

# Dynamometer System for Hybrid Electric Aircrafts

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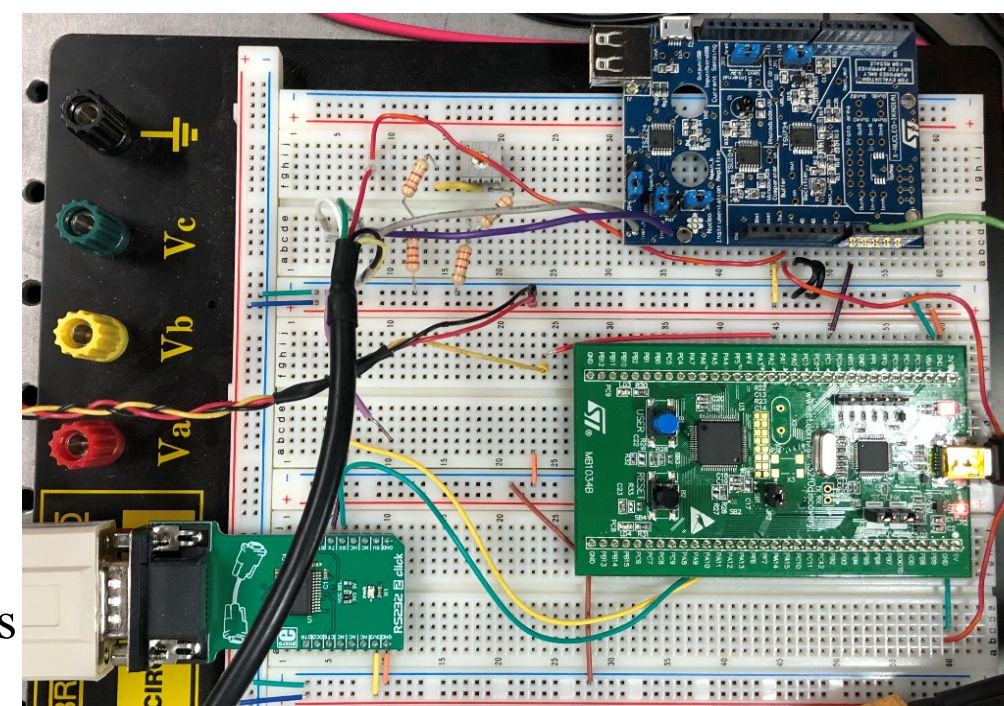
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## Abstract

The Centre for Aerospace Research at the University of Victoria provides research services, design, fabrication, and testing for electric, aerial vehicles. To provide competitive services, their progression and data needs to be quantified throughout the testing procedures. A dynamometer or dyno is such a device that provides measurements for the essential parameters for the technology being tested at CfAR. The design and adaptation of CfAR's current dyno is the focal point of this project. Unfortunately, due to the large scope this proved difficult to meet the time constraints, so only a portion of the original goals for this project were accomplished. Valuable contributions to the design were accomplished however, such as the Graphical User Interface, integral software, component selection and testing of a basic prototype with the existing Hybrid test bench. It is recommended that CfAR acquires the Kistler 9369A torque sensor and U1511 series motor for continuation of the system. Once these components are implemented the system should meet the required 5kW of power and 10,000rpm of speed with accurate torque and rpm measurements. The goal of using pre-programmed loads was not achieved. Further testing is needed before determining if overheating will be an issue. We do not anticipate it to be an issue because the motor has a cooling fan as well as the programmable load. If necessary, forced air can be added with a simple household fan blowing on the apparatus.

