ECEN4024/MAE4374

Senior Design Capstone

Turboelectric UAS/Propulsion, Semester 2

Final Documentation

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Team Introductions

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Design Introduction

Turboelectric propulsion is a relatively new field of study in the world of unmanned aerial system propulsion. Conceptually, it is a simple concept: a turboshaft is mechanically coupled to a generator, converting the mechanical energy from the turboshaft to electrical energy. This electrical energy is then conditioned to desired values and then distributed to propulsors. The interest in turboelectric energy is in the properties of the hydrocarbons used. Turboelectric systems have been observed to reduce overall fuel consumption and emissions while demonstrating comparable ranges, speeds, and versatility to traditional propulsion methods. Essentially, turboelectric systems provide a more environmentally friendly and economic solution to aviation problems while retaining performance. Since the system features electric conditioning, there exists the option for versatility in the electrical side of things, such as the implementation of batteries and switching circuits.

Turboelectric propulsion can exist at multiple scales as well. From smaller UAV applications, like the one utilized in this project, to larger, manned aircraft on the scale of a Cessna aircraft and even, at least conceptually, very large passenger aircraft such as the NASA N3-X concept aircraft.

This project tests three turboelectric systems at different levels of power generation: a five-kilowatt system, a seven-kilowatt system, and a thirteen-kilowatt system (power generation is on the UAV scale) and seeks to demonstrate efficiency, both mechanically and electrically, performance, scalability, power conditioning, and electrical versatility.

This project's funding comes from the C3 FirePoint competition, sponsored by the United States Army Combat Capabilities Development Command Aviation and Missile Center, and after providing concepts to the competition and advancing to the next round of the competition, this project has a budget of $10,000.

Design Concept

Turbine Theory

A gas-burning turboprop engine is at the initial stage of the power development process for the turboelectric power plant. The turboprop uses the burner within its first, primary turbine engine to ignite the energy-dense, hydrocarbon fuel, thus converting and ultimately transferring it into mechanical energy through a rotating shaft at the turboprop's final stage.

After the fuel ignites within the burner of the primary turbine engine, the hot, fast-moving exhaust gases travel through an exhaust duct into a separate, secondary turbine. Once the gases reach the second turbine with the required amount of velocity, the second turbine rotates. This secondary turbine mechanically drives a gear-reduction-box to lower the RPM further. Finally, the gearbox drives the turbine output driveshaft. The output shaft is then mechanically coupled to the electric generator shaft.

There are several benefits of choosing the mechanically uncoupled turboprop. The first turbine engine and the second turbine from one another as opposed to having one turbine engine driving an output shaft directly. One of these reasons is that the primary engine turbine can achieve angular velocities of 150,000+ RPM. Whereas, the generator has a maximum angular velocity of 10,000 RPM due to its voltage limitations and KV rating.

By uncoupling the turbines, the secondary turbine effectively drives at a lower speed than the first due to mechanical and friction losses. The speed is then reduced and maintained via the gear-reduction-box to its final, usable, angular velocity.

The generator load attached to the secondary turbine is therefore not mechanically bound to the primary turbine. This uncoupling allows for the power-producing, first turbine to have increased time to react to the applied load on the turboprop system by the electric generator. All of this helps prevent the turbine from stalling or being damaged under heavy or quickly changing loads.

The highly energy-dense hydrocarbon fuel burned within the turboprop engine allows for a higher endurance versus the system's overall weight and size when compared to a battery-only setup. Once this power is converted into electrical energy, it can then be utilized to drive electric motors that can be used to potentially increase the overall efficiency of the aircraft by directly increasing its propulsive efficiency. This is accomplished by using fans or propellers to displace large amounts of air. Mattingley & Boyer define thermal, propulsive and overall efficiencies as follows. (Mattingly & Boyer.)

$$\boxed{\eta_T = \frac{\dot{W}_{\text{out}}}{\dot{Q}_{\text{in}}}}$$

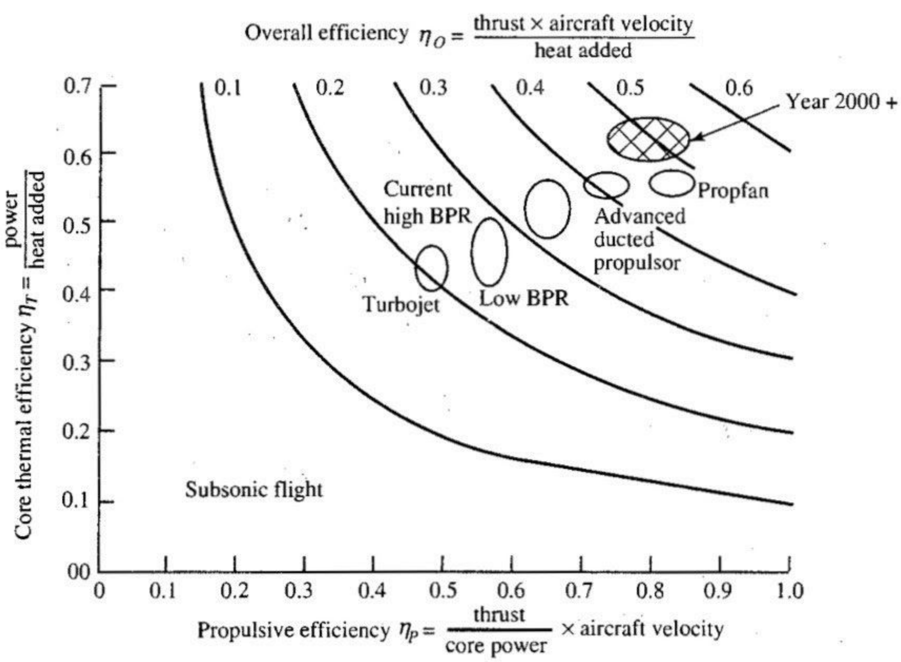
where η_T = thermal efficiency of engine
$\dot{W}_{\text{out}}$ = net power out of engine
$\dot{Q}_{\text{in}}$ = rate of thermal energy released ($\dot{m}_f h_{PR}$)

$$\dot{W}_{out} = \frac{1}{2g_c}\left[(\dot{m}_0 + \dot{m}_f)V_e^2 - \dot{m}_0 V_0^2\right]$$

$$\boxed{\eta_P = \frac{TV_0}{\dot{W}_{out}}}$$

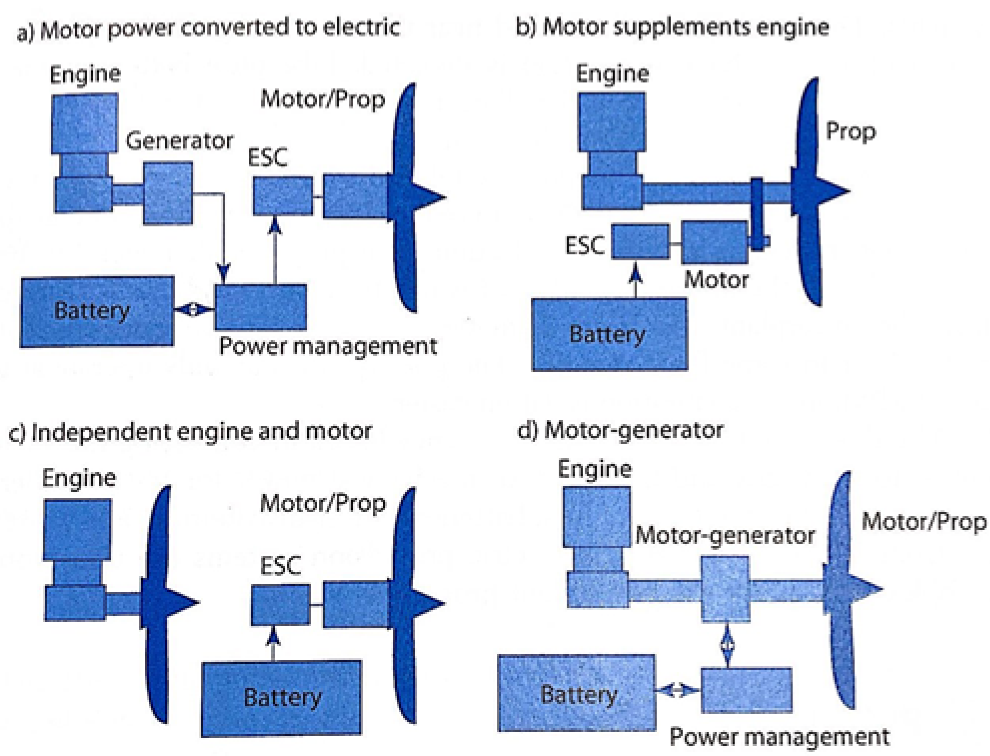
where η_P = propulsive efficiency of engine
T = thrust of propulsion system

V_0 = velocity of aircraft
$\dot{W}_{out}$ = net power out of engine



(Mattingly & Boyer.)

