pa71 = (1/2).*p.*A.*g1.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l;
figure
plot(MAtp,Pa71, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa71','Ph')
```

10

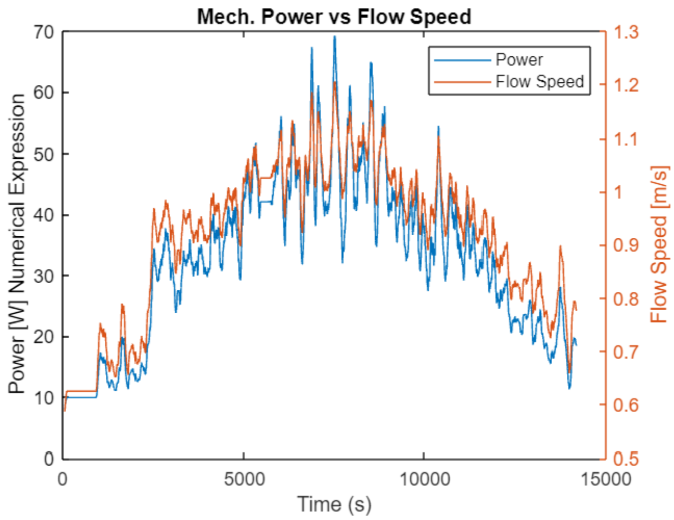



```
c71 = corrcoef(Pa71,Ph)
```

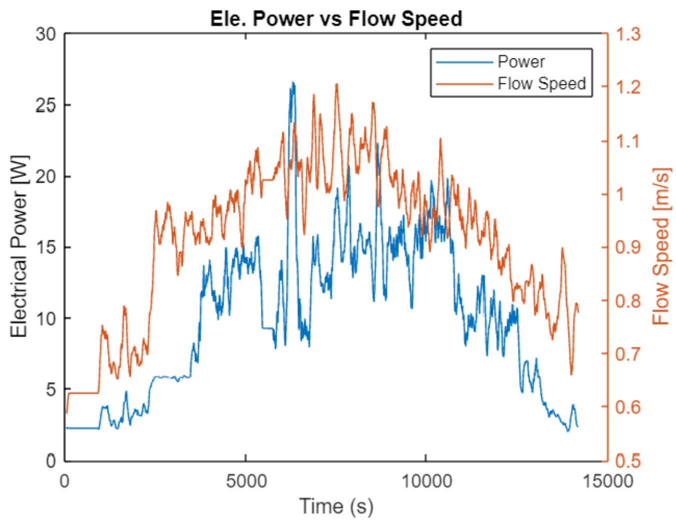
```
c71 = 2×2
    1.0000    0.8734
    0.8734    1.0000
```

```
figure
plot(MAtp,Pa);
ylabel('Power [W] Numerical Expression');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Mech. Power vs Flow Speed');
```

11



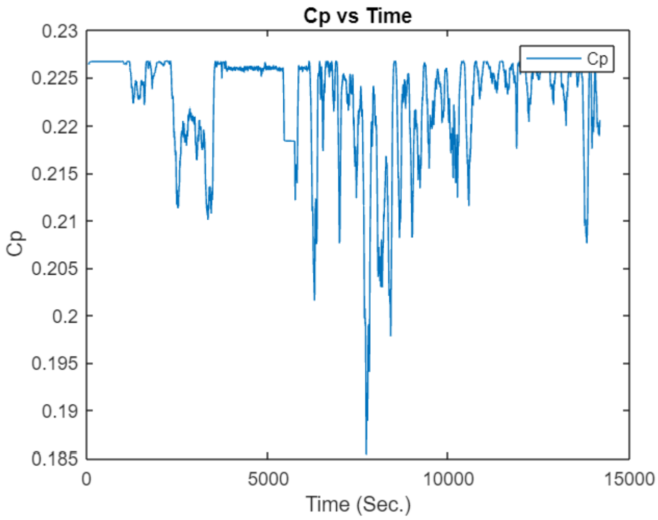

```
Pe = MAVgp.*MAIgp;

figure
plot(MAtp,Pe);
ylabel('Electrical Power [W]');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Ele. Power vs Flow Speed');
```



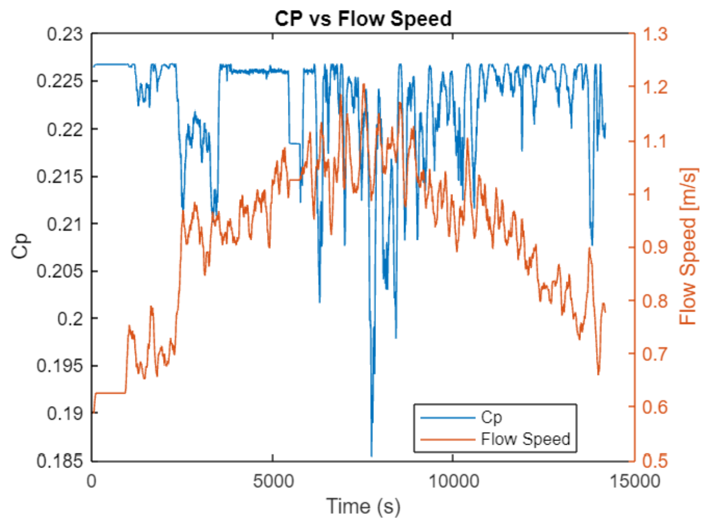

```
% Cp of Numerical Expression
Cp = Pa./((1/2).*p.*A.*(MAfsp.^3));
Cpsdt = std(Cp)
```

```
Cpsdt = 0.0060
```

```
figure
plot(MAtp,Cp)
title("Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')
```

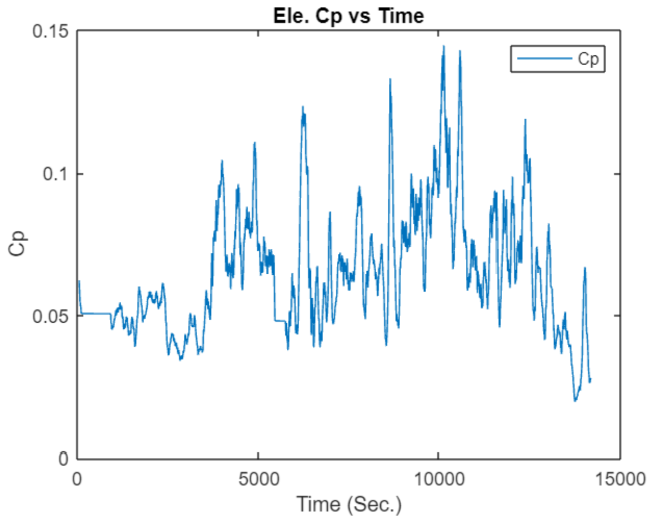



```
figure
plot(MAtp,Cp);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('CP vs Flow Speed');

legend("Position", [0.59104,0.1243,0.23123,0.092742])
```

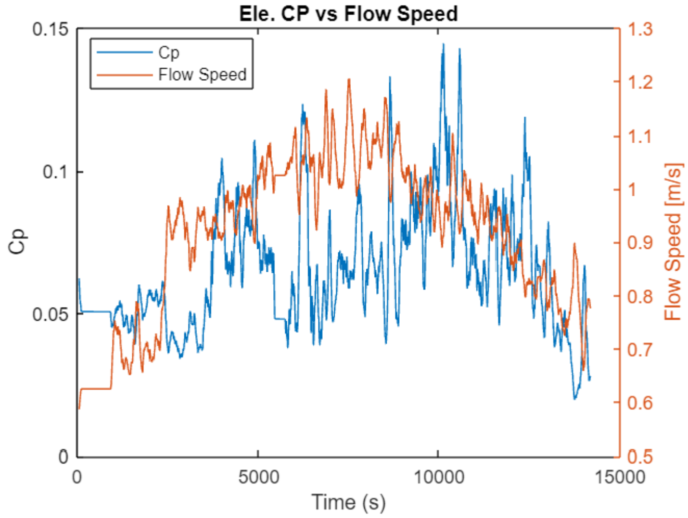



```
% Cp of the Pe
Cpe = Pe./((1/2).*p.*A.*(MAfsp.^3));

figure
plot(MAtp,Cpe)
title("Ele. Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')
```

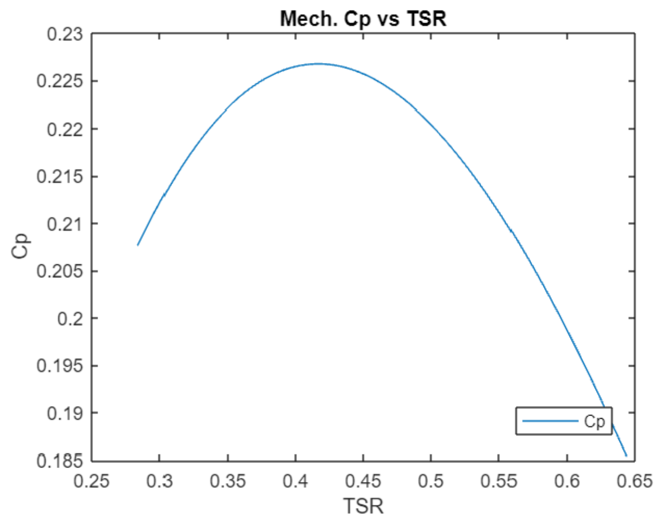
15



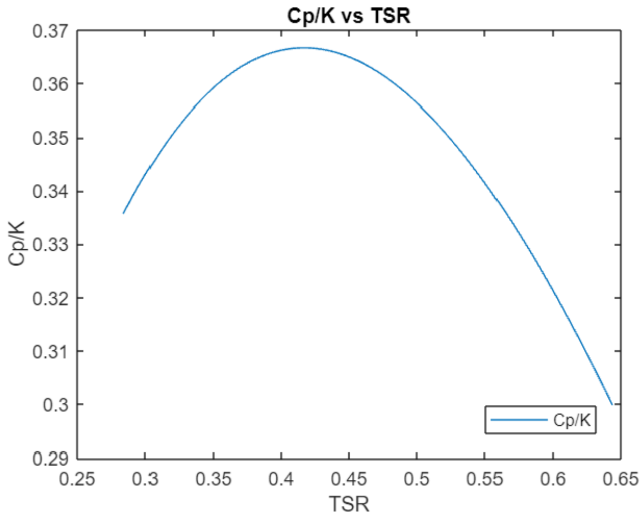

