CEDARVILLE UNIVERSITY
SOLAR BOAT TEAM

Solar Splash Technical Report

Boat #1

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I. EXECUTIVE SUMMARY

The overall goal of the Cedarville University 2017 Solar Boat team is to win the 2017 Solar Splash Competition and establish the viability of a hydrofoil system for the 2018 Dutch Solar Challenge (DSC). In order to accomplish these goals, we have set a target speeds for Solar Splash of 55 km/hr (35 mph) in the Sprint event and 14.5 km/hr (9 mph) in the Endurance event. To achieve these goals we focused on several individual projects including electronics and data acquisition, motors, and propulsion.

The 2017 Cedarville University Solar Boat Team has concentrated its efforts on developing and optimizing the DSC boat which includes the use of hydrofoil technology. Though we concentrated on the European competition track, all of our developments in this area affect the Solar Splash boat. We made great improvements from previous year's work on understanding and implementing CAN communication protocol, improving our knowledge of motor characteristics with our dynamometer testing, along with other improvements to the endurance drivetrain. The following information gives a description of the work we accomplished on the DSC boat, and how these developments are being implemented in this year's Solar Splash boat.

For many years the Solar Boat team has been trying to develop a robust electronic control and instrumentation system. Our new design uses faster and more powerful microprocessors along with the industry-standard. In developing this system for the DSC boat, we used Controller Area Network (CAN bus) protocol to communicate with a high number of devices; the newer microprocessors allow us to have better energy management and the CAN communication protocol greatly reduces noise in our data. This system must have a way to store and analyze data, monitor height, pitch, roll and yaw (necessary for flight), and enable the driver or the Vehicle Control Board (VCB) to control outputs to drive the foil articulation system. The electronics control system has the ability to store all data transmitted on the boat's CAN bus using the display module and a USB stick. The data on the bus includes various variables like height, speed and battery status for the VCB to sustain flight. Since the VCB is connected to the boat's CAN, it has the ability to send messages over the network to control the foil articulation system and give a suggested speed to the driver. As a result of this work, we are now able to implement the same technology in our Solar Splash boat, using the same CAN bus technology and data acquisition system.

Our focus for the motor subsystem, was to establish a means to measure the efficiency of or motors and controllers separately. Thus, we have purchased a new DYNOmite dynamometer for our solar boat motors and have spent the year setting up our dynamometer test facility and demonstrating its capabilities. We then conducted tests on an old brushless motor from our Solar Splash boat, and tested a new brushless DC motor and its motor controller as well. The goal of this testing is to measure motor and drivetrain efficiency and to match motor torque-speed curves to propeller torque-speed curves. To measure this data, it was necessary to have computer control on the dynamometer, motor, and controller along with a data acquisition system for input electrical power and output mechanical power. The work completed so far on the motor subsystem begins with implementing computer-controlled dyno-testing capability. We have learned how to use the DYNOmax software, provided by the dynamometer manufacturer, to an extent necessary for testing and it has been configured to work properly with an electric motor. The dyno has been calibrated and used on a motor with known torque-speed curves for comparison of proper results. Additionally, the brushless DC motor has been tested at endurance race conditions of 1.5 kW. Finally, in addition to responding to pulse-width-modulation (PWM) and serial signals, the motor controller has been programmed to read and respond to messages on the CAN bus and to upload operating data onto the CAN bus.

The propeller team was responsible for the manufacturing, design, and testing of our team's propellers. This included learning CAMWorks software, learning OpenProp software, and learning how to operate the CNC mill. The work this year has focused on learning how to use CAMWorks to develop tool-cutting paths for the CNC machining of propellers. This year we developed several techniques for significantly reducing the setup time on the CNC mill when machining propellers.

The hull team focused on experimentally validating drag results from numerical analysis. We developed an experimental drag test setup and performed many tests on our fleet of solar boat hulls. This setup allows us to measure hull drag and both lift and drag of hydrofoils. In the drag and stability analysis section of the project, the team had to learn how to the use open source codes AVL, XFOIL, as well as the in-house code HydrofoilFlight.m. This work required us to make adjustments to these codes to make them more accurate and functional.

The developments made to our endurance drivetrain involve the development of a new coupling device between our podded motor and the gearbox. The collar coupling has failed many times over the years, and this year we are replacing that with a keyed coupler

These concurrent projects have been a full-team effort to improve on the work of previous years and perform competitively in both 2017 and the future. With improvements to pre-existing electronic control algorithms we have optimized the power flow from the batteries to the motors of both races. We have created an electronic system which is capable of running the boat successfully for several hours in race conditions.

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III. PROJECT GOALS AND OBJECTIVES

The primary goal of the 2017 Cedarville University Solar Splash team is to win the Solar Splash competition in June of 2017 and to make improvements in the design and analysis process for future teams. To accomplish our primary goal of winning, we have set specific goals for each event based upon the past several years' performances.

For the Endurance event our goal is to travel at an average speed of 9 mph (14.5 km/hr) for both of the two-hour races. Our goal for the Sprint portion of the competition is to complete our run in under 20 seconds. We calculate that we can obtain a top speed of 35 mph (55 km/hr). Our goal for the Slalom event is to complete the course in 45 seconds or less. To attain these speeds we created a power budget to determine performance specifications for each subsystem. Fig. 1 shows a visual representation the power budget for the Endurance event without hydrofoils.

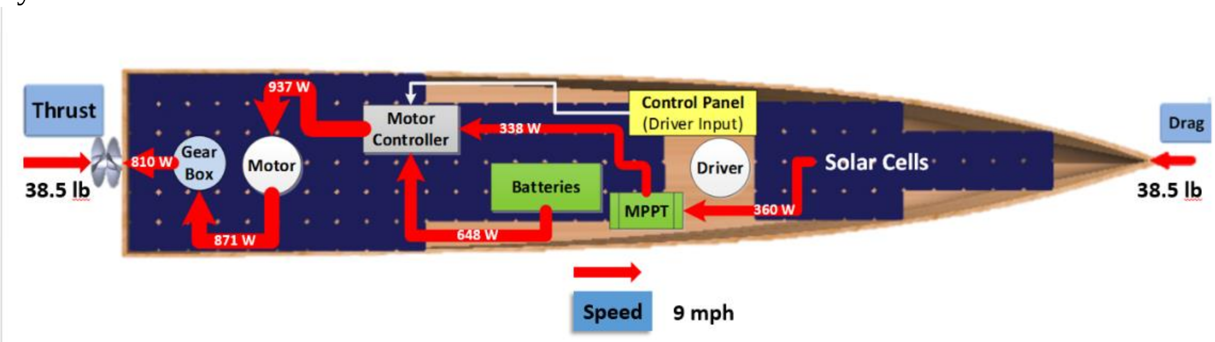

Fig. 1. *Power flow diagram for the Solar Splash Endurance event.*

Fig. 2 shows the power flow for the Sprint event. The power values shown are determined by using the efficiencies specified in the power budget. During the Sprint event the solar cells are not in use which explains why there are 0 W coming into the motor controller from the cells.

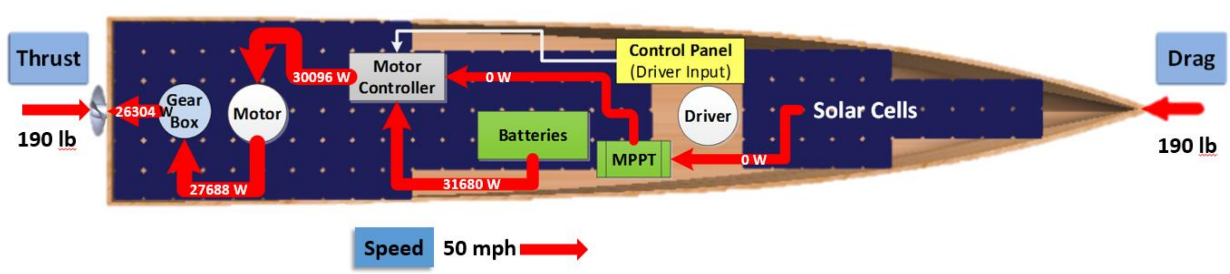

Fig. 2. *Power flow diagram for Solar Splash Sprint event*

These figures show the amount of power coming into and going out of each component, which are based on target efficiencies for each component and thus dictate performance specifications for the solar panels, MPPT, batteries, motor controller, motor, gear box, and propellers. The full power and weight budgets are shown in Appendix E-Power and Weight Budgets.

IV. CURRENT DESIGN AND PROBLEM DEFINITION

The Cedarville University Solar Splash team has made several improvements to the 2016 boat design. These changes are reflected in the following sections: Solar System, Electrical System, Power Electronics, Hull Design, Drivetrain and Steering, and Data Acquisition and Communication. Documentation of the boat batteries, flotation calculations, proof of insurance, and team roster are located in Appendices A, B, C, and D respectively.

A. Solar System

1) Current Design: The solar panels designed and used in 2014 allow for more low-angle light to enter the solar panels by changing the top layer of the panels to one with triangular prisms rather than a flat top. The layout of the solar cells was then finalized, as shown in Fig. 3. This design proved useful in the 2016 competition and will be used again by the 2017 team. However, the max peak power trackers (MPPT) used in past years are unreliable.

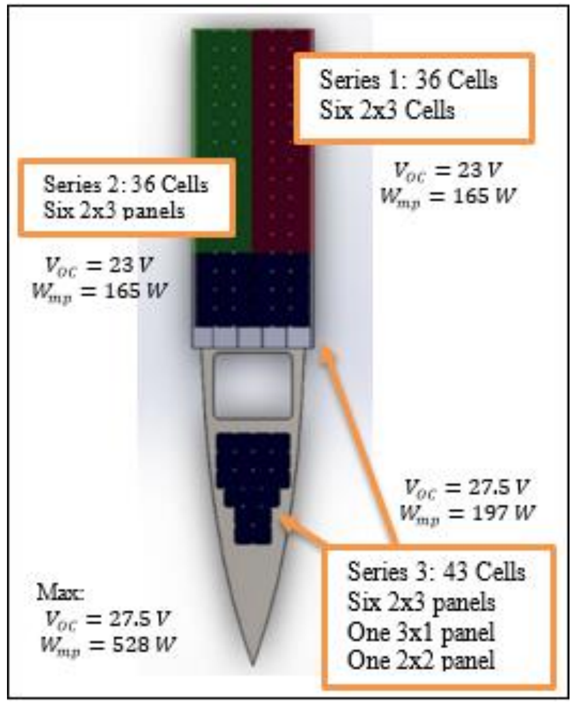

Fig. 3. *Solar array layout for three series*

2) Analysis of Design Concepts: For the Dutch Solar Challenge (DSC) our team has designed a boat that uses the GV-Boost MPPTs (a list of component information is available in Appendix F) that are more reliable. We are replacing the current MPPT system on the Solar Splash competition boat with the new components.

3) Design Testing and Evaluation: The new MPPT's have functioned satisfactorily on the DSC boat so we can be confident that they will improve the reliability of the Solar Splash boat. The solar panels were extensively tested in 2014 and shown to produce power that is just under the competition rules.

B. Electrical System

1) Current Design: Last year we ran into many problems with the electrical system. The electronics developed in the past had not been maintained and were not functioning properly. It was designed to have a CAN bus that communicated between the dash and the control box. A picture of the control box layout is shown in Fig. 4. The dash included a display and command switches. The control systems allowed for energy management. It measured the expected power inside the batteries and then adjusted the motor current to keep the boat running throughout an endurance race. An overview of the electrical system is shown in **Error! Reference source not found.**5. Unfortunately the system stopped functioning and no one on the team had the expertise to repair it in time for competition. As a result, during the Endurance

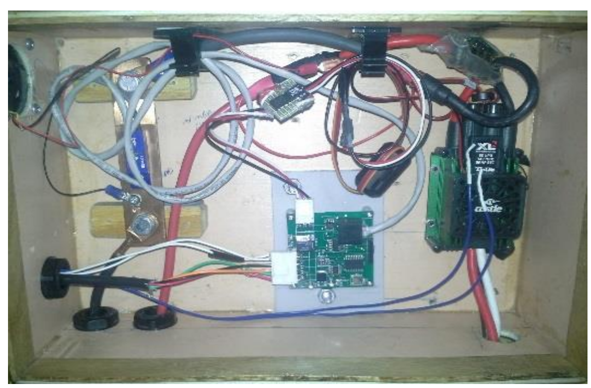

Fig. 4. *Endurance motor control box. It consists of a Mamba XL2 motor controller, Motor Control Card, and GMW current sensor*

event in 2016, the team bypassed the electrical system and installed an AstroFlight RC servo tester to control the motors.

2) Analysis of Design Concepts: Our work on the DSC boat has included developing a new and elaborate electronics system that we are implementing on the Solar Splash boat. While the DSC electronics system is much more elaborate, several different parts are relevant to the Solar Splash boat and are described below.

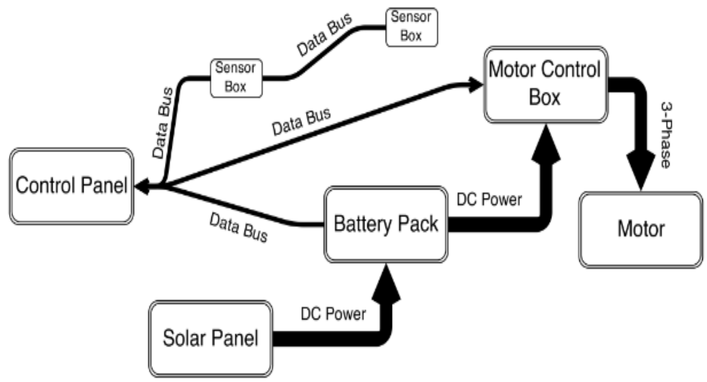

***Fig. 5**. Overall electrical system block diagram*

The CAN system is the foundation of our electronics network. It allows devices that are "CAN-compatible" to attach to the network and view the information travelling on the bus. Our CAN operates at 500 kbps, and therefore all components connected to the network must operate at the proper speed, otherwise the device will not be able to communicate properly. We have several devices already connected to the network: ECR CAN expanders (a circuit, developed by the 2016 team, for loading analog signals onto the CAN bus), a VeeCAN320 used to display and record data, IPESpeed (a GPS unit that is CAN compatible), and Parker CM0711, which is a programmable control module that can read several types of input (i.e. analog, digital, CAN) and output control commands.