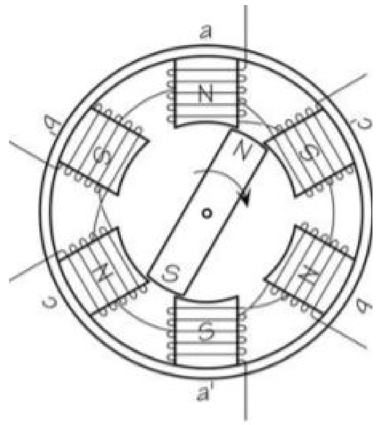
There are multiple types of configurations that the turboelectric system can be setup to operate within. Gundlach shows an example of four different hybrid system configurations. The configuration chosen to test on the 5 kilowatt, 7 kilowatt and 13 kilowatt systems was option "a," shown below. This is considered a series hybrid propulsion system. (Gundlach.)



(Gundlach.)

Electrical Theory

The power being generated from the mechanically coupled generator is three-phase alternating current AC electricity. We want to use a three-phase generator for the sheer reason you can deliver more power with it with a similar sized single-phase generator. This is created using an induction generator. Simply, the rotor (which has magnets attached to it, connected to the conductors for each phase) of the generator revolves around a stator (which is made of a single magnet) at some rpm to induce a current in the phases. A diagram of this system and the polarization of the magnets can be seen:



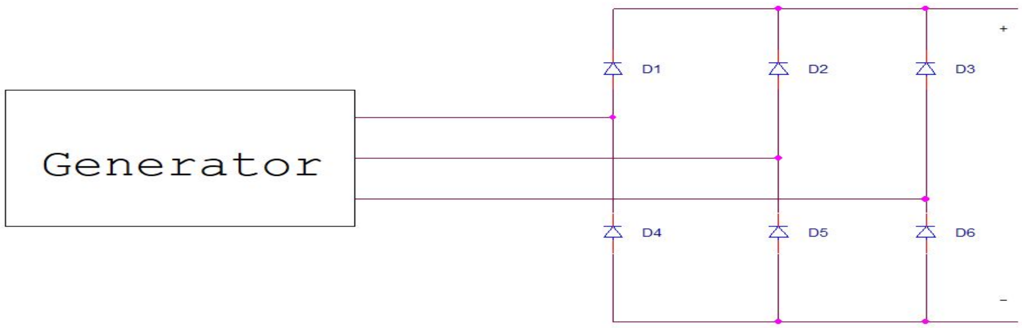
Each of the voltages that come off of phases A, B, and C will be the same except they will have a 120^0 phase shift. Each phase will look like:

$$V_A = V \angle 0^0$$

$$V_B = V \angle -120^0$$

$$V_C = V \angle -240^0$$

The three-phase power coming from the generator must be rectified to direct current (dc), so as to condition the power. To do this, we use a three-phase full-bridge rectifier. This system uses a network of diodes to restrict the current flowing to the load to the proper polarization. It works like this: when a phase is positive in polarity entering the system and the voltage exceeds the diode forward voltage, that phase of the rectifier will conduct and deliver power to the load. The other two phases will be negative in polarity and be delivering power the opposite way which, to the load, appears positive. The diode schematic looks like this:



The average output of the rectifier can be described as:

$$V_o = 1.654 V_{P,L-N}$$

Where Vm is the peak line-to-neutral voltage of the generator. Described in terms of the line-to-line voltages, the average value of the output is:

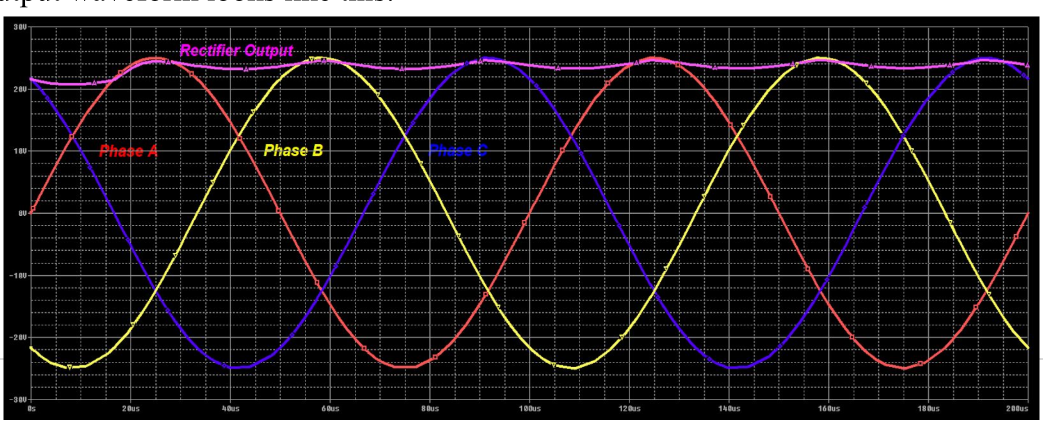
$$V_{P,L-L} = \sqrt{3} * V_{P,L-N}$$

$$V_0 = \frac{3}{\pi} * V_{P,L-L} = .955 * V_{P,L-L}$$

The three phase rectifier will create a rippled "DC" output with the magnitude described by the equation above and the frequency of the signal equal to:

$$f_{out} = 6 * f_{gen}$$

The output waveform looks like this:



We want as smooth of a DC output as we can possibly get for power conditioning purposes. An easy way to “rectify” this issue is the use of a smoothing capacitor. The smoothing capacitor allows for a charge to be stored and removes the ripple, or at a minimum will minimize the ripple (Copello). In its simplest form, the capacitor will be shunted from hot to ground across the output of the rectifier. The conductors will have some internal resistance, and with the capacitor will exhibit a discharge rate proportional to the RC time constant, **τ**.

Knowing that the alternating voltage of a single phase can be modeled as:

$$V_L = V_m sin(\omega t)$$

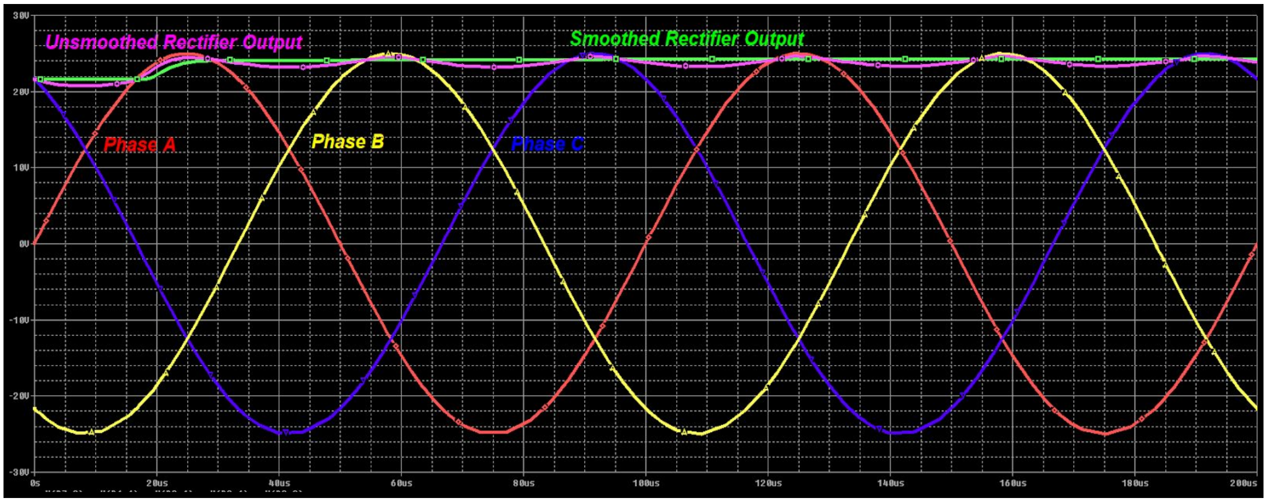
Where V_L is the changing voltage based on a sinusoidal pattern with a magnitude of V_M, a loop can be set up such that

$$R_L C \frac{dv_L}{dt} + v_L = 0$$

And in solving for V_L using the laplace transform technique we can find the discharge rate of a capacitor given a steady state input.

$$v_L = ke^{(\frac{-t}{R_L C})}$$

Where k is a constant, usually the maximum seen voltage. Strategically choosing a large capacitor such that we have a large time constant will mean that the fluctuation in DC voltage ripple will be elongated. (Copello) This makes it so that in the time it takes to go from the peak of one phase to the peak of the other, the discharge rate will be so slow that the voltage appears to be a true DC. Implementing such a capacitor will provide an output such as the waveform below.



With this, we have a "true DC" and this can be readily sent into the electronic speed converter. However, the resistance, R_L, is defined by several parameters, most notably the length of the conductors chosen. (Glover, J. Duncan, Thomas J. Overbye, and Mulukutla S. Sarma)

To determine the resistance of the wire, we must know the operating temperature of the system, T. Once that is known or determined, the resistance of the conductors can be derived as:

$$R_{DC,\,T} = \frac{\rho_T l}{A} \text{ in ohms, } \Omega$$

Where ρ_T is a known conductor resistivity dependent on the temperature of a system and A is the cross sectional area of the conductor. (Glover, J. Duncan, Thomas J. Overbye, and Mulukutla S. Sarma) Generally, the longer the conductor, the lower the resistance. In small systems such as this, resistance is non-negligible and can cause power losses in the conductors. However, the losses are very minimal, given that the only resistance in the system is that in the conductors.