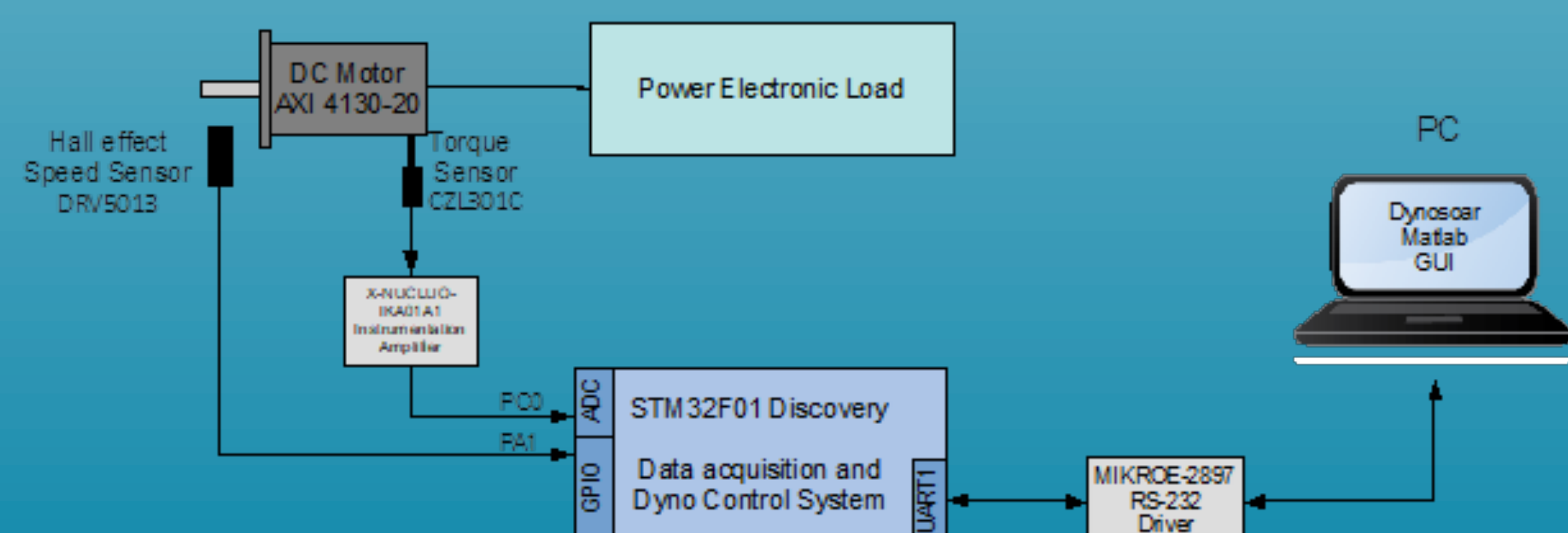
## Introduction

The UVic Center for Aerospace Research (CfAR) is constantly adapting and creating unmanned aerial vehicles (UAV) for research and innovation. To quantify their accomplishments and improvements they need a system to measure the outputs and parameters of such aerial vehicles. A dynamometer is a test bench that typically measures motor: speed (rpm), power (watts), and mechanical torque (Newtons). To achieve accurate measurements of these parameters, the use of precise and durable electrical, mechanical and software components are essential.



Dynamometers can be used to test any motor within their peak performance numbers, variations in components and design concepts to optimally test a specific motor. For testing UAVs, dynamometers tend to be relatively small as opposed to a dynamometer for cars and trucks. In this project, the main physical components are the motor-generator, speed sensor, torque sensor as well as a variable load which is provided by CfAR. The constraints laid out at the beginning of this project were exclusively for the power and cooling of the system; due to multiple parties being involved in this design, cooling system and power dissipation will not be addressed. In addition, requirements were modified during the project and the final version is outlined in "Design Objectives". The constraints for the power range and maximum speed threshold were 3-5kW and 10,000rpm, respectively.

However, to get all these components to work in unison the data acquisition and user interface must be held to a high standard for efficient, real-time data readings and computations. The hardware that was chosen for this project is the STM32F051R8T6 microcontroller. This unit provides both an inexpensive and powerful computation system to take in the data inputs and translate them into the chosen computing language, MATLAB. Finally, the Graphical User Interface (GUI) which was custom built specifically for this project using MATLAB software.