Last year, the team decided to use New Eagle's Raptor platform to program the control module, Parker CM0711. This control module allows us to take analog inputs and turn them into CAN messages. The Raptor_DEV programming takes place in the Simulink Environment and uses block programming to build the code. After comprehending how to program the I/O channels, Raptor_CAL is used to "flash" the Parker module with the proper program. For monitoring the boat's CAN messages, we use Raptor_CAN, another program from New Eagle. Using another New Eagle associated product, the VeeCAN320, we are able to store and display information that is available on the bus. This allows us to see how the system functions as a whole. Testing the sub-systems shows us the performance of each individual piece, but having data for the whole system simultaneously, in one place, allows us to see how the motor and battery function under load.

In addition to the Parker CM0711, we have ECR CAN expanders to convert analog signal inputs into a message for the CAN. This device is a proprietary design that the solar boat team has permission to use. We use this device so that we continue to limit the number of signal wires to operate the boat. Each of these are being implemented into the 2017 Solar Splash boat. We have also added the IPESpeed module to measure GPS data and convert that data to CAN messages.

3) Design Testing and Evaluation: We have tested the electrical system on the DSC boat and will follow a similar procedure for the Solar Splash boat. To validate the functionality of the DSC system, we started by testing all the control boxes individually before trying to connect them together. We began with the forward control box since it only has one ECR

Expander and a PMC (Polulu Motor Contoller; a microcontroller for controlling linear actuators for our hydrofoil system). Even the forward control box proved more complicated since it requires a message from the dash to move the linear actuator. Once we modified the PWM output from the Parker, we proved the forward control box could move the linear actuator and read the measurements from the height sensors.

We followed this same procedure to test the main control box. After we tested all control boxes, we put the system together on land to do a final check of message transmission on the CAN bus. Once we confirmed this, we assembled the boat and began doing tests with the control boxes, making sure that inputs were received and outputs were driven from the display and dash.

C. Power Electronics

1) Current Design: We designed and constructed a Battery Controller Box (BCB) for the Endurance race of the 2014 Solar Splash competition. The BCB consisted of nine 1-1414939-4 relays and three PN-9012 solenoids that were controlled by a CPLD with inputs from the driver interface. The BCB allowed the user to connect the lead-acid batteries in parallel or series according to the finite state machine algorithm within the CPLD. The algorithm also allowed the user to switch the battery voltage from 12 V DC (nominal mode) to 24 V DC (high power mode for passing) under load. The 12V-24V high power mode system was designed to change the configuration of the three 12V batteries to a 24V system with one battery in series with two paralleled batteries. In 2014 we designed a current controller card to limit and stabilize the current in the Solar Splash races. The 12V-24V switching circuit has been tested under various environments including a two hour drawdown test on the water. It successfully switches in and out of high power mode while under load.

This system has been left unchanged in past years and will continue to be used in the 2017 competition. However, it is difficult to separate the power electronics from the control electronics. Much of the control electronics from 2016 was deficient alterations to that system have minor effects upon the power electronics.

2) Analysis of Design Concepts: The ability to increase power to the motor for passing has proven to be invaluable in past races and continues to be an integral part of the boat design. This portion of the boat works very well and we will continue to use it this year.

3) Design Testing and Evaluation: Success in past competitions have proven the reliability of this power circuit. As well, we have used the Solar Splash boats for many tests this year, during all those tests this circuit has functioned effectively and allowed for higher speed over short distances.

D. Hull Design

1) Current Design: The existing design for the Solar Splash hull shape is very good and will not be modified. The current hull is designed to be a planing hull for the Sprint event, and a displacement hull for the Endurance Event. In 2014 the team manufactured a hull using a Kevlar shell and a honeycomb core. Analysis indicated that a 1 inch core was sufficient to meet the strength and stiffness requirements. Also, by using core we are able to meet the Solar Splash buoyancy requirements without using bulkheads or other means of buoyancy. Buoyancy calculations, showing that our hull meets Solar Splash regulations, are provided in Appendix C. Additionally, we used wooden gunnels for increased stiffness, aesthetics, and to provide a means of attaching the steering system and deck. The current hull weighs just under 70 lb (311 N).

Two-phase flow Fluent analysis was completed for the 2014 hull. However, we had no real testing capabilities to measure actual drag on the hull during competition.

2) Analysis of Design Concepts: The existing design for the Solar Splash hull shape will not be modified this year. We did develop a new testing procedure that will allow for the hull drag verification. We built a mount for the bow that connects load cells to both the bow and a cable. The cable is then attached to another boat and pulled through the water at different speeds. The load cells will measure the tension in the cable. This cable tension is equal to the drag force on the hull as it moves through the water. This testing procedure has proven effective.

3) Design Testing and Evaluation: This past year we have been able to run several of these tests on one of our hulls. These tests can be used in the future for any new hull designs and continued characterization of the current hulls used at Cedarville. Appendix G contains the full report on the drag tests and Fig. 5 shows the results of that testing.

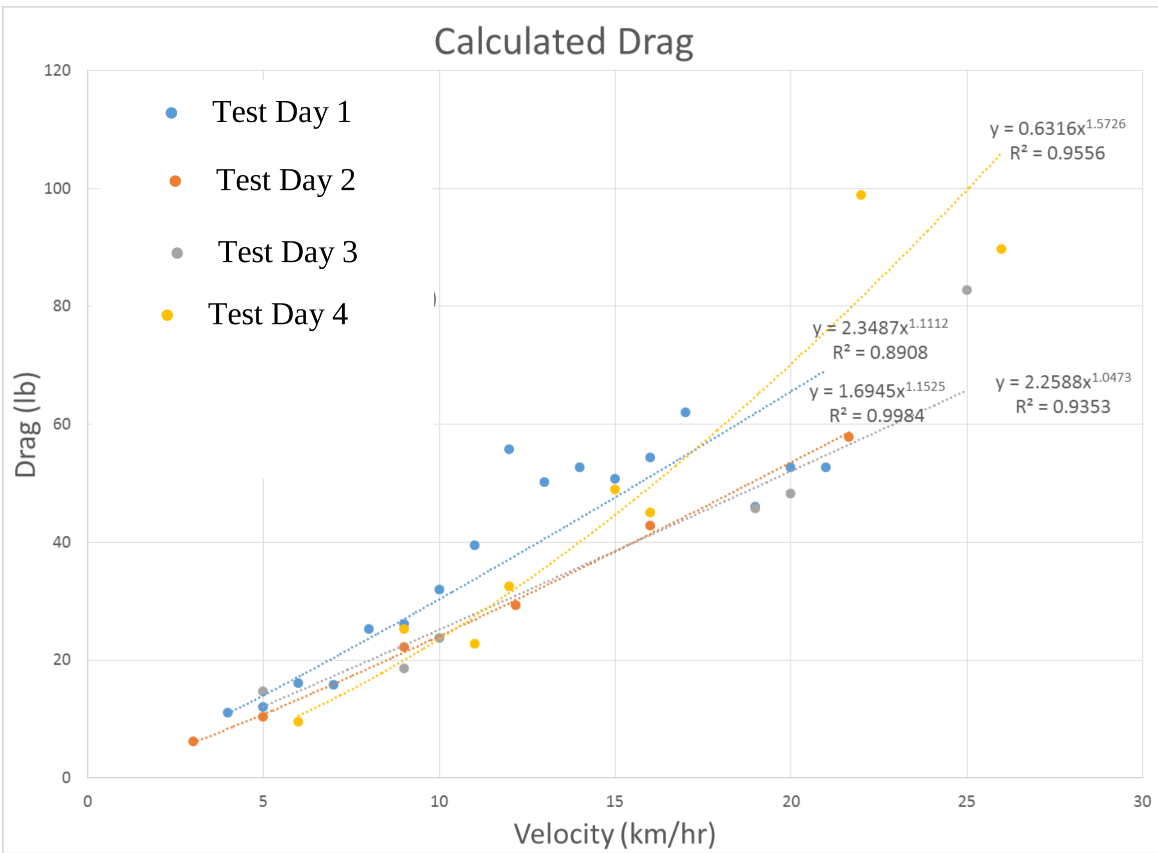

Fig. 5 *Compiled Hull Drag Test Results*

E. Drivetrain and Steering

1) Current Design:

a) Endurance drivetrain: The Cedarville team has used the 12V-24V endurance drivetrain for many years, but it has a critical failure issue. As the drivetrain ages, the collar that attaches the gearbox to the motor shaft completely slips. This results in a complete loss of thrust while under power. We experienced this in a local competition, the Paw Paw Festival in the fall of 2016. We have used this collar design since 2010, but it has been a constant area of concern.

The Paw Paw festival is the first time this coupling failed in competition, but over the years we have had to consistently disassemble the drivetrain and attempt to make the collar coupling more reliable.

b) Sprint drivetrain: The sprint drivetrain that the Cedarville University team uses is an excellent system. It performs very well and has not been changed this year. The system uses two motors that simultaneously dive a synchronous belt. This belt drive a pulley attached to our driveshaft. This downshaft drives the bevel gear in the housing, which causes the rotation of the rear facing 4-bladed propeller.

c) Propellers: The current propeller design is a single propeller in a forward facing pod attached by a downleg to the hull of the boat. For the sprint drivetrain we have a single rear facing four blade propeller. The steering system is connected to the downleg. The pod houses the motor and the 5:1 planetary gear box in line with the Endurance motor. Though we are still using the same drivetrain, there is always a need for the manufacturing of propellers in house. The team this year focused on improving the milling process to eliminate the need to outsource complex blade geometries.

2) Analysis of Design Concepts:

a) Endurance drivetrain: This year's focus on the endurance drivetrain was to eliminate the slipping of the shaft and gearbox. In previous solutions we used a collar, set screw, and a combination of both. The design this year uses a key way to ensure the transfer of torque from the shaft to the gearbox. Using a key in this application will provide the best way to link these two components. Some of the advantages for utilizing a keyed connection include: 1) a keyed connection will provide a positive stop until failure, whereas a keyless connection could allow slippage between the two mating parts if it is not assembled correctly or the design torque is exceeded; 2) a keyed connection provides a visual that the mating parts are locked in place. A keyless connection could only do so if the two mating parts were inscribed with a timing mark; 3) a keyed connection will allow for more tolerance between the two mating parts. The mating parts for keyless connections must be cleaned and machined to precise tolerances (Moulis, Keyed vs. Keyless). Figures 6-8 show the design modification.

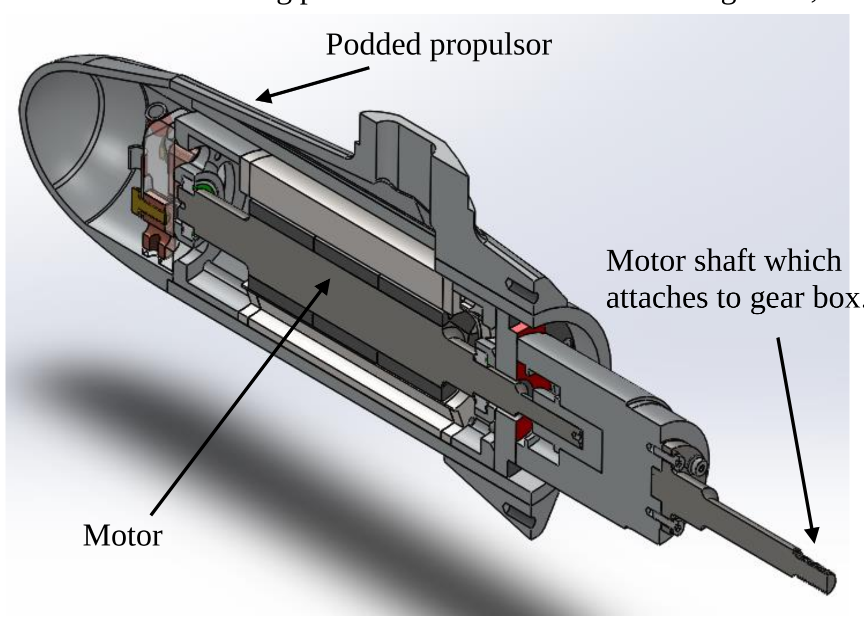

Figure 6. The endurance motor and drivetrain assembly shown with design solution.