The final power conditioning element in this system is an electronic speed controller, known as an ESC. The ESC acts as an inverter, meaning that the voltage is changed from DC to AC. However, the output of the ESC is controlled via digital logic (or the use of a potentiometer), meaning that the AC voltage magnitude changes depending on the user. That means the user can adjust the voltage output which will change the throttle of the aft propellor.

Standards and Guidelines

In order to safely build and test the Unmanned Aircraft System, we needed to follow safety guidelines and ensure the airworthiness of the system. The table below shows the aircraft safety regulations and electrical regulations we considered required to follow, with a brief explanation of what each regulation is.

Regulation	Description
CFR 14-I-F-107	Small Unmanned Aircraft Systems
CFR 14-I-C-23	Airworthiness Standards – Normal Category Airplanes.
(ANSI) UAS Standardization Collaborative (UASSC)	ANSI UASSC Standardization Roadmap For Unmanned Aircraft Systems
OSHA Standard - 29 CFR - 1910.137	Electrical, PPE
OSHA Standard - 29 CFR - 1926 (All Sub Parts)	Protection against recognized hazards
NFPA 70E	Electrical Safety in the workplace

The most important of these is safety. Electrical equipment in the UAS field can be highly sensitive and currents of 100 or more amps are very common. As a result, proper electrical safety equipment is required during operation. All of the OSHA standards listed recognize these safety requirements and outline the equipment needed. The NFPA 70E standard covers essential electrical safety in the workplace. The other standards cover airworthiness of small scale and commercial aircrafts, and what is considered “airworthy.”

Aircraft Realization

Parts List

Part	Number	Cost Per Unit	Cost
Kingtech K100TP0	1	$ 3,850.00	$ 3,850.00
Great Planes Rimfire 1.60 Brushless Motor	3	$ 179.99	$ 539.97
15kW 12090 Brushless Motor 50-130Kv	1	$ 457.50	$ 457.50
EDF Ducted Fan JP Hobby 120mm+12s motor 760Kv	1	$ 591.73	$ 591.73
Castle Creations Pheonix Edge 160HV 50.4V 160A ESC	1	$ 259.99	$ 259.99
Arduino Uno	1	$ 22.00	$ 22.00
MDS200A 3Phase Full Bridge Rectifier	1	$ 31.89	$ 31.89
DC-DC Step Up Converter	1	$ 11.99	$ 11.99
10uF 80V Capacitor	2	$ 7.33	$ 14.66
ATMega Programmer	1	$ 16.95	$ 16.95
Power resistor (100W, 0.01ohm)	2	$ 11.63	$ 23.26
ATMega328P	2	$ 2.08	$ 4.16
Diode	2	$ 42.19	$ 84.38
Power Mosfets	4	$ 3.09	$ 12.36
10AWG Conductor (20ft)	1	$ 43.25	$ 43.25
STPS200170TV1 Diode	1	$ 24.32	$ 24.32
LTO100FR2500FTE3 (100W, .25ohm)	1	$ 13.56	$ 13.56
TEH140MR030FE (140W, .03ohm)	1	$ 15.35	$ 15.35
RH05036R00FE02 (50W, .36ohm)	1	$ 5.36	$ 5.36
15FR090E (5W, .09ohm)	1	$ 2.71	$ 2.71
Flex Seal	1	$ 12.50	$ 12.50
AL-24P Aluminum Box	1	$ 7.20	$ 7.20
Master Airscrew K Series 16x8 Propeller	3	$ 12.45	$ 37.35
1500W Heat Gun Kit	1	$ 31.13	$ 31.13
Adjustable Boost Regulator	2	$ 11.95	$ 23.90
Female to Male EC5 Connectors (10 Pack)	1	$ 13.99	$ 13.99
1S LiPo Battery	1	$ 8.49	$ 8.49
710026-7 Terminal Compression Lug, 3AWG	12	$ 1.87	$ 22.44
Shipping			$ 48.35
		Total =	$ 6,230.74

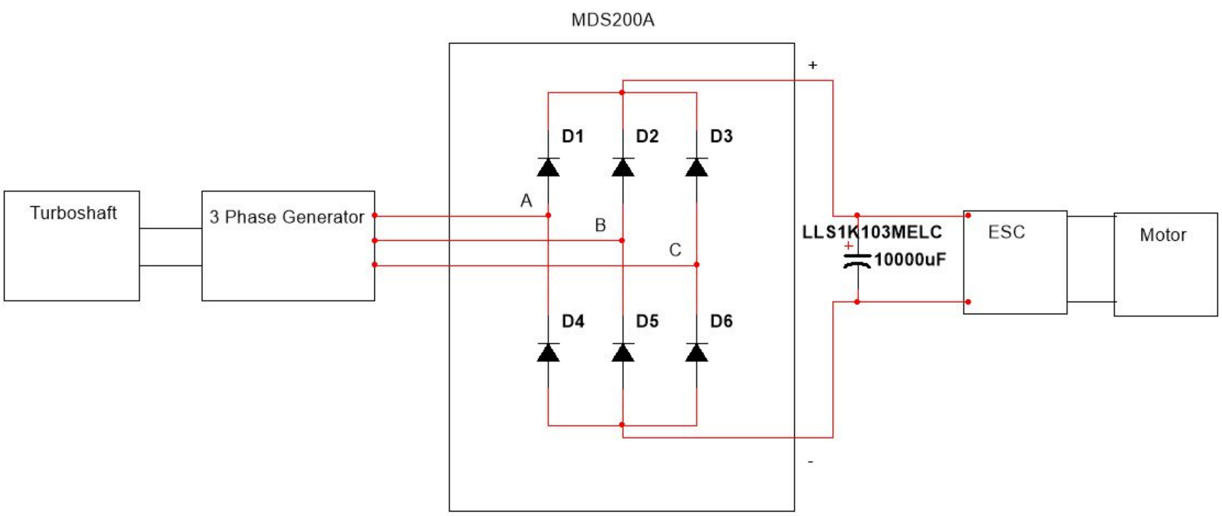
Selection Trade Offs

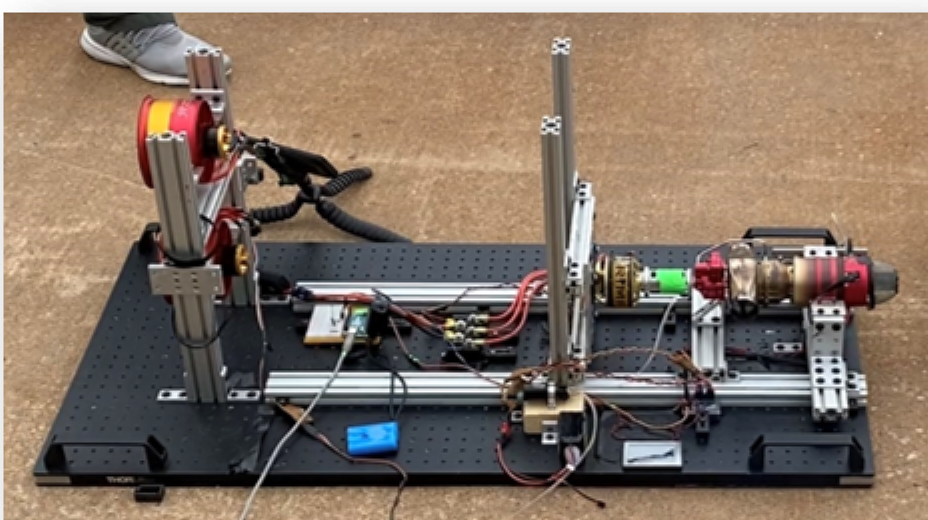
Since we have to account for a system on the kilowatt power scale, we need parts that are rated for higher voltage and currents. Following rpm/torque curves for our motors and following Kv (rpm/V) ratings for the motors, we could deduce the expected voltages that we would need to supply to the systems. For example, for the 5 kilowatt system, we deduced that 36 volts would be necessary to properly drive our motor. For safety, we assume 100% efficiency (which is wholly unrealistic) and got a current using P=IV. The max current we were anticipating was 138A. In transient conditions, voltage would spike but we weren't sure by how much, so we selected components of at least twice the voltage we expected, about 72 volts. To satisfy this, we needed larger parts designed for higher power applications. Our capacitor is rated for 80V and our 3-phase rectifier is rated for 1600V and 200A (the only reason the voltage is so high is because it was much harder to find rectifiers with ratings at our current level). All MOSFETs are rated at 60V (a tradeoff made necessary by the exponential rise in costs for higher rated power MOSFETS) and 200A and the diodes are rated for at least 100V and 200A. The only part that is not rated within these parameters are the conductors themselves. The 10-gauge wire is only rated for 40A, but the insulation of the wire can handle the heat created by the high current without compromising the conductors. Another point, using conductors at the rated level would have been bulky, expensive, and difficult to manipulate. The 10-gauge worked without a hitch, the only issue is in energy lost to heat, a tradeoff but the right call nonetheless. These parts are generally more expensive, due to needing to be larger and handle higher power, but thanks to modern advancements in materials, no individual part cost more than $100 and with a budget of

$10000 from the C3 FirePoint competition, electrical costs were very low compared to the costs of the motors, turboshaft, and generator on the MAE side of the project.