```
figure
plot(MAtp,Cpe);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('Ele. CP vs Flow Speed');

legend("Position", [0.14987,0.81128,0.23123,0.092742])
```




```
% Mech. Cp vs Lambda
figure
plot(l,Cp)
title("Mech. Cp vs TSR");
xlabel("TSR");
ylabel("Cp");
legend('Cp')

legend("Position", [0.73674,0.158,0.13472,0.051075])
```




```
% Cp/K vs Lambda
CPk = Cp/K;
figure
plot(l,CPk)
title("Cp/K vs TSR");
xlabel("TSR");
ylabel("Cp/K");
legend('Cp/K')

legend("Position", [0.71313,0.15601,0.15684,0.051075])
```




```
AVGPa=mean(Pa)
```

AVGPa = 34.1375

```
MAXPa=max(Pa)
```

MAXPa = 69.2568

```
AVGPe=mean(Pe)
```

AVGPe = 10.4935

```
MAXPe=max(Pe)
```

MAXPe = 26.5799

```
AVGCp=mean(Cp)
```

AVGCp = 0.2222

```
MaxCp=max(Cp)
```

MaxCp = 0.2267

```
AVGCpe=mean(Cpe)
```

AVGCpe = 0.0666

```
MAXCpe=max(Cpe)
```

MAXCpe = 0.1446

```
% Load Data & Set Names
data = readtable("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed
1-31\rd131.csv");
%disp(data)


datast.time = rd131.time_elapsed;
datast.values = table2array(data(:,2:6));
%disp(datast.time)
%disp(datast.values)

% Checking that all FS values have a proper time stamp
freq = 0.1;
results = check_timestamp(datast,freq);
%disp(results.values)

% Checking the Data Range
bounds = [0.001,45];
results = check_range(results,bounds);
%disp(results.values)

% %Checking for Stagnant Data
% bound = {0.00001, py.None};
% window1 = 0.01;
% results = check_delta(results, bound, window1);
% disp(results.values)

% Make CSV
h = {'Time' 'FS' 'Wrmp' 'Vg' 'Ig' 'Tww'};
body = [datast.time, results.values];
tabel = [h; num2cell(body)];
%disp(tabel)

% writecell(tabel, "qc131.csv")
% type qc131.csv
```

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-31\New
Way\qc131.mat");
tqc = qc131.Time;
FSqc = qc131.FS;
Wrpmqc = qc131.Wrmp;
Vgqc = qc131.Vg;
Igqc = qc131.Ig;
Twwqc = qc131.Tww;

window = 1000;

% Remove Outliers
FSrm = rmoutliers(FSqc);
Wrpmrm = rmoutliers(Wrpmqc);
Vgrm = rmoutliers(Vgqc);
Igrm = rmoutliers(Igqc);
Twwrm = rmoutliers(Twwqc);

size(tqc)
```

```
ans = 1×2
      56557          1
```

```
size(FSrm)
```

```
ans = 1×2
      56281          1
```

```
size(Wrpmrm)
```

```
ans = 1×2
      56554          1
```

```
size(Vgrm)
```

```
ans = 1×2
      56557          1
```

```
size(Igrm)
```

```
ans = 1×2
      56524          1
```

```
size(Twwrm)
```

```
ans = 1×2
      54277          1
```

```
% Trim Wrpmrm to match the length of Twwrm
Wrpmrm = Wrpmrm(1:length(Twwrm));
% Trim Vgrm to match the length of Twwrm
Vgrm = Vgrm(1:length(Twwrm));
```

```
disp(length(Wrpmrm));
```

```
1814
```

```
disp(length(Vgrm));
```

```
1814
```

```
disp(length(Igrm));
```

```
1814
```

```
disp(length(Twwrm));
```

```
1814
```

```
% Smoothing the Data
MAFS = movmean(FSrm, window);
MAWrpm = movmean(Wrpmrm, window);
MAVg = movmean(Vgrm, window);
MAIg = movmean(Igrm, window);
MATww = movmean(Twwrm, window);

% Plotting
figure
plot( tqc, Wrpmqc(1:length(tqc)), tqc, Vgqc(1:length(tqc)))
hold on
plot( tqc,MAWrpm, tqc,MAVg)
legend('Wrpmqc','Vgqc','MAWrpm','MAVg')
hold off
```

```
% Trim Igrm to match the length of Twwrm
Igrm = Igrm(1:length(Twwrm));
% Trim FSrm to match the length of Twwrm
FSrm = FSrm(1:length(Twwrm));

% Now they all should have the same length
disp(size(FSrm))
```

```
       54277           1
```

```
disp(size(Wrpmrm))
```

```
       54277           1
```

```
disp(size(Vgrm))
```

```
       54277           1
```

```
disp(size(Igrm))
```

```
       54277           1
```

```
disp(size(Twwrm))
```

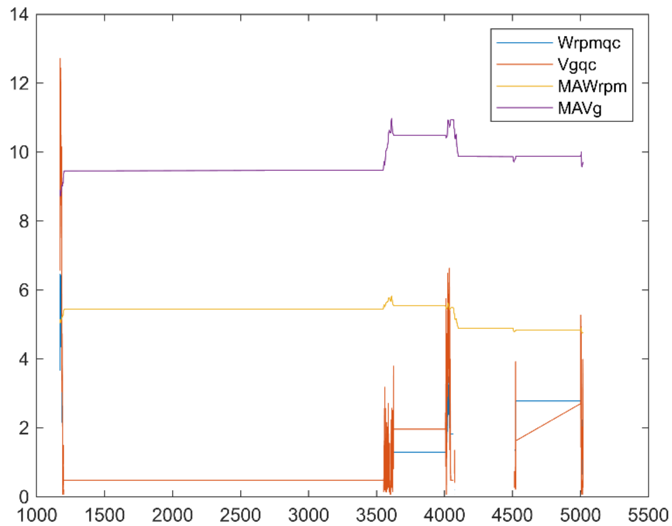
```
       54277           1
```

```
% Ensure that the time vector has the same length as the other data vectors after
removing outliers
FSrm_valid = ~isnan(FSrm);  % Find valid indices for FSrm
Wrpmrm_valid = ~isnan(Wrpmrm);  % Find valid indices for Wrpmrm
Vgrm_valid = ~isnan(Vgrm);  % Find valid indices for Vgrm
Igrm_valid = ~isnan(Igrm);  % Find valid indices for Igrm
Twwrm_valid = ~isnan(Twwrm);  % Find valid indices for Twwrm
valid_indices = FSrm_valid & Wrpmrm_valid & Vgrm_valid & Igrm_valid & Twwrm_valid;
% Combine valid indices

tqc = tqc(valid_indices);  % Filter the time vector to match the lengths of FSrm,
Wrpmrm, Vgrm and Igrm
FSrm = FSrm(valid_indices); %Filter FSrm
Wrpmrm = Wrpmrm(valid_indices); %Filter Wrpmrm
Vgrm = Vgrm(valid_indices);  % Filter Vgrm
Igrm = Igrm(valid_indices);  % Filter Igrm
Twwrm = Twwrm(valid_indices);  % Filter Twwrm

% Now, FSrm, Wrpmrm, Vgrm, Igrm, and tqc should have the same length
disp(length(tqc)); % Display the length to verify
```

```
        1814
```

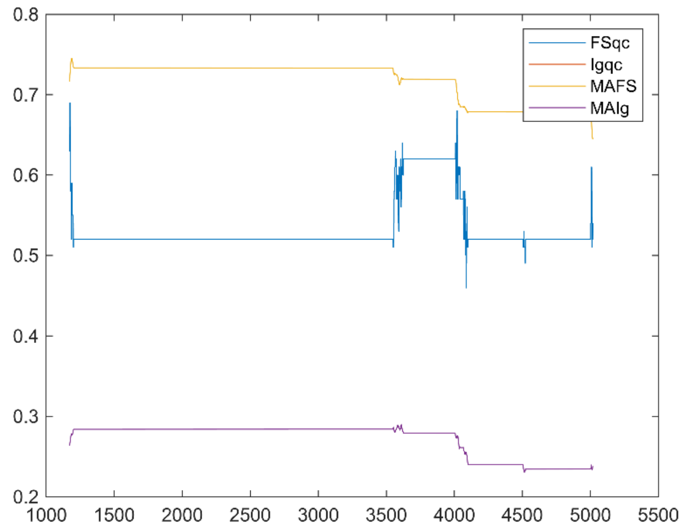
```
disp(length(FSrm));
```

```
        1814
```




```
figure
plot(tqc, FSqc(1:length(tqc)), tqc, Igqc(1:length(tqc)))
hold on
plot(tqc,MAFS, tqc,MAIg)
legend('FSqc', 'Igqc','MAFS', 'MAIg')
hold off
```

