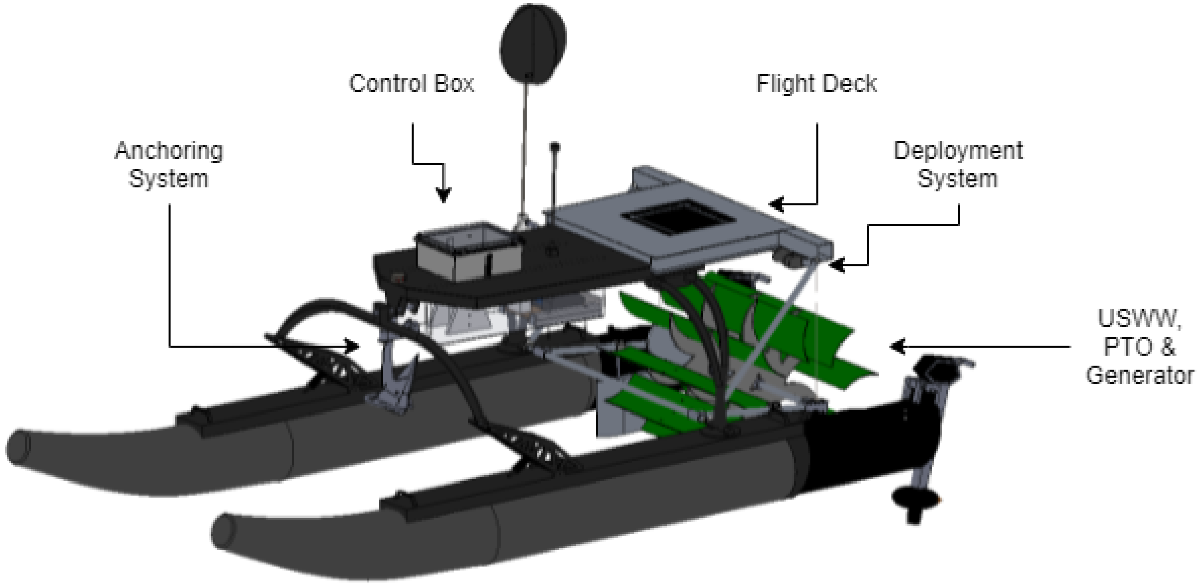
Low-Flow Marine Hydrokinetic Turbine for Small Autonomous Unmanned Mobile Recharge Stations



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Project Overview

Project Summary

The project goal is to develop a prototype low-flow (0.5-1.0 m/s) marine current turbine to provide partial power to recharge battery banks onboard an unmanned mobile floating recharge station for small aerial drones. A small autonomous surface vehicle (USV) available at FAU serves as the mobile floating platform from which the turbine is to be deployed. Sub-components of the system being developed include: an undershot waterwheel (USWW), a power takeoff (PTO) device, an automated anchoring system for the platform, and a flight-deck onboard the platform to support landing, takeoff and charging of small aerial drones.

Intended Outcomes

Specific objectives are:

- Design and develop a prototype USWW and other subsystems, utilizing COTS components wherever possible.
- Conduct laboratory and once environmental permits are granted, field testing. Field tests will be conducted (i) in the tidal-flow driven intracoastal waterways, and (ii) in coastal waters offshore of Ft. Lauderdale, Florida.
- Analyze acquired data for assessment of system performance
- Develop plans for market transformation and engage industry

Project Information

Principal Investigator(s)

- Professor Manhar Dhanak (PI)
- Professor Pierre-Phillip Beaujean (Co-PI)

Project Partners/Subs

- NREL.
    - Mr. Robert Raye

Project Status

Ongoing

Project Duration

- Project Start Date: 7/1/2019
- Project End Date: 6/30/2022 (NCE requested)

Total Costed (FY19–FY21)

$683K

Project Objectives: Relevance

Relevance to Program Goals:

The project is relevant to marine energy program's goal of overcoming the challenge of difficult engineering to convert marine energy through foundational R&D aimed at driving innovation in components, controls, materials, manufacturing, and systems. In particular, the project falls under maturing early-stage tidal/current systems supported under Topic Area 1 (TA1) of FOA-0001837. It involves R&D in support of consideration of the viability of a novel deployment of a MHK turbine from an autonomous mobile surface platform with a selected application of serving as a recharging station for aerial drones. A recent DOE EERE Report (April, 2018) suggests unmanned marine and aerial vehicles as an emerging market for MHK energy. In particular, the report sees significant potential market within the DOD sector (Navy and Air Force) involving use of unmanned aerial vehicles or drones in ocean areas. Such unmanned aerial vehicles can benefit from capabilities to recharge at sea, rather than returning to a land-based recharging station, thereby enhancing mission range, and reducing cost. Similar charging is required for unmanned underwater and surface vehicles (UUVs and USVs). The project involves innovations in the development of

- Components that are light weight and are suitable for the marine environment including minimization of adverse impact on marine life
- A small-scale USWW turbine with a diffuser system for flow acceleration
- A CVT-based PTO for converting small-scale current energy to electricity and associated electronic systems for power management onboard the platform
- An automated anchoring system for the mobile platform
- A flight deck onboard the MHK platform to provide at-sea recharging capability for aerial drones.

It involves addressing the engineering challenges in fabrication of small-scale marine systems, and laboratory and field testing of such systems, including meeting regulatory permitting requirements for at-sea testing.

Project Objectives: Approach

Approach:

- Design with detailed drawings, the MHK system and subsystems and evaluate the feasibility of the concept
- Develop plans for system fabrication, testing, and risk management
- Following the Go-No-Go decision, fabricate the MHK system and subsystems including associated electronics
- Conduct a biological evaluation of the proposed field testing
- Develop support structures for installation of the subsystems onboard the USV as well as electronics and electrical interfaces for generation, and storage of harnessed electricity onboard the USV and for data acquisition
- Test the MHK system and subsystems in the laboratory
- Implement the MHK system onto the unmanned surface vehicle (USV) and program the USV to carry out appropriate missions for harnessing tidal and coastal currents
- Once NEPA permits are granted, test the assembled prototype system (I) in the tidal-flow driven waterways at SeaTech, FAU, and (ii) in coastal waters offshore of Ft. Lauderdale, Florida and acquire environmental and turbine performance data
- Analyze data for assessment of system performance
- Demonstrate application of harnessed energy for at-sea recharging of a small ANAFI drone
- Conduct system refinement studies and engage industry in support of market transformation

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

- A prototype mobile MHK platform for harnessing tidal and coastal currents that can serve as an at-sea recharging station for aerial drones. The platform will include a USWW turbine, a PTO, an automated anchoring system and a flight deck for recharging aerial drones
- Software for CVT-based PTO system and for path planning of the mobile USV platform
- Datasets on the performance of the USWW turbine operating in tidal flows in the Intracoastal Waterways and in coastal currents
- A detailed final report of the project
- Publications in the form of MS theses, PhD dissertations, and journal and conference papers.

Outcomes:

- The developed prototype MHK system will serve to demonstrate its capability as a recharging station for small aerial drones in the maritime environment. Drones such as the ANAFI will be able to land on the flight deck onboard the MHK platform, get restrained and undergo direct contact recharging, and takeoff autonomously.
- Target audiences are expected to be the Department of Defense, developers of USVs, and those involved in aerial mapping, surveying and surveillance in the coastal region. Uptake of the protype by industry may potentially lead to development of a network of larger mobile MHK systems.
- The MHK platforms can potentially serve other maritime applications such as acting as mother ships for USVs and unmanned underwater vehicles (UUVs).

Project Timeline (Budget Period 1: FY19-FY 20; Budget Period 2: FY20-FY 22)

Budget Period #	Task Type	Task #	Subtask #	M or D #	Description of work, milestone, or deliverable	Planned Project Month START	Planned Project Month DUE	Percent Complete (for reporting)
1	T	1	0	0	**Develop components and subsystem designs**	3	12	
1	ST	1	1	0	MHK turbine design	3	22	100%
1	M	1	1	1	Confirmation of selected MHK turbine configuration.	3	5	100%
1	ST	1	2	0	CVT-based PTO and controller design	5	17	100%
1	M	1	2	1	CVT-based PTO and its controller passes simulation tests	5	17	100%
1	ST	1	3	0	Generator selection and placement on platform	5	7	100%
1	M	1	3	1	Generator selected to meet power and weight requirements; ~300W power and weight not to exceed 140lbs.	5	17	100%
1	ST	1	4	0	Flow concentrator design	5	17	100%
1	ST	1	5	0	MHK turbine deployment subsystem design	8	13	100%
1	M	1	5	1	The MHK turbine deployment subsystem design passes simulation tests.	9	13	100%
1	ST	1	6	0	Platform anchoring subsystem design	3	18	100%
1	M	1	6	1	The anchoring subsystem design is completed and passes Orcaflex simulation tests, and meets the standards for regulation and certifications.	9	18	100%

Project Timeline (Budget Period 1: FY19-FY 20; Budget Period 2: FY20-FY 22)

Budget Period #	Task Type	Task #	Subtask #	M or D #	Description of work, milestone, or deliverable	Planned Project Month START	Planned Project Month DUE	Percent Complete (for reporting)
1	ST	1	8	0	Platform battery charge adaptor design	7	18	100%
1	M	1	8	1	The battery charge adaptor design passes simulation tests.	10	18	100%
1	ST	1	9	0	Performance and health monitoring sensor system design	10	19	100%
1	M	1	9	1	The designed sensor system passes simulation tests.	11	19	100%
1	ST	1	10	0	Evaluation of the UAV charging pad and plan for its accommodation on the USV	3	7	100%
1	M	1	10	1	The UAV charging pad passes preliminary laboratory testing.	3	9	100%
1	D	1	0	1	Technical report providing detailed considerations in designing system component	3	22	100%
1	**T**	**2**	**0**	**0**	**Numerical modeling studies**	**3**	**22**	**100%**
1	M	2	0	1	(Go-No-Go baselines): Techno-economic potential and other system attributes established, including the efficiency of the power conversion, the total weight, ease of deployment and operation, how well the platform maintains its position in the anchored configuration.	3	22	100%
1	D	2	0	2	Technical report describing numerical modeling studies	3	22	100%

Project Timeline (Budget Period 1: FY19-FY 20; Budget Period 2: FY20-FY 22)

Budget Period #	Task Type	Task #	Subtask #	M or D #	Description of work, milestone, or deliverable	Planned Project Month START	Planned Project Month DUE	Percent Complete (for reporting)
1	T	3	0	0	Plans for fabrication, testing, IO&M, and risk management	15	21	100%
1	ST	3	1	0	Fabrication and lab testing plan	15	21	100%
1	M	3	1	1	A best practice fabrication and lab-testing plan is created with due specificity and drawings to enable machining and installation of components.	15	21	100%
1	D	3	0	3	Plans for fabrication, testing, IO&M, and risk management	15	21	100%
1	ST	3	2	0	IO&M plan	16	21	100%
1	M	3	2	1	A best practice IO&M plan is created	16	21	100%
1	ST	3	3	0	Plan for field-testing	17	21	100%
1	M	3	3	1	A best-practice plan for field-testing is created.	17	21	100%
1	ST	3	4	0	Risk management and mitigation Plan	15	21	100%
1	M	3	4	1	Project risks identified and mitigation strategies developed.	15	21	100%
1	T	4	0	0	Engage Industry for market transformation	5	34	30%
1	M	4	0	1	Commercial partners identified.	5	34	30%
	D	4	0	1	Market Transformation Plan	5	37	20%
1	GNG	0	0	0	Budget Period 1 Go/No-Go Decision Point (End BP1)	23	23	100%
2	T	5	0	0	Update system design and plans for fabrication, IO&M, testing and risk management	27	29	90%
2	M	5	0	1	Plans finalized, accommodating DOE feedback	27	29	90%

Project Budget

Total Project Budget – Award Information		
DOE	**Cost-share**	**Total**
$1,044K	$274K	$1,318K

FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	**Costed**	**Costed**	**Total Costed**
$0K	$381K	$272K	$653K

- Describe any variances from planned budget and identify if/how the project plan was modified.
- Describe any relevant context for your project budget. This is an opportunity to explain any sizeable discrepancy in the costed vs authorized numbers, delay in budget execution, mid-year scope increase/decrease, etc.
- Note, if any, other funding sources.