5 Kilowatt System

The 5 kilowatt system is as simple as it gets: the turboshaft coupled to the 3-phase generator which is rectified, smoothed, and delivered to the ESC to be used by the motor.

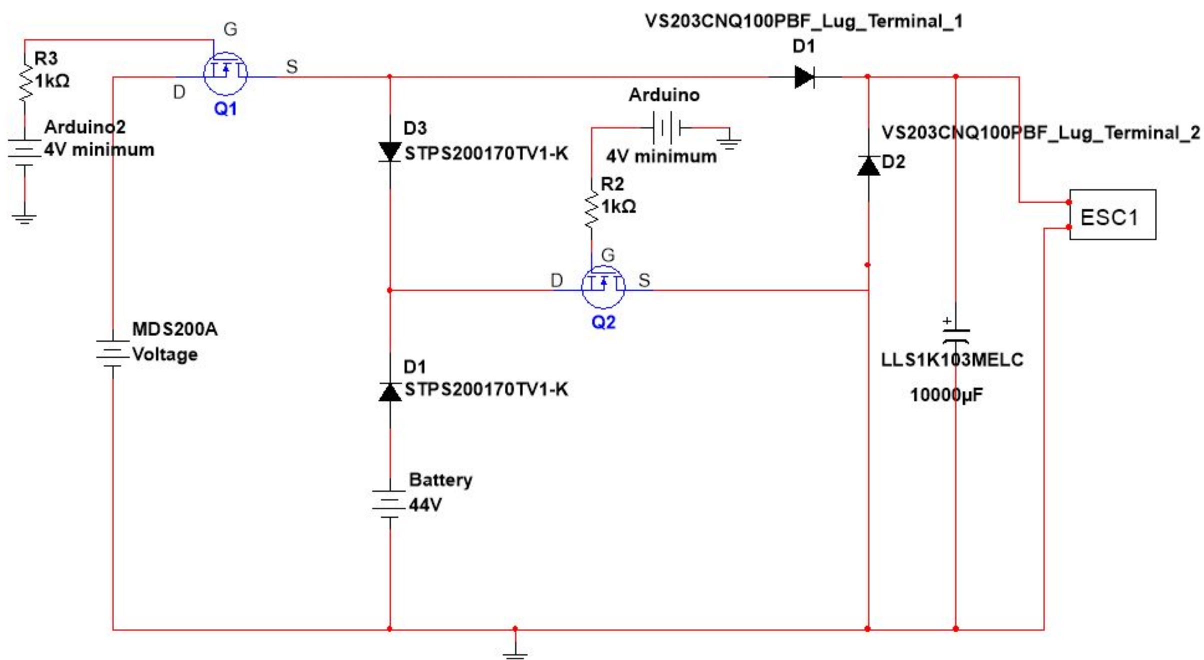




The purpose of the 5 kilowatt system is to test our concept, debug code, observe heat effects, and observe efficiencies. When this system was successful, we could readily move up the chain to higher power generation systems.

7 Kilowatt System

After the successful tests of the 5 kilowatt system, we were ready to test some new concepts in a higher power generation system. The circuit of the 5 kilowatt system would remain (the rectifier, the smoothing capacitor, ESC), however we wanted to introduce a battery into the system. To do this, we developed a switching circuit that could switch between turbine power and battery power. At the simplest level, all this switching circuit does is deliver turbine power to the motors while cutting off battery power and vice versa, delivering battery power and cutting off turbine power.



By controlling the Arduinos that deliver voltage to the gates of the MOSFETs we can control which source delivers power to the battery. The switching matrix for the switches indicated in the schematic is as follows:

Mode	Q1	Q2
Turboelectric	1	0
Battery	0	1

This circuit would test the system's ability to switch between sources and test reliability as well as gather transient and steady-state analysis to observe any effects we may not have foreseen.

Operating Procedure

Transport of System

This system uses the airframe of the Mugin Plus 4500 and includes all the propulsion and power components, as well as all the command and control components. Due to the limitation of the plane size, it can only be transported by Pickup truck or SUV. The plane is packed into three boxes during transport: the fuselage part, empennage, and wing part. If a pickup truck is used, then all the significant components, inside of their assigned boxes, need to be properly secured to the vehicle using ratchet straps. The wings are folded in three-parts and appropriately boxed, as a precaution, given that any of the wing parts can quickly fly out of the back of an open-air pickup truck. With proper loading, you can eliminate loss or breakage - as well as the chance of accidents - due to poorly secured loads.

Handling of the Fuselage

1. The wings, once dismounted from the fuselage, should be handled with care, due to the fragile material they are made of, which handled improperly might break easily.
2. The fuselage itself should be carried by two individuals, as its weight may reach up to 40 pounds with the engine, generator, and electrical components inside.
3. The fuselage should be carried from the bottom, preferably from the wheel mount points. Do not hold the fuselage by the exhaust nozzles; they are not made to properly support that amount of weight.

4. Disconnect all batteries from the system to insure that no DC power is flowing through any of the components.
5. If there is fuel inside the fuel tank, then the fuel lines must be all closed and safely tucked inside the fuselage.
6. It must be noted that if the fuselage is turned upside down, the fuel tank may leak fuel through its air exhaust port.

Handling of the wings and tail

1. The wings and tail are made from balsa wood in several places, making the airframe very fragile and prone to breakage when handling. They are the most fragile components of the plane.
2. The wings can be dismounted in three parts and can be fixed into one load in a proper box and covered. Do not attempt to transport the wings in high winds, or the wings could be damaged from improper handling.
3. It is essential to be careful when unplugging the servo wires that run along the wings and tail into the fuselage. After unplugging the servo wires, the wires should be taped in place to prevent them from falling inside of the wing or tail.
4. The V-shape empennage should be separated into two parts for transportation. The hinge that connects the two halves is a weak point and should not have forces applied to it.
5. If possible, bubble wrap or foam should be used when transporting the tail and wing, due to the jostling that results from a moving vehicle and the likelihood of something inside the car/truck damaging the surfaces of the plane components.
6. Secure the boxes with ratchet straps if transported by a pickup truck.

Setup of System at Operating Location

1. There are situations where the system should not be set up. Since water and excessive moisture can damage the electrical components and the mechanical components of this system, any air operations will be suspended prior to inclement weather. The vehicle has to be adequately covered in case of sudden rain.
2. If the air temperature is above 80-90 °F, then caution should be used to prevent overheating the electric components. The plane should not stay outside in the hot sun before trying to taxi, and it should not taxi on the ground long.
3. However, if the weather is good, the plane should be carefully unloaded and mounted. The wings and tail are the weakest points for the plane structurally, and they should be handled carefully to avoid structural damage that might delay any air operation.
4. The first step in setting up the plane is wiring the servo motors back up, and this can be accomplished by plugging them back into their respective extension wires (there is only one wire port at each intersection). Then the three-part wings and the tail should be assembled using the provided screws.
5. Once the plane is built and wired up, the battery can be plugged in and the servo motors can be tested. Once all ground testing is complete the fuel can be added and the batteries can be connected. Once the control systems are tested, the aircraft is ready to taxi.

Use of Developed Software to Acquire and Save Data

1. The purpose of this plane is not to log data; it is a proof of concept.
2. The plane has an onboard Arduino microprocessor that can be used to log any flight performance data. The Engine Control Unit (ECU) also stores the engine performance during flight.
3. Currently, there is not a system of variables that the Arduino is logging.
4. Separately, a program was developed for logging the internal temperatures of the system. This program utilized a separate Arduino along with a suite of thermocouples. The detailing of this program can be found in its package with comments, and it is not specified here.

Start-Up Sequence Procedures

1. Make sure that all of the required batteries are fully charged before attempting to power-on the turbine.
2. Tighten and secure all engine and generator mounting bolts that bind the engine/generator assembly to the UAS.
3. Tighten the electric motor base to the UAS.
4. Tighten the propeller bolts in an alternating sequence to properly secure the propeller to the electric motor.
5. Secure all the LiFe batteries (1) 3s and (1) 2s. Connect them accordingly:
    a. The 3s, LiFe battery should be connected to the turbine's ECU via the Dean's T-Connector to the fuel pump lead wire.

   b. The 2s, LiFe battery should be connected to the ECU in the "RX Aux" position.

6. Fill up the fuel tank to the desired fuel level and inspect it for leaks.
7. Secure the fuel tank.
8. Ensure that there are no air bubbles in the fuel line. If so, connect the GSU to the ECU to manually engage the fuel pump to remove air bubbles before start-up.
9. Connect the fuel pump wires to the turbine and ECU.
10. Connect the starter cable to the turbine engine and ECU.
11. Hook up the voltage divider connections to the rectifier and Arduino.
12. Verify the Arduino digital throttle signal, 5V+ and ground cables are connected to the "RX Throttle" position of the ECU.
13. Connect the user desired throttle controlling device to the ESC to directly control the throttle of the electric motor after start-up is initiated.
14. Turn on the ESC throttle controller. Make sure all of the connections are secured properly on the controller.
15. Verify that all wires are clear of the exhaust and rotating parts.
16. Connect the Arduino battery cable to power-on the Arduino and initiate the start-up sequence.
17. After the start-up sequence is successfully completed, (typically 45-60 seconds), the pilot can assume full control over the electric motor(s) throttle through its ESC(s). The Arduino embedded throttle controller will automatically adjust the throttle of the turbine based on the input load requirements from the electric motor(s).