4




```
% Make CSV
h = {'Time' 'MAFS' 'MAWrpm' 'MAVg' 'MAIg' 'MATww'};
body = [tqc, MAFS, MAWrpm, MAVg, MAIg, MATww];
tabel = [h; num2cell(body)];
%disp(tabel)
```

```
% writecell(tabel, "MA131a.csv")
% type MA131a.csv
```

5

```
% Load Data & Set Names
load("C:\Users\missd\OneDrive\Documents\MATLAB\FT_24\FlowSpeed 1-31\New Way\MA131a.mat");
MAtp = MA131a.Time;
MAfsp = MA131a.MAFS;
MAWrpmp = MA131a.MAWrpm;
MAVgp = MA131a.MAVg;
MAIgp = MA131a.MAIg;
MATwwp = MA131a.MATww;

Wrs = ((MAWrpmp.*2.*pi)./60);

% Constants
A = 0.349;
Cd = 1.98;
R = 0.4858;
p = 1023.6;
a = 0.8; %Ph/Pa = 3.21/22.8
a1=0.8;
a2=0.85;
a3=0.9;
a4=0.95;
a5=0.33; %Ph/Pa = 1.78/36.37
a6=0.5; %Ph/Pa = 1.78/31.09
a7=0.98;
a8=0.9;
g1=0.173;

K=(3.21/22.8)
```

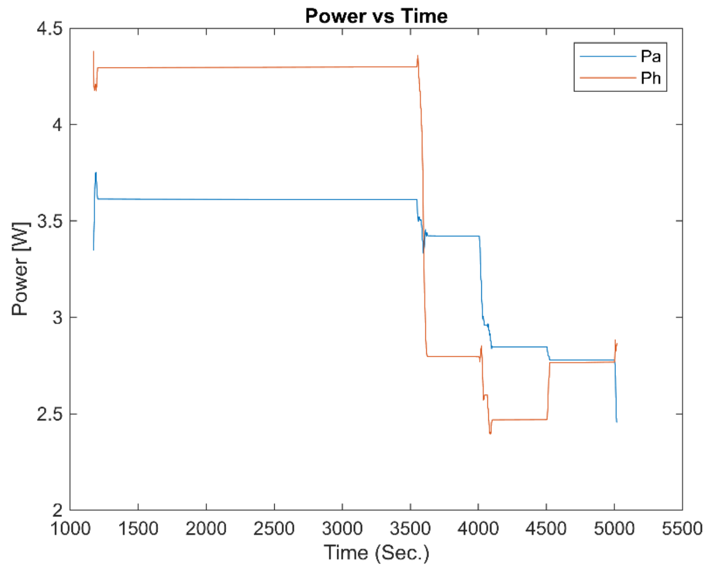
```
K = 0.1408
```

```
AVGFS=mean(MAfsp)
```

```
AVGFS = 0.7039
```

```
window = 1000;


l = ((Wrs.*R)./MAfsp);
Pa = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l.*(K);

% Theoretical
Ph = MATwwp.*Wrs;
figure
plot(MAtp,Pa, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
```

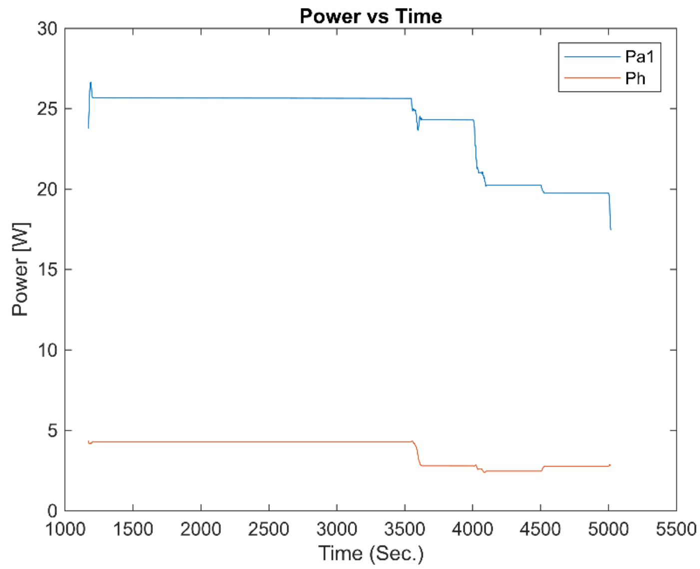
```
legend('Pa','Ph');
```




```
c = corrcoef(Pa,Ph)
```

```
c = 2×2
    1.0000    0.7842
    0.7842    1.0000
```

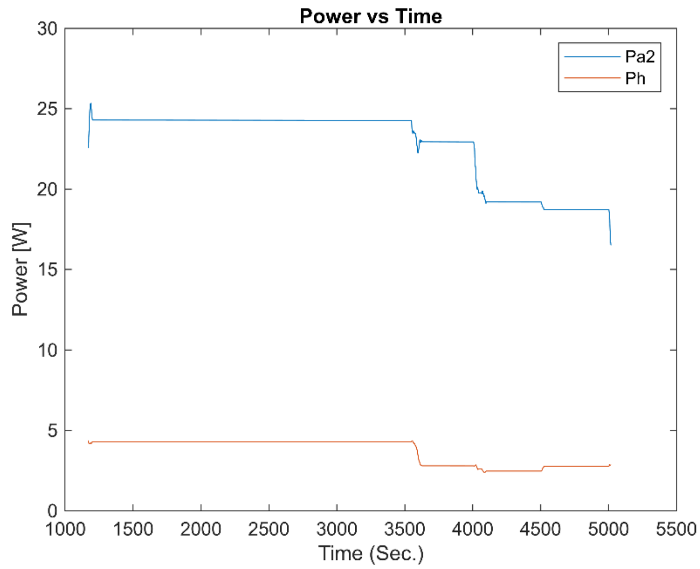
```
Pa1 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a1.*l).^2).*l;
figure
plot(MAtp,Pa1, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa1','Ph')
```




```
c1 = corrcoef(Pa1,Ph)
```

```
c1 = 2×2
    1.0000    0.7842
    0.7842    1.0000
```

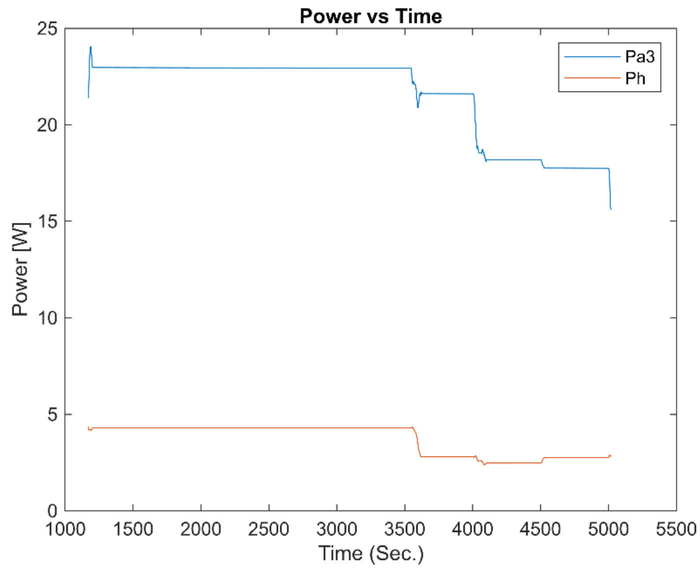
```
Pa2 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a2.*l).^2).*l;
figure
plot(MAtp,Pa2, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa2','Ph')
```




```
c2 = corrcoef(Pa2,Ph)
```

```
c2 = 2×2
    1.0000    0.7938
    0.7938    1.0000
```

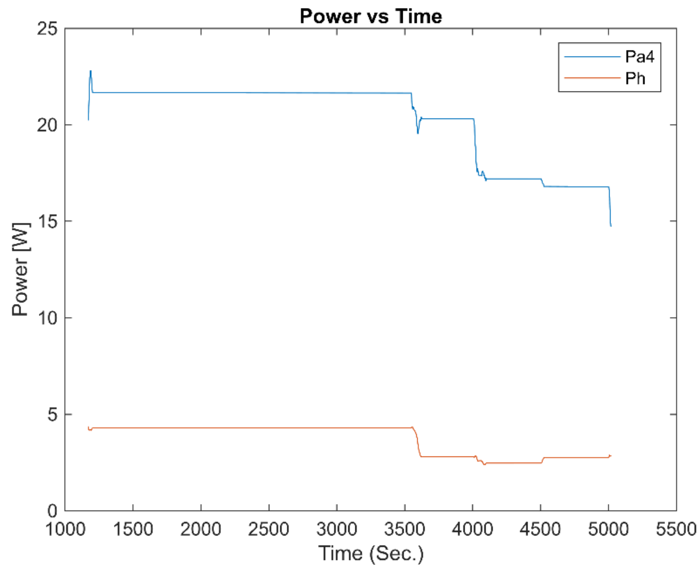
```
Pa3 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a3.*1).^2).*1;
figure
plot(MAtp,Pa3, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa3','Ph')
```




```
c3 = corrcoef(Pa3,Ph)
```

```
c3 = 2×2
    1.0000    0.8026
    0.8026    1.0000
```

```
Pa4 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a4.*l).^2).*l;
figure
plot(MAtp,Pa4, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa4','Ph')
```