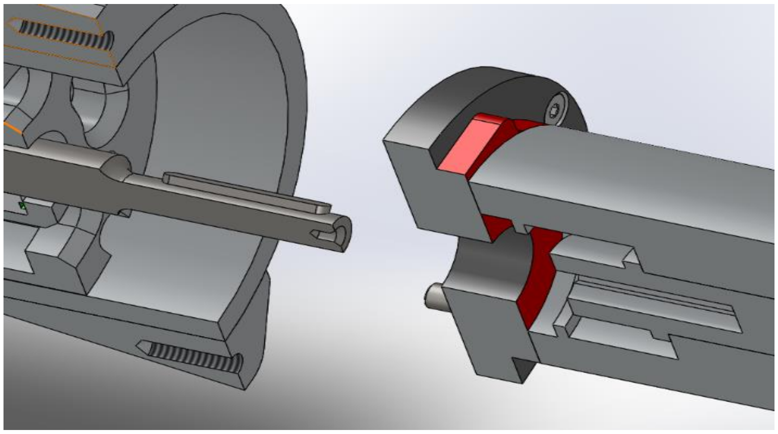

Figure 7. Design solution including keyed shaft and keyed gearbox

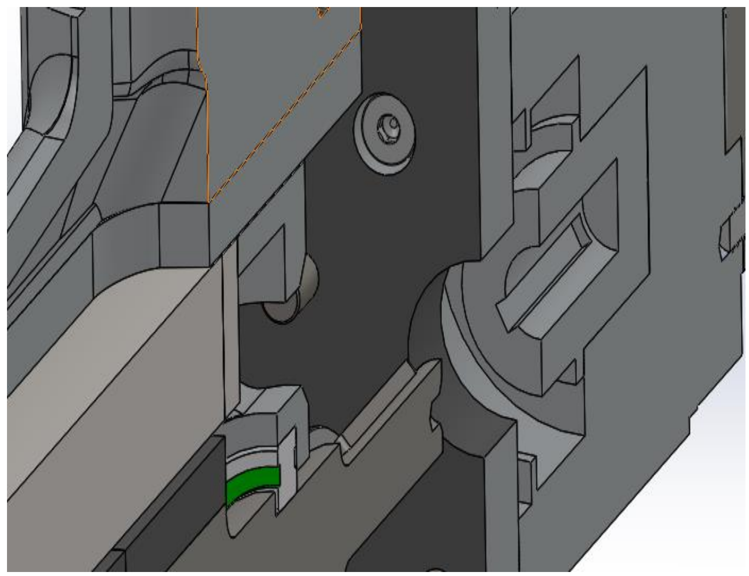

Figure 8. Design solution including keyed shaft and keyed gearbox

b) Propellers: Throughout the design phase, we were able to make a few important changes to the manufacturing process of propellers. These changes will help future teams to manufacture propellers more quickly. One thing that we changed in the design phase was the number of operations needed to "clear" each blade in the milling process. A 2016 team member made major contributions to the propeller manufacturing process. One of the more important ones was to change the cutting order. He cut material from the tip of each blade into the center. Since this is only necessary on the final pass (when the blades will be fully cleared from the stock), we were able to condense many of the operations into a single pass. For example, by passing from the tip of one blade to the tip of the other blade on rough cutting operation, we were able to eliminate multiple operations. Although this only saved a small amount of machining time, it saved many hours of set-up. Every time an operation is eliminated in CAMWorks, it eliminates the need for containment sketches, avoid sketches, operation parameter setup, tooling set-up, and G-code post processing. During our manufacturing, the automatic tool changer was fixed, and we were able to learn how to use this. Figure 9 shows an example of set-up time that we were able to eliminate due to learning how to operate the automatic tool changer.

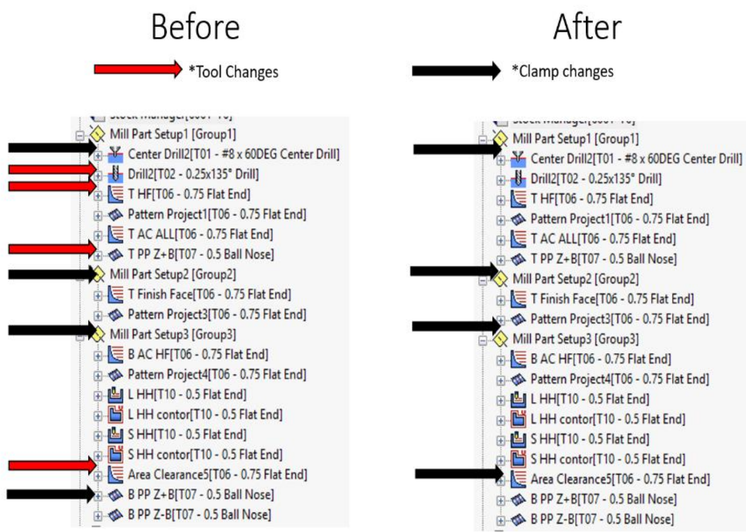

Figure 9. This represents the number of times that we had to manually adjust something during the machining

The final manufacturing change that we developed was to cut tabs on the first side of the stock to be machined, before beginning the propeller machining. These tabs would lower the clamp surface below the rest of the stock (which needs to be faced). This eliminates the need to implement a clamp setup change while machining the first side of the stock. By not having to change clamps, this also eliminates the need for more containment sketches and operation setups in CAMWorks. This concept is shown by Figure 10. There will still be a clamp setup to cut these tabs, but then there is less setup in CAMWorks as well as no need to change set-ups once the propeller machining begins.

Figure 10. This shows the tabs that can be cut to eliminate the need for multiple clamp setups.

3) Design Testing and Evaluation:

a) Endurance drivetrain: To test the endurance drivetrain and the new design change to the shaft and gearbox interface, we will be completing tests on Cedar Lake. The motor and drivetrain work very well together already besides this interface. If the solution works we will know it promptly after starting to run the boat.

b) Dynamometer: Last year's team acquired an eddy current brake dynamometer from Dynomite. This dynamometer has the capability of testing our drivetrains and all our motors. The motor and dyno subsystem objectives were to get the new dyno working with computer control and measurement sensors, wire and program the motor controller to run the a brushless DC motor, and perform tests on this new motor to characterize its efficiency. There were also two significant pieces of software necessary for learning: the dyno's DYNOmax software for performing tests and the controller's Roborun software for programing the motor controller. We determined some of the tests that this dynamometer would be performing. These tests include: step torque test at constant motor speed, ramp torque test at constant motor speed, step motor speed test at constant torque, and a ramp motor speed test at constant torque. The testing software is able to collect the necessary data for motor and controller efficiency calculations. Torque – load cell, Motor Speed – tachometer, DC Voltage – voltmeter or controller's internal sensor, DC Current – current transducer or controller's internal sensor. These are all part of what goes into running the dyno ad collecting valuable information. Figure 11 shows data curves collected from the dynamometer for one of our motors.

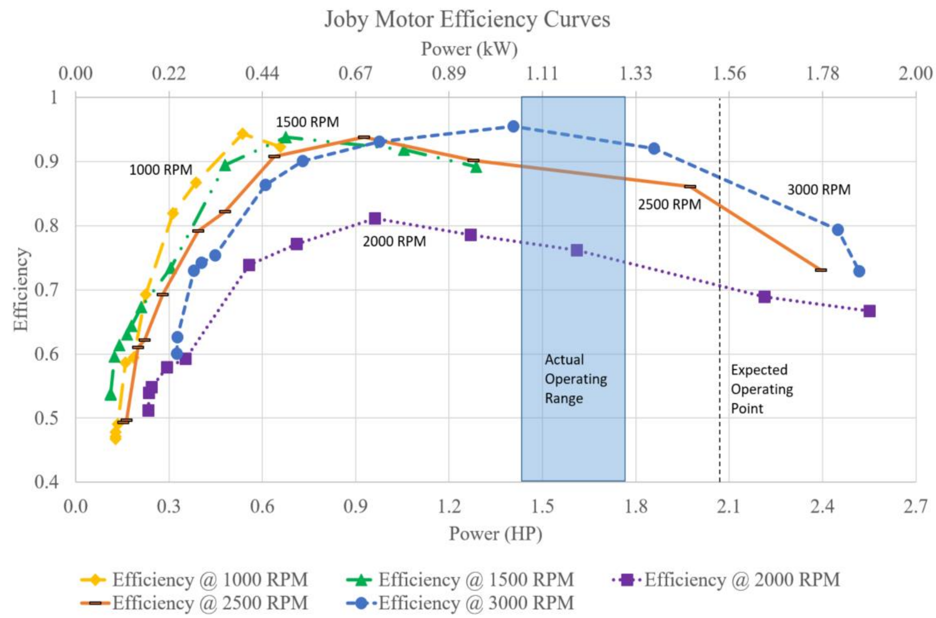

Figure 11. Motor efficiencies at various speeds calculated from loaded testing

F. Data Acquisition and Communication

1) Current Design:

In previous years, the team has had mixed results in data acquisition. One previous method used NI Labview software, which needed a laptop with careful handling requirements to store data. In 2012, the team developed an inboard data acquisition system to monitor and record measurements during the DONG Energy Solar Challenge competition. These developments were not fully successful, but set the foundation for designing a data acquisition system for the Solar Splash competition. In 2014, we were successful in monitoring data, but failed to fully achieve recording. In 2015 the team was able to record data, but the system developed has proven to be unreliable and no longer functions.

2) Design Analysis: Our display module, the VeeCAN320, is also a data logger. This part of the system connects directly to the CAN bus and allows for logging all communication across the bus. This new design will allow us to record all the information that we provide as signals on the CAN bus including battery voltage and current, throttle, speed, etc.

3) Design Testing and Evaluation: This system has proven reliable on the DSC boat testing that we have done this year. By moving this electrical system to the Solar Splash boat we can log data the same way that we have on the DSC boat and measure boat performance during both testing and competition.

IV. CURRENT DESIGN AND PROBLEM DEFINITION

V. **PROJECT MANAGEMENT**

G. Team Organization

Cedarville University's Solar Splash teams have primarily been composed of senior mechanical engineering students as part of their capstone courses, Mechanical Engineering Senior Design I and II. The team was split up into 7 sub teams focused on our work with the DSC boat that we will apply to the Solar Splash boat. 5 of those teams will contribute to changes in the Solar Splash boat.

- Electrical
    - Control Systems
    - Data Acquisition
- Motors
    - Motor Testing
- Propulsion
    - Drive-Train Efficiency Testing
    - Contra-rotating Propellers

The whole team met for one hour each week with the faculty advisors to discuss progress. Our team is advised by two faculty members: one mechanical engineer and one electrical engineer. In a paper written by our faculty advisors, Dewhurst and Brown (2013), they explain their approach to advising in light of three different educational models: the teacher-student model, the manager-engineer model, and the master-apprentice model. They attribute much of the solar boat team's past success to the mentoring—which balances different aspects of each of these three types of relationships—that they have provided as faculty to students on the solar boat team.

H. Project Planning and Schedule

We organized this year's team in August 2016 and each team member decided on measureable individual milestones to track their progress. We have been able to meet many of those goals for both the DSC boat and the Solar Splash boats.

I. Financial and Fund-raising

The Cedarville University engineering department provides our team with a budget to complete some design work and fabricate and/or purchase components and parts. This year, very little money has been spent on the Solar Splash boat. The major purchase for the boat is a new VeeCan display, duplicating what is on the DSC boat. IPEtronics has loaned us a CAN compatible GPS unit.

The School of Engineering is considering a major investment in a Yokagawa ScopeCorder before the end of this year. This scopecorder would allow us to independently measure the efficiencies of our motor and our controller for our asynchronous, brushless motors.

J. Continuity and Sustainability

Team continuity remains a challenge for Cedarville's Solar Splash teams. Since the project is part of a capstone course, there are few underclassmen who remain involved in the project throughout the year. The most important means of project continuity has been the shared network drive that enables each team to access work completed by previous teams. It helps maintain research, contacts, part specifications, reports, and test data, passing all of the information from team to team. The end-of-the-year reports are especially useful as a summary of work completed as well as the extensive appendices detailing specific work. This year the team focused on creating tutorials, maintaining the network drives to decrease clutter, and organize our work in a concise and straight forward manner.

Additionally, we spent significant time training some juniors on the use of CAMWorks and CNC machining. The Cedarville University Solar Boat Team typically leads all the senior design teams in the use of the CNC equipment at Cedarville. Much of our time is spent training students, on other projects, how to use the CNC equipment.

VI. **CONCLUSIONS AND RECOMMENDATIONS**

K. Conclusions

The following discussion addresses our overall project strengths and weaknesses from this year:

Strengths:

- We have added a key to the endurance system to remove the slipping in the shaft.
- Utilizing MPPT's from the DSC boat allows for more reliable power from the solar panels.
- The new dynamometer allows us to develop motor curves for any of the many types of motors we use for the Cedarville Solar Boat Team.
- The new electronics system developed for the DSC boat give us reliability, control, and data acquisition that can continue forward into future years and competitions.

Weaknesses:

- Our work on the DSC boat has made it difficult to make many improvements to the Solar Splash boat, but much of the work done is applicable and can make significant improvements to the Solar Splash boat.

L. Summary of Goal Completion

Our goal is to win the 2017 Solar Splash Challenge and prepare next year's team for the 2018 DSC. These objectives were used to set individual system goals.

- We have developed an electrical system which includes data logging, motor control, and a driver interface.
- We have improved the machining process for making designed propellers for competition.
- The new dynamometer testing setup allows for motor and drivetrain testing any type for future design.
- We can now measure the hull drag generated at a range of speeds.
- The slipping gear train has been replaced with a more reliable keyway to transfer load.

M. Where do we go from here?

Our team has made significant progress refining the 2016 boat. We are close to achieving stable flight on hydrofoils with our DSC boat. Once this is reliable, we plan to implement this technology on our Solar Splash boat

N. Recommendations

- Future teams must continue to document and annotate their work: part design files, analysis work, test procedures, test data, and user guides for each process. Good documentation greatly helps future students understand the work already completed.

VI. CONCLUSIONS AND RECOMMENDATIONS

- At the beginning of the year, set goals that advisors think are realistic: teams may have to underestimate what they think they can complete. Once those deadlines are in place, resolve to follow them as closely as possible.
- Future teams should develop the process of designing and manufacturing a hydrofoil system.
- Continue improvement of the electrical system
- Spend time understanding how the electrical systems work to come up with new improvement ideas

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APPENDICES

APPENDIX A: BATTERY DOCUMENTATION

This year we will be utilizing one of each battery pack that has been used in the past. A set of three Genesis 42EP batteries weighting 32.9 lb (14.9 kg) each giving us a total weight of 98.34 lb (44.7 kg) for the first set. The second set we will use the Genesis 13EP batteries, each weighing 10.8 lb (4.9 kg); we will use 9 of these for the second set of batteries for a total weight of 97.2 lb (44.1 kg). This is in compliance with the new Solar Splash rule 7.4.1 having both of the battery sets under the 100 lb (45.5kg) limit.