18. To abort the start-up sequence or to turn-off the turbine, press the "Engine-Off" button at any point during engine operation.

Shutdown of the System and Getting the System Ready for Transport

1. The system should be given adequate time to cool down since the engine and electrical components can reach temperatures near to 300℉. The cooling wait time is a minimum of five minutes, and after that period, the system can be handled but still with precaution.
2. The most crucial step is the removal of the battery. The battery operates at a relatively high voltage and amperage and should be handled with care.
3. The battery should then be stored in a battery bag made from flame-resistant material like fiberglass.
4. The fuel lines should also be shut-off to prevent fuel leakage into the engine or an engine restart if the Arduino decides to try and restart.
5. Afterward, the transport of the system should follow the procedures outlined above in "Transport of System."

Test Procedures

A number of our tests were done on the existing 7 kW system this semester. We also bench tested the 5 kilowatt system several times and the 13 kilowatt system a couple of times prior to Spring Break. A more detailed list of test procedures can be found in the appendix, but this section will give you a brief overview of the operating procedures as it stands.

First, we tested the benchtop setups the same way as the existing 7 kilowatt turboelectric system in the mugin. We made an effort to place it on a flat surface with lots of free space on every side. We also ensured that we had a CO_2 fire extinguisher and one person was manning it every time we tested it. No other type of fire extinguisher was going to work because they expel materials that would be harmful to the engine. Materials that are not compatible with the engine system can damage the internal mechanism, so it's important to ensure the area of testing is clean and free of debris. Four people were required to test this device at a time, too. One to man the fire extinguisher, one for the throttle controller, one for the refueling and defueling, and one to monitor the safety of the area.

The way all three systems were designed was “plug and play,” meaning that you can disconnect all elements relatively easily. This means that in order to run the system the generator must be hooked up to the rectifier, then the smoothing capacitor, and then into the rest of the system. In addition, we have an in-line power meter we used to gather our measurements that would go after the smoothing capacitor and into the ESC. We would use a camera to record the LCD screen on the power meter.

After hooking up all of the connections, we had to ensure the exhausts were clear of obstructions, then connect the Arduino to the computer to run the startup code for the engine. After the engine has been run and data has been gathered, it’s as simple as allowing the engine to cool down completely, disconnecting the arduino and power supplies, and then all of the other connections to the power conditioning elements.

Results and Conclusions

Efficiency

Initial testing of all the 5 and 7 kilowatt systems using similar power conditioning elements produced the following table of results. The ‘*’ indicates a predicted value based on a model developed by the MAE team members.

Engine Power Level	Maximum Power Output after Conditioning	Electrical Efficiency, η
5,000 Watts	3,070 Watts	$\eta = 61\%$
7,200 Watts	5,240 Watts	$\eta = 72\%$
13,000	7730*	$\eta = 61\%$*

However, it should be noted that the 13 kilowatt system was built and the start-up sequence was initiated but there is no viable data because it was never brought up to maximum throttle due to COVID-19 cutting testing time short.

Some notable distinctions between these two systems we ran is that the 5 kilowatt system ran two parallel EDF’s (electric ducted fans) , whereas the 7 kilowatt system ran a single aft, 5-blade, 23” propellor with an electric motor. EDF’s produce higher thrust than a propeller of equal diameter. However, it is not normally a viable option to have an EDF large enough to produce thrust equivalent to a 23” propeller. This increase in efficiency is lost due to the lack of practicality of large EDF’s, therefore EDF’s tend to be less efficient by nature as compared to a propellered motor. Power losses occur in the form of heat losses in the rectifier (specifically the diodes inside them), resistive losses in the conductors, and mechanical losses in the conversion from mechanical to electrical power.

These tests showed that we can expect a typical electrical efficiency as low as 60% to just over 70% dependent on the load and setup. These systems each used 10 AWG tinned-copper, silicone-insulated conductors, but had different models of rectifiers. The 5 kilowatt system also had a smoothing capacitor in place. These differences skew the data comparison slightly from the 5 kilowatt and 7 kilowatt systems. The data gathered also implies that the higher power a system is, the more electrically efficient it is.

Specific Power

Another important figure of merit is Specific Power, $\mathbf{P}_{sp}$ in W/kg. Specific Power is a measure of the power generated by the system related to the system's mass. This value is useful in assessing the overall performance of each system.

Engineer Power Level	Specific Power (W/lb)	Specific Power(W/kg)
5,000 watts	387	853
7,2000 watts	415	912
13,000 watts	576*	1267*

Future Additions

Integrate 5 and 13 kilowatt system into airframe:

Originally, this semester's capstone project was to develop three fully functioning systems. Largely, this semester's goal was to show versatility and scalability of the basic power conditioning components for the turboelectric power system. However, the furthest we were able to go was test benching both the 5 and 13 kilowatt KingTech engines. Fully assembled, both systems were tested and data was gathered such as fuel consumption and electrical efficiency. However, due to concerns over COVID-19, we were unable to integrate either system into an airframe because we could not be in a labspace to build it.

Battery Recharge Circuit:

Originally, we designed a basic battery recharge circuit using a network of resistors to draw a specific current based on the C rating of our 9s battery. However, after further research, a battery protection circuit would've needed to be implemented and by the time we discovered that, it was too late to acquire the parts and further research is still needed.

Battery Augmentation:

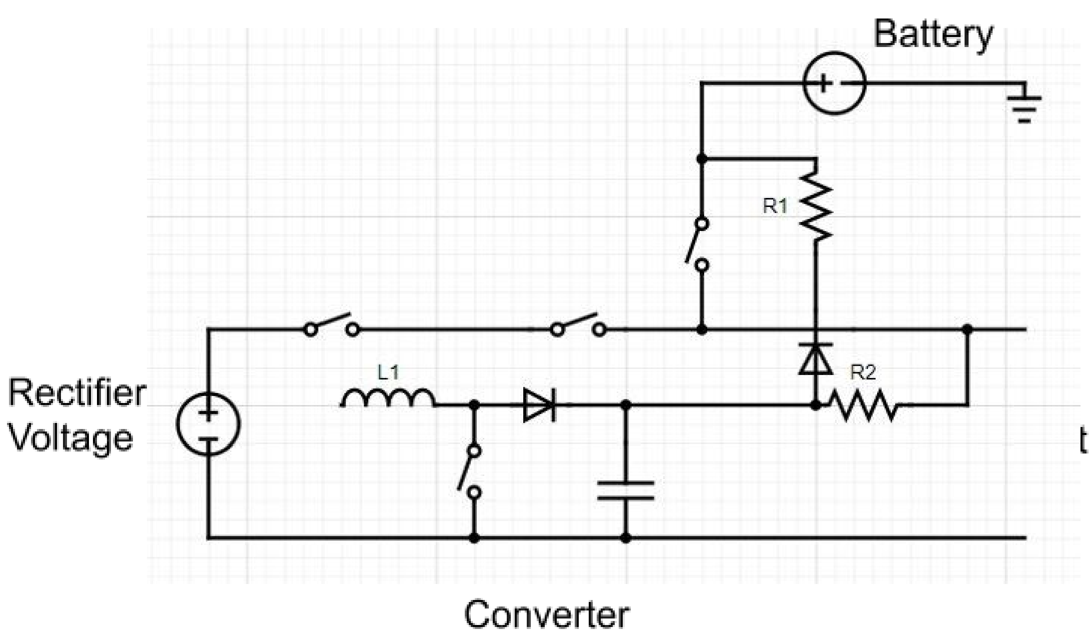
Due to back EMF from the system, the voltage output from the rectifier will lower. In order to raise efficiency of the system, augmenting the voltage from the turboelectric system with that of a battery can be implemented. However, that in itself is a serious undertaking because regulating the voltage from the battery output to match that of the turboelectric output requires a buck converter (if using a 9s battery) and in high current applications such as this, building a DC to DC converter is extremely challenging.