## Design Objectives

1. Dynamometer power rating must be between 3 to 5 kW
2. Motor speed capable of 10k rpm
3. Capable of max power for 3 minutes without overheating
4. Dissipated power in a form of DC current.

## Materials

- Hall Sensor**
  - Littelfuse Inc. 55100-3M Hall sensor**
    - Voltage pulse detection
    - 10mm range (magnet dependent)
    - Inexpensive
    - Reliable
- Motor-Generator**
  - T-Motor KV100 motor**
    - Run time of 1 at 100%
    - 5000W for 10 minutes
    - Peak power of 8,550W
    - Maximum 3473rpm
- Torque Sensor**
  - Kistler 9369A in-line sensor**
    - Measures -200Nm to 200Nm
    - Specific flange or shaft dimensions can be requested upon
    - No pricing was available
- Power Electronic Load**
  - The Kikusui PLZ1004W power electronic load**
    - Constant voltage mode
    - Constant current mode
    - Constant resistance mode
    - Accepts pre-set load profiles
- Miscellaneous**
  - Additional materials such as an STM32F051R8T6 microcontroller, various wires, connectors and mounting materials are necessary.

## Methodology

This comprehensive design project encounters several areas that required a well-thought-out approach prior to finalization of parts and simulations. Namely, the data acquisition aspects (sensors) and the electrical-mechanical parts (motor-generators). The below excerpts touch on the specific elements that required more intensive research and analysis to meet the project requirements.

The data acquisition will include real time current, voltage, torque and shaft speed. From these measurements, power will be calculated. Torque measurement is best done through an in-line torque sensor such as the Kistler 9369A. This sensor is capable of measuring torque between -200Nm and 200Nm which is more than required [10], leaving room for future growth. Specific flange or shaft dimensions can be requested upon order for simple integration with the rest of the system. Pricing is not available online and we are currently waiting for a response from Kistler for further information.

Due to tight time and budgetary constraints, an in-line torque sensor will not be used. Instead, two S-type load cells will be mounted to the motor housing and will measure the applied force. The CZL301C load cells cost only \$45.00 and can measure up to 120kg maximum load each and require a 5-18V DC supply [11]. To achieve a torque value from the load cells it is important to have accurate measurement from the cell to the center of the shaft. Torque can be calculated simply using the equation  $T=Fd$ . This method of measuring torque will cost approximately 10% of the cost of an in-line torque sensor.

For the motor-generator, the power is required to be in the range of 3-5kW while capable of up to 10,000rpm. The KV100 motor was first suggested by Mr. Matlock at CfAR in the weekly team meeting, as a follow up to the concerns surrounding the AquaStar motor's reliability. The KV100 motor has a cited run time of 1 minute while operating at 100% throttle [13], which would output a maximum 3473rpm, and 8,550W. Mr. Matlock had also contacted the manufacturer, T-Motor, to confirm that this specific model can operate at 5,000W for 10 minutes; these simulation parameters will give CfAR ample experimental data that they require. In comparison to the motors that were reviewed early in the project process, the KV100 motor is still relatively inexpensive at \$689.90CAD [13]. It was unanimously decided that the reliability is worth the extra money over the least expensive motor (the Aquastar), and that going forward, the KV100 is the motor-generator of choice.