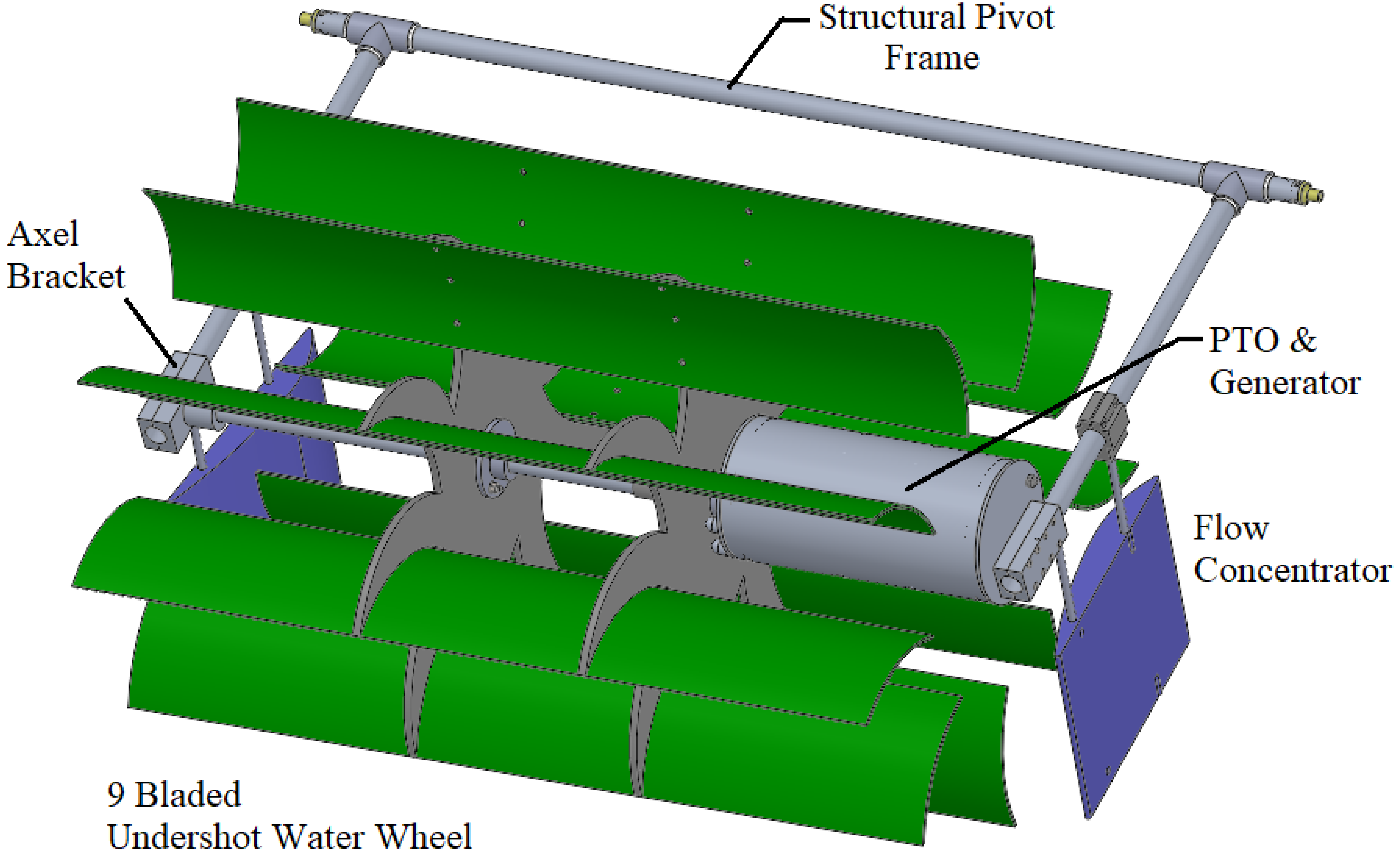
End-User Engagement and Dissemination

- Stakeholder and end-user engagement strategy
  - There is a rapidly growing global market in commercial, military, and scientific research applications for maritime autonomy and use of unmanned automated underwater, surface and aerial vehicles (Research and Markets 2017). Applications include routine coastal surveillance and monitoring, and ship, pipeline and aquaculture station inspections. The unmanned vehicles are typically limited by onboard battery power and require periodic recharging. The market for at-sea recharging stations for these vehicles is not developed but is expected to have a similar growth rate on a smaller scale. A DOE EERE Report (2018) points out a particular potential large niche for low-visibility, low-surface-expression platforms that could recharge unmanned aerial vehicles at sea so that they do not need to return to land-based recharge stations, thereby enhancing their mission success, range, and cost.
  - Industry partners could include original equipment manufacturers, defense contractors, oil and gas inspection contractors, pipeline and subsea cable inspection service providers, ocean observation sensor and equipment companies, and navigation and buoy manufacturers. Efficient recharging stations need to be reliably demonstrated, once developed. Challenges include charging efficiencies, reliability and robustness, station-keeping, marine fouling, corrosion, wave and current forces, and deployment and recovery (see Gish and Hughes, 2017 for example). Additional research, standardization to serve variety of unmanned vehicles, and numerical modeling of system dynamics will help advance the market. The results of the current project will support this advancement.
  - Engagement with industry is underway in conjunction with NREL. Marine Advanced Research Inc. (MAR) and L3Harris have been identified as potential companies for market transformation. MAR develop USVs and have expressed interest in the project. L3-Harris have expressed interest in the automated anchoring system and would like to see how the overall system performs. We are continuing to work with Marine Advanced Robotics and L3-Harris. Potential additional partners include Searobotics, and wireless charging companies, such as Skysense - we are collaborating with Skysense in the development of the recharging flight deck onboard the MHK platform and the collaboration can be developed further. Engagement with ONR is being made through the program manager for the USV under development at FAU.
  - The rationale for engaging these companies and ONR is that they are involved in development of USVs and other at-sea autonomous systems which would benefit from harnessing renewable MHK energy for long term deployments.
- Dissemination of results of the project will be through publications in the form of 4 MS theses, 2 PhD dissertations, and journal and conference papers

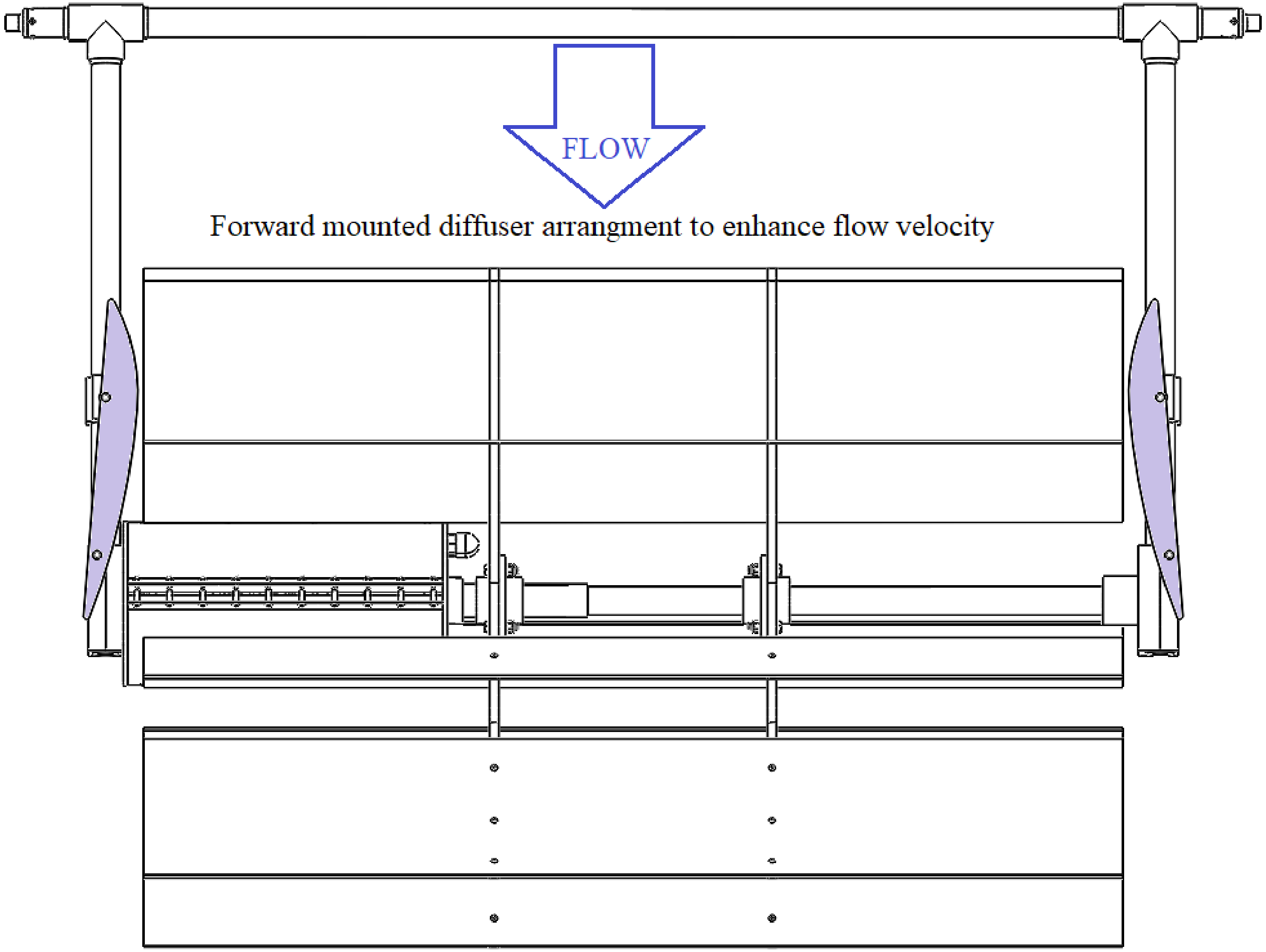
Performance: Accomplishments and Progress

- Detailed designs of the MHK system and subsystems have been developed (Slides 12 – 19).
- The USWW has been fabricated, and the PTO has been assembled and bench tested (Slides 20 -30). The drone restraint system and recharging flight deck are being put together (Slides 31, 32).
- Implementation of the MHK turbine system onto the USV platform is underway.
- Detailed plans for field testing have been developed. Environmental permits for testing have been obtained. Field testing is restricted to November – March to avoid turtle nesting season in South Florida.
- Process for selection of specific field test sites is underway. One site will be in the Intracoastal Waterway in Dania Beach, FL and the other site will be off the coast near Ft. Lauderdale.

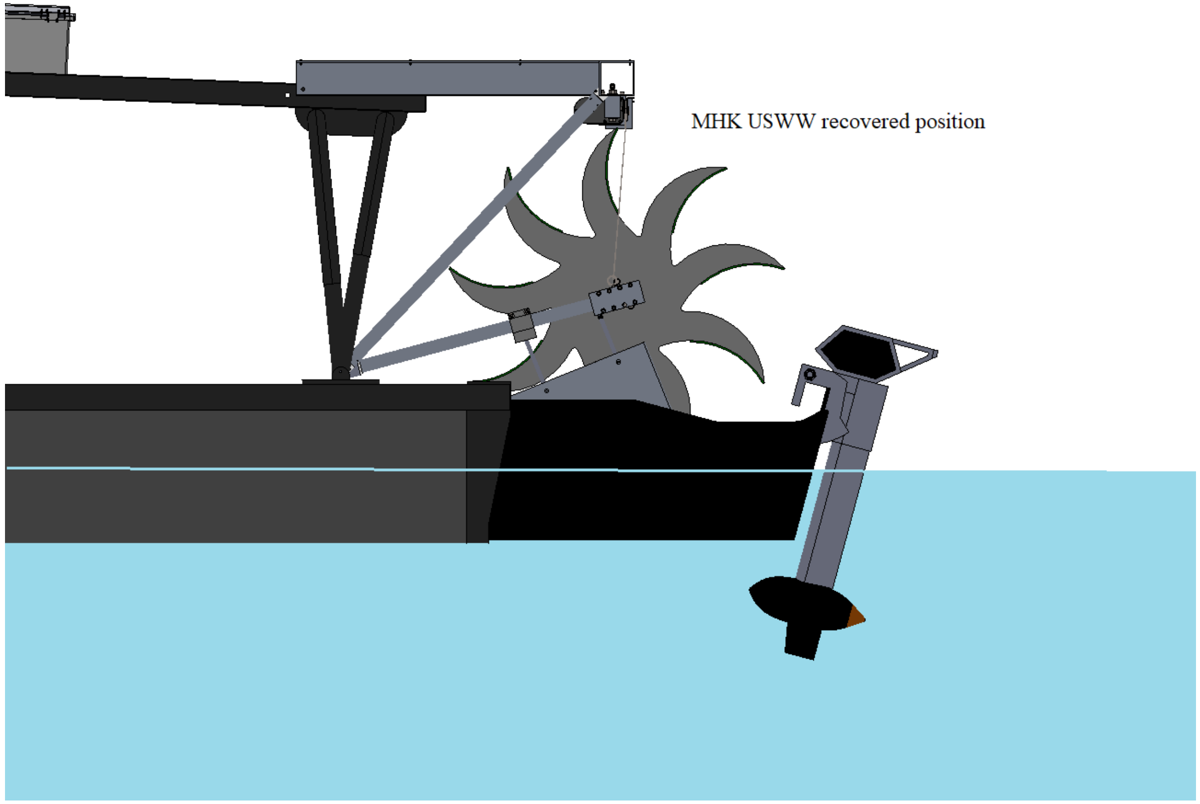
USWW Turbine and Flow Concentrator:

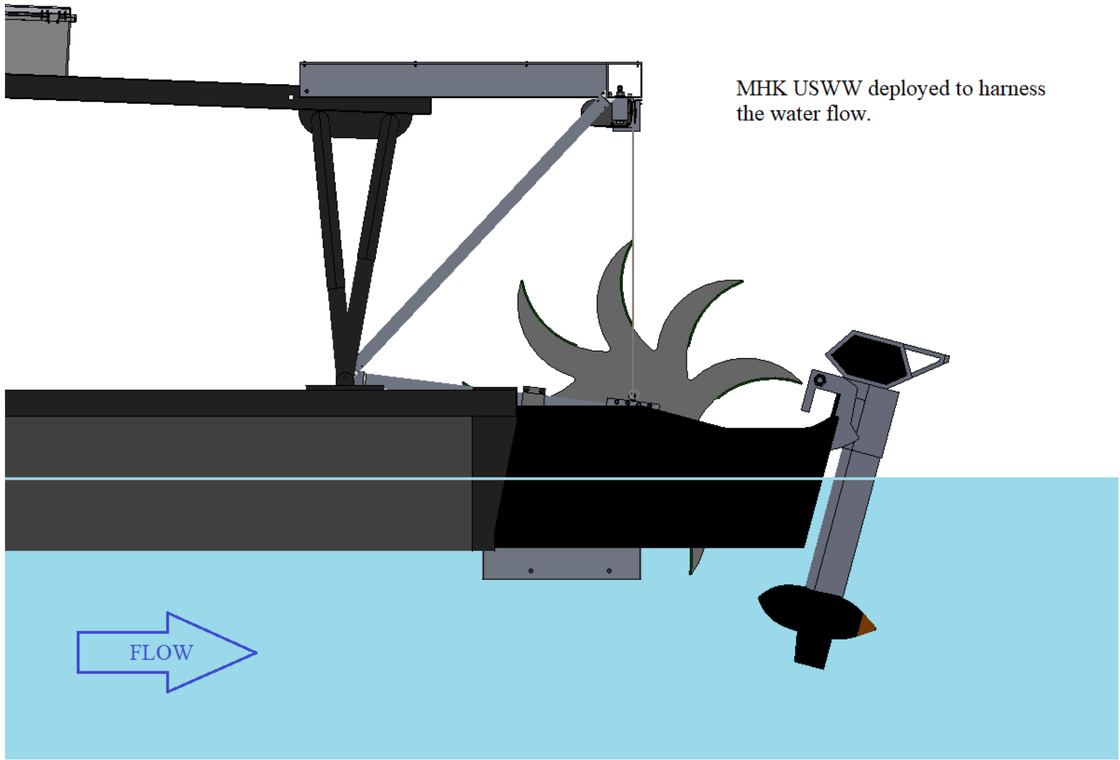


Flow Concentrator Details:

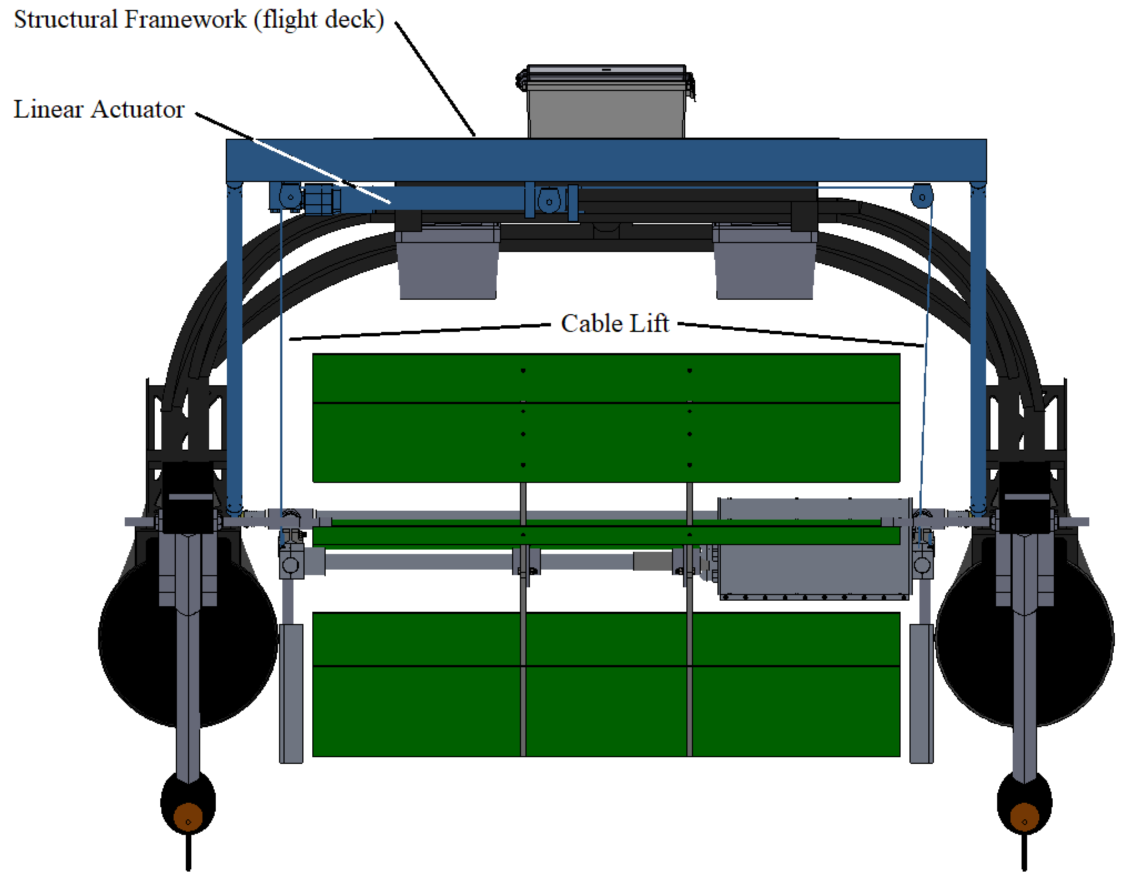


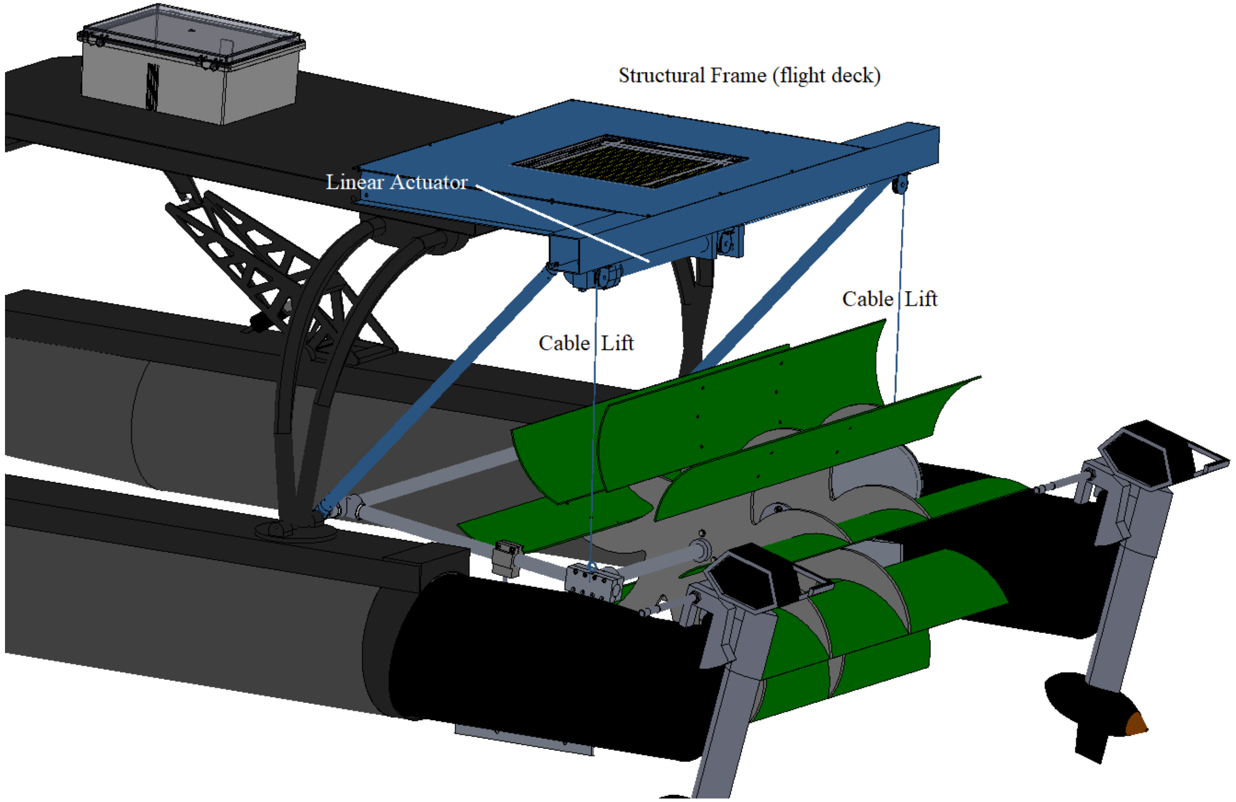
Deployment Subsystem:



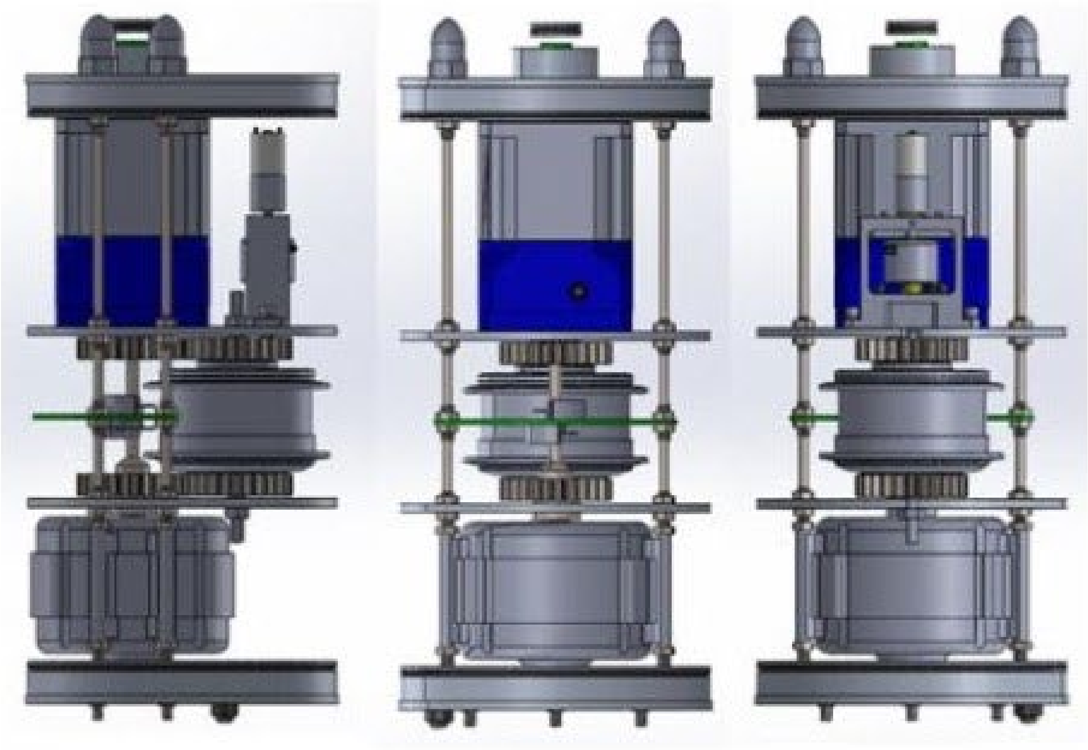


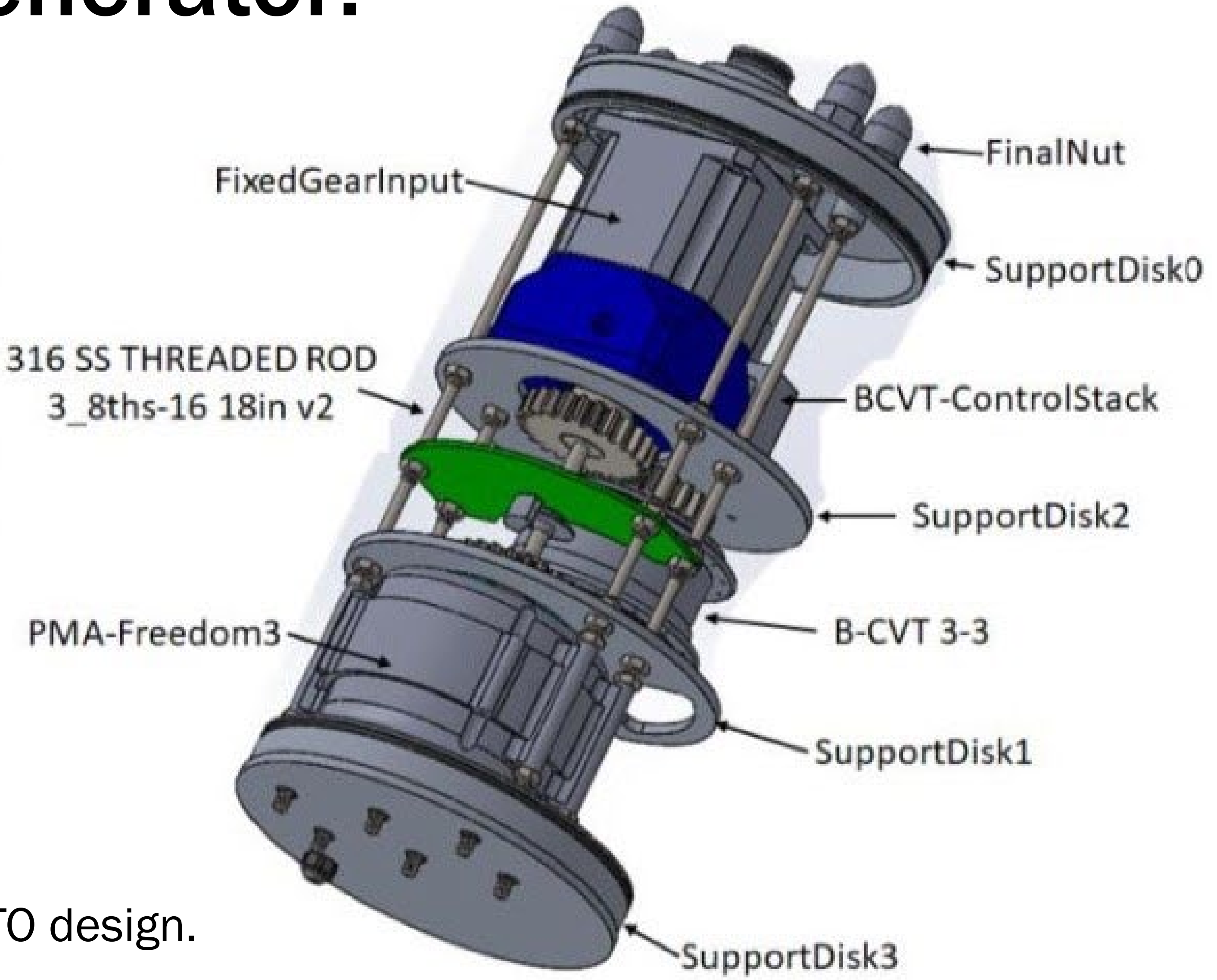
Deployment Subsystem Continued:





Power Take-off and Generator:

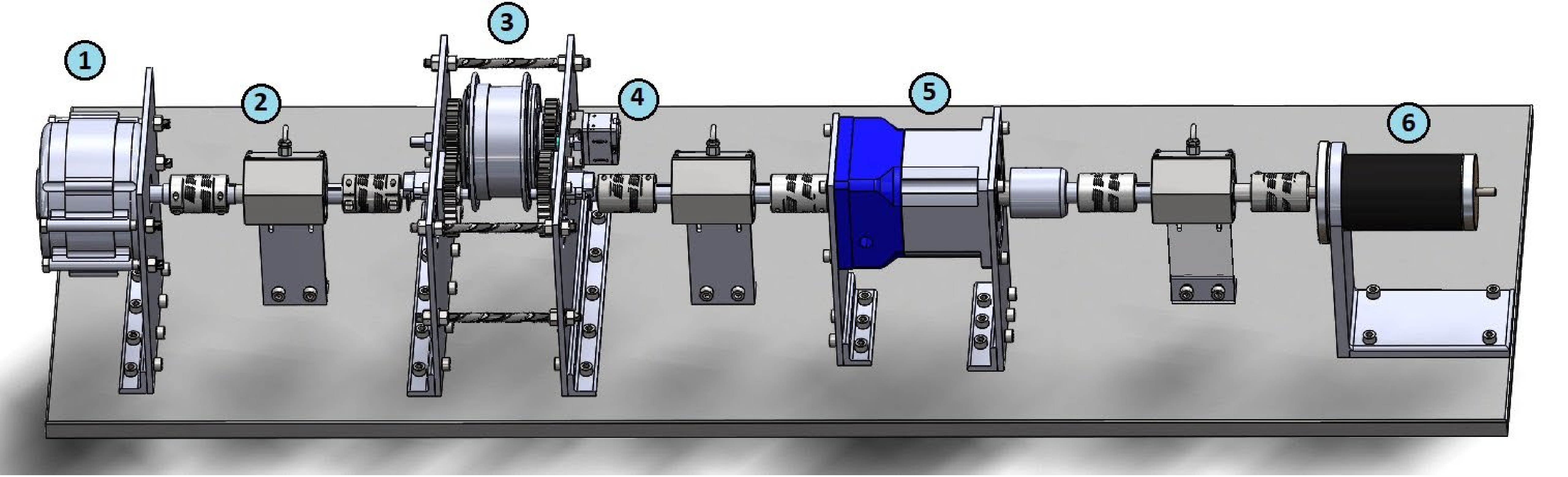




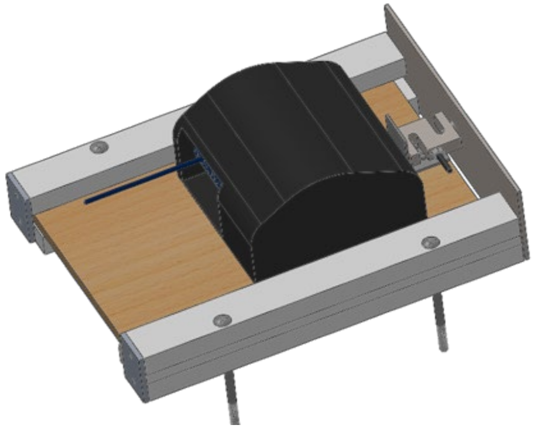
Final PTO design.

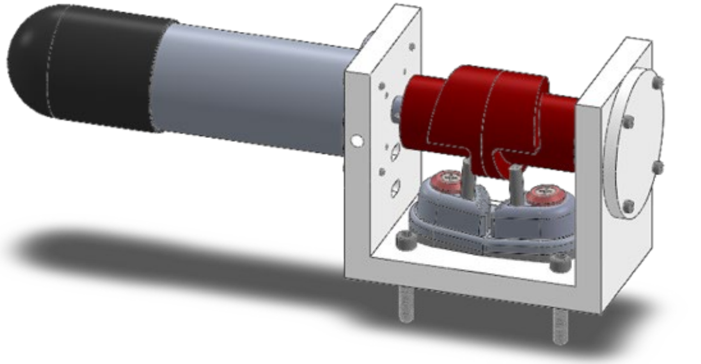
Benchtop Test Setup CAD Model:

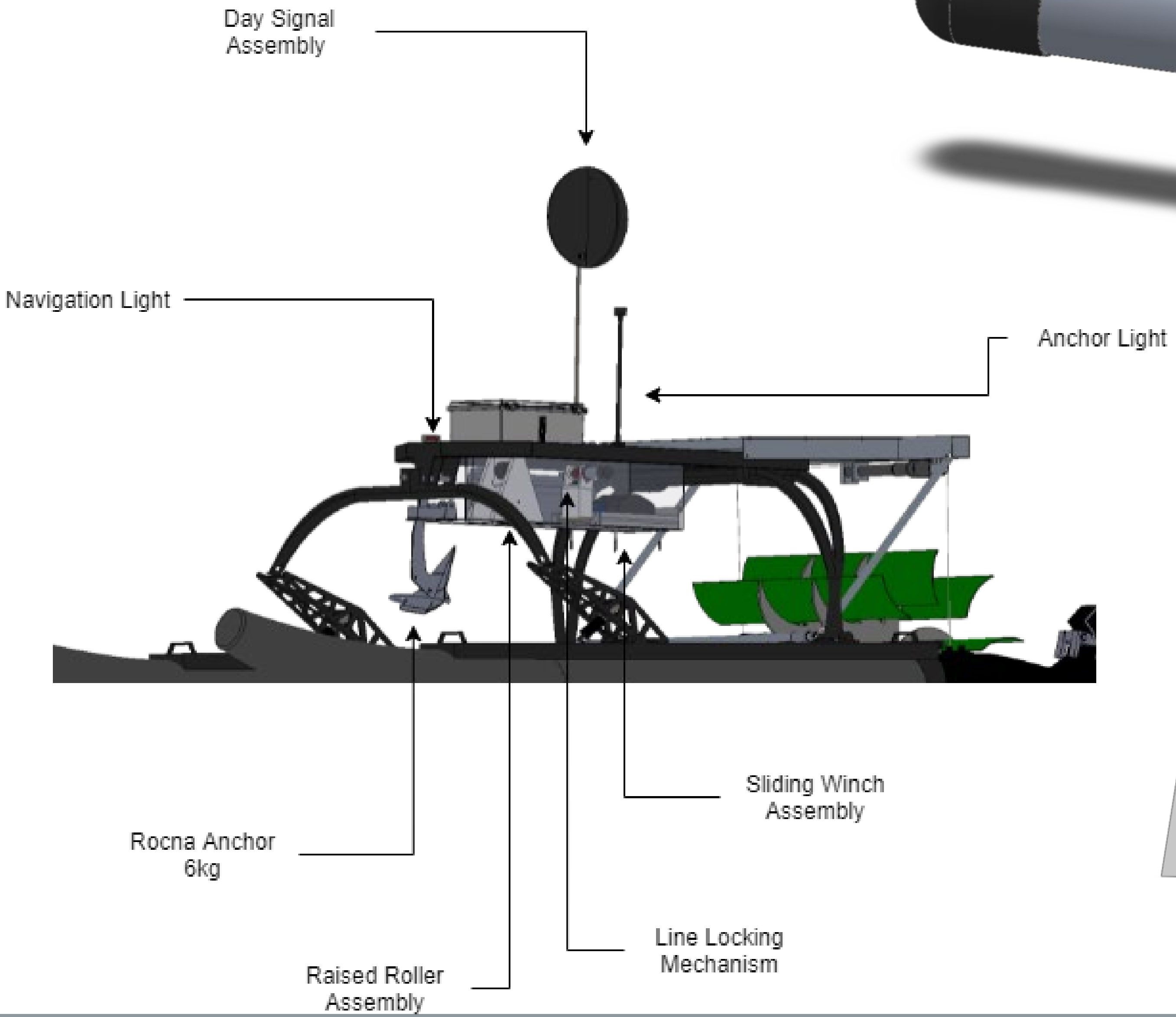
1. PM Generator
2. Torque Sensor
3. NuVinci Ball-CVT
4. CVT Shift Servo
5. Gearbox
6. DC Motor

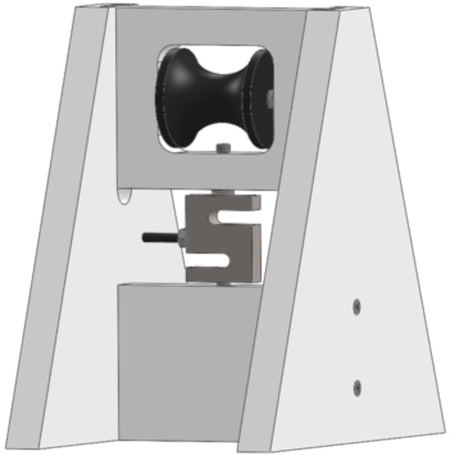


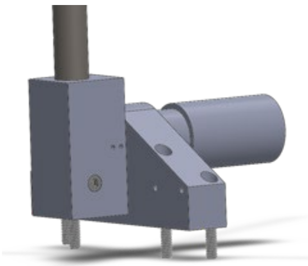
Automated Anchoring System:



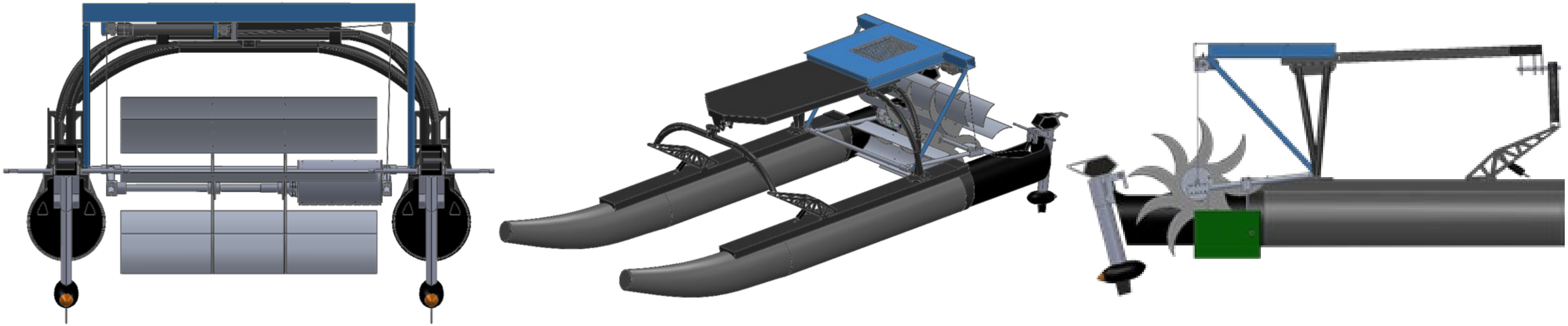








Flight Deck:



Shown in blue, the Flight Deck is an additional aluminum structure mounted to the existing WAM-V vessel

- Provides the structural support for the wireless charging platform
- Provides the mounting points and support for the MHK deployment system cable lift

Fabrication and testing of components and subsystems

1. Fabrication of the USWW Blades and Spoke Discs Completed

Accomplishments:

- Fabrication of rolled aluminum blades completed.
- Fabrication of 7, 9, 11 blade USWW spoke discs, hubs, motor mounts & spacers and final nut(s) completed
- Assembly of blades on 9-blade spoke discs completed
- Alternate carbon fiber blades are pending

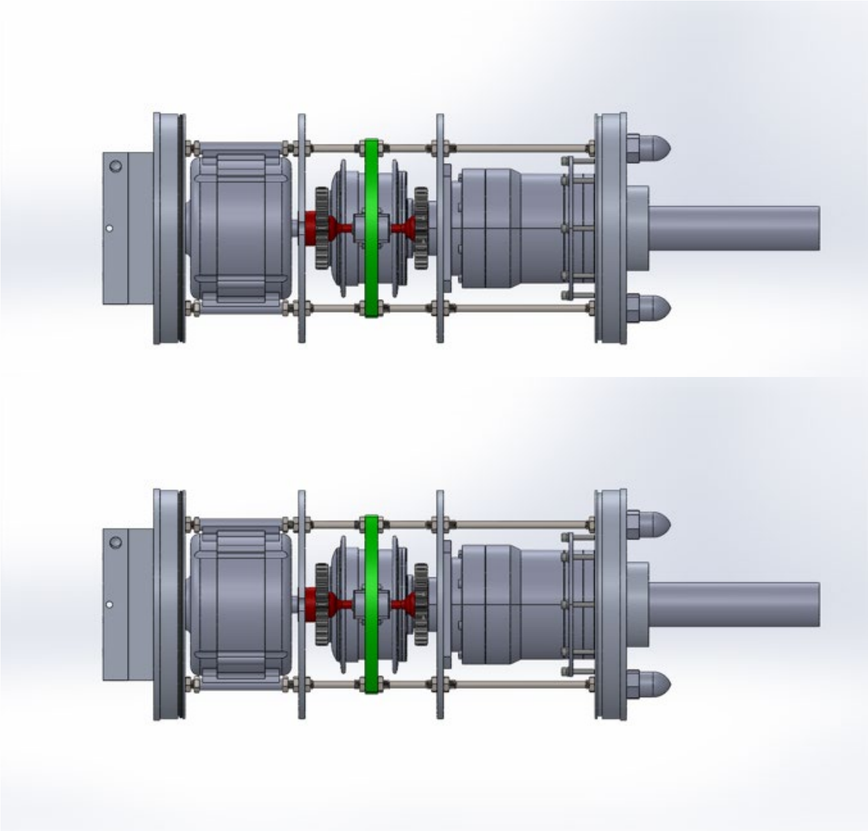
Fabricated 11 and 7 blade spokes

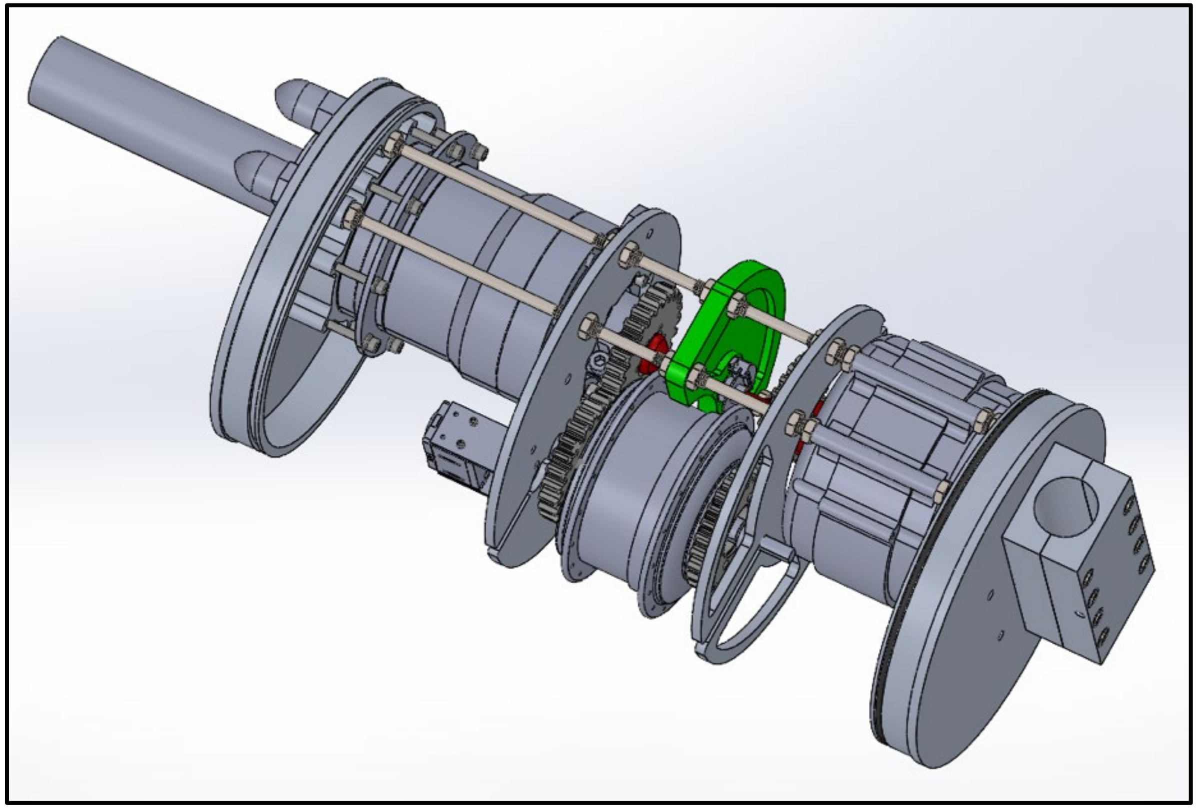
Fabricated and Assembled: 9 blade USWW

Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

Accomplishments:

- SolidWorks model confirmed for the PTO





PTO SolidWorks Model

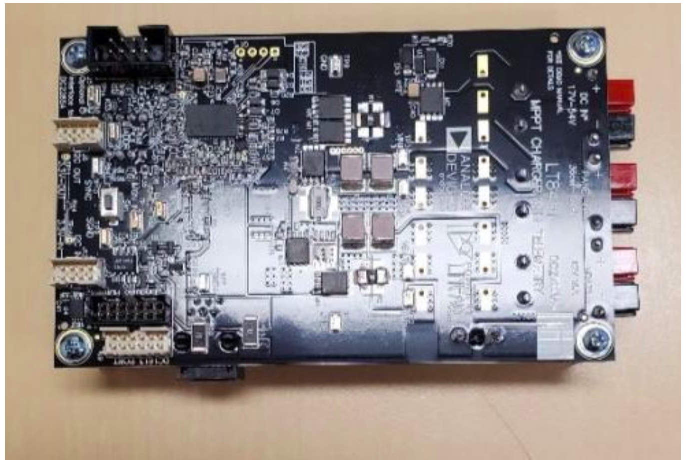
Fabrication and testing of components and subsystems

2. PTO – Fabrication and Bench Testing

Accomplishments:

- PCB completed. Main Components:
  - DC/DC converter 1
  - DC/DC converter 2
  - MCU
  - Charge Controller
- Completed:
  - Software package for motor simulation of USWW
  - Motor simulation tests
  - Software package for PTO controllers
  - PTO all up tests

Populated CVT/Charge Control PCB



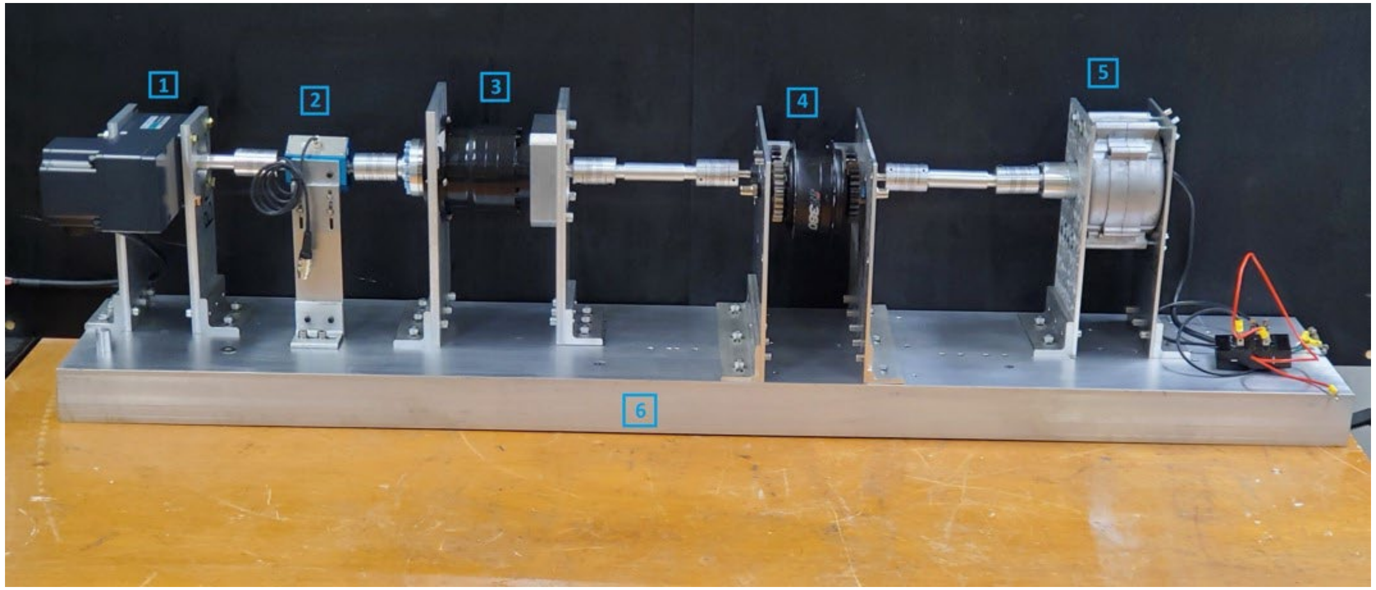
Charge Control Evaluation Board

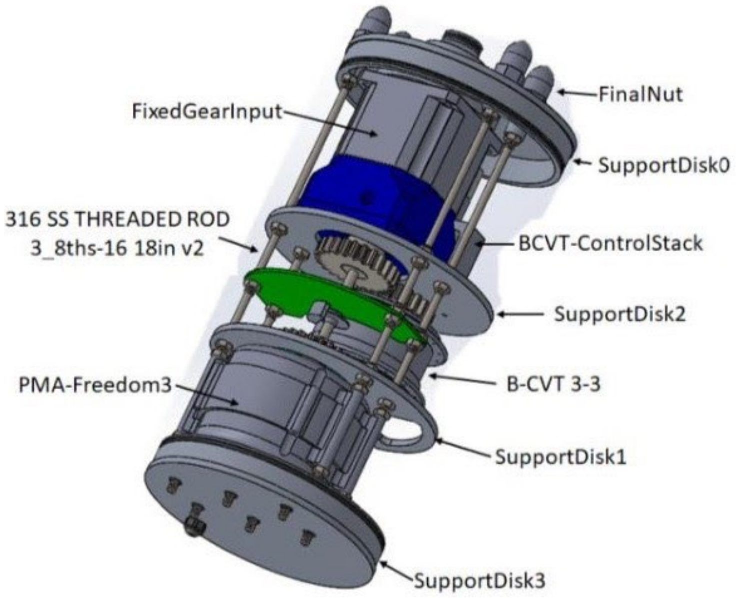
Fabrication and testing of components and subsystems