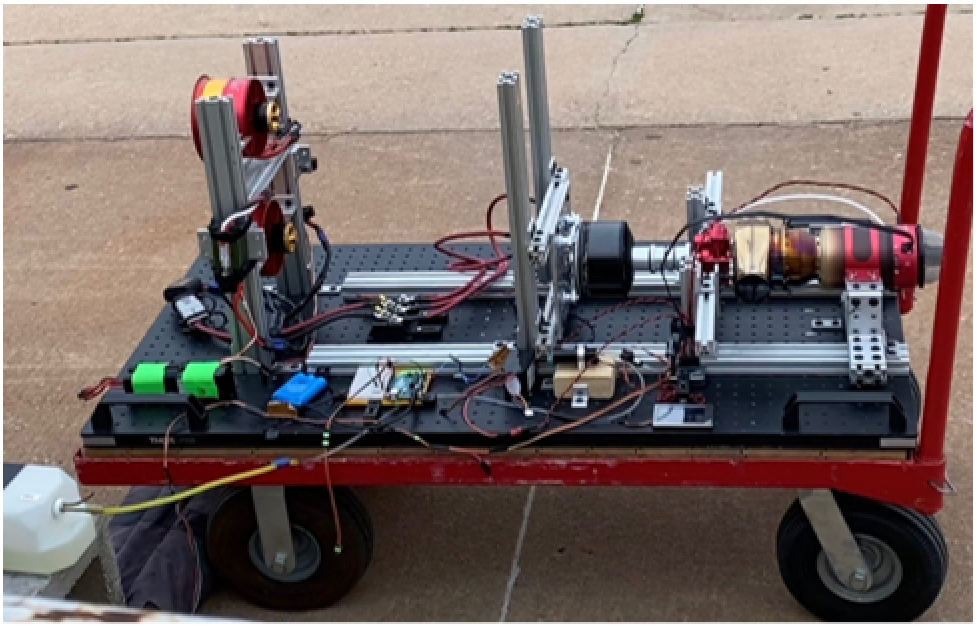
Distributed Propellers:

Originally, our plan was to modify the existing mugin for the 7 kilowatt system and wire two leading edge propellers. That way, we have three propellers running off of one engine. However, due to COVID-19, we never got to see that come to fruition because of the stay at home order.

Physical Switching Circuit:

Although we got to design the switching circuit, we never got to physically build it. This is something that was out of control due to COVID-19, but as a result, we have a very polished out and theoretically correct design that is ready for building.





Recommendations:

Acquisition of parts earlier:

In one of our original designs, we wanted to use a boost converter to raise the voltage coming out of the turboelectric power. That way, part of that voltage can be used to recharge the battery while also maintaining power to the motor and propellor. However, in order to do that, we needed a very specific inductor - one that was rated for super high current. High current inductors need to be specially manufactured and can take several months to be shipped. In addition, inductors of that sizing are extremely heavy, so take that into account when ordering one.

Small Scale Switching Circuit Testing:

Our design for the switching circuit is similar to that of the Fall 2019 capstone teams design. However, we made an effort to make all of our components rated for ultra high current and high voltage. It is recommended to build a small scale version of the switching circuit that can safely operate off of 9 volt batteries. That way you can test the coding and refine the logic to operate the MOSFETS correctly.

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[1] Ramspacher, D. (2015). Experimental Testbed for 1-MW Turboelectric Distributed Propulsion Aircraft. *Advanced Technologies & Aerospace Collection*.

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"Ampacity Charts." *Cerrowire*, Cerrowire, 2020, www.cerrowire.com/products/resources/tables-calculators/ampacity-charts/.

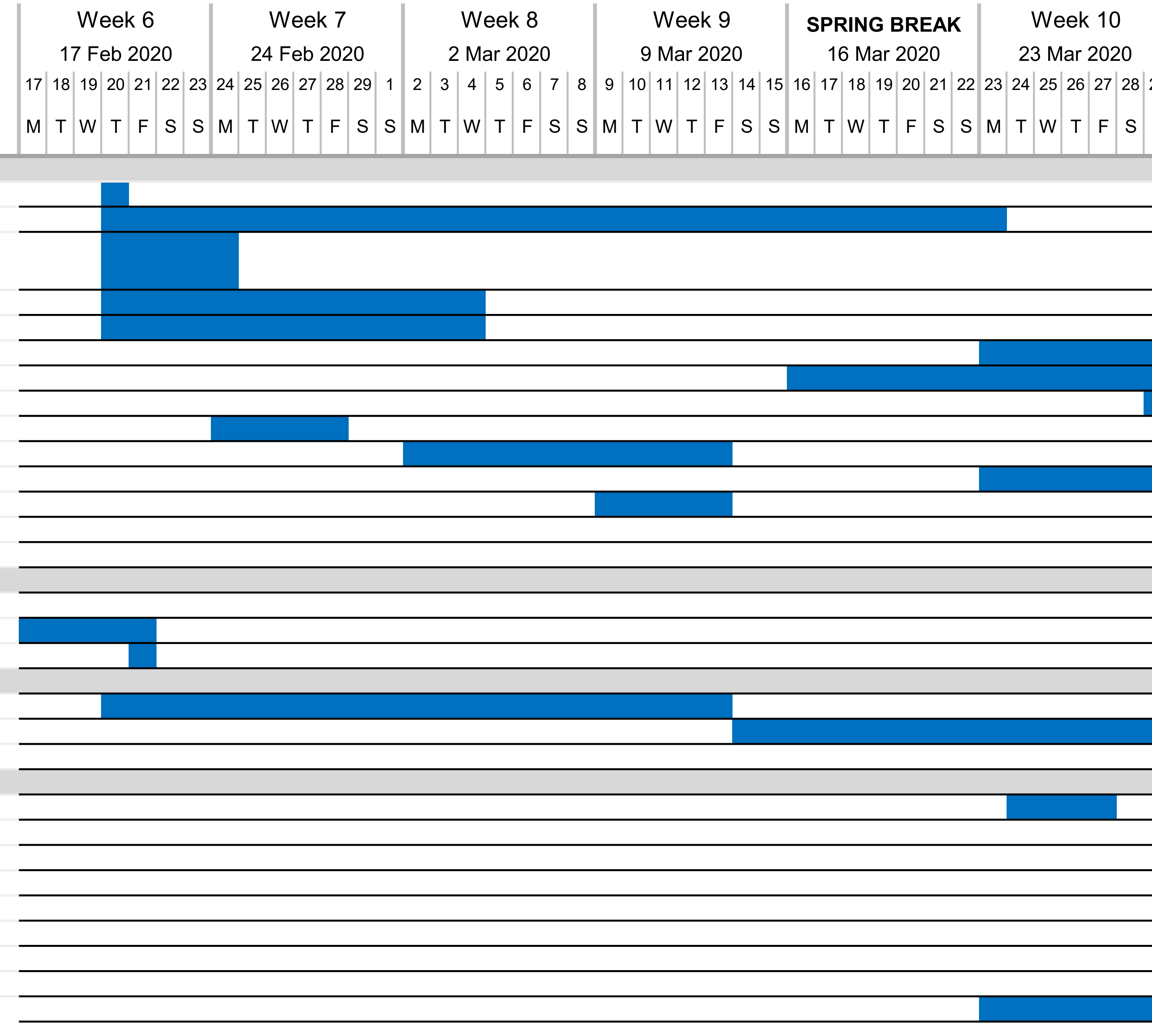
"Bare Copper Wire Data." *Ness Engineering Inc.*, www.nessengr.com/technical-data/bare-copper-wire/.

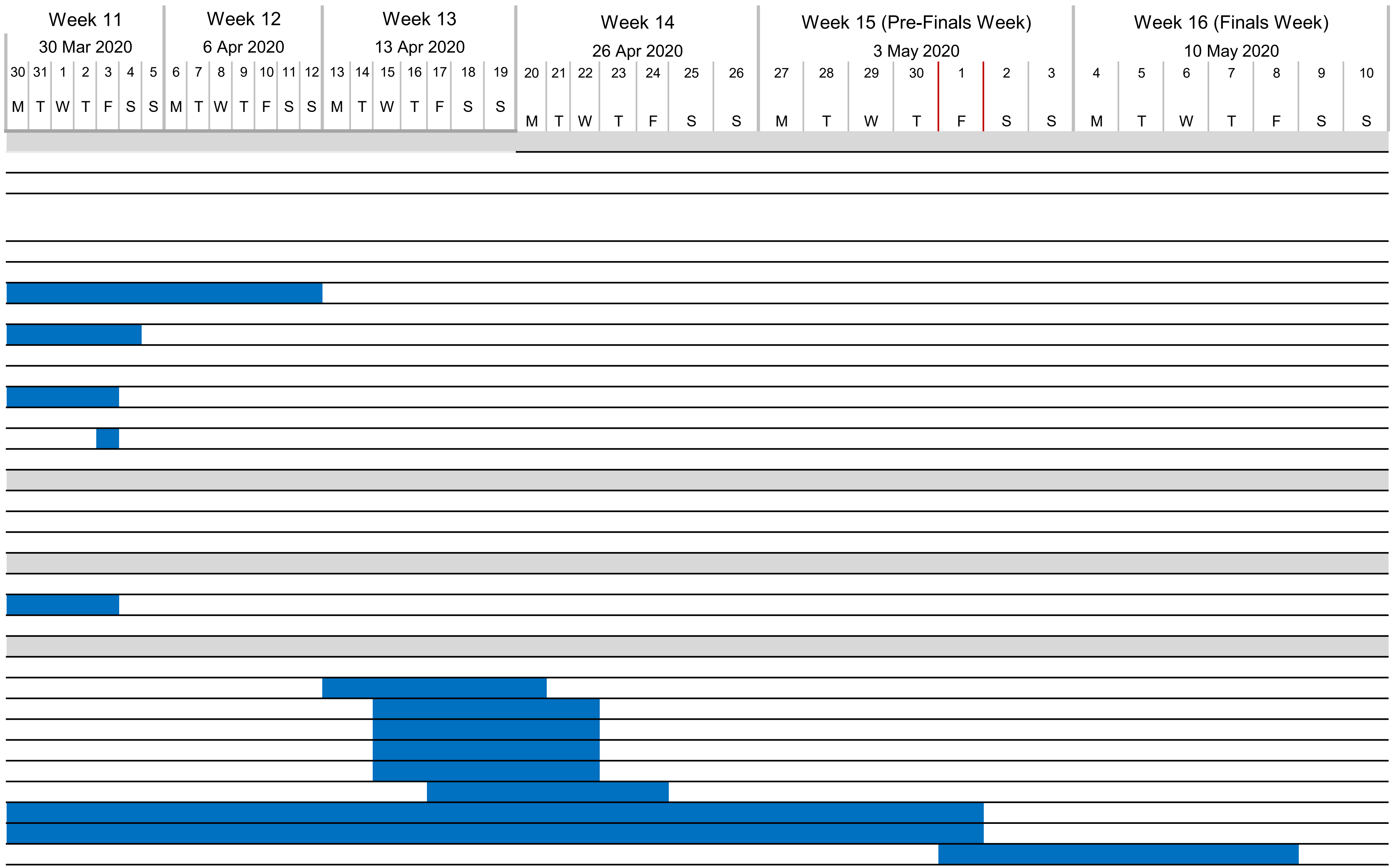
Turboelectric UAS - Prior to and Post COVID-19 Gantt Chart