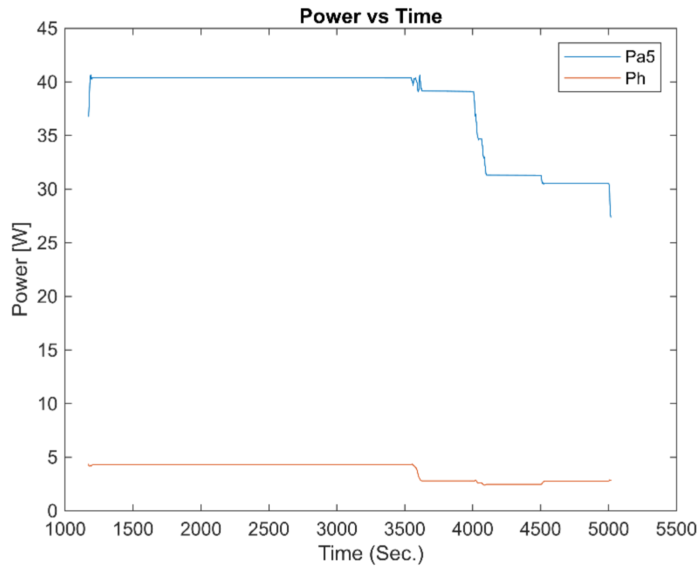



```
c4 = corrcoef(Pa4,Ph)
```

```
c4 = 2×2
    1.0000    0.8105
    0.8105    1.0000
```

```
Pa5 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a5.*l).^2).*l;
figure
plot(MAtp,Pa5, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa5','Ph')
```

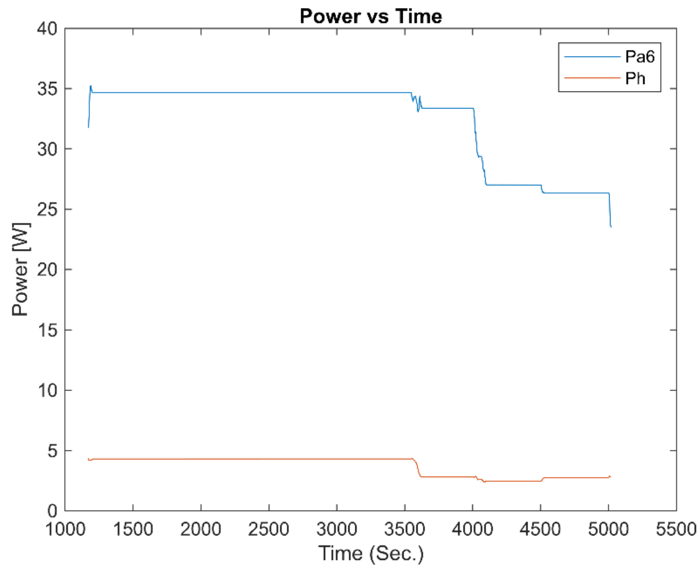
6




```
c5 = corrcoef(Pa5,Ph)
```

```
c5 = 2×2
    1.0000    0.6854
    0.6854    1.0000
```

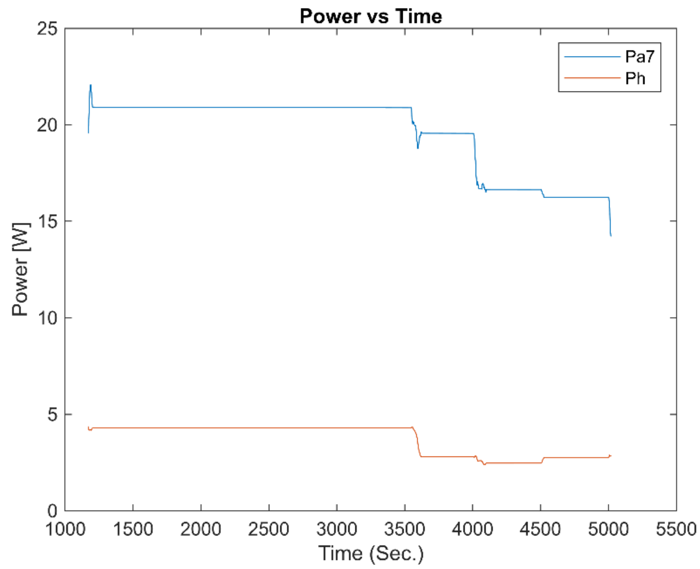
```
Pa6 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a6.*l).^2).*l;
figure
plot(MAtp,Pa6, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa6','Ph')
```




```
c6 = corrcoef(Pa6,Ph)
```

```
c6 = 2×2
    1.0000    0.7205
    0.7205    1.0000
```

```
Pa7 = (1/2).*p.*A.*Cd.*(MAfsp.^3).*((1-a7.*l).^2).*l;
figure
plot(MAtp,Pa7, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa7','Ph')
```




```
c7 = corrcoef(Pa7,Ph)
```

```
c7 = 2×2
    1.0000    0.8146
    0.8146    1.0000
```

```
g = Ph./Pa7;
AVGg = mean(g)
```

```
AVGg = 0.1730
```

```
AVGPh=mean(Ph)
```

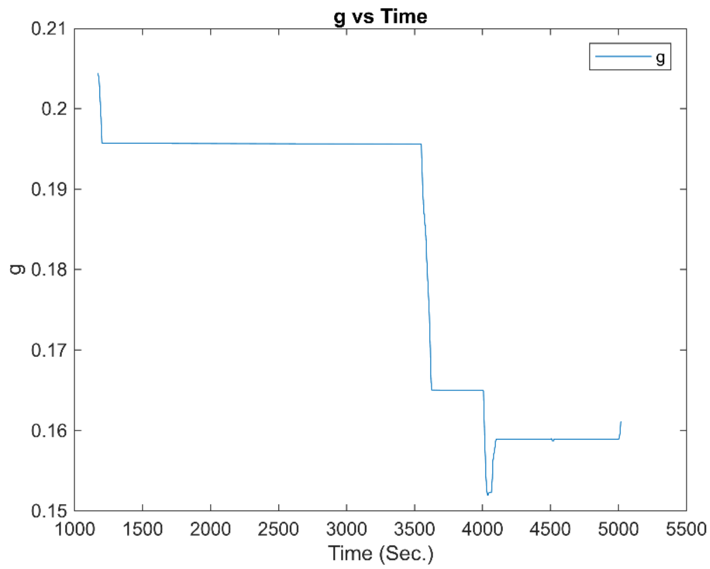
```
AVGPh = 3.2130
```

```
AVGPa=mean(Pa)
```

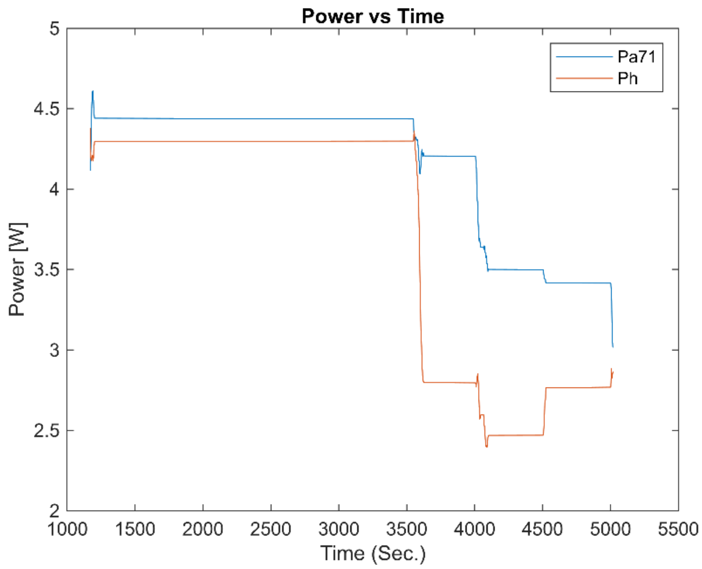
```
AVGPa = 3.2096
```

```
MAg = movmean(g, window);
figure
plot(MAtp,MAg)
title("g vs Time");
xlabel("Time (Sec.)");
ylabel("g");
legend('g')
```