The specification and MSDS sheets for these two types of batteries, which were selected from the available batteries provided by Genesis as shown in Figure Al.1, are on the following pages in Figure A.2.

GENESIS PRODUCT FAMILY (All capacities at 10 hr. rate 25°C to 1.67 vpc)

GENESIS EP:

				DIMENSIONS				
Product (capacity)	Part Number	Internal res. of fully charged battery mΩ @ 25°C	Nominal short circuit current for charged battery	Length in. (mm)	Width in. (mm)	Height in. (mm)	Weight lb. (kg)	Brass Terminal (metric)
G13EP (13Ah)	0770-2007	8.5	1,400A	6.910 (175.51)	3.282 (83.36)	5.113 (129.87)	10.8 (4.9)	M6 w/ss hardware
G13EPX (13Ah)	0770-2003	8.5	1,400A	6.998 (177.75)	3.368 (85.55)	5.165 (131.19)	12.0 (5.4)	M6 w/ss hardware
G16EP (16Ah)	0769-2007	7.5	1,600A	7.150 (181.61)	3.005 (76.33)	6.605 (167.77)	13.5 (6.1)	M6 w/ss hardware
G16EPX (16Ah)	0769-2003	7.5	1,600A	7.267 (184.58)	3.107 (78.92)	6.666 (169.32)	14.7 (6.7)	M6 w/ss hardware
G26EP (26Ah)	0765-2001	5.0	2,400A	6.565 (166.75)	6.920 (175.77)	4.957 (125.91)	22.3 (10.1)	M6 w/ss hardware
G26EPX (26Ah)	0765-2003	5.0	2,400A	6.636 (168.55)	7.049 (179.04)	5.040 (128.02)	23.8 (10.8)	M6 w/ss hardware
G42EP (42Ah)	0766-2001	4.5	2,600A	7.775 (197.49)	6.525 (165.74)	6.715 (170.56)	32.9 (14.9)	M6 w/ss hardware
G42EPX (42Ah)	0766-2003	4.5	2,600A	7.866 (199.80)	6.659 (169.14)	6.803 (172.80)	35.1 (15.9)	M6 w/ss hardware
G70EP (70Ah)	0771-2001	3.5	3,500A	13.020 (330.71)	6.620 (168.15)	6.930 (176.02)	53.5 (24.3)	M6 w/ss hardware
G70EPX (70Ah)	0771-2003	3.5	3,500A	13.020 (330.71)	6.620 (168.15)	6.930 (176.02)	56.0 (25.4)	M6 w/ss hardware

Figure A.1. *Genesis 13EP and Genesis 42EP Battery Specifications*

Section I - Product and Manufacturer Identity

Product identity:
Sealed Lead Battery
Cyclon®, Genesis®, SBS, SBS J, Hawker XE™ Odyssey® or Trolling Thunder™

Manufacturer's Name and Address:
EnerSys Energy Products Inc. (formerly Hawker Energy Products Inc.)
617 North Ridgeview Drive
Warrensburg, MO 64093-9301
Emergency Telephone Number: (660) 429-2165
Customer Service Telephone Number: 800-964-2837

Section II – Ingredients

Hazardous Components	CAS #	OSHA PEL-TWA	% (By weight)
Lead	7439-92-1	50µg/m3	45 - 60 %
Lead Dioxide	1309-60-0	50µg/m3	15 - 25 %
Sulfuric Acid Electrolyte	7664-93-9	1.0 mg/m3	15 - 20 %
Non-Hazardous Materials	N/A	N/A	5 - 10 %

Section III - Physical/Chemical Characteristics

Boiling Point - N/A Specific Gravity (H2O=1) - NA
Vapor Pressure (mm Hg.) - N/A Melting Point - N/A
Solubility in Water - N/A Appearance & Color - N/A

Section IV - Fire & Explosion Hazard Data

Flash Point (Method Used): N/A **Flammable Limits:** N/A **LEL**: N/A **UEL**: N/A

Extinguishing Media:
Multipurpose Dry chemical, CO2 or water spray.

Special Fire Fighting Procedures:
Cool Battery exterior to prevent rupture. Acid mists and vapors in a fire are toxic and corrosive. Unusual Fire and Explosion Hazards: Hydrogen gas may be produced and may explode if ignited. Remove all sources of ignition.

Section V - Reactivity Data and Shipping/Handling Electrical Safety

Conditions to Avoid: Avoid shorting, high levels of short circuit current can be developed across the battery terminals. Do not rest tools or cables on the battery. Avoid over-charging. Use only approved charging methods. Do not charge in gas tight containers.

Requirements for Safe Shipping and Handling of Cyclon® Cells: Warning – Electrical Fire Hazard – Protect Against Shorting

- Terminals can short and cause a fire if not insulated during shipping.

Figure A.2. *Enersys and Odyssey MSDS Sheets (1 of 3).*

- Cyclon® product must be labeled "NONSPILLABLE" during shipping. Follow all federal shipping regulations. See section IX of this sheet and CFR 49 Parts 171 through 180, available anytime online at wwww.gpoaccess.gov.

Requirements for Shipping Cyclon® Product as Single Cells

- Protective caps or other durable inert material must be used to insulate each terminal of each cell unless cells are shipping in the original packaging from EnerSys, in full box quantities.
- Protective caps are available for all cell sizes by contacting EnerSys Customer Service at 1-800-964-2837.

Requirements for Shipping Cyclon® Product Assembled Into Multicell Batteries

- Assembled batteries must have short circuit protection during shipping.
- Exposed terminals, connectors, or lead wires must be insulated with a durable inert material to prevent exposure during shipping.

Section VI - Health Hazard Data

Routes of Entry: N/A

Health Hazards (Acute & Chronic): N/A

Emergency & First Aid Procedures:
Battery contains acid electrolyte which is absorbed in the separator material. If battery case is punctured, completely flush any released material from skin or eyes with water.

Proposition 65:
Warning: Battery posts, terminals and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

Section VII - Product and Manufacturer Identity

Steps to be taken in case material is released or spilled:
Avoid contact with acid materials. Use soda ash or lime to neutralize. Flush with water.

Waste Disposal Method:
Dispose of in accordance with Federal, State, & Local Regulations. Do not incinerate. Batteries should be shipped to a reclamation facility for recovery of the metal and plastic components as the proper method of waste management. Contact distributor for appropriate product return procedures.

Section VIII - Control Measures - Not Applicable

Section IX - Transportation, Shipping and Handling

EnerSys Energy Products Inc. batteries are starved electrolyte batteries which means the electrolyte is absorbed in the separator material. The batteries are also sealed. As of September 30, 1995, EnerSys Energy Products Inc. batteries were classified as "nonspillable batteries", and as such are not subject to the full requirements of 49 CFR § 173.159. The previous exempt classification, "Dry Batteries, Not Restricted" was discontinued effective September 30, 1995. "Nonspillable" batteries are excepted from the regulation's

Figure A.2 (cont.). *Enersys and Odyssey MSDS Sheets (2 of 3).*

comprehensive packaging requirements if the following conditions are satisfied: (1) The battery is protected against short circuits and is securely packaged. (2) For batteries manufactured after September 30, 1995, the battery and outer packaging must be plainly and durably marked "NONSPILLABLE" or "NONSPILLABLE BATTERY". (3) The battery is capable of withstanding vibration and pressure differential tests specified in 49 CFR § 173.159(d). (4) At a temperature of 55 ºC (131ºF), the battery must not contain any unabsorbed free-flowing liquids, and is designed so that electrolyte will not flow from a ruptured or cracked case.

EnerSys Energy Products Inc. batteries have been tested by WYLE Scientific Services & Systems Laboratories Group and determined to be in compliance with the vibration and pressure differential tests contained in 49 CFR § 173.159(d), and therefore as of September 30, 1995, excepted from the DOT requirements set forth in 49 CFR § 173.159, other than paragraph (d).

Battery shipments from EnerSys Energy Products Inc. Warrensburg location, will be properly labeled in accordance with applicable DOT regulations.

Packaging changes performed at other locations may require additional labeling, since in addition to the battery itself containing the required marking, the outer packaging of the battery must also contain the required marking: "NONSPILLABLE" OR "NONSPILLABLE BATTERY". Because the batteries are classified as "Nonspillable" and meet the three conditions above, [from § 173.159(d)] they do not have an assigned UN number nor do they require additional DOT hazard labeling.

The regulation change effective September, 1995, was to clarify and distinguish to shippers and transporters, all batteries that have been tested and determined to be in compliance with the DOT Hazardous Material Regulations, the International Civil Aeronautics Organization (ICAO), and the International Air Transport Association (IATA) Packing Instruction 806 and Special Provision A67, and therefore excepted from all other requirements of the regulations and classified as a "nonspillable battery".

Per 42 USC Section 14322 (US Code Title 42 – The Public Health and Welfare), packaging must be marked with the following: "Contains Sealed Lead Battery" and "Battery Must Be Recycled".

Section X - Additional Information

The EnerSys Energy Products Inc. sealed lead acid battery is determined to be an "article" according to the OSHA Hazard Communication Standard and is thereby excluded from any requirements of the standard. The Material Safety Data Sheet is therefore supplied for informational purposes only.

The information and recommendations contained herein have been compiled from sources believed to be reliable and represent current opinion on the subject. No warranty, guarantee, or representation is made by EnerSys Energy Products Inc., as to the absolute correctness or sufficiency of any representation contained herein and EnerSys Energy Products Inc. assumes no responsibility in connection therewith, nor can it be assumed that all acceptable safety measures are contained herein, or that additional measures may not be required under particular or exceptional conditions or circumstances.

N/A or Not Applicable - Not applicable for finished product used in normal conditions.
Informational MSDS Part Number 2602-0043 Rev. 2 (09/07/06)

Figure A.2 (cont.). Enersys and Odyssey MSDS Sheets (3 of 3).

APPENDIX B: FLOTATION CALCULATIONS (SEE RULE 7.14.2)

The surface area of the new hull which utilizes 1 layer of 1.25 inch of Nomex honeycomb is 65.0 ft^2 and the surface area which utilizes 2 layers of 0.472 inches of Nomex honeycomb is 7.1 ft^2. Thus, the buoyant force provided by the hull alone, neglecting the Kevlar skins is given by the following.

$$\begin{aligned} B_H &= \left(\sum_{i=1}^{n} A_i t_i\right)\rho_{water} \\ &= \left(65.0\, ft^2 * 1.25\, in * \frac{ft}{12\, in} + 7.1\, ft^2 * 2 * 0.472\, in * \frac{ft}{12\, in}\right)\frac{62.4\, lb}{ft^3} \\ &= 468\, lb \end{aligned}$$

Where B_H is the buoyant force on the hull when submerged, A_i is the surface area covered by a given core thickness, t_i is thickness of the core in a given region, and ρ_{water} is the density of water. Because the batteries are secured to the hull, their buoyant force also contributes the overall buoyant force on the boat. The volume of 3, 42 EP batteries is less than that of 12, 13 EP batteries, and will therefore be used for our calculations.

$$\begin{aligned} B_B &= 3V_{42EP}\rho_{water} \\ &= 3 * 0.175\, ft^3 * 62.4\frac{lb}{ft^3} \\ &= 33\, lb \end{aligned}$$

Where B_B is the buoyant force of the batteries and V_{42EP} is the volume of the Genesis 42EP batteries. Therefore, the maximum possible buoyant force exerted on the hull is given by the following.

$$\begin{aligned} B_{tot} &= B_H + B_B \\ &= 468\, lb + 33\, lb \\ &= 501\, lb \end{aligned}$$

Also, the weight of the hull, as given by the power budget is shown in Table B.1. Based on our calculations, our new hull can easily support its own weight plus a 20% safety factor as the buoyant force of 501 lb is much greater than the required buoyant force of 370 lb.

Table B.1. *Weight Budget for 2014 Solar Splash Boat*

Components	Weight [lb]	
	2014 Sprint	2014 Endurance
Solar Array	N/A	42
Batteries	100	100
Sprint Drivetrain & Controllers	70	70
Endurance Drivetrain	24	24
Hull	53	53
MPPT	N/A	4
Control Panel	5	5
Miscellaneous	10	10
Total	**262**	**308**
120% Total (Rule 7.14.2)	**314**	**370**

APPENDIX C: PROOF OF INSURANCE (SEE RULE 2.8)

ACORD

CEDAR-3 OP ID: CW

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY) 05/02/2017

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

IMPORTANT: If the certificate holder is an ADDITIONAL INSURED, the policy(ies) must be endorsed. If SUBROGATION IS WAIVED, subject to the terms and conditions of the policy, certain policies may require an endorsement. A statement on this certificate does not confer rights to the certificate holder in lieu of such endorsement(s).