2. PTO – Fabrication and Bench Testing

Accomplishments:

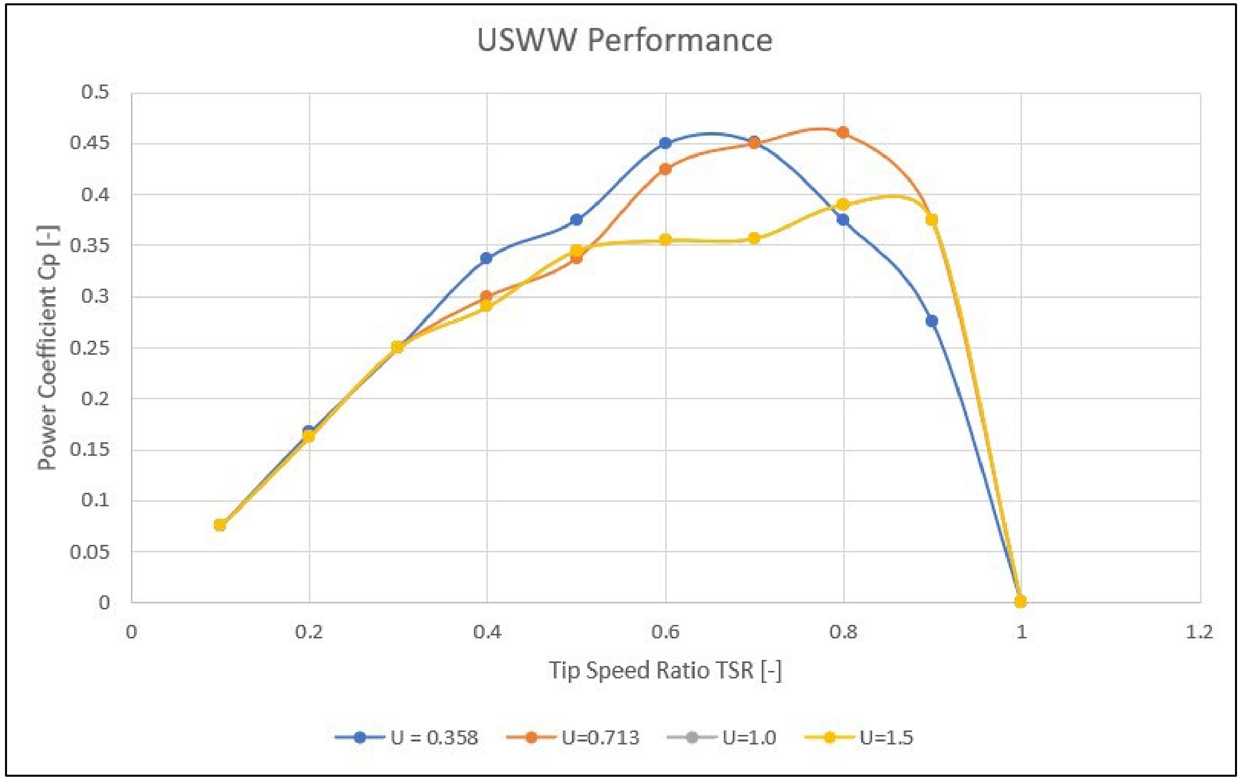
- Position 1: Motor for USWW emulation with buildout of manufactured components.
- Position 2: Torque Sensor with buildout of manufactured components.
- Position 3: Gearbox with buildout of manufactured components.
- Position 4: CVT with buildout of manufactured components.
- Position 5: Generator (PMG) with buildout of manufactured components.
- Position 6: Platform base machined.





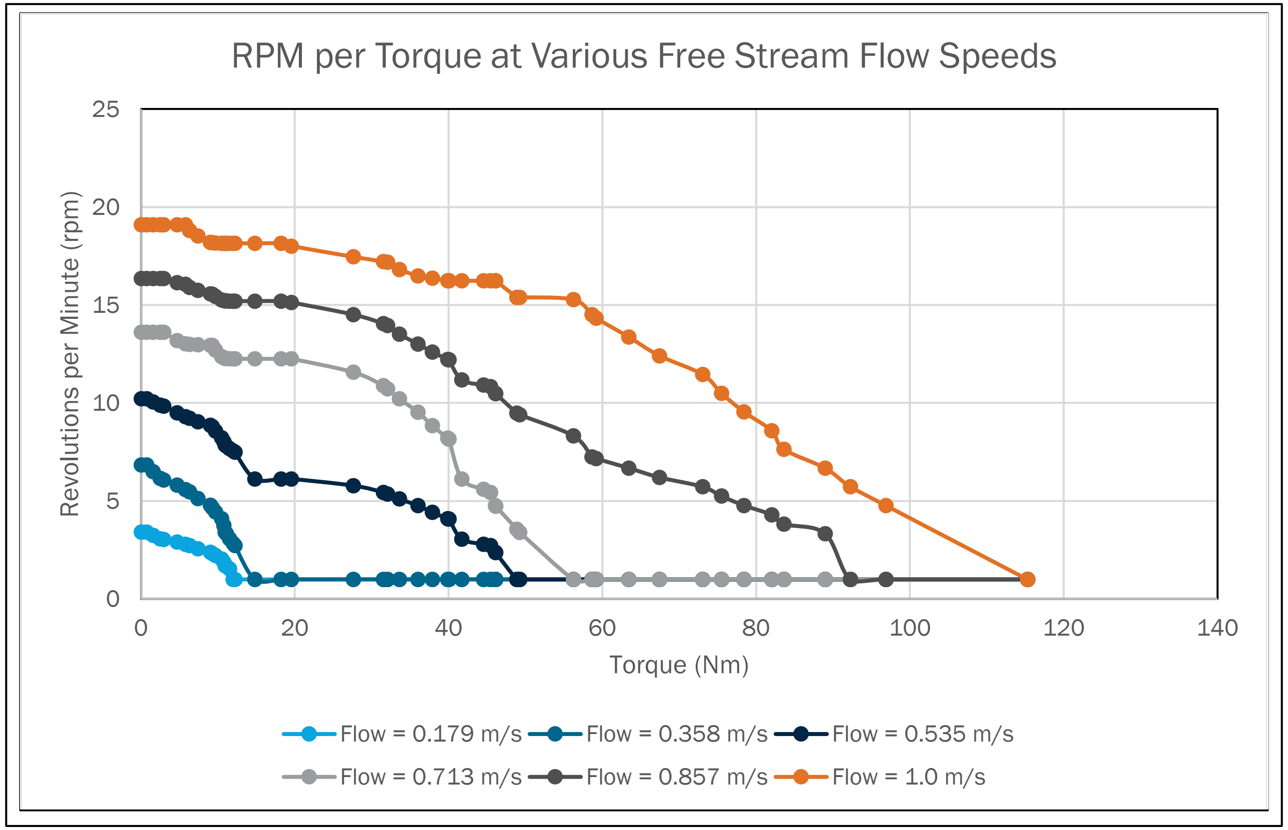
Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

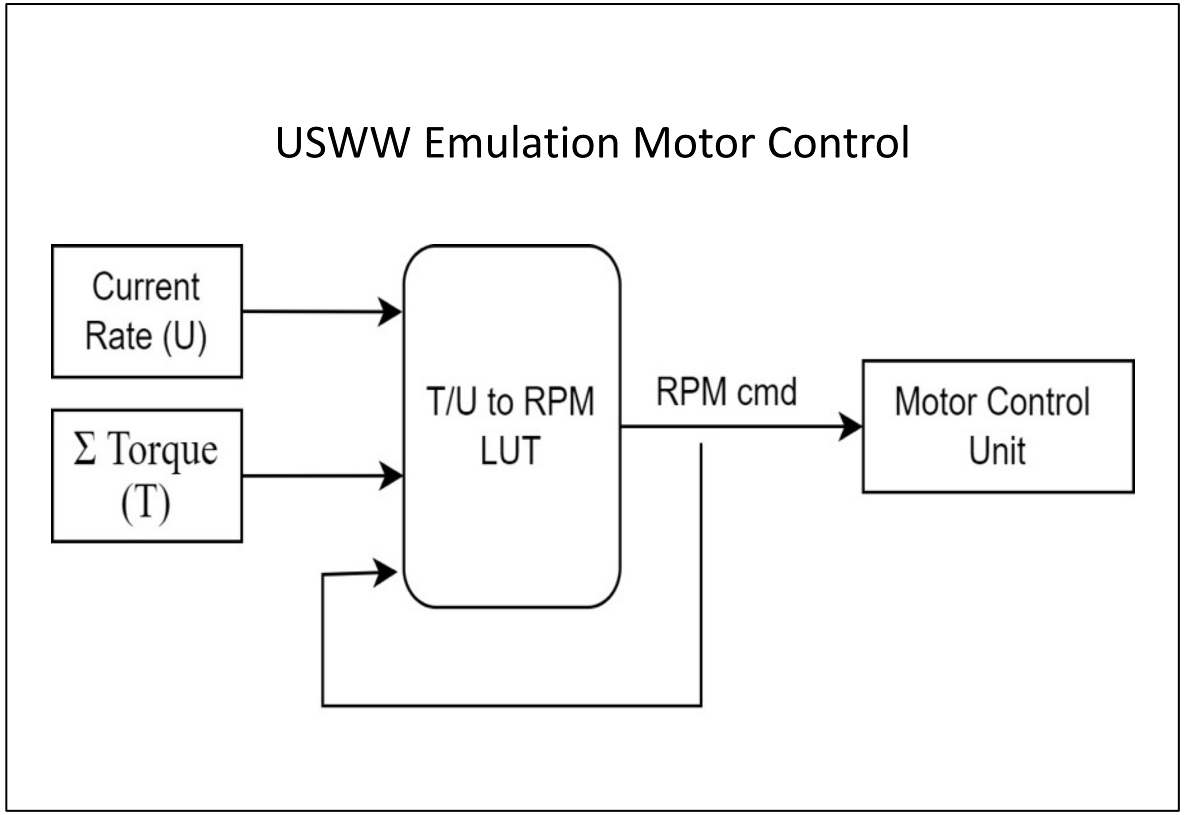
USWW Turbine Performance Characteristics



Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

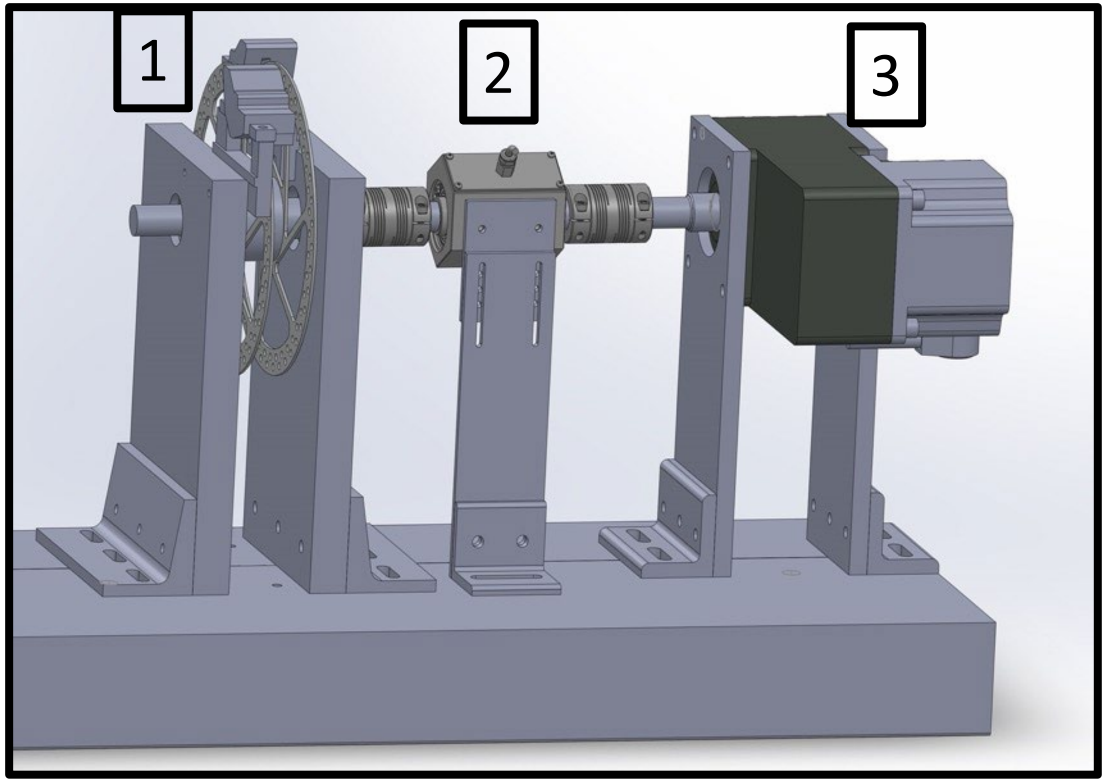
- USWW Emulation

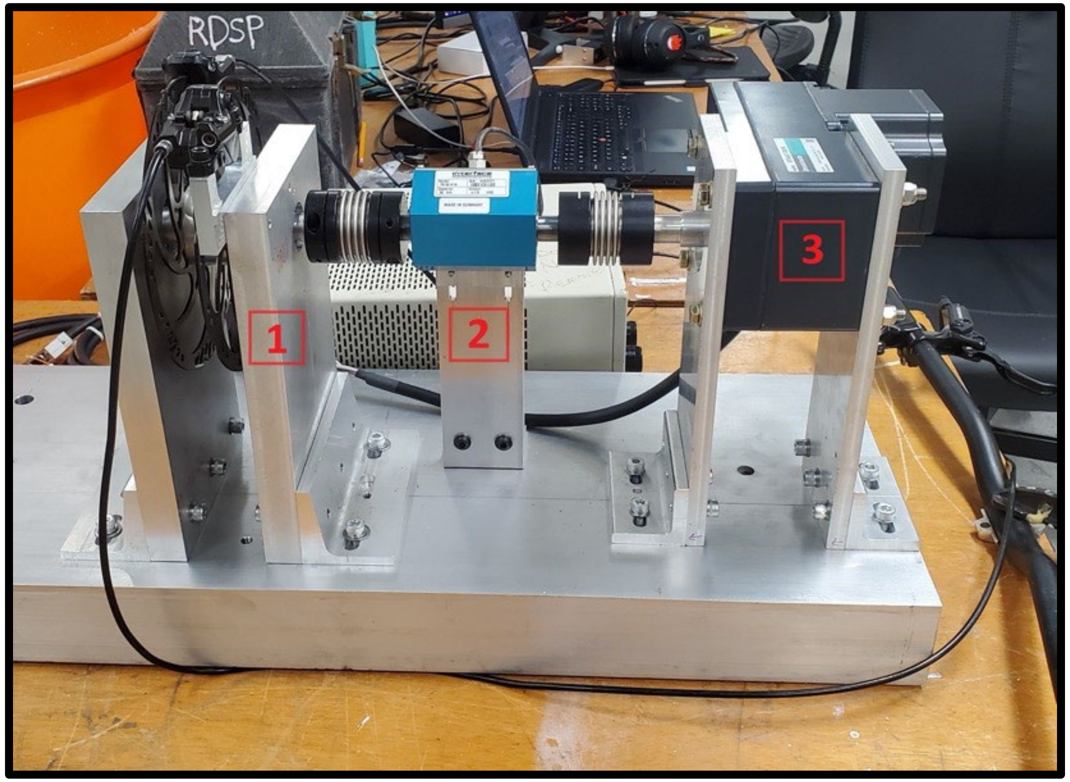




Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

- USWW Turbine Emulation Tuning Platform Model

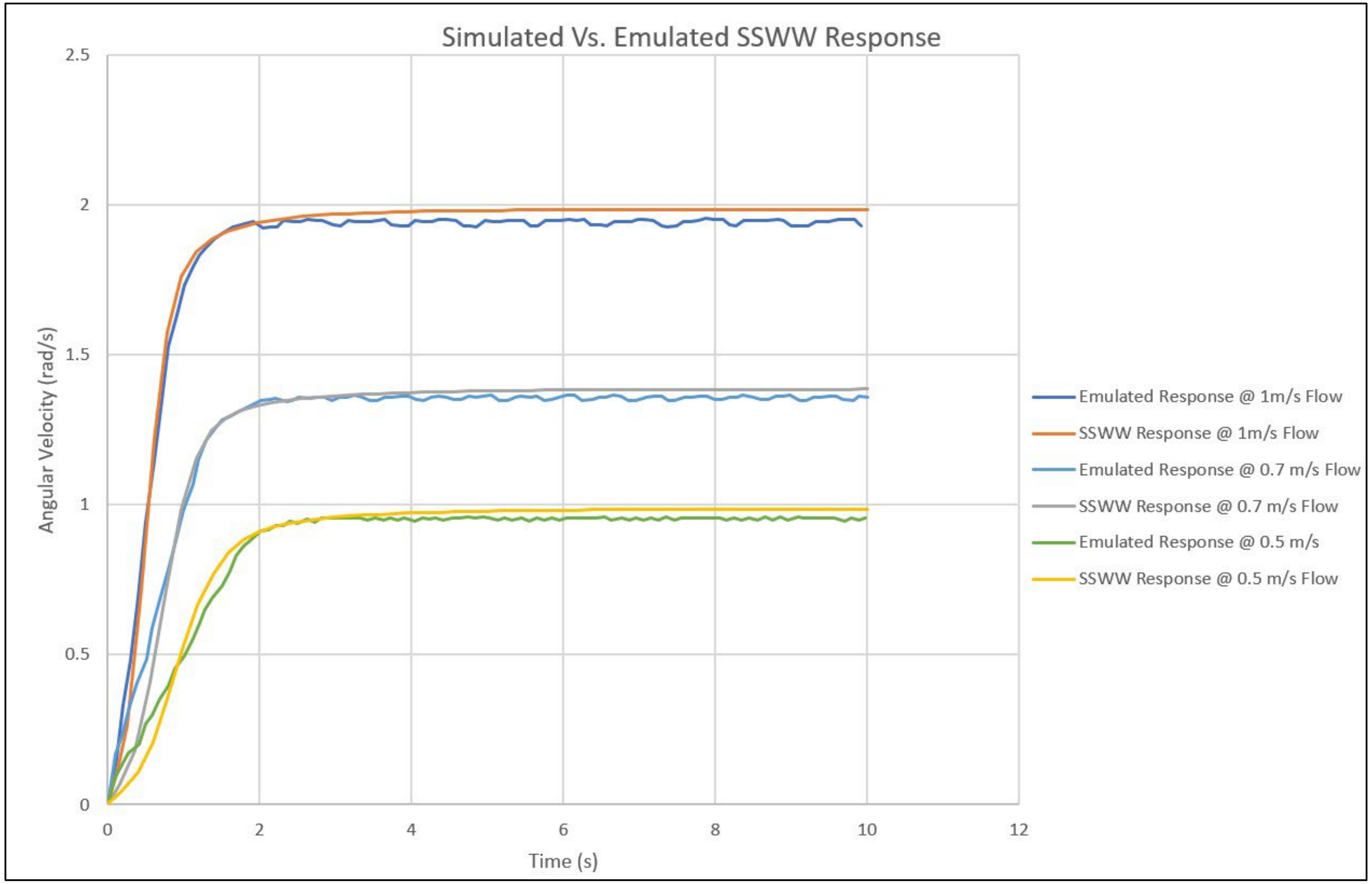




1. Torque Brake
2. Torque Sensor
3. DC Motor (USWW Emulator)

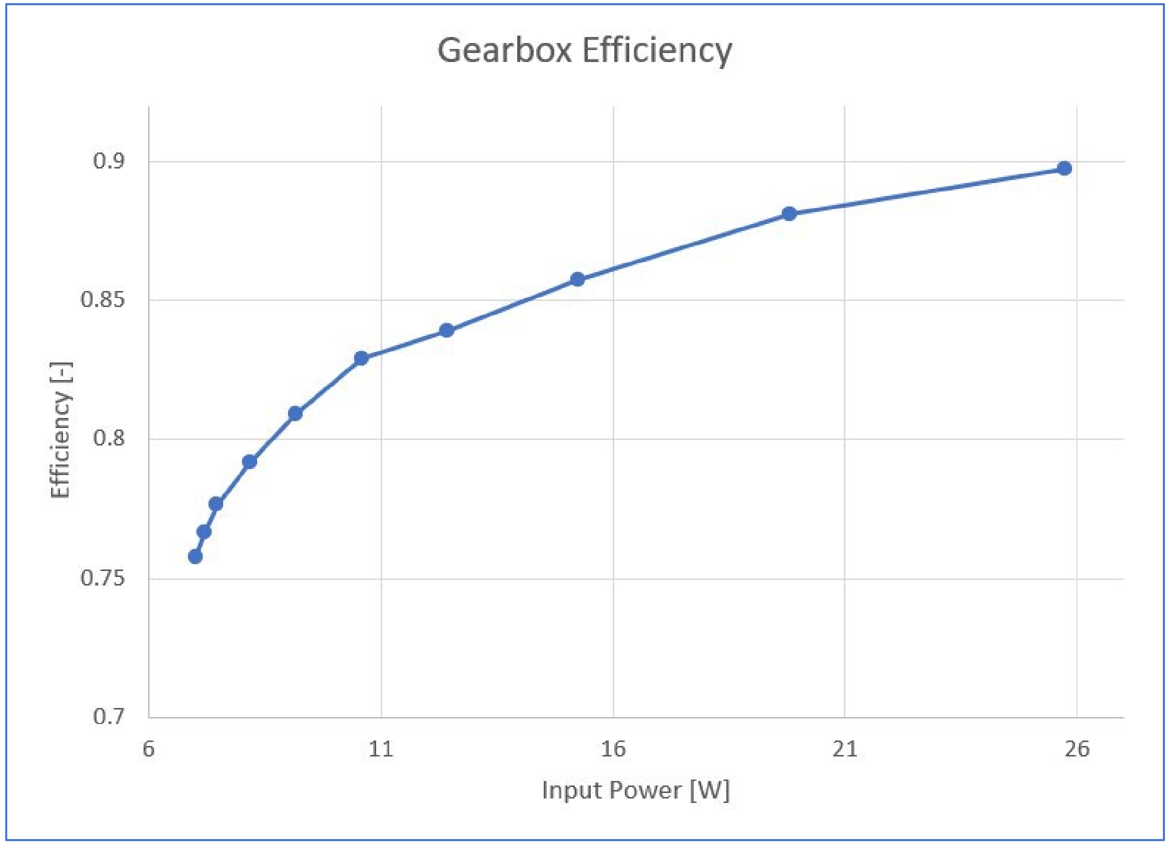
Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