9



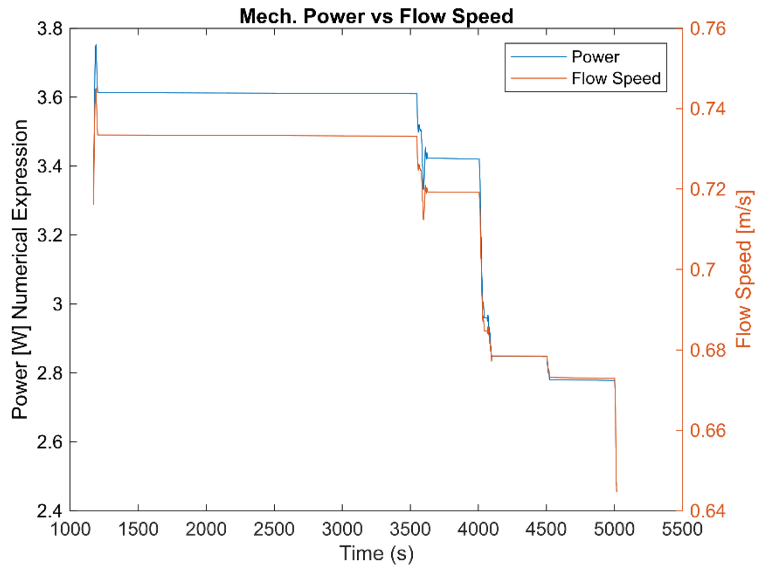

```
Pa71 = (1/2).*p.*A.*g1.*Cd.*(MAfsp.^3).*((1-a.*l).^2).*l;
figure
plot(MAtp,Pa71, MAtp,Ph)
title("Power vs Time");
xlabel("Time (Sec.)");
ylabel("Power [W]");
legend('Pa71','Ph')
```



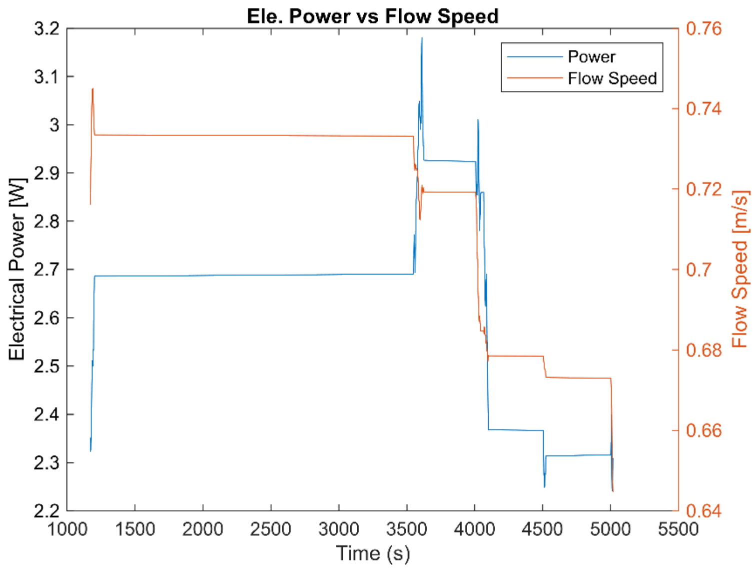

```
c71 = corrcoef(Pa71,Ph)
```

```
c71 = 2×2
    1.0000    0.7842
    0.7842    1.0000
```

```
figure
plot(MAtp,Pa);
ylabel('Power [W] Numerical Expression');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Mech. Power vs Flow Speed');
```



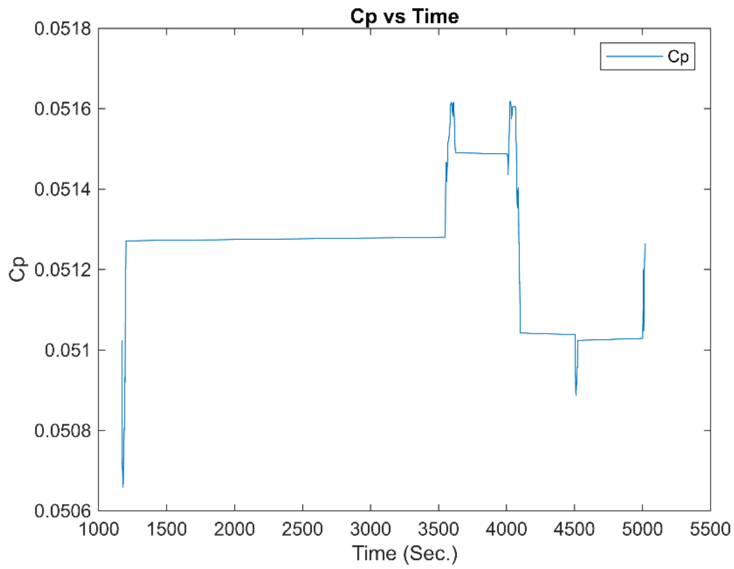

```
Pe = MAVgp.*MAIgp;

figure
plot(MAtp,Pe);
ylabel('Electrical Power [W]');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Power','Flow Speed');
title('Ele. Power vs Flow Speed');
```



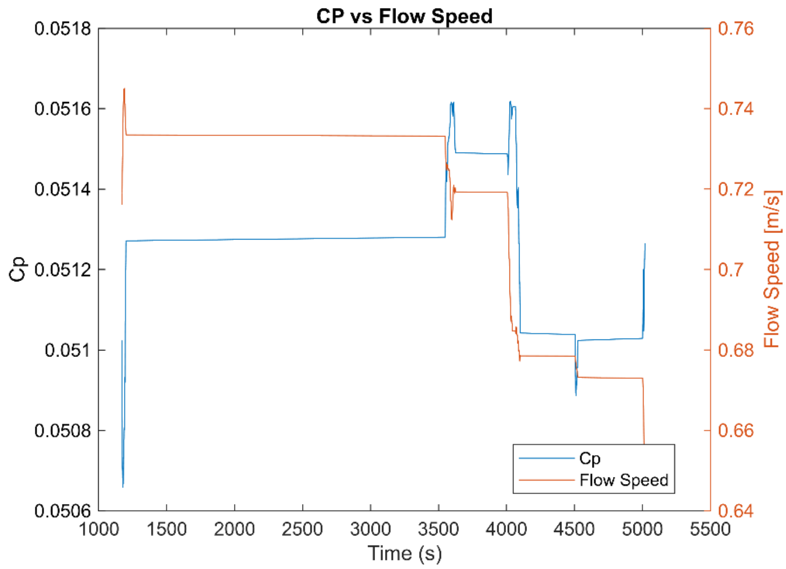

```
% Cp of Numerical Expression
Cp = Pa./((1/2).*p.*A.*(MAfsp.^3));
Cpsdt = std(Cp)
```

```
Cpsdt = 2.9319e-04
```

```
figure
plot(MAtp,Cp)
title("Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')
```

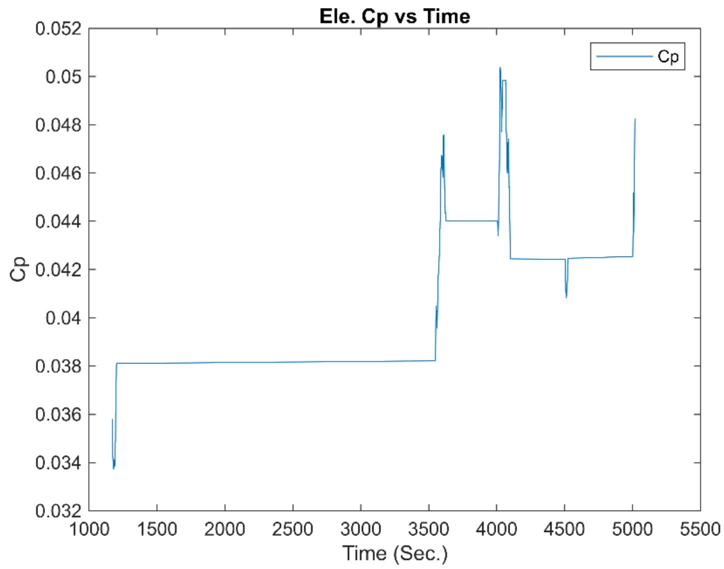



```
figure
plot(MAtp,Cp);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('CP vs Flow Speed');

legend("Position", [0.64157,0.13426,0.23123,0.092742])
```

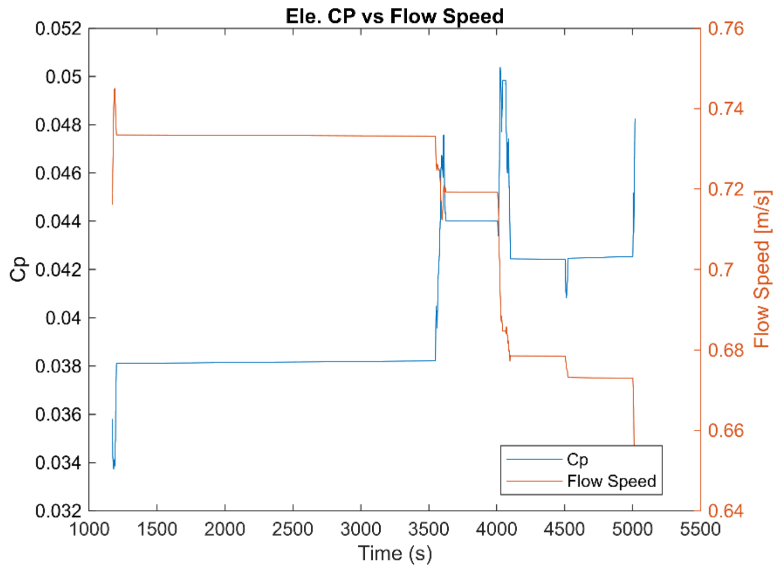



```
% Cp of the Pe
Cpe = Pe./((1/2).*p.*A.*(MAfsp.^3));

figure
plot(MAtp,Cpe)
title("Ele. Cp vs Time");
xlabel("Time (Sec.)");
ylabel("Cp");
legend('Cp')
```