PRODUCER Wallace & Turner, Inc. P. O. Box 209 30 Warder Street #200 Springfield, OH 45501-0209 Patrick E. Field	CONTACT NAME: Patrick E. Field PHONE (A/C, No, Ext): 937-324-8492 FAX (A/C, No): 937-325-1069 E-MAIL ADDRESS:
INSURED Cedarville University 251 North Main Street Cedarville, OH 45314	

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A : Cincinnati Insurance Company	10677
INSURER B :	
INSURER C :	
INSURER D :	
INSURER E :	
INSURER F :	

COVERAGES CERTIFICATE NUMBER: REVISION NUMBER:

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	X COMMERCIAL GENERAL LIABILITY						EACH OCCURRENCE	$ 1,000,000
	CLAIMS-MADE X OCCUR			SIP0003158	07/01/2016	07/01/2019	DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 500,000
							MED EXP (Any one person)	$ 10,000
	X Empl Liab Defense						PERSONAL & ADV INJURY	$ 1,000,000
	GEN'L AGGREGATE LIMIT APPLIES PER:						GENERAL AGGREGATE	$ 3,000,000
	X POLICY PRO-JECT LOC						PRODUCTS - COMP/OP AGG	$ 3,000,000
	OTHER:							$
	AUTOMOBILE LIABILITY						COMBINED SINGLE LIMIT (Ea accident)	$ 1,000,000
A	X ANY AUTO			SIP0003158	07/01/2016	07/01/2019	BODILY INJURY (Per person)	$
	ALL OWNED AUTOS SCHEDULED AUTOS						BODILY INJURY (Per accident)	$
	X HIRED AUTOS X NON-OWNED AUTOS						PROPERTY DAMAGE (Per accident)	$
								$
	X UMBRELLA LIAB X OCCUR						EACH OCCURRENCE	$ 15,000,000
A	EXCESS LIAB CLAIMS-MADE			SIP0003158	07/01/2016	07/01/2019	AGGREGATE	$ 15,000,000
	DED X RETENTION $ 0							$
	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y/N						PER STATUTE OTH-ER	
A	ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH)	N/A		SIP0003158	07/01/2016	07/01/2019	E.L. EACH ACCIDENT	$ 1,000,000
							E.L. DISEASE - EA EMPLOYEE	$ 1,000,000
	If yes, describe under DESCRIPTION OF OPERATIONS below						E.L. DISEASE - POLICY LIMIT	$ 1,000,000

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)

Event: Solar Splash 2017 held June 7-11th, 2017 at lake adjoining Clark County Fairgrounds, 4401 S. Charleston Pike, Springfield, Ohio 45505

CERTIFICATE HOLDER	CANCELLATION
SOLARSP SOLAR SPLASH Headquarters c/o Jeffrey Morehouse, PhD, PE 309 Newridge Road Lexington, SC 29072	SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS. AUTHORIZED REPRESENTATIVE Patrick E. Field

ACORD 25 (2014/01) The ACORD name and logo are registered marks of ACORD

APPENDIX D: TEAM ROSTER

Name	Degree Program	Year	Role
John Hilderbrand	BSME	Senior	Electronics and Data Acquisition
Kevin DeGroft	BSME	Senior	Hydrofoil Actuation
Emanuel Horst	BSME	Senior	Height Sensor
Tad Williams	BSME	Senior	Motor and Controller Dyno Testing
Tyler Rea	BSME	Senior	Drag and Pitch Stability Analysis and Testing
Brian Zurlinden	BSME	Senior	Drivetrain Testing and Roll Stability Analysis
Jordan Burns	BSME	Senior	Propeller Design and Manufacture

APPENDIX E: POWER AND WEIGHT BUDGETS

This year we made significant improvements in weight and efficiency. The weight gains are summarized in Table E.1 Also, the power budgets for both the Sprint and Endurance events are shown in Tables E.2 and E.3 respectively.

Table E.1: *Weight budget for the 2017 competition.*

Components	Weight [lb]	
	2017 Sprint	2017 Endurance
Solar Array	N/A	42
Batteries	100	100
Sprint Drivetrain & Controllers	70	70
Endurance Drivetrain	24	24
Hull w/ Bulkheads	53	53
Driver	155	155
MPPT	N/A	4
Control Panel	5	5
Miscellaneous	10	10
Total	417	463

Table E.2: *Power budget for Sprint event.*

Solar Splash Sprint Event							
Variable Name	**Variable**	**Value**	**Unit (metric)**	**Value**	**Unit (US)**	**Comments**	**Governing Equation**
BATTERIES							
Battery Impedance	Batt_Z	0.008	Ω				
Nominal Battery Voltage	Batt_N	36	V				
Battery Voltage under load	Batt_VFL	26.4	V			Sprint batteries	
Battery Current	Batt_I	1200	A			Design to draw power at this current	
Battery Power Gain	Batt_Pgain	31680	W				Batt_Pgain=Batt_V*Batt_I
Battery Power Output	Batt_Pout	31680	W				Batt_Pout=Batt_Pgain
CONTROLS							
Controls Efficiency	C_e	0.95				Assuming 95% efficiency	
Controls Voltage	C_V	25.1	V				C_V=C_Pout/C_I
Controls Current	C_I	1200	A			Assume current is the same as from batteries	C_I=Batt_I
Controls Power Gain	C_Pgain	-1584	W				C_Pgain=C_Pout-Batt_Pout
Controls Power Output	C_Pout	30096	W				C_Pout=Batt_Pout*C_e
MOTOR							
Motor Efficiency	M_e	0.90				per conversations w/ Neu Motors (12/03/13)	
Motor Torque	M_T	51.7	N*m	38	lbs*ft		M_T=M_Pout/M_ω
Motor Angular Velocity	M_ω	524	rad/s	5000	RPM	design motor speed for 5000 at 26.4 V	
Motor Power Gain	M_Pgain	-3010	W				M_Pgain=M_Pout-C_Pout
Motor Power Output	M_Pout	27086	W				M_Pout=C_Pout*M_e
LOWER GEAR UNIT							
Drive Train Efficiency	DT_e	0.98				Assuming 98% efficiency	
Drive Train Torque	DT_T	50.7	N*m	37	lbs*ft		DT_T=Mot_T
Drive Train Angular Velocity	DT_omega	524	rad/s	5000	RPM		DT_ω=DT_Pout/DT_T
Drive Train Power Gain	DT_Pgain	-542	W				GP_Pgain=DT_Pout-Mot_Pout
Drive Train Power Output	DT_Pout	26545	W				GB_Pout=Mot_Pout*DT_e
PROP							
Prop Efficiency	Prop_e	0.72				Assuming 70% efficiency	
Prop Thrust	P_Thrust	1145	N	257	lb		P_Thrust=Prop_Pout/(P_v*(1000/3600))
Prop Velocity	P_v	60.1	km/hr	37.4	MPH	Desired goal speed	
Prop Power Gain	Prop_Pgain	-7433	W				Prop_Pgain=Prop_Pout-DT_Pout
Prop Power Output	Prop_Pout	19112	W				Prop_Pout=DT_Pout*Prop_e
HULL							
Hull Drag	H_Drag	1145	N	257	lb		H_Thrust=P_Thrust
Hull Velocity	H_v	60	km/hr	37.4	MPH		H_v=P_v
Hull Power Gain	Hull_Pgain	-19112	W				Hull_Pgain=Hull_Pout-Prop_Pout
Hull Power Output	Hull_Pout	0	W			All the power should be used	
Denotes input value	Efficiencies		Output Power	Represents power in the system directly after the given component			

Table E.3: *Power budget for Endurance event.*

Solar Splash Endurance Event

Variable Name	Variable	Value	Ouput Power	Unit (metric)	Value	Unit (US)	Comments	Governing Equation
SOLAR PANELS								
PV Power Gain	PV_Pgain	360		W			Assuming avg of 75% of one sun condition max (Insolation data for Dayton OH in June)	PV_Pgain=480W*(% of one sun conditions)
PV Voltage	PV_V	16		V				
PV Current	**PV_I**	**22.5**		A				PV_I=PV_Pgain/PV_V
PV Output Power	**PV_Pout**		**360**	W				PV_Pout=PV_Pgain
PEAK POWER TRACKER								
MPPT Efficiency	MPPT_e	0.94					Assuming 94% efficiency	
MPPT Current	MPPT_I	28.2		A			Assuming current stays same from panels to PPT	MPPT_I=MPPT_Pout/MPPT_V
MPPT Voltage	MPPT_V	12		V				MPPT_V=Batt_V
MPPT Power Gain	**MPPT_Pgain**	**-21.6**		W				MPPT_Pgain=MPPT_Pout - PV_Pout
MPPT Output Power	**MPPT_Pout**		**338.4**	W				MPPT_Pout =MPPT_e*PV_Pout
BATTERIES								
Battery Voltage	Batt_V	12		V			Two 12 V Endurance batteries in series	
Battery Current	Batt_I	54		A			Based on available amp-hours in 2 hour race	
Battery Power Gain	**Batt_Pgain**	**648**		W				Batt_Pgain =Batt_Pout
Battery Output Power	**Batt_Pout**		**648**	W				Batt_Pout=Batt_V*Batt_I
MOTOR CONTROLLER								
Controls Efficiency	C_e	0.99					Assuming 99% efficiency because we are saving the 40 W that is lost from the battery to the controller	
Controls Voltage	C_V	12.0		V				C_V=Batt_V
Controls Current	C_I	82.2		A				C_I=MPPT_I+Batt_I
Controls Power Gain	**C_Pgain**	**-9.864**		W				C_Pgain=-(Batt_Pout+MPPT_Pout)+C_Pout
Controls Output Power	**C_Pout**		**976.54**	W				C_Pout=(Batt_Pout+MPPT_Pout)*C_e
MOTOR								
Motor Efficiency	M_e	0.85					From testing @ 3000 RPM without the gearbox got 75 %, but with the new motor design we are saving 60-70 W which is a 10% of our motor out put (70/703)	
Motor Torque	M_T	2.6		N*m	1.9487	lbs*ft		M_T=M_Pout/M_ω
Motor Angular Velocity	M_ω	314.2		rad/s	3000	RPM	Motor designed most efficient at 4000 RPM	M_n=GR*GB_n
Motor Power Gain	**M_Pgain**	**-146**		W				M_Pgain=M_Pout-C_Pout
Motor Output Power	**M_Pout**		**830**	W				M_Pout=Cont_Pout*Mot_e
GEAR BOX								
Gear Box Efficiency	GB_e	0.95					Assuming 95% efficiency	
Gear Ratio	GR	5					Gear box designed with 5:1 gear ratio	
Gear Box Torque	GB_T	12.6		N*m	9.2566	lbs*ft		GB_T=GB_Pout/GB_omega
Gear Box Angular Velocity	GB_ω	62.8		rad/s	600	RPM	Due to gear ratio	
Gear Box Power Gain	**GB_Pgain**	**-42**		W				GB_Pgain=GB_Pout-Mot_Pout
Gear Box Power Output	**GB_Pout**		**789**	W				GB_Pout=M_Pout*GB_e
PROP								
Prop Efficiency	Prop_e	0.853					Assuming 81% efficiency	
Prop Thrust	P_Thrust	167		N	37.584	lb		P_Thrust=Prop_Pout/(P_v*(1000/3600))
Prop Toruqe	P_Torque	10.7		N*m				
Prop Angular Velocity	P_ω	600		RPM				
Prop Velocity	P_v	14.5		km/hr	9	MPH	Desired goal speed	
Prop Power Gain	**Prop_Pgain**	**-116**		W				Prop_Pgain=Prop_Pout-GB_Pout
Prop Output Power	**Prop_Pout**		**673**	W				Prop_Pout=GB_Pout*Prop_e
HULL								
Hull Drag	H_Drag	167		N	37.584	lb		
Hull Velocity	H_v	14		km/hr	9.0243	MPH		P_Thrust=Prop_Pout/(P_v*(1000/3600))
Hull Power Gain	**Hull_Pgain**	**-673**		W				
Hull Power Output	**Hull_Pout**		**0**	W				Prop_Pgain=Prop_Pout-GB_Pout
Denotes Input Value	Efficiencies			Output Power	Represents power in the system directly after the given component			

APPENDIX F: COMPONENT LIST

There are several parts of our system that are purchased or donated from companies. The table below includes a list of these parts and where we received them from.

TYPE	PART NAME	PART NUMBER	COMPANY	COMPANY ADDRESS
MOTOR	Agni 95R motor	EMS-AGNI-B-95R	Saietta	210 Heyford Park Upper Heyford Bicester Oxfordshire OX25 5HE UK
VELOCITY SENSOR	IPESpeed	N/A	IPETronik	IPETRONIK GmbH & Co. KG Im Rollfeld 28 76532 Baden-Baden, Germany
DISPLAY	VeeCAN 320	DISP-IMX286-024-1204	New Eagle	New Eagle 110 Parkland Plaza Ann Arbor, MI 48103
CONTROL MODULE	Parker 711	HCM-5604-36-1303	New Eagle	New Eagle 110 Parkland Plaza Ann Arbor, MI 48103
MOTOR CONTROLLER	Mamba XL2	010-0095-01	Castle Creations	Castle Creations 540 N. ROGERS RD. OLATHE, KS 66062
MOTOR CONTROLLER	Sevcon Gen4	G2465	Sevcon	Sevcon UK (Head Office) Kingsway South Tyne and Wear NE11 0QA
DYNO	#12-HSx1 LC Eddy Absorber Kit	013-12S1-1K	Land and Sea	25 Henniker Street Concord, NH 03301
MPPT	GV-Boost	GVB-8-Pb-48V	GENASUN	Genasun LLC c/o Blue Sky Energy 28 Dane Street Somerville, MA 02143 USA

APPENDIX G: HULL DRAG TESTNG REPORT

2016 DSC Hull Drag Testing

Conducted by Tyler Rea on 1/20/17-1/25/17

<u>Objective:</u>

This test is meant to understand the drag caused by the hull at speeds before takeoff. Knowing the power consumption of the boat when the hull is in the water will be important for power management during race conditions. Also, if the hull is ever redesigned it is important to understand its current performance.