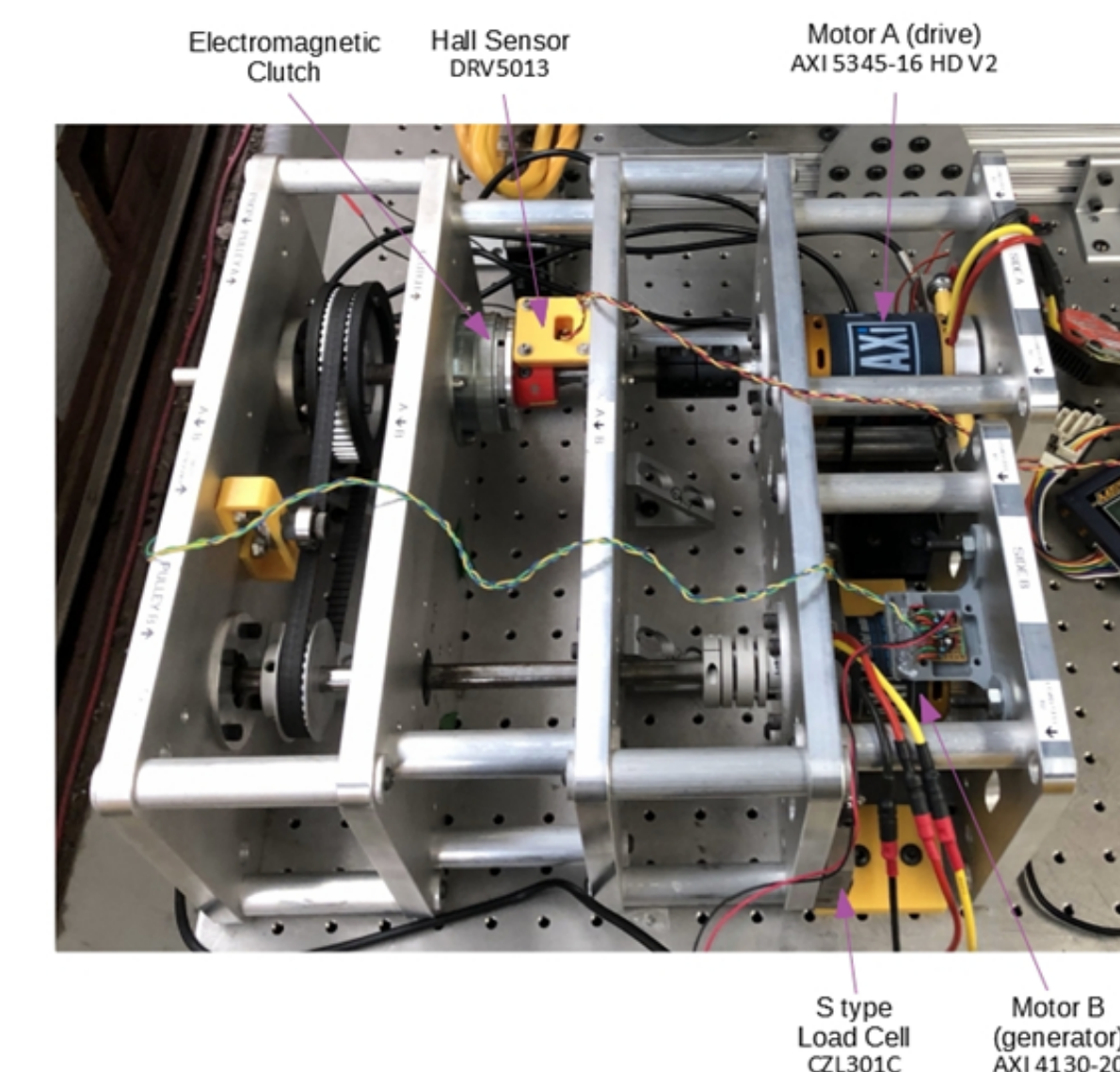
## Testing & Results

### Hall sensor speed detection

- 6 magnets were spaced equally around the motor shaft each producing a high pulse when passing the hall sensor
- Firmware detects and times consecutive rising pulse edges
- The time is multiplied by 6 to achieve the period for a complete revolution and converted to rpm
- A simulated signal was used to test the firmware and performed as expected
- Varying the pulse period was detected by the firmware

### Load Cell interface

- Testing was completed with load cell B2
- Varying input voltages for the instrumentation amplifier were measured with output voltage and gain
- No load on the cell produced 0V
- Output of the amplifier was approximately midscale (1.5V), the measured output was 1.46V.