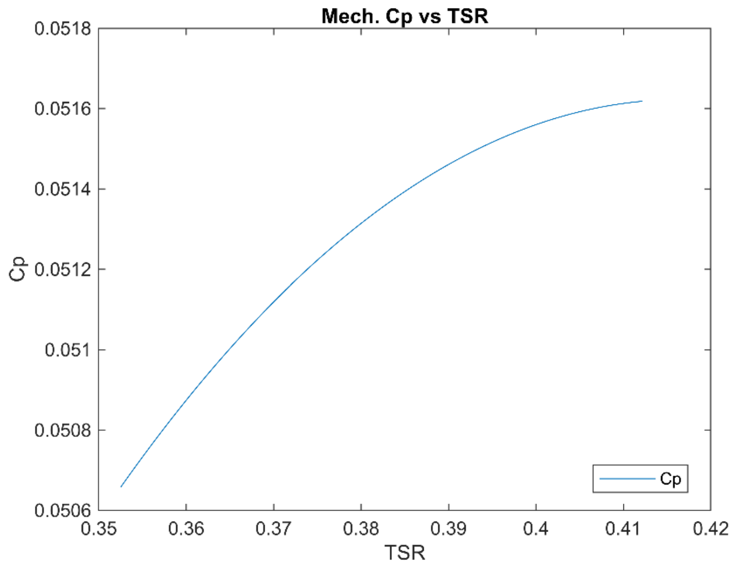
15



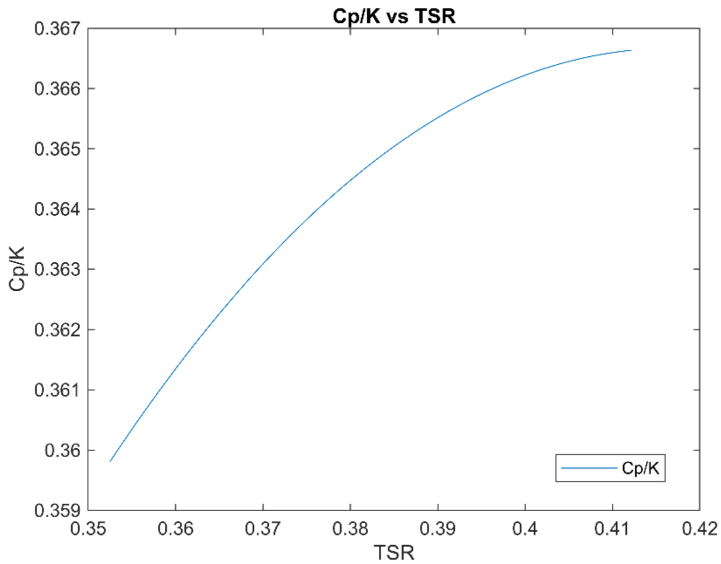

```
figure
plot(MAtp,Cpe);
ylabel('Cp');
xlabel('Time (s)');
hold on
yyaxis right
plot(MAtp,MAfsp)
ylabel("Flow Speed [m/s]");
legend('Cp','Flow Speed');
title('Ele. CP vs Flow Speed');

legend("Position", [0.63859,0.13227,0.23123,0.092742])
```




```
% Mech. Cp vs Lambda
figure
plot(l,Cp)
title("Mech. Cp vs TSR");
xlabel("TSR");
ylabel("Cp");
legend('Cp')

legend("Position", [0.74866,0.13809,0.13472,0.051075])
```




```
% Cp/K vs Lambda
CPk = Cp/K;
figure
plot(l,CPk)
title("Cp/K vs TSR");
xlabel("TSR");
ylabel("Cp/K");
legend('Cp/K')

legend("Position", [0.71313,0.15601,0.15684,0.051075])
```




```
AVGPa=mean(Pa)
```

AVGPa = 3.2096

```
MAXPa=max(Pa)
```

MAXPa = 3.7528

```
AVGPe=mean(Pe)
```

AVGPe = 2.7014

```
MAXPe=max(Pe)
```

MAXPe = 3.1803

```
AVGCp=mean(Cp)
```

AVGCp = 0.0513

```
MaxCp=max(Cp)
```

MaxCp = 0.0516

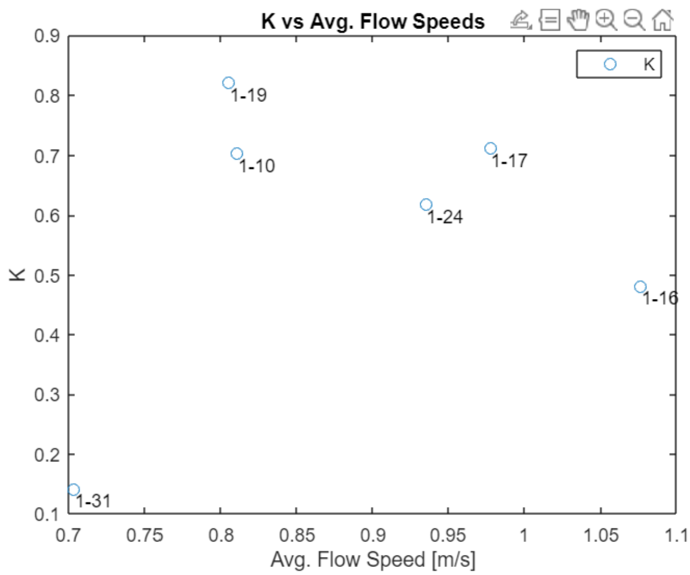
```
AVGCpe=mean(Cpe)
```

AVGCpe = 0.0435

```
MAXCpe=max(Cpe)
```

```
MAXCpe = 0.0504
```

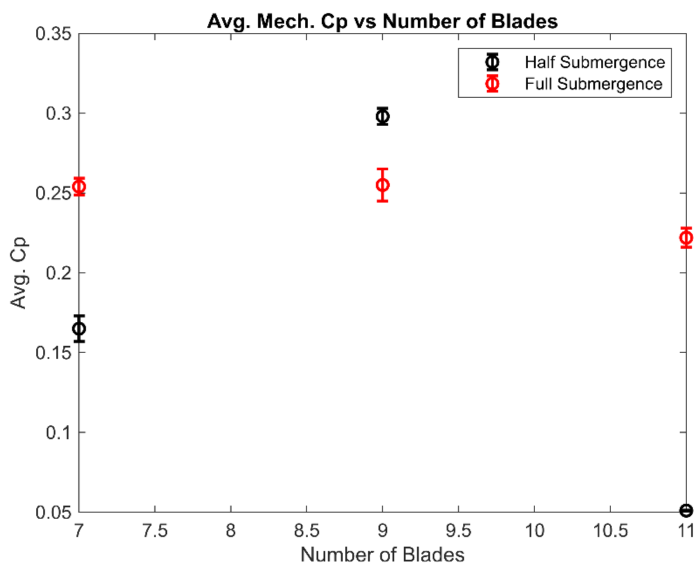
```
% Graph Avg. Flow Speed vs K
% when K = (AVG. Ph/ AVG. Pa)

AVGFS = [0.7039, 0.8054, 0.8109, 0.9356, 0.9781, 1.0767];
K = [0.1408, 0.8207, 0.7037, 0.6184, 0.7127, 0.4818];
labels = {'1-31','1-19','1-10','1-24','1-17', '1-16'};

figure
plot(AVGFS,K, 'o')
title("K vs Avg. Flow Speeds");
text(AVGFS,K,labels,'VerticalAlignment','top','HorizontalAlignment','left')
xlabel("Avg. Flow Speed [m/s]");
ylabel("K");
legend('K')
```



```
% AVG. Mech. Cp vs Number of Blades

Blades=[7, 7, 9, 9, 11, 11];
Cp_mean=[0.254, 0.165, 0.255, 0.298, 0.222, 0.051];
Cp_std=[0.0052, 0.008, 0.01, 0.0051, 0.006, .00029];

errorbar(Blades([2 4 6])',Cp_mean([2;4;6]),Cp_std([2;4;6]),'ko','linewidth',1.5) ;
hold
```

```
Current plot held
```

```
errorbar(Blades([1 3 5])',Cp_mean([1;3;5]),Cp_std([1;3;5]),'ro','linewidth',1.5) ;
title("Avg. Mech. Cp vs Number of Blades");
ylabel("Avg. Cp");
xlabel("Number of Blades");
legend('Half Submergence','Full Submergence');
```