<u>Test Setup:</u>

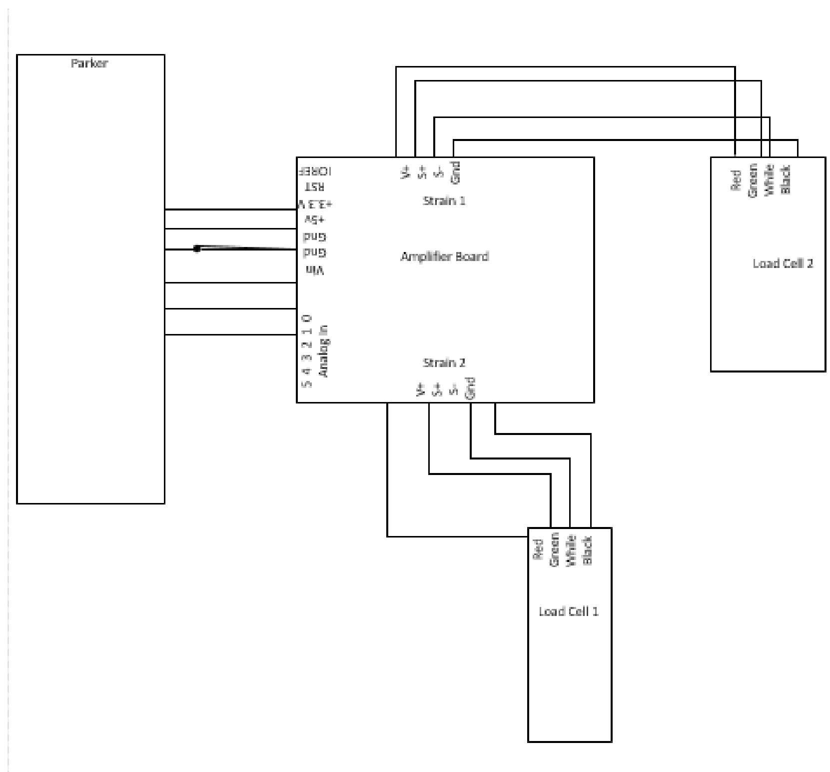

Figure G.7.1. Wiring diagram of Load Cells

Figure G.7.2. Drag Test Theory FBD

Figure G.7.3. Mount on DSC boat bow

Figure G.7.4. Mount on Solar Splash wood boat

Procedure and Data:

First, the data acquisition system was prepared (See John Hilderbrand's work with the Parker 711 and VeeCan for onboard testing setups) and connected to the load cells using the wiring diagram shown above. Then the VeeCan and a cell phone using its GPS for velocity readouts were placed in the DSC hull with a GoPro for video recording the output of the VeeCan and phone displays. The first four tests used a 13' steel cable the final test used a 26' steel cable to connect the boats. Once both boats were placed in the water, the boats were connected by the cable. The DSC boat hade the cable already attached to its mount and the other end of the cable was then attached to the mount on the Solar Splash boat. Once connected, the DSC boat was then pulled near the bank by the bridge and then pulled across the lake to the BTS at steady speeds. This allowed for steady-state regions where average drag could be measured at roughly constant speeds. Once the data was collected the offset was measured on the load cells and that was subtracted from the measured drag data. The data was then plotted in the figures below with power law fits. The power law was used to check if the data shows good results because drag should vary by the square of the speed. These drag values allow us to predict the boat drag before takeoff and know how our hull design performs. This gives a benchmark for future improvements. The videos for these tests can be found at T:\Engineering Competitions\SOLAR BOAT\2016-2017\2. Hydrofoils\Hull Drag Testing\Videos, and the raw data is in T:\Engineering Competitions\SOLAR BOAT\2016-2017\2. Hydrofoils\Hull Drag Testing\CANLogs. The reduced data is located in the file T:\Engineering Competitions\SOLAR BOAT\2016-2017\2. Hydrofoils\Hull Drag Testing\Hull Drag Test Data.xlsx.