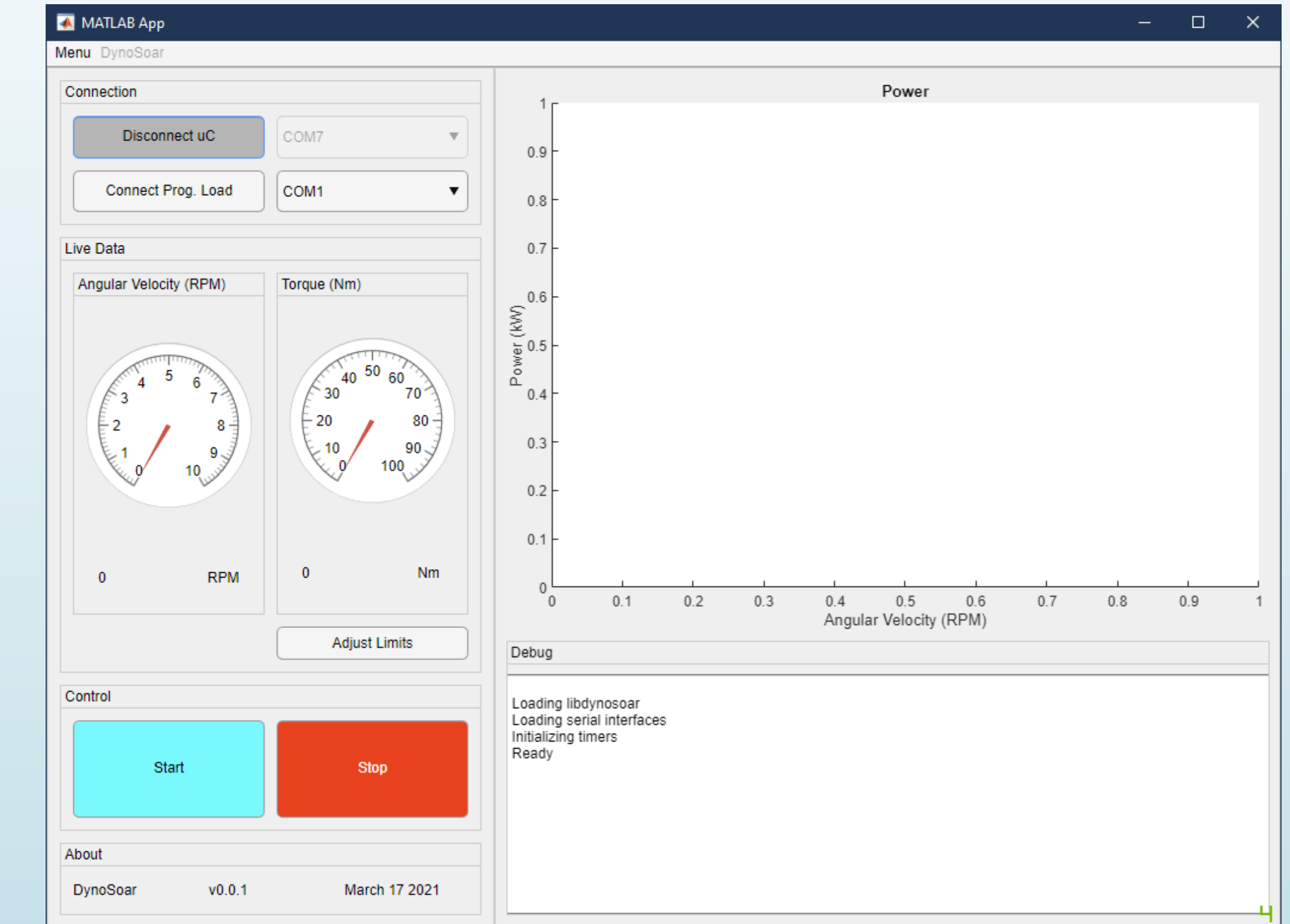


### Hybrid Drive Dyno simulation

- Motor A and motor B were connected through a 1.875:1 gear ratio
- Determine losses with no-load test (drive motor A, no power to motor B)
- 0.7A applied to motor B, five data point were collected at no load and full load
- 25.2V was driving motor A via batteries
- Speed A was collected with a servo tester, speed B = 1.875\*speed A
- A current clamp meter was used to measure the DC input current from the batteries to motor A
- Input voltage, current, rpm and throttle position of motor A were recorded
- The output voltage and current were recorded from the power electronic load

Results are shown in the table below

	No Load Test					Load Test				
	1	2	3	4	5	6	7	8	9	10
<b>Input</b>										
<b>Current (A)</b>	1.08	1.63	2.28	2.86	3.40	4.25	5.07	6.19	7.95	7.95
<b>Voltage (V)</b>	24.36	24.25	24.21	24.16	24.11	24.07	23.99	23.90	23.78	23.71
<b>rpm (Ω)</b>	621.00	1034.00	1405.00	1750.00	2181.00	979.00	1204.00	1454.00	1694.00	2065.00
<b>Power (W)</b>	26.31	39.53	55.20	69.10	81.97	102.30	121.63	147.94	189.05	188.49
<b>Throttle uS</b>	1200.00	1250.00	1300.00	1350.00	1400.00	1300.00	1350.00	1400.00	1450.00	1500.00
<b>Output</b>										
<b>Current (A)</b>	N/A	N/A	N/A	N/A	N/A	7.00	7.00	7.00	7.00	7.00
<b>Voltage (V)</b>	N/A	N/A	N/A	N/A	N/A	4.72	6.55	8.26	9.84	11.47
<b>rpm (Ω)</b>	N/A	N/A	N/A	N/A	N/A	1835.63	2257.50	2726.25	3176.25	3871.88
<b>Power (W)</b>	N/A	N/A	N/A	N/A	N/A	33.04	45.85	57.82	68.88	80.29
<b>Torque (Nm)</b>	0.14	0.37	0.47	0.75	1.03	0.37	0.47	0.70	0.70	0.98



## Conclusion

Overall, only a portion of the original goals for this project were accomplished. This was largely due to the budget and time constraints that were required to be worked around and mitigated. Successful literature review, current market research and component selection was performed. It is recommended that CfAR acquires the Kistler 9369A torque sensor and U1511 series motor for continuation of the system. Once these components are implemented the system should meet the required 5kW of power and 10,000rpm of speed with accurate torque and rpm measurements. The entire system is light and portable for storage as required. The goal of using pre-programmed loads was not achieved. The GUI developed in MATLAB for this project gives a user-friendly approach to the testing strategy. The inner workings of the GUI and the software required for this project are defined in Appendix A of this report. Further testing is needed before a determining if overheating will be an issue. We do not anticipate it to be an issue because the motor has a cooling fan as well as the programmable load. If necessary, forced air can be added with a simple household fan blowing on the apparatus.

## Recommendations

- Replacing the load cells with an in-line torque sensor
  - This would provide more accurate torque readings
- Secondly, the Axi gold motor should be replaced
  - The U1511 motor as shown previously in section VI is our recommendation because it provides a balance between cost, reliability and performance.
- Further integration of the power electronic load is required.
  - Currently, programmable load profiles cannot be implemented.
- Continued development of the data collection system is also needed.

## Acknowledgements

We would like to personally thank everyone who contributed to this project in various, impactful ways. Firstly, Dr. Babak Manouchehrinia who guided us and provided valuable feedback throughout the project's timeline. Jay Matlock for explaining the current CfAR dynamometer, allowing access to the CfAR shop and providing components with short notice as well as actively helping the team find new components to better the project. Lastly, Jordan Shultz for his presentation on the current dynamometer and mechanical background.

\*References found on "Group8 - Final Project Report"