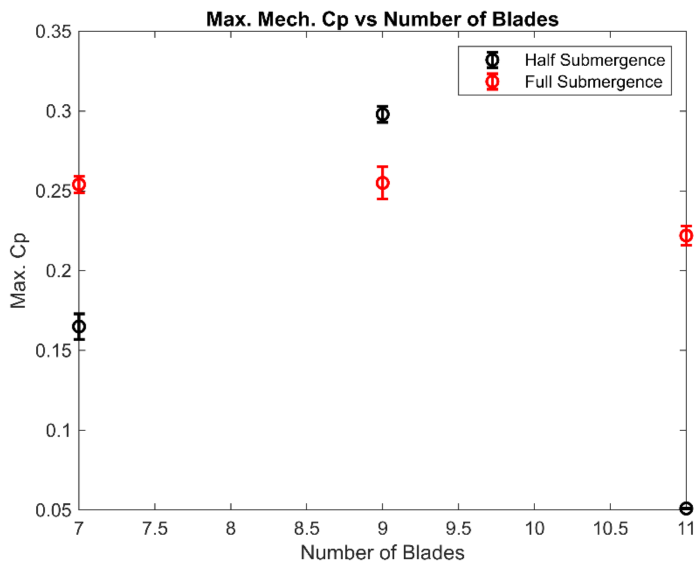


1

```
% AVG. Mech. Cp vs Number of Blades

Blades=[7, 7, 9, 9, 11, 11];
Cp_max=[0.258, 0.177, 0.261, 0.300, 0.227, 0.052];
Cp_std=[0.0052, 0.008, 0.01, 0.0051, 0.006, .00029];

errorbar(Blades([2 4 6])',Cp_mean([2;4;6]),Cp_std([2;4;6]),'ko','linewidth',1.5) ;
hold
```

```
Current plot held
```

```
errorbar(Blades([1 3 5])',Cp_mean([1;3;5]),Cp_std([1;3;5]),'ro','linewidth',1.5) ;
title("Max. Mech. Cp vs Number of Blades");
ylabel("Max. Cp");
xlabel("Number of Blades");
legend('Half Submergence','Full Submergence');
```



Appendix L: Scaling Analysis

```
% WAMV Scaling Analysis

% Constants
b=0.7431; %blade width
d=4.23; %blade length
A = (b*d);
Cd = 1.98;
R = 1.4574;
p = 1023.6;
a = 0.8;

U = 0.9356; %AVGVFS from 1-24 testing, thus the same K value will be used
K = 0.6184;
Wrs = 0.8518; %AVGWrs selected from the same dataset

l = ((Wrs*R)/U);
Pa = (1/2)*p*A*Cd*(U^3)*((1-a*l)^2)*l*(K)
```

```
Pa = 8.0935
```

```

% A=0.349 Pa=33.10 *Original FSWW size
% A=0.525 Pa=49.65 b=0.372 d=1.41 *1.5X wide blades
% A=0.6985 Pa=66.20 b=0.2477 d=2.82 *2X length blades
% A=0.349 Pa=26.19 R=0.729 *The same blades with 1.5X the R
% A=0.349 Pa=13.55 R=0.972 *The same blades with 2X the R
% A=1.39 Pa=54.20 R=0.972 *2X blades with 2X the R
% A=3.14 Pa=8.09 R=1.457 *3X blades with 3X the R
```

1

11.0 BIBLIOGRAPHY

A. L. McKinney, et al., “Site-selection for Field-testing of a Marine Hydrokinetic Turbine Platform to Serve as a Floating Unmanned Mobile Recharging Station for Aerial Drones.” *Offshore Technology Conference, Huston Texas, 1-4 May 2023.*

“ANAFI Parrot Product Sheet.” Parrot, 2021.

A. Pascoal and et al., “Robotic Ocean vehicles for marine science applications: the European asimov project,” in Proc. of Oceans 2000, 2000.

Ahmadi, Mehran. “Analysis and Study of Floating Offshore Wind Turbines.” *The University of Toledo*, University of Toledo, 2013, pp. 1–113.

Anyi, Martin, and Brian Kirke. “Evaluation of Small Axial Flow Hydrokinetic Turbines for Remote Communities.” *Energy for Sustainable Development*, vol. 14, no. 2, 2010, pp. 110–116., https://doi.org/10.1016/j.esd.2010.02.003.

Bassett, Christopher. “Operation of a Tidal Turbine on a Moored Vessel in Agate Pass, WA.” University of Washington.

Bowker, J. A., et al. “Experimental Study of a Wave Energy Scavenging System Onboard Autonomous Surface Vessels (Asvs).” *OCEANS 2015 - Genova*, 2015, https://doi.org/10.1109/oceans-genova.2015.7271484.

Caccia, M., et al. “Design and Exploitation of an Autonomous Surface Vessel for the Study of Sea-Air Interactions.” *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*, Apr. 2005, pp. 3583–3587., https://doi.org/10.1109/robot.2005.1570665.

Cavagnaro, Robert J., and Brian Polagye. "Field Performance Assessment of a Hydrokinetic Turbine." *International Journal of Marine Energy*, vol. 14, 2016, pp. 125–142., https://doi.org/10.1016/j.ijome.2016.01.009.

Cleynen, Oliver, et al. "Optimal design for a free-stream waterwheel: A two-dimensional study." *Energy*, vol. 214, no. 118880, 1 Oct. 2020, pp. 1–11. *2021*, https://doi.org/https://doi.org/10.1016/j.energy.2020.118880.

"Coefficient of Determination, R-Squared." *Numeracy, Maths and Statistics - Academic Skills Kit*, www.ncl.ac.uk/webtemplate/ask-assets/external/maths-resources/statistics/regression-and-correlation/coefficient-of-determination-r-squared.html. Accessed 3 Mar. 2024.

Dhanak, Manhar, et al. pp. 1–22, Field Work Specifications in Support of Permitting.

Etcheverry, Jose R. *Challenges and Opportunities for Implementing Sustainable Energy Strategies in Coastal Communities of Baja California Sur, Mexico, University of Toronto*, University of Toronto, 2008, https://tspace.library.utoronto.ca/bitstream/1807/16765/1/Etcheverry_Jose_R_200811_PhD_thesis.pdf. Accessed 25 Apr. 2022.

Evans, Luke, et al. "Tidal turbine power performance assessments following IEC TS 62600-200 using measured and modelled power outputs." *Renewable Energy*, vol. 212, Aug. 2023, pp. 138–150, https://doi.org/10.1016/j.renene.2023.05.031.

Filippone, A. "Drag Coefficients." *Aerodynamic Drag, Data for Airfoils, Wings, Aircraft, Automobiles*, www.if.ufrj.br/~carlos/palestras/futebol/dragData/Aerodynamic%20Drag%20Data.htm. Accessed 29 Feb. 2024.

Fosbrook, A. (2021). An Automated Anchoring System for an Unmanned Surface Vehicle. MS Thesis. Florida Atlantic University.

H. Pimentel, et al., “A Power Takeoff Device for a Small Marine Hydrokinetic Turbine Deployed from an Unmanned Floating Platform.” Oceans 2023, IEEE/MTS Conference. Biloxi MS. September 2023.

Hall, Adam, “Design, Simulation, and Testing of a CVT Based PTO and Controller for a Small Scale MHK-Turbine for Low Flow Speed Operation”, 2022, MS Thesis, Ocean Engineering, Florida Atlantic University.

Harvey, H T, and Marcus Lehmann. Los Gatos, California, 2019, pp. 1–46, *Biological Evaluation of CalWave Open Water Demonstration*.

Hauck, M.; Rumeau, A.; Bratcu, A.; Bacha, S.; Munteanu, I.; Roye, D. (2018). Identification and Control of a River-Current-Turbine Generator—Application to a Full-Scale Prototype. IEEE Transactions on Sustainable Energy, 9(3), 1365-1374.

Hess, S. (2020). Localized Flow Modification to Increase Power Capture of a Small Scale Floating Undershot Waterwheel. MS Thesis. Florida Atlantic University.

J. Majohr, T. Buch, and C. Korte, “Navigation and automatic control of the Measuring Dolphin (MESSIN),” in Proc. of MCMC 2000, 2000, pp. 405–410.

J. Manley, “Development of the autonomous surface craft ”ACES”,” in Proc. of Oceans’97, vol. 2, 1997, pp. 827–832.

J. Manley, A. Marsh, W. Cornforth, and C. Wiseman, “Evolution of the autonomous surface craft AutoCat,” in Proc. of Oceans’00, vol. 1, 2000, pp. 403–408.

Jeffcoate, P.; Cresswell, N. (2018). *Field Performance Testing of a Floating Tidal Energy Platform-Part 2: Load Performance*. Paper presented at 4th Asian Wave and Tidal Energy Conference (AWTEC), Taipei, Taiwan.

Jeffcoate, P.; Starzmann, R.; Elsaesser, B.; Scholl, S.; Bischoff, S. (2015). Field measurements of a full-scale tidal turbine. International Journal of Marine Energy, 12, 3-20. https://doi.org/10.1016/j.ijome.2015.04.002

Jeffcoate, P.; Whittaker, T.; Elsaesser, B. (2016). Field tests of multiple 1/10 scale tidal turbines in steady flows. *Renewable Energy*, 87(Part 1), 240-252. https://doi.org/10.1016/j.renene.2015.10.004

Johnson, E, Fontaine, A. A., Jonson, M. L., Meyer, R. S., Straka, W. A., Young, S. A., van Dam, C. P., Shiu, H. and Barone, M.," A1:8.7 scale water tunnel test of an axial flow water turbine," Proceedings of the 1rst Marine Energy Technology Symposium, METS13, Washington Dc, 2013.