Oklahoma State University

Project Start Date: 1/13/2020 (Monday)
Display Week: 6
Project Lead: Cole Replogle/Max Lewis

WBS	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
1	**System 1: K60TP (7kW)**			-			-
1.1	Ground test	Cole	Thu 2/20/20	Thu 2/20/20	1	50%	1
1.2	Flight test preparation	Cole	Thu 2/20/20	Mon 3/23/20	33	0%	23
1.3	Finish stability and control calculations	Cole	Thu 2/20/20	Mon 2/24/20	5	0%	3
1.4	Schedule a pilot	Cole	Thu 2/20/20	Wed 3/04/20	14	0%	10
1.5	Construct switching circuit	Max	Thu 2/20/20	Wed 3/04/20	14	0%	10
1.6	Distribute power	Max	Mon 3/23/20	Fri 4/24/20	33	0%	25
1.7	Print wing mounts	Cole	Mon 3/16/20	Sun 3/29/20	14	0%	10
1.8	Integrate wing mounts on Mugin	Cole	Sun 3/29/20	Sat 4/04/20	7	0%	5
1.9	Order electrical components	Cole	Mon 2/24/20	Fri 2/28/20	5	0%	5
1.1	Build electrical system	Max	Mon 3/02/20	Fri 3/13/20	12	0%	10
1.11	Test electrical system	Max	Mon 3/23/20	Fri 4/03/20	12	0%	10
1.12	Build recharge system	Max	Mon 3/09/20	Fri 3/13/20	5	0%	5
1.13	Electrical system integration	Max	Fri 4/03/20	Fri 4/03/20	1	0%	1
1.14	Speedfest flight	Cole	Sat 4/25/20	Sat 4/25/20	1	0%	0
2	**System 2: K45TP (5kW)**			-			-
2.1	Finish test stand	Cole	Mon 2/03/20	Sat 2/08/20	6	100%	5
2.2	Finish electrical circuits	Max	Sat 2/08/20	Fri 2/21/20	14	50%	10
2.3	Firepoint C3 test	Cole	Fri 2/21/20	Fri 2/21/20	1	0%	1
3	**System 3: K100TP (13kW)**			-			-
3.1	Finish electrical system designs	Max	Thu 2/20/20	Fri 3/13/20	23	0%	17
3.2	Order electrical parts	Max	Sat 3/14/20	Fri 4/03/20	21	0%	15
3.3	Build electrical system	Cole	Mon 4/13/20	Fri 5/08/20	26	0%	20
4	**Post COVID-19 Rescoping**						
4.1	Rescoping agreement	Max	Tues 3/24/20	Fri 3/27/20	4	100%	4
4.2	Project Poster	Max	Mon 4/13/20	Mon 4/20/20	7	100%	4
4.3	ABET Criteria Report	Max	Wed 4/15/20	Wed 4/22/20	7	100%	4
4.4	Decommissioning Guide	Max	Wed 4/15/20	Mon 4/20/20	7	100%	4
4.5	Maintenance Manual	Max	Wed 4/15/20	Mon 4/20/20	7	100%	4
4.6	User Manual	Max	Wed 4/15/20	Mon 4/20/20	7	100%	4
4.7	Final Design Presentation	Max	Fri 4/17/20	Fri 4/24/20	7	100%	4
4.8	Final Project Report	Max	Mon 3/30/20	Fri 5/01/20	33	100%	33
4.9	Journal Article First Draft	Max	Mon 3/23/20	Fri 5/01/20	40	100%	40
4.1	Journal Article Final Draft	Max	Fri 5/01/20	Fri 5/08/20	7	100%	7




Week 11
30 Mar 2020
Week 12
6 Apr 2020
Week 13
13 Apr 2020
Week 14
26 Apr 2020
Week 15 (Pre-Finals Week)
3 May 2020
Week 16 (Finals Week)
10 May 2020
30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10
M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S

OKLAHOMA STATE UNIVERSITY
NCL STANDARD OPERATING PROCEDURE

This document is for use by the Project Team to develop a Standard Operating Procedure (SOP) and sent to the NCL Safety Review Board. **The completed SOP should be shared with all the members of the team.** The SOP should be revised whenever a significant change to the location or scope of work occurs. The NCL Safety Review Board (SRB) is available to assist in completion or review of the SOP. For questions, please call (405) 744-5915 or email ceatncl@okstate.edu. Submit the completed SOP to the NCL SRB by emailing an electronic copy to ceatncl@okstate.edu with the subject heading: SOP_<Team/Group name>. Save the file name in the following format (<team/group name>_<date-of-submission> Ex: ImpactTester_2018-01-31). Please allow at least two business days for approval or requested revisions. Hand written documents will not be approved.

The following SOP generally follows under:

☐	SOP is for a general lab operation/process that could apply to several chemicals
☒	SOP is for a specific protocol/experiment/procedure
☐	SOP is for a specific chemical or class of chemicals with similar hazards

Section I.

Project Title:	Turboelectric Powered Unmanned Aircraft System		
Principal Investigator/Project Manager:	Kidd/Fala MAE 4223	Department:	Mechanical and Aerospace Engineering
Email:	James.kidd@okstate.edu	Phone:	(405) 744-5900
Project Duration:	Spring 2020, February 17 through May 8		

Location of Fabrication/Testing Include room number(s) as appropriate

CEAT North Labs		UAFS	
ATRC		Richmond Hills	Outside, north side of building
Other			

OSU Contact Person:	Cole Replogle	Phone:	918-978-1928

Local (Field) Contact Person:	Kylar Moody	Phone:	918-287-7766

Group/Project Members (Attach separate sheet of paper if necessary)

Name	Email	Team Leader	Team Member
Cole Replogle	coreplo@okstate.edu	☑	☐
Cooper Tiderman	cooper.tiderman@okstate.edu	☐	☑
Johnathan Burgess	Jmburge@okstate.edu	☐	☑
Malorie Travis	malorie.travis@okstate.edu	☐	☑
		☐	☐

Section II.

Procedure Overview: Provide a brief description of the project and/or procedure.

(Attach separate sheet of paper if necessary)

This procedure covers the power measurement testing of the turboelectric system that is mounted in the UAS in order to verify the power draw from the propeller and power output of system. This system possesses the capability to power a single electric motor, charge batteries and rotate a propeller. This SOP is designed for a purely static ground test.

Section III.

Hazards Inherent to the Project (Check all that Apply)

☒Extreme Temperature
☒Electrical Hazard > 50 volts or high current
☒Noise Generated > 85 dBA
☐Sharp Edges
☐Flying Debris or Impact
☐Pressure Vessel/Compressed Gas
☐Bungee Cables/Elastic Energy Storage

☐Heights (roofs, lifts, towers, catwalks, etc.)
☐Potential for Oxygen Deficiency or Other Atmospheric Hazard (i.e. gas, vapor)
☐Storage of Hazardous Materials on site
☒Lithium Batteries
☐Transportation of Hazardous Materials
☐Other:_____

☒Fire Hazards (open flame, welding, cutting) ☐Handling Hazardous Materials ☐Dusts/Other Particulate Hazards ☐Work in Confined Space (natural or man-made) ☐Falling Objects ☐Trenching/Excavating ☐Explosion	**Equipment Used** ☐Golf Cart/ATV ☐Forklift ☐Tractor ☐Other _____

Health and Safety Information: Briefly describe the hazards associated with the materials or equipment used during the procedure. (Attach separate sheet of paper if necessary)

There are several hazards associated with this project.

Preventing Unexpected Movement
Each landing gear leg should be screwed to a plank of wood in order for the UAS to stay upright. To prevent movement on startup, lay sandbags and concrete blocks on top of the wood planks and UAS legs, which are available on-site. Attempt to move the UAS to verify it is secured before testing.

Propeller Safety
Failure of the propeller or turbine. Verify no one is within the propeller plane and that all persons are standing at least 10 feet away from the turbine testing location.