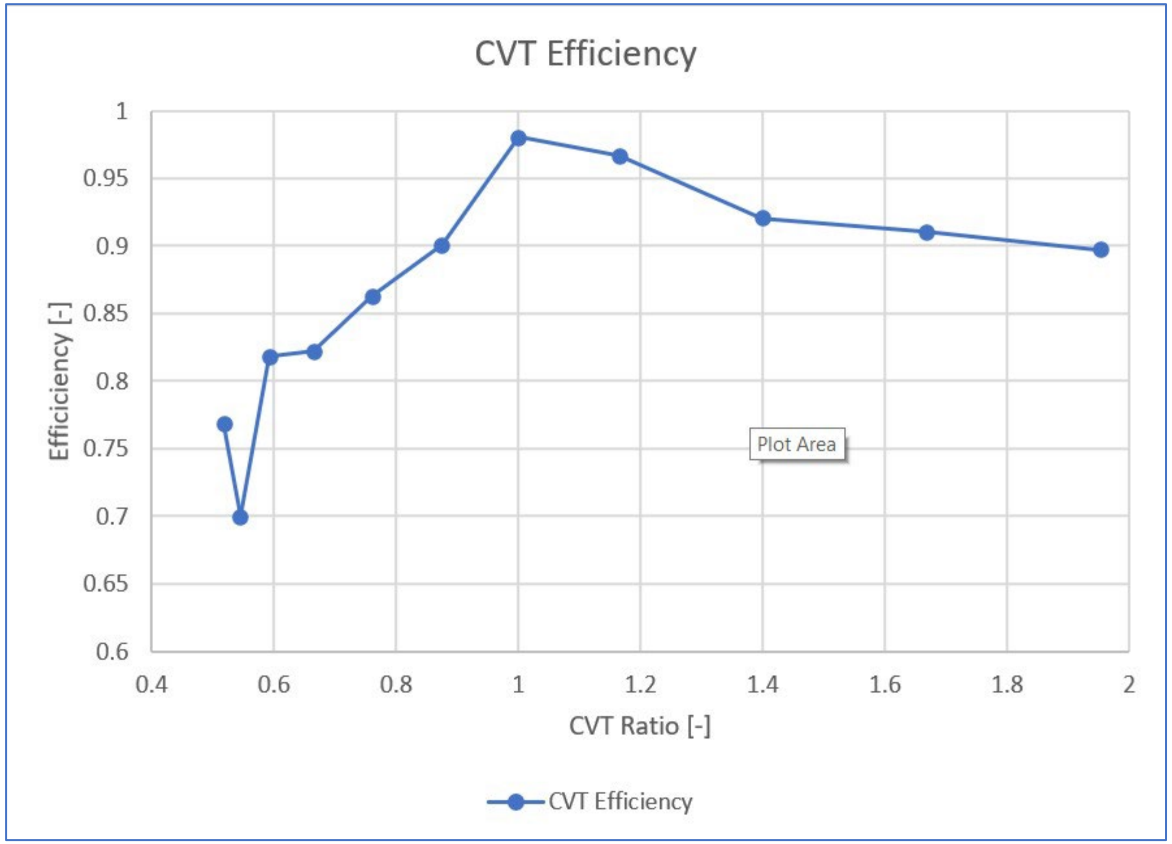
- USWW emulation



Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

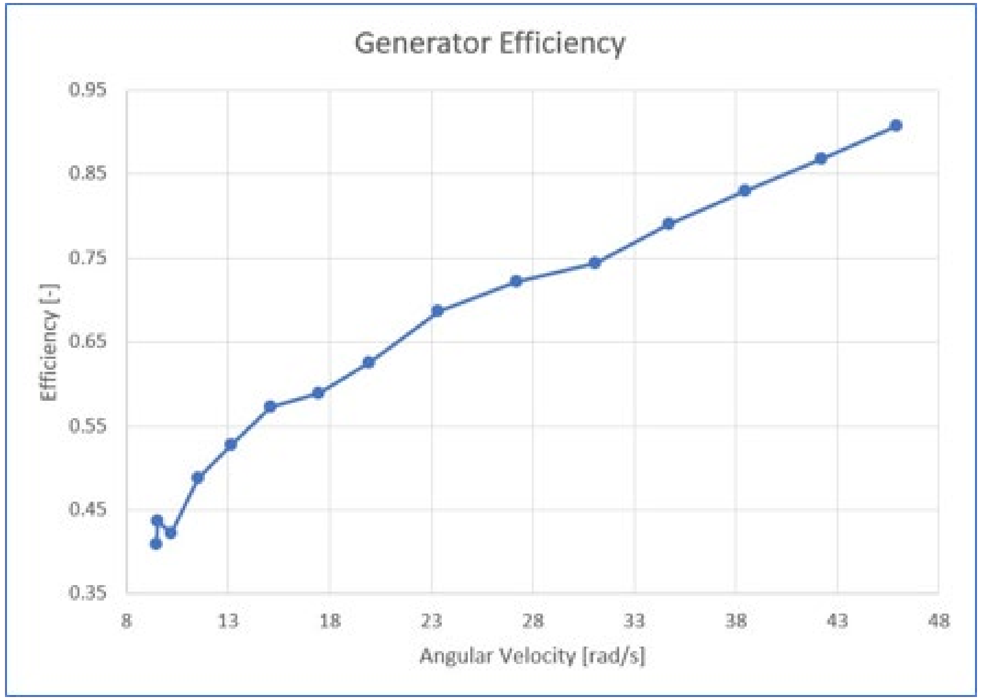
- Efficiency Test Results





Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

- Efficiency Test Results



Fabrication and testing of components and subsystems
2. PTO – Fabrication and Bench Testing

- MPPT-Control Test Results

Flow Speed Average	TSR	MPPT Power Average [W]	Expected Power [W]
0.5	0.73	9.41	9.6
0.7	0.68	24.06	24.68
1	0.66	42.08*	71.96*

* Battery acquired full. - Retest in progress.

Fabrication and testing of components and subsystems
3. The Drone Flight Deck

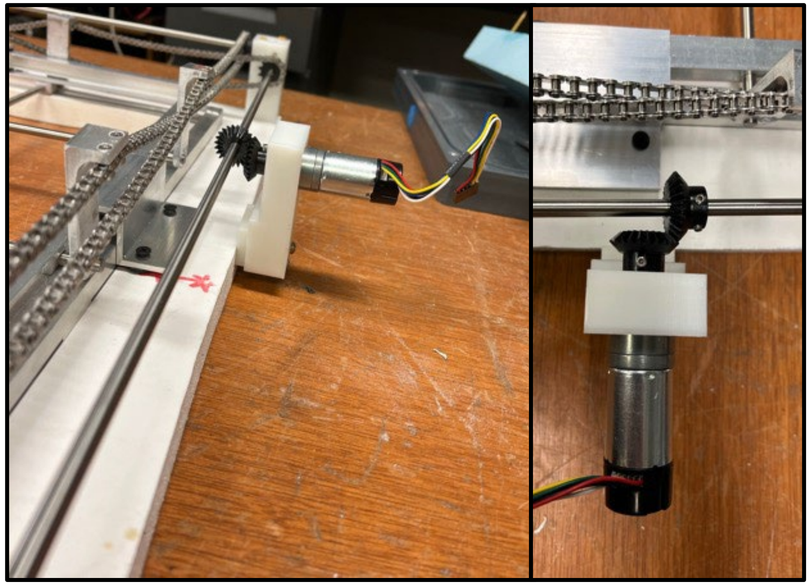
- Drone Restraint Mechanism

  Accomplishments:

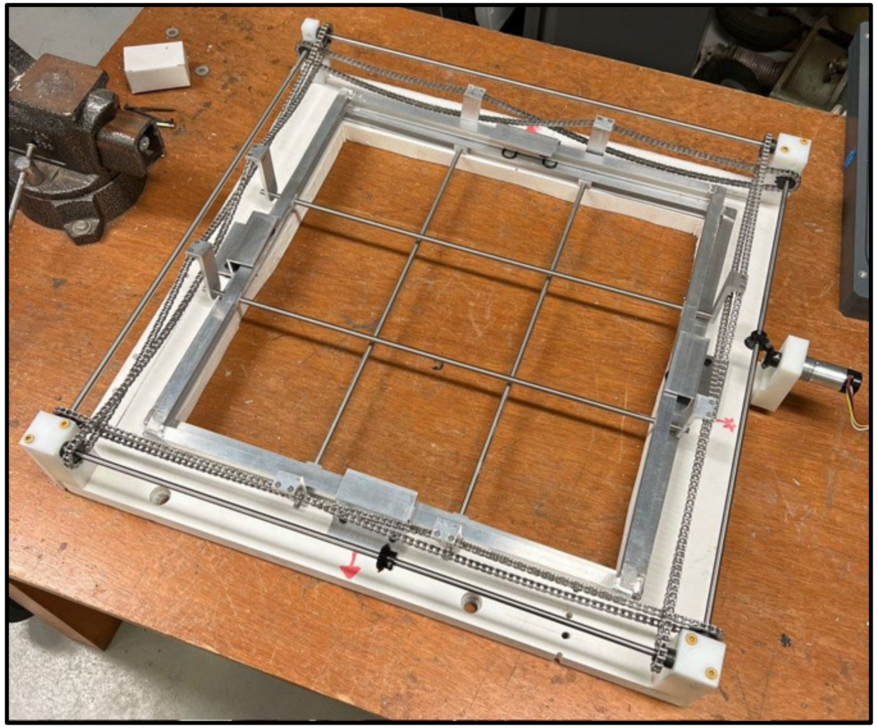
  - Motors programed
  - Motor Mounts Redesigned

  Next steps:

  - 2nd Motor mounting (awaiting part arrival)



Motor mount redesign



Lab Test Drone Restraint Mechanism

Fabrication and testing of components and subsystems

3. The Drone Flight Deck

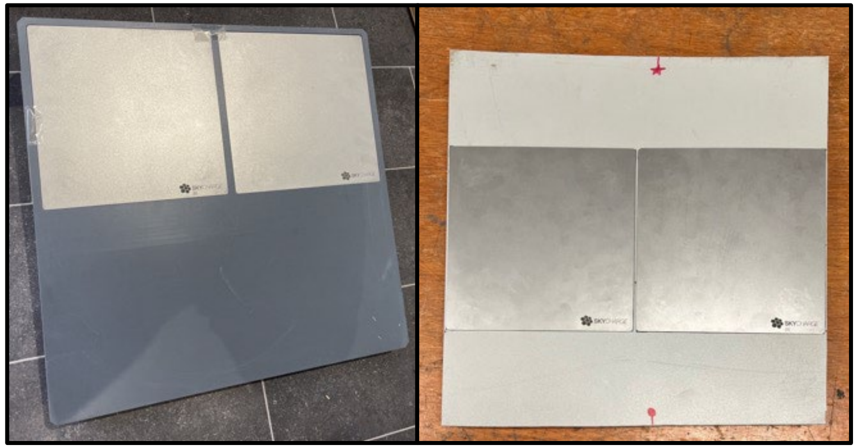
- Wireless Charging Pad

  Accomplishments:

  - Repacked Electronics Box for DC-DC Battery Charging
  - Test WCP milled

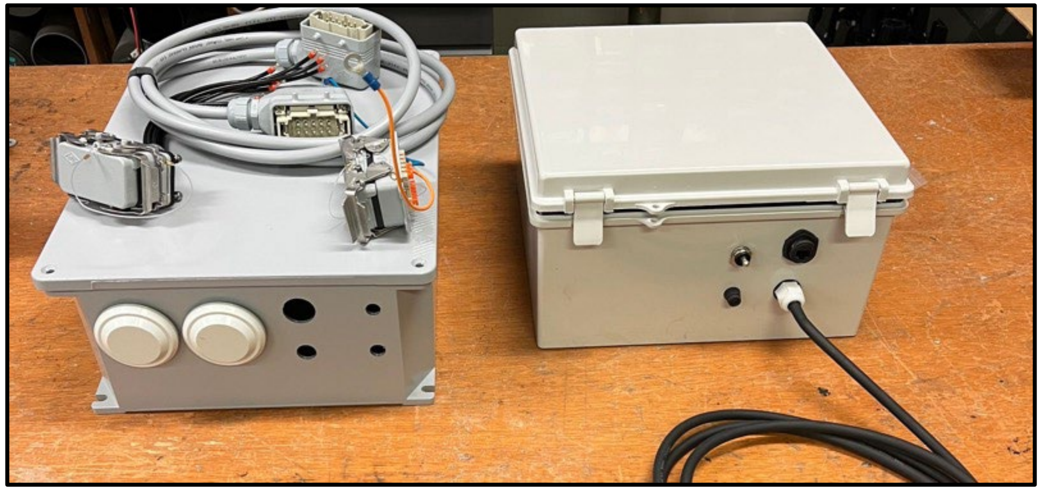
  Next steps:

  - Final rewire and test run

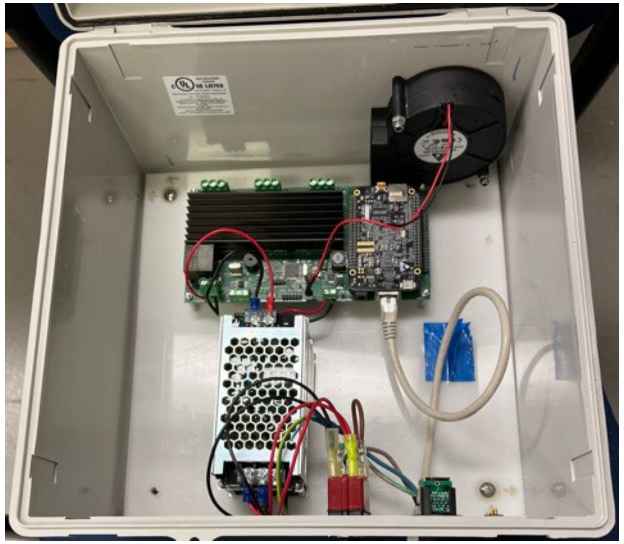


Left; SkyCharge Wireless Charging Pad

Right; FAU Wireless Charging Lab Test



Left; SkyCharge Wireless Charging Pad Electronics Box, Right; FAU repackaged Electronics Box



Inside view of FAU repackaged Electronics Box

Work in Progress /Future Work

Budget Period #	Task Type	Task #	Subtask #	M or D #	Description of work, milestone, or deliverable	Planned Project Month START	Planned Project Month DUE
2	**T**	**7**	**0**	**0**	**Assembly and Installation on the floating platform**	**34**	**36**
2	M	7	0	1	Installations operate as designed.	34	36
2	D	7	0	1	Technical report on fabrication and laboratory testing and photos of assembled system	34	37
2	**T**	**8**	**0**	**0**	**Field testing**	**27**	**44**
2	ST	8	1	0	Prepare for testing – site surveying and NEPA/BE preparation and Permitting	27	37
2	M	8	1	1	Site survey, EQ1 and Biological Evaluation complete	27	37
2	D	8	1	1	EQ-1, and Biological Evaluation complete	27	29
2	ST	8	2	0	Testing in open waters	38	44
2	M	8	2	1	Performance characteristics in tidal and coastal waters determined	38	44
2	M	8	2	2	Successful demonstration of UAV re-charging onboard the USV platform	38	44
2	M	8	2	3	Sufficient performance data acquired for developing final techno-economic potential evaluation.	38	44
2	D	8	0	1	Report on Field testing	38	45
2	**T**	**9**	**0**	**0**	**Development of final project deliverables**	**38**	**45**
2	ST	9	1	0	Market Transformation Plan	38	45
2	D	9	1	1	Market Transformation Plan	38	45

Q&A