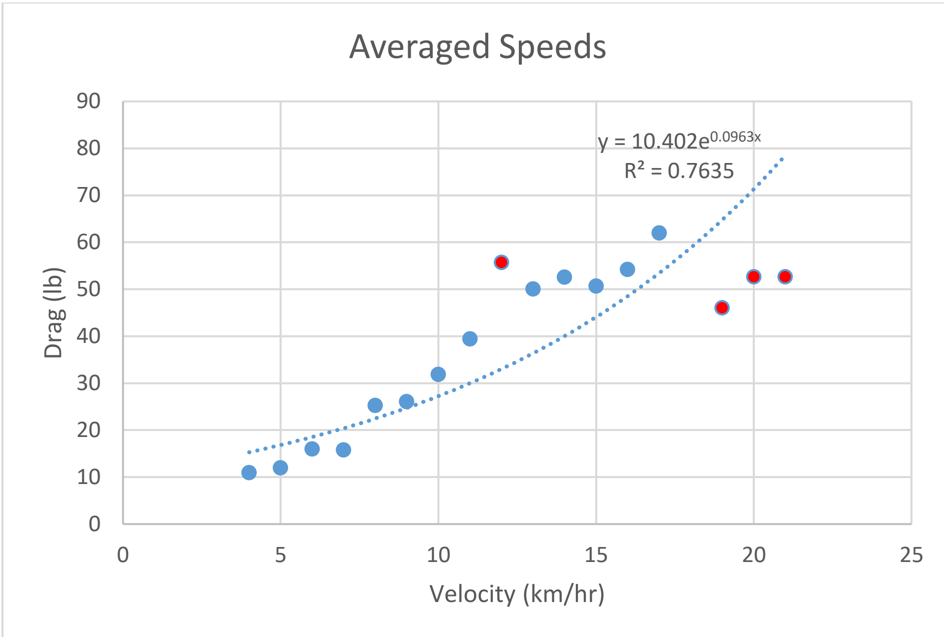

Figure G.7.5. 1/19/17 Drag Data

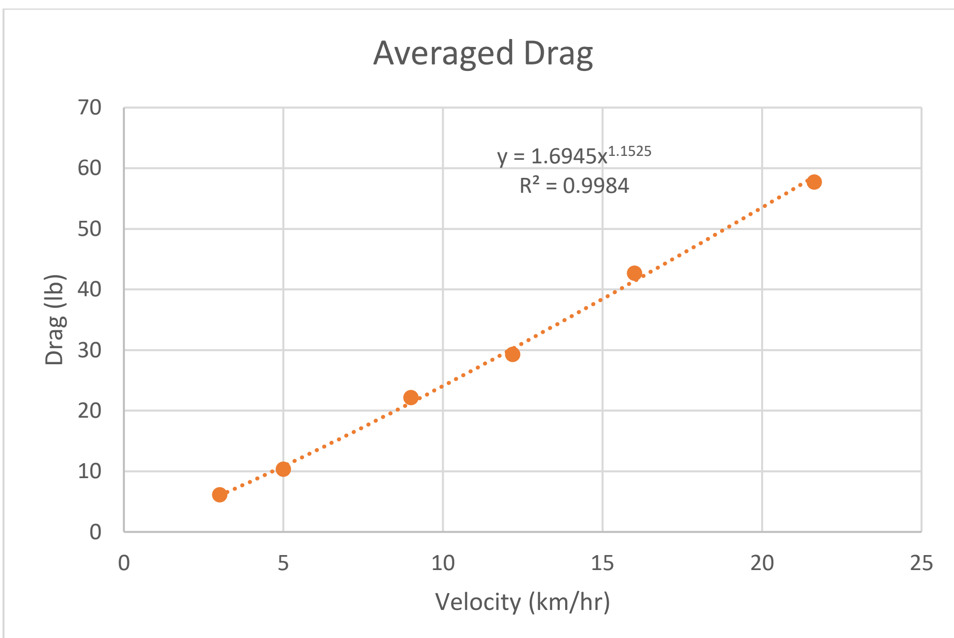

Figure G.7.6. 1/22/17 Drag Data

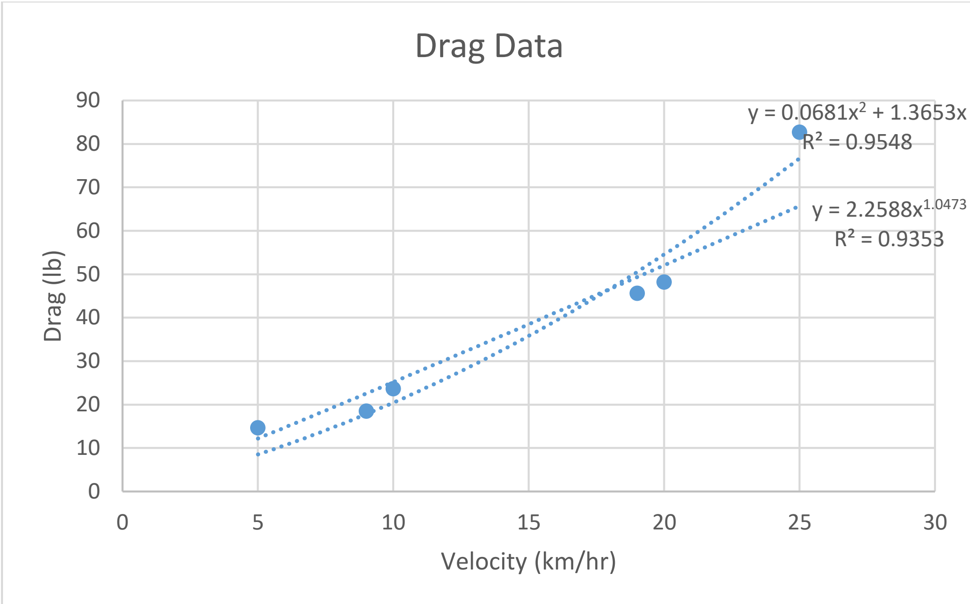

Figure G.7.7. 1/24/17 Drag Data

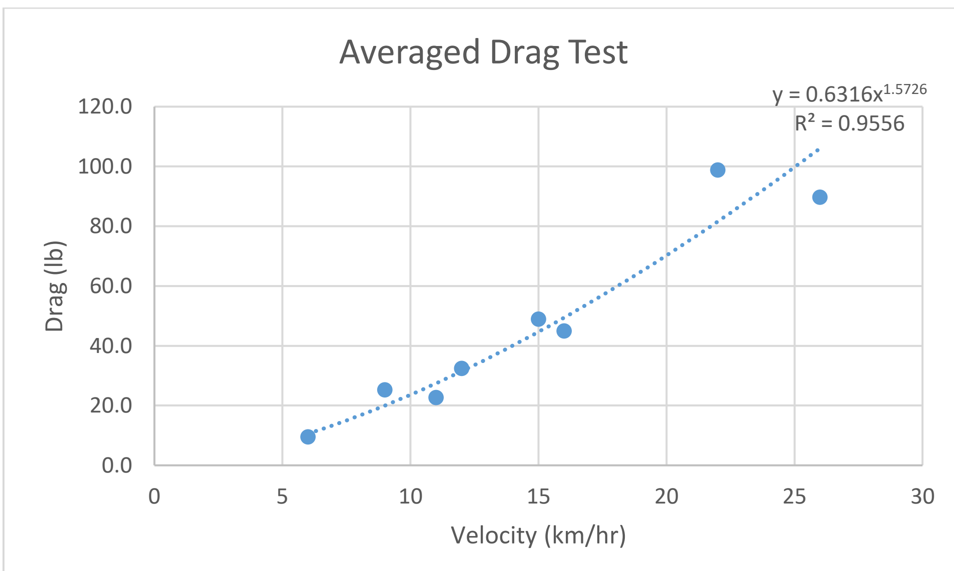

Figure G.7.8. 1/25/17 Drag Data

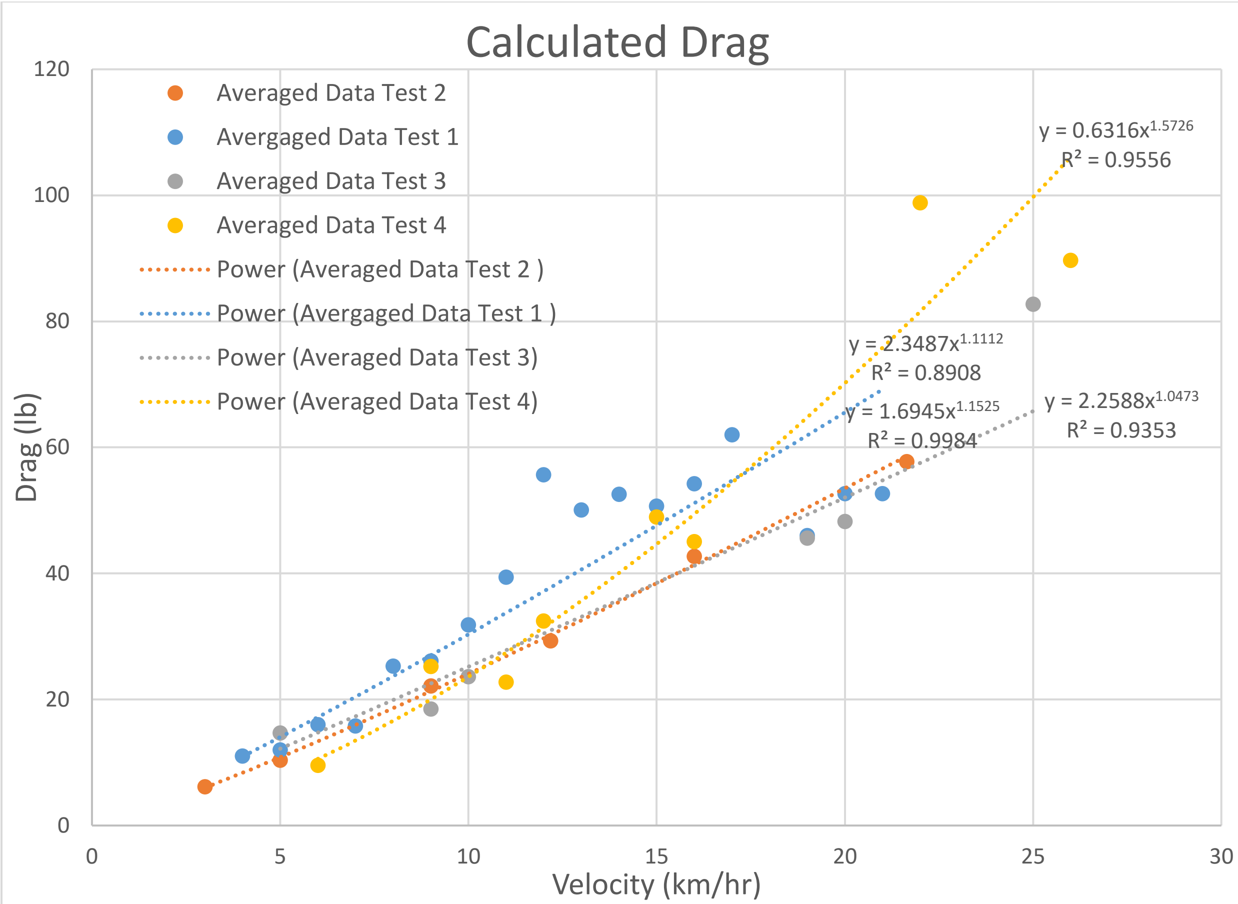

Figure G.7.9. Combined Data for Comparison

APPENDIX H: PROPELLER MANUFACTURING

How to Generate Propeller Tool Paths Using CAMWorks

Author: Jordan Burns

Objective

I intend to use this paper to help beginners get a quick grasp on how to use CAMWorks (CW) with regard to propeller tool paths. Caleb Tanner (2016) has made extensive video guides as well as a systematic outline for his propeller work. These videos are very detailed and I highly recommended using them to gain further knowledge of the process (T:\Engineering Competitions\SOLAR BOAT\2015-2016\6. Propellers\Caleb Tanner\Guides\Propeller Walkthrough). My intent is not to duplicate or ignore his guides, but rather create a simplified guide for students with little to no experience using CAMWorks. This guide should answer many of the questions you might have going into this project as well as give a solid foundation for machining propellers for the team. In this paper, I will first introduce the basic parts of CAMWorks that you will use. Then I will give an overview of how we approach the propeller tool paths. Following that, I will give a detailed systematic walkthrough of my current propeller tool path set-up (tapered hub). Finally, I will include a list of terms and brief explanations that should help you understand CAMWorks better.

Introduction

I assume in this guide that you already made a propeller in SolidWorks. Tieg (2015) and Tanner (2016) both have very good guides on how to transfer OpenProp designs into SolidWorks and make a propeller body. The basic setup and order of operations for making the propeller goes as follows: Part, Sketches, Features, Toolbox, Operations, Toolpath, Simulation, Troubleshooting, and Machining. Please note that this guide does not integrate the new stock tabs as mentioned in the body of the main report. These can be added with some ease once you fully understand the rest of the processes.

1. **Part:** This is your propeller. Start with this in SolidWorks and use its dimensions to determine stock size.
2. **Sketches:** You will create these SolidWorks sketches prior to entering the CW tabs. These are outlines of things that you will need for constraints in CAMWorks (such as stock size, or

clamp avoid areas to restrict the tool path). You can always go back and add sketches, but it is best to have them done before generating toolpaths. If you do not, then CAMWorks will have to recalculate every time you change a sketch.

3. **Features:** This is where you will define your *mill part setups (MPSU).* You will have a new MPSU for every time you change the clamp set-ups on your stock. You will also choose the types of cuts here, i.e. 2.5 axis, multi surface, areas clearance (AC), pattern projects (PP). *See last page for more definitions on terms*. You will also be able to restrict the cut depth here. **It is best to start with features before moving into operations. You can start with operations, but this gets confusing.**
4. **Toolbox:** Here you tell CAMWorks what tools you will be using. This was very confusing to me at first, because I did not know much about tools. I will explain later the basic tools you will need. Any extra tools are usually a special case and you will probably know why you need it when you get to that point.
5. **Operations:** Here you will set up contain areas (CA) and avoid areas (AA) to restrict the tool path. You will also set up things such as tool size, tool speed, path direction, cutting depth, etc. This is where you fine-tune all of the cuts.
6. **Toolpath:** Once all of the operations are finished you can generate the toolpath. You can always go back and change things after you generate a toolpath. You will have to use the toolpath in order to see what needs to be changed, but it is best to have the bulk of the operations set up before generating a tool path. Once you generate it, CAMWorks will ask you to recalculate tool paths every time you make a change in a previous step.
7. **Troubleshooting:** This is where you will spend a majority of your time. Ideally, the toolpath would be good on your first run through, but as you create propellers with different blade or hub sizes, you have to change minor things along the way. I hope to give a very good template, but the details will change depending on the propeller you are working on. I especially recommend using Tanner's video guides to help with troubleshooting.

Overview

Now I will explain the basic concept for setting up the propeller toolpath. This is not the step-by-step, but more of a general overview to help you see the big picture. You will need to have a stock size that is slightly larger than your propeller (this size is determined on a case by case basis, but I recommend at least 0.2 inches on each side of the propeller to allow for the ball mill). Be sure to include enough space (maybe an inch) on the ends of the stock for precision pins. You can always go measure the plate in the mill to determine the best precision pin distance. You will need 2 clamp setups for each side (total of 4). This requires 4 mill part setups. Figure 1 shows a basic stock surrounding a propeller.

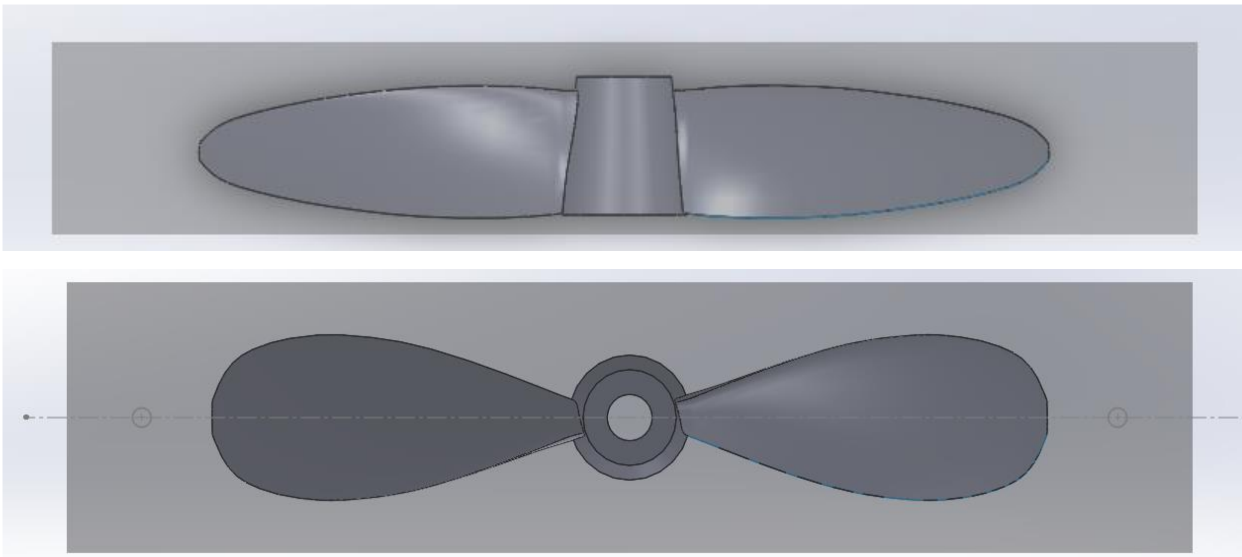

Figure G.6.1. This is the stock surrounding the propeller body. Above is the side view, below is the top down view. You can also see the precision pin sketches here.

I have found that cutting down from the small part of the tapered hub first works best. This is due to how you clear the hub, which I will explain later.

For side 1 (which I tend to call "A") you will need the following:

1. The first thing you will do is drill precision pinholes. These serve to help align the second side along the same cut axis as the first. See the explanation at the end of this paper.
2. Face the stock down to the propeller. Since there are clamps, you will need to split this into 2 different mill part setups, which I label A1, and A2. Note: if you machine tabs on an oversized stock and use these as the clamp setups, then you can eliminate A2 completely. You will be able to perform all of the facing on one setup. See report for more information on tabs.

Figure G.6.2. A1 face cut

3. Next, you will need to Area Clear (AC) the blade and hub.

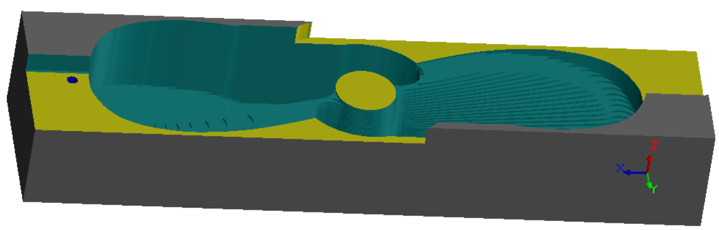

Figure G.6.3. A1 Area Clearance (hub and blades)

4. Then you will Pattern Project the blade. Since this is the first side (A1), you can start the cut at the tip of one blade and sweep all the way to the other blade tip. For the bottom side it will be different.

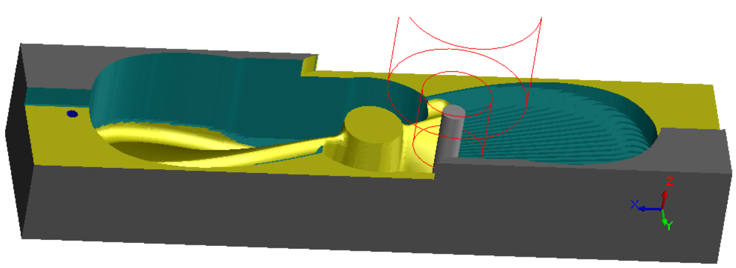

Figure G.6.4. A1 Pattern Project (hub and blades)

5. Now you need to face the remaining tabs. This will require a clamp change as well as a new mill part setup: A2.

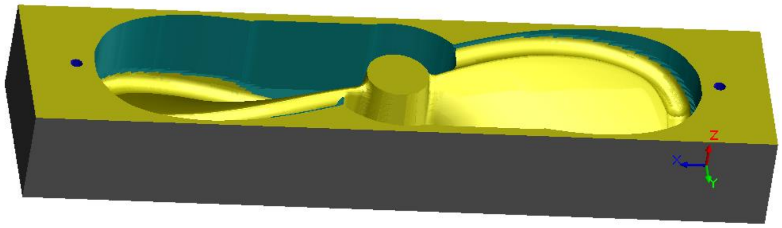

Figure G.6.5. A2 final facing

For side 2 (I label as B1 and B2) you will do the following:

1. Face the stock around the hub down to the hub surface this will obviously require you to flip the stock and set up new clamps. I call this mill part setup B1.

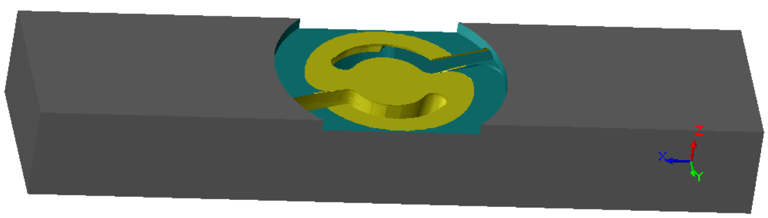

Figure G.6.6. B1 hub face

2. Next, drill the hub holes. Since you will need a splined bushing, there will be two different size hub holes.
   Once the holes are cut, you will then clamp the propeller through this center hole. The following steps will clear the blades completely from the stock, so this clamp is necessary to hold the propeller to the table.

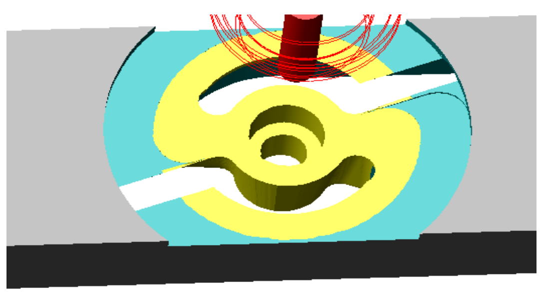

Figure G.6.7. B1 Hub holes

3. Now, using another mill part setup (B2) cut another area clearance over the blades.

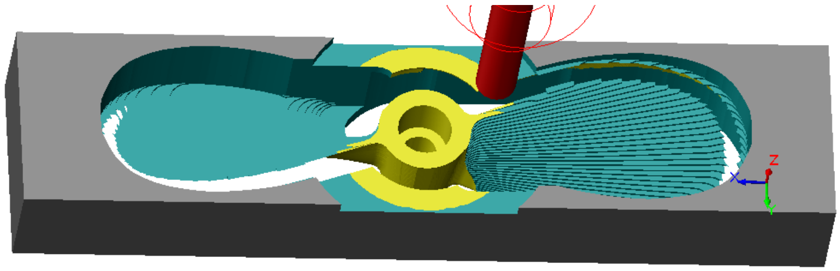

Figure G.6.8. B2 Area Clearance (blades)

4. Finally, you will do the last pattern projects to finish the blades. This requires two operations. Since it will be clearing the blades from the stock, it is best to cut from tip to hub. This reduces the amount of vibration along the blades as the bit cuts.