Exhaust Safety
Another area of concern is the heat coming from the exhaust. We want to make sure that everyone is at least 10 feet away from the turbine engine exhaust upon operation of the turbine engine. A CO_2 fire extinguisher should be ready to be used at all times during testing.

Battery Care
The following batteries are being used:

- 12S Lithium Polymer (LiPo)
- 3S Lithium Iron (LiFe)
- 5S Nickel-Metal Hydride (NiMH)

All batteries will be stored in a safe area within the UAS and away from the engine during testing. Each battery should be fully charged in the lab before testing; to do this, connect to the battery charger in the ATRC and select the appropriate cell number, chemistry, and charge rate (capacity divided by 100). When not in use, the batteries shall be stored in an aptly-rated bag. If a battery needs to be disposed, discard it as hazardous waste, with the exception of the LiPo batteries. For the LiPo batteries, discharge the battery while in the bag down to 1 V per cell or lower, and afterwards soak the battery in a tub of saltwater with a lid (does not need to be airtight) for at least two weeks (1/2 cup of salt per gallon of water). After soaking for the allotted time, the LiPo battery may be discarded with normal trash. **Note: if the battery is damaged, do not attempt to discharge the battery before soaking.**

Before starting the test, be sure to check all battery wires for cuts and make sure that they are in good condition (e.g., not swollen).

Fuel Storage

Any extra fuel that is not being used in the UAS should be stored at least 10 feet from the testing location, in the rated cabinet available at Richmond Hill.

Section IV.

Personal Protective Equipment or Clothing Required: All activities require basic protection including appropriate clothing, hand protection, safety shoes/boots, and eye protection. Any additional PPE requirements based on the hazards identified as part of minimizing risk of exposure, injury or illness. (Check all that Apply)

☒Face Shields/Safety Glasses ☒Hearing Protection ☐Hard Hat ☒Gloves (Electrical) ☐Fall Protection	☐Respirator Type:_____ Cartridge/Filter Type: _____ ☐N95 Particulate Mask ☐Portable Eye Wash	☐Emergency Shower ☐Extraction Equipment (Confined Space) ☐Other: _____

Safety Training Required

☐ Advanced First Aid	☐Confined Space
☐CPR	☐Laser Safety
☐Emergency Action and Preparedness	☐Forklift/Other Heavy Equipment
☐Project Specific Hazard Communication	☐N95 Particulate Mask Disclaimer
☐Compressed Gasses	☐Respiratory Protections
☐HotWorks (Welding, Torch/Plasma Cutting)	☒Fire Extinguisher
☐Ladder	☐Other:_____

Section V.

Method Procedures: Give a step-by-step instruction for the procedure. (Attach separate sheet of paper if necessary)

See attached.

Section VI.

Waste Disposal Procedure: Give a step-by-step instruction for the procedure (if applicable). (Attach separate sheet of paper if necessary)

If excess fuel is left in the on-board fuel tank, follow the following procedures:

1. Hook the off-board fuel tank up to the onboard fuel tank via the fueling line

2. Turn on the off-board fuel tank pump

3. Pump the remaining fuel out of the onboard fuel tank back into the offboard fuel tank

4. Once the onboard fuel tank is empty of all fuel, turn off the pump

5. Unhook the fuel line and pour any primed fuel into a smaller fuel tank

6. Pour the fuel in the small fuel tank into the larger fuel tank

7. Make sure both all fuel tanks have secure lids before moving

Section VII.

First Aid Procedures: Give a step-by-step instruction for the procedure. (Attach separate sheet of paper if necessary) This section should also contain the address and location(s) that the SOP will be used.

All incidents require that as soon as possible the Instructor of Record and Profession Staff over lab be notified.

Location:

5202 N Richmond Hill Dr, Stillwater, OK 74075

Location of Nearest Hard Phone Line: Lobby: through the hallway from the North side, take the third hallway on the left

Nearest Location of a solid Cell phone signal: On site, with designated member

Emergencies:

- One person is assigned to stay with the injured personal
- One person is assigned to call 911, this person will stay on the phone and state the following
    - Location of the accident (This should include building and room)
    - Type of injury
- One person is assigned to escort the emergency response crew to the location

Specialized First Aid Procedures as related to this project:

N/A

Section VIII.

Spill/Release Containment, Decontamination, and Clean-up Procedures: Give a step-by-step instruction for the procedure (if applicable). (Attach separate sheet of paper if necessary) 1. Locate fuel spill pads 2. If the fuel tank leaks, shut the turbine down immediately, allow it to cool, and immediately clean up the fuel with spill pads.

Section IX.

Approvals Required: Describe any special approvals required before conducting this work such as approval by Principal Investigator or lab supervisor before beginning work (if applicable). (Attach separate sheet of paper if necessary)
Approval required from MAE 4223 course instructors and assignment of course instructor or TA for witnessing of experiment. Notify Dr. Kurt Rouser or the graduate research assistant, Kylar Moody, of expected testing date and time.

Section X.

Designated Area/Communications: (For work involving particularly hazardous dangers, identify the area where the work will be conducted and to where it will be confined; identify any communication that will be done to assure others know the hazards and location of this work.) (if applicable). (Attach separate sheet of paper if necessary)
The test will be performed at Richmond Hill, in the concrete area North of the building, which is away from vehicles and the building. CO2 fire extinguishers and first aid kits will be available in the immediate area, with a team member immediately available to use either. Users will communicate the start of the machine and any problems that arise **verbally**. Signage will be used around the work area to alert newcomers to the operating area of the assembly.

Section XI.

Piping, Wiring, and Instrumentation diagram: (This should include a detailed schematic illustrations of the functional relationship of piping, instrumentation and system equipment components. (Attach separate sheet of paper if necessary)
See attached.

Once the SRB has approved the document, all team members will be required to electronically sign the document below.

By signing below, I certify that I have read the Standard Operating Plan (SOP) and agree that all listed participants and I will abide by the SOP and adhere to all OSU policies and procedures as well as any local policies, procedures or guidelines.

PI Signature: ______________________________

Participants:

____

____

____

____

____

____

SRB:

____

____

____

____

Method Procedures

1. Verify that all people are wearing the proper PPE. Proper PPE that should be worn by all persons are: safety glasses, hearing protection, long pants, and closed toe shoes. One person must be wearing level 5 cut resistant gloves in case that the engine needs to be handled. See steps 22-23 for information about propeller plane safety.

2. At least four persons should be on hand when performing this static test.

3. Designate a test location that keeps all persons safe from danger. This location should be a safe distance from all bystanders in order to protect them from possible engine or propeller failure.

4. Locate a CO2 fire extinguisher.

5. Ensure the UAS will remain in place by putting sandbags and cinderblocks on the landing gear, as instructed in the safety information.

6. Make sure all batteries are fully charged prior to testing.

7. Tighten all bolts which are holding the engine to the UAS.

8. Tighten the electric motor base to the UAS.

9. Tighten the propeller bolts at least 3 times around in sequence to secure the propeller to the electric motor. There are four propeller bolts. They should be tightened starting with the top right bolt, then moving to the bottom left bolt and finishing with the top left then the bottom right bolt. A diagram is attached to this SOP.

10. Secure all the batteries (2) 6s, (1) 3s and (1) 2s. Connect them accordingly:

- The two 6s batteries should be connected to a splitter which converts the two 6s batteries into one connection. This new single connection coming from the two 6s batteries should then be connected into one of the two connections available on the speed controller.

- The 3s battery should be connected to the turbine engine's GSU in to the "RX Throttle" port. The other connection coming off of the 3s battery should then be connected to the fuel pump.

- The 2s battery should be connected to the transponder.

11. Fill up the fuel tank to the desired fuel level and inspect it for leaks.

12. Secure the fuel tank.

13. Ensure that there are no air bubbles in the fuel line. If so, connect to the GSU to remove air bubbles.

14. Connect the fuel pump to the turbine and ECU.

15. Connect the starter cable to the turbine engine and ECU.

16. Hook up the voltage divider connections to the rectifier and Arduino.

17. Hook up the three generator connections to the rectifier.

18. Connect the rectifier connection to the open splitter connection that is attached to the speed controller.

19. Connect the three speed controller cables to the electric motor.

20. Connect the speed controller to channel three of the transponder.

21. Connect the Arduino cable and run it back to the designated testing area. Do not plug it into the computer yet.

22. Verify that all wires are clear of the exhaust and rotating parts.

23. Place cones around the test stand to mark areas that are not to be entered while the turbine is running. These cones should be placed in a 15 foot square surrounding the test stand. Another set of cones should be placed 5 feet aft and forward of the propeller plane so that everyone is aware of where the propeller plane lies.

24. Verify that all cones are in their correct locations and that all persons are clear from the propeller plane and engine exhaust pipes. Make sure that they are standing at a 45 degree angle from the test location.

25. Turn on the Futaba controller and make sure all connections are showing up on the controller.

26. Alert your team that the machine is starting by yelling 'clear' and count down from three.

27. Start the engine by plugging in the Arduino cable to your computer.

28. The four test personnel are responsible for the following items during the entire test:

- Person 1 is to control the throttle controller.
- Person 2 is to monitor refueling and defueling procedures.
- Person 3 is to monitor safety of the area being used for testing.
- Person 4 is to man the CO2 fire extinguisher.