Junaid, A. B., Konoiko, A., Zweiri, Y., Sahinkaya, M. N., & Seneviratne, L. (2017). "Autonomous Wireless Self-Charging for Multi-Rotor Unmanned Aerial Vehicles", energies, 1-14.

Kusuma, Ardy. *Ocean Energy Overview: Feasibility Study of Ocean Energy Implementation in Indonesia*, *World Maritime University*, World Maritime University, 4 Nov. 2018, https://commons.wmu.se/cgi/viewcontent.cgi?article=1607&context=all_dissertations. Accessed 25 Apr. 2022.

L. Luznik, K.A. Flack, E.E. Lust, D.P. Baxter, Hydrodynamic performance of a horizontal axis tidal turbine under steady flow conditions, Oceans 2012, Hampton Roads, Virginia, October 16, 2012.

Maklakov, D. V., and A. N. Uglov. "On the maximum drag of a curved plate in flow with a wake." *European Journal of Applied Mathematics*, vol. 6, no. 5, Oct. 1995, pp. 517–527, https://doi.org/10.1017/s0956792500002011.

M Barone, T. Griffith, J. Berg, Reference Model 2: "Rev 0" Rotor Design, Sandia Report, SAND2011-9306, November 2011..

Manwell, J. F., et al. "Wind Characteristics and Resources and Aerodynamics of Wind Turbines." *Wind Energy Explained; Theory, Design and Application*, 2nd ed., WILEY, 2009, pp. 1–689.

McKinney, Adriana, "Design & Development of a Secure Self-Leveling Wireless Recharging Platform for an Aerial Drone on an Unmanned Surface Vessel", 2021, MS Thesis, Ocean Engineering, Florida Atlantic University.

McKinney, A., et al. "A Low-Flow Marine Hydrokinetic Turbine for a Floating Unmanned Mobile Platform", Oceans 2022, IEEE/MTS Conference. Hampton Roads VA. October 2022.

"MHKiT Matlab Webinar." *YouTube*, YouTube, 9 Apr. 2021, www.youtube.com/watch?v=30OFFfkSZTc&t=1555s.

"MHKiT (Marine and Hydrokinetic Toolkit)." *MHKiT (Marine and Hydrokinetic Toolkit) - MHKiT v0.7.0 Documentation*, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories, 2019, mhkit-software.github.io/MHKiT/index.html.

"MHKiT Offers Marine Renewable Energy Mavens Tools for Success." *NREL*, 10 June 2020, www.nrel.gov/news/program/2020/mhkit-tools-for-success.html.

Montero, Adolfo Mejía. *Prospects for Community Wind Projects on the Tehuantepec Isthmus, Oaxaca, Mexico, The University of Edinburgh*, The University of Edinburgh, Aug. 2015, http://static1.squarespace.com/static/536b92d8e4b0750dff7e241c/t/55e28e48e4b06620ed827317/1440910920169/Dissertation_S1416198.pdf. Accessed 25 Apr. 2022.

Murray J; Barone M (2011) The Development of CACTUS, a Wind and Marine Turbine Performance Simulation Code. 49th AIAA Aerospace Sciences Meeting. Paper AIAA 2011-147. January 4-7, 2011, Orlando, FL.

N. Frew and R. Nelson, "Spatial mapping of sea surface microlayer surfactant concentration and composition," in Geoscience and Remote Sensing Symposium, vol. 3, 1999, pp. 1472 –1474.

Neary, V S, et al. "US Department of Energy (DOE) National Lab Activities in Marine Hydrokinetics: Scaled Model Testing of DOE Reference Turbines." *Tethys.pnnl.gov*, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://tethys.pnnl.gov/sites/default/files/publications/Neary_et_al_2013_EWTEC.pdf. Accessed 13 Jan. 2023.

NREL, NWTC Information Portal, Computer-Aided Engineering Tools, WT_Perf, http://wind.nrel.gov/designcodes/simulators/wtperf/, Aug 10, 2013

Odetti, Angelo, et al. "Swamp, an Autonomous Surface Vehicle Expressly Designed for Extremely Shallow Waters." *Ocean Engineering*, vol. 216, 12 Nov. 2020, pp. 1–19., https://doi.org/10.1016/j.oceaneng.2020.108205.

Pimentel, Hugo. “Modeling, Implementation and Control of a CVT Based PTO for a Small Scale MHK-Turbine in Low Flow Seed Current.” *Florida Atlantic University*, 2024.

“QC Module.” *QC Module - MHKiT v0.7.0 Documentation*, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories, 2019, mhkit-software.github.io/MHKiT/mhkit-matlab/api.qc.html.

“Quality Control Tests.” *Quality Control Tests - Pecos 0.2.1 Documentation*, National Technology & Engineering Solutions of Sandia, LLC (NTESS) Revision 8d95ba4f, 2016, pecos.readthedocs.io/en/latest/qc_tests.html.

Quaranta, Emanuele. “Investigation and Optimization of the Performance of Gravity Waterwheels.” Politecnico di Torino, 2017.

Reece, Karla. “National Marine Fisheries Service Consultation Request.” Received by Ms. Aguilar, NMFS, 12 Jan. 2022, St. Petersburg, Florida, pp. 1–6.

Schmitt, Pál, et al. “A Comparison of Tidal Turbine Characteristics Obtained from Field and Laboratory Testing.” *Journal of Marine Science and Engineering*, vol. 10, no. 9, 2022, p. 1182., https://doi.org/10.3390/jmse10091182.

Scripter, Matthew J. Jensen Beach, Florida, 2021, pp. 1–89, *Biological Evaluation.*

Shingala, Abhishekkumar, et al. “Genetic optimisation of a free-stream waterwheel using 2D computational fluid dynamics simulations points towards design with fully immersed blades.” *Energies*, vol. 15, no. 10, 19 May 2022, pp. 3723–3743, https://doi.org/10.3390/en15103723.

Starzmann, R.; Goebel, I.; Jeffcoate, P. (2018). *Field Performance Testing of a Floating Tidal Energy Platform-Part 1: Power Performance*. Paper presented at 4th Asian Wave and Tidal Energy Conference (AWTEC), Taipei, Taiwan.

Strickland, J D, and T Devine. "Unmanned Surface Vehicles: Realizations & Applications." 2017, pp. 37–43.

Talukdar, Parag K., et al. "Field-Testing of Model Helical-Bladed Hydrokinetic Turbines for Small-Scale Power Generation." *Renewable Energy,* vol. 127, 18 Apr. 2018, pp. 158–167., https://doi.org/10.1016/j.renene.2018.04.052.

Technical Specification IEC/TS 62600-200. 1.0 ed., vol. 5, International Electrotechnical Commission, 2013.

Technical Specification: IEC TS 62600-202. 1.0 ed., vol. 140, International Electrotechnical Commission, 2022.

Tongco, Alejandro F. "Field-testing of a Crossflow Water Turbine." Oklahoma State University, 1988.

Tran, Thanh Toan (2022). *A Characterization Study of Hydraulic Performance for A Floating Free-Stream Waterwheel using High-Fidelity Modeling*. Manuscript in preparation. National Renewable Energy Laboratory.

Turnock SR, Müller GU, Nicholls-Lee R, Denchfield S, Hindley S, Shelmerdine R, et al. Development of a floating tidal energy system suitable for use in shallow water. In: Proceedings of the 7th European wave and tidal energy conference. Portugal: Porto, 2007.

United States, Congress, Office of Scientific and Technical Information, et al. *Experimental Test Plan – DOE Tidal And River Reference Turbines*, Aug. 2012. UT-Battelle. Accessed 13 Jan. 2023.

VanZwieten, James, pp. 1-13, Ideal Horizontal Axis Turbine with Wake Rotation.

Walton, Steven A. “The Three Types of Waterwheels.” Medieval Technology and American History - One-Minute Essays - Three Types of Waterwheels, Pennsylvania State University, www.engr.psu.edu/mtah/essays/threetypes_waterwheels.htm. Accessed 2 Dec. 2023.

Wiesebron, Lauren E. “Evaluating Biological Characteristics of Marine Renewable Energy Sites for Environmental Monitoring.” *Evaluating biological characteristics of marine renewable energy sites for environmental monitoring, University of Washington*, 2015, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://depts.washington.edu/pmec/docs/Wiesebron_thesis_final.pdf. Accessed 1AD.

Wright, Laura. “United States Department of the Interior Fish & Wildlife Service Informal Consultation Request.” Received by NEPA Specialist, Department of Energy, Golden Field Office, Golden, CO, NFWS, 23 Feb. 2022, Vero Beach, FL, pp. 1–6.

Zhang, Aiming, et al. “Field Tests on Model Efficiency of Twin Vertical Axis Helical Hydrokinetic Turbines.” *Energy*, vol. 247, 2022, p. 123376., https://doi.org/10.1016/j.energy.2022.123376.

Zhao, Mengshang, et al. "Performance investigation of the immersed depth effects on a waterwheel using experimental and numerical analyses." *Water*, vol. 12, no. 4, 30 Mar. 2020, pp. 982–999, https://doi.org/10.3390/w12040982.