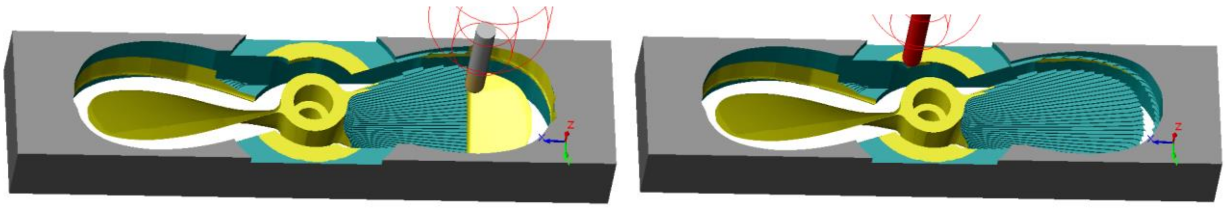

Figure G.6.9. B2 Pattern Projects (one for each blade)

<u>Step-by-step instructions</u>

Start by loading your propeller into SolidWorks. The first thing you will need to do is set up the appropriate sketches that you will need in order to create the tool path, check to see that your toolbox is correct, and ensure that your post processor is correct. The post processor is a file path that is located on the S:drive as well as the T:drive. You can find a copy in my folder under the following path: T:\Engineering Competitions\SOLAR BOAT\2016-2017\7. Propellers\5. CamWorks. The following steps should help you move quickly through the CAMworks processes:

<u>Tools</u>

I highly recommend watching Tanner's third video (<u>3 Editting CAMWorks Data)</u> in order to understand Tool crib setup. Do this before moving on. You can find this video at T:\Engineering Competitions\SOLAR BOAT\2015-2016\6. Propellers\Caleb Tanner\Guides\Propeller Walkthrough. I recommend starting at time 00:02:05 and watching to the end. You will also find how to choose your post processor in this video.

The basic tools you will need are as follows:

Flat end mill (3/4 inch): Use this tool for facing, area clearance and some large pockets.

Ball end mill (1/2 inch): Use this tool for the pattern projects on the blades.

Drill (1/4 inch)/Center drill/Ream: Use these tools for the precision pinholes.

***Flat end mill (1/2 inch):** I needed this size to mill the hub holes.

*You may need some smaller flat end mill bits for the hub holes (determined by the size of the holes).

Sketches, Planes, Origins

See Tanner's video: 2 Setting up sketches.mp4 for more details on creating sketches. You do not need to watch this video, but it will help if there you are confused about sketches. Caleb uses different sketches than I do, but the concept is the same.

Planes: Start by making a TOP PLANE and a BOT PLANE in SolidWorks (reference geometry). The bottom plane will be about 0.2 inches offset from the bottom of your hub. This will change depending on your stock size and how much material you want to face below the hub (second side). Offset the top plane from the bottom a distance equal to your stock thickness.

Stock sketch: This is the width and length of your stock. Set this on the BOT PLANE. You will use this later to create your stock.

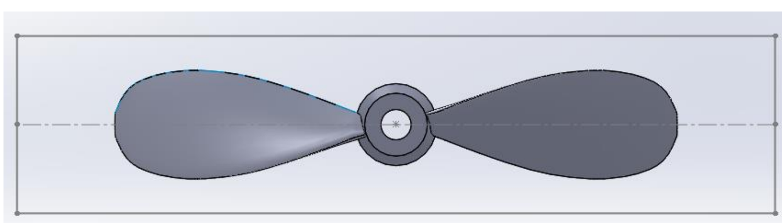

Figure G.6.10. Stock sketch

Face contain: This is how you keep the blades contained from hitting the clamps. You use this as a contain area in A1 and an avoid area in A2. It helps to set this sketch on the top plane.

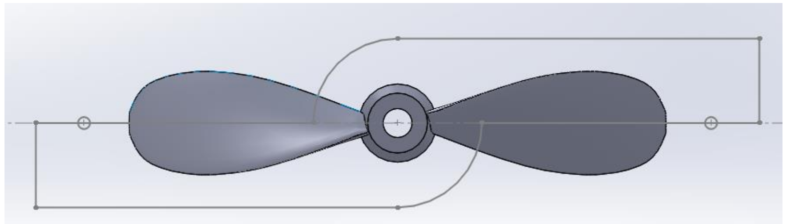

Figure G.6.11. Face sketch

Precision pin sketch: These are simply 0.25-inch diameter holes that are set a specified equal distances from the center of the hub. Set these on the top plane. I used 13 inches apart, but this distance will change depending on your propeller size. I had to drill my own holes for 11 inch blade propellers.

Origin points: You will need an origin point for both sides of the stock. These are just point sketches where the origins of your operations will be. I label them AO and BO. Set AO on the center of one of the precision pinholes on the BOT PLANE. Set BO on the same precision pin center but set its reference plane as the **TOP OF THE HUB.** Be careful not to set it on the top plane since after you face down to the hub that material will no longer be there.

Extra shapes: Sometimes it may be necessary to add some extra "shapes" around the hub in order to allow the tool bit to cut properly. I won't go into much detail here, because these shapes are determined by your propeller geometry. Once you have your tool path set up, you will be able to see where you should add more contain or avoid areas.

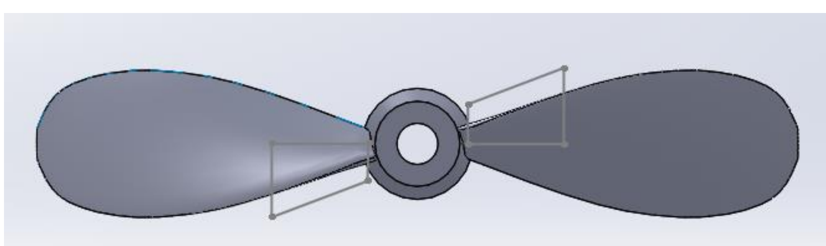

Figure G.6.12. Extra sketches

Features Tab:

Create 4 mill part setups. Two mill part setups will be selecting the top face of the hub, and two mill part setups will be selecting the bottom of the hub. I recommend naming them A1, A2, B1, B2 for clarity. Note: for all Multi Surface Features I recommend using Area Clear/Pattern Project. Also, most features can be setup by right clicking on your mill part setup tab.

1. **A1:** This is your first clamp setup where you will create precision pins, face, and cut out the blades on the top side.
    a. **Create a 2.5 axis hole feature** and select a drill/ream on the precision pin sketches. I recommend setting a depth that will be about 0.25 inches below the top of the hub. This ensures that there is enough depth after you face the stock (usually 0.6 inches works, depending on your stock size).
    b. **Create 2 Multi Surface Features** and select all faces. One will be for facing, and the other will be for the blade AC and PP.
2. **A2: Create 1 Multi Surface Feature** and select all faces. This will clear the tabs left by the clamps in A1.
3. **B1:** This is the first clamp setup on the bottom side. The goal is to clear the hub in order to put the clamp in the center.
    a. **Create 1 Multi Surface Feature** and select all faces.
    b. **Create 2 Pocket (2.5 axis) Features.** Rough/Finish or Rough, Rest, Finish work well. These will cut the hub holes.
        i. **Select the large hole first and set the end condition as the end of the hole.**
        ii. **Select the small hole second and set the end condition as the end of that hole.**
4. **B2: Create 2 Multi Surface Features** and select all faces on each. Now that you have cut the hub holes, you will add a clamp to through the hub. Here is where we clear the remainder of the propeller from the stock.

Operations Tab:

Once all of the features are complete click "generate operation." This will generate the operations for the features you have created and move you to the operation tab. If something remains pink in the features tab, that means there was a problem and CAMWorks could not create the operation.

1. **A1: Double click the mill part setup and set the origin as AO.**
    a. **Centerdrill, Drill, Ream:** these do not need any contain areas. Ensure correct tools.
    b. **First AC and PP:** Set a contain area for the shape in figure 11. Ensure that you do not cut deeper than the top of the hub plane. Use the ¾-inch flat end mill.

    c. **Second AC and PP:** These will cut the blades. Use the following shape as contain areas. Be careful that you do not cut into the precision pins (may need to set the pinholes as avoid areas). I typically offset the area about 0.4 inches, but this will depend on blade and stock size (you will have to troubleshoot this later). Use the ¾-inch flat end mill for the AC and the ½-inch ball end mill for the PP.

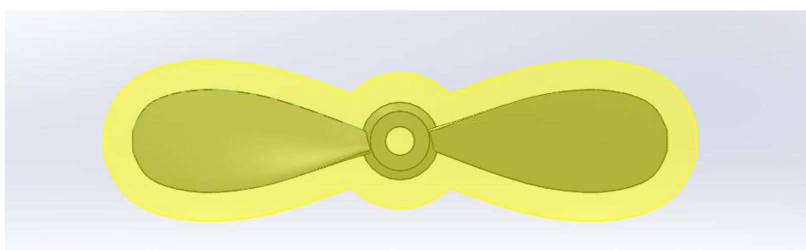

Figure G.6.13. Blade/hub contain area

2. **A2: Double click the mill part setup and set the origin as AO.**
   For the AC and PP use the sketch used in figure 11 as an avoid area now. (When using avoid areas, you must set the blind distance—see terms at the end of this paper for help).
3. **B1: Double click the mill part setup and set the origin as BO.**
    a. **First AC and PP:** Set a contain area around the hub center and offset it until it is tangent with the width of the stock.

   b. **Hub holes:** There will be a rough and a contour for both the large and small holes. The only things that you should need here is to ensure the correct tools.

4. **B2: Double click the mill part setup and set the origin as BO.**
   a. **First AC and PP:** The AC will use the same contain area from figure 13. The PP will use a similar contain area, but should be restricted to one blade. *Use necessary extra sketches and contain areas here to ensure that the toolpaths come out correctly*
   b. **Second AC and PP:** Delete the AC (you do not need it since the previous one cleared both blades. The PP should then be contained to the remaining blade.
   c. **Note: It is very important here that both PP have the toolpath starting from the tip and cutting towards the center. You can change this setting when you change the operation parameters, which I will explain next.**

<u>Defining Operation Parameters:</u>

Now that you have finished all of the operations, you must go into every operation and change the parameters such as the following: tool used, feed/speed, cut amount, rapid and clearance planes, tool path pattern, etc. This step can be very time consuming and confusing at first. Once you get the hang of what settings to use for different operations, then it will become much easier. Here I would also highly recommend watching Tanner's sixth video (<u>6 Defining Operations_Edit Definitions)</u>. This video is very long and confusing at times because Tanner links multiple operations and later unlinks them. I recommend doing every operation individually until you get the feel for which operations can be linked without messing up the tool path. You will find after a while, that almost all of similar operations have similar parameters. The major exceptions are when you need to restrict the cut depth, or change the cutting patter (such as in the pattern projects).

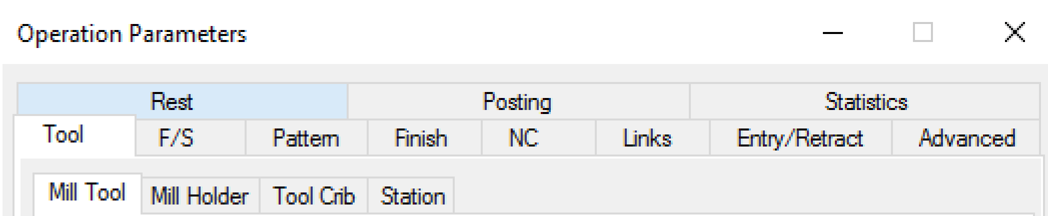

Figure G.6.14. This is the operation parameters tab. Here is where you fine-tune the machining specifications.

Tool Path, Simulation, Troubleshooting:

Once you finish, you can generate the tool paths. Use the simulation to watch how the machine will cut the part. You should spend a lot of time watching the simulation before taking your part to the mill. Using both the tool path lines and the simulation, you can then begin troubleshooting. You can watch Tanner's trouble shooting video for help. Typical things to watch for will be cutting too deep, setting your avoid areas correctly, changing the sizes of contain areas—especially on pattern projects, and ensuring that you never cut through where a clamp will be positioned. After everything is finished, you can post process each mill part setup individual. Tieg's guide is very helpful for fixing any G-code errors before starting machining. I hope that this guide helped you better understand how to use CAMWorks. Feel free to email me at jordanburns@cedarville.edu and I will try my best to answer any questions that you might have. Also, never hesitate to ask Dr. Dewhurst or Mr. Kinsinger for help. Even if they cannot answer you directly, they might be able to point you to someone who can.

Terms:

Avoid Areas (AA): Setting a sketch as an avoid area will restrict the tool path from entering that area. What I have found is that avoid areas work more as avoid volumes. The tool will not enter the volume that is covered by the avoid area. If you leave the avoid area as a flat 2D sketch, then the tool can still cut everything above it as long as it does not pass through that area. In order to restrict everything above that area, you must set the end condition up to either a face, up to stock, or some blind distance.

Contain Areas (CA): Contain areas work much like avoid areas, except that they force the tool path to remain within the selected area. They work more like a "fence" that keeps the tool path within their area, regardless of what plane it is on.

2.5 Axis Features: Think of this type of feature as a step. The machine will cut in an x-y direction on a specified z level. It can move to a new z level but not while it is moving in an x-y direction. This is good for pockets or facing, when you need to cut a level—move down—and cut more.

Multi Surface Features: This enables the machine to cut in x-y-z directions at the same time. This is required for cutting tappers and blades on the propeller. The reason you would not use this is if a 2.5 axis feature could do the job just as well. A 2.5 axis feature is simpler and requires less code in some cases.

Area Clearance (AC): This is what I usually will use when clearing the hubs, blades, or even on most facing cuts. This fast/crude cut removes a lot of material quickly. Even though it is “crude”, it still can hold very tight tolerances if necessary.

Pattern Project (PP): This type of cut is much slower and closer to the part. It is not that the AC cannot get close to the part, but rather one is a roughing and the other is a finish. PP lets you finish the blade, and usually uses a ball end mill.

Precision Pins: These holes allow you to ensure that the second side you cut will be exactly in line with the first side. Theoretically, you could cut the first side at any orientation in your stock (as long as it fits, although it is best to keep it as square as possible). As long as the axis passing through the precision pins is along the machine axis, then when you flip the part over the pins will line up the stock along this axis.

Post Processor: This file allows CAMWorks to generate the GCode for your tool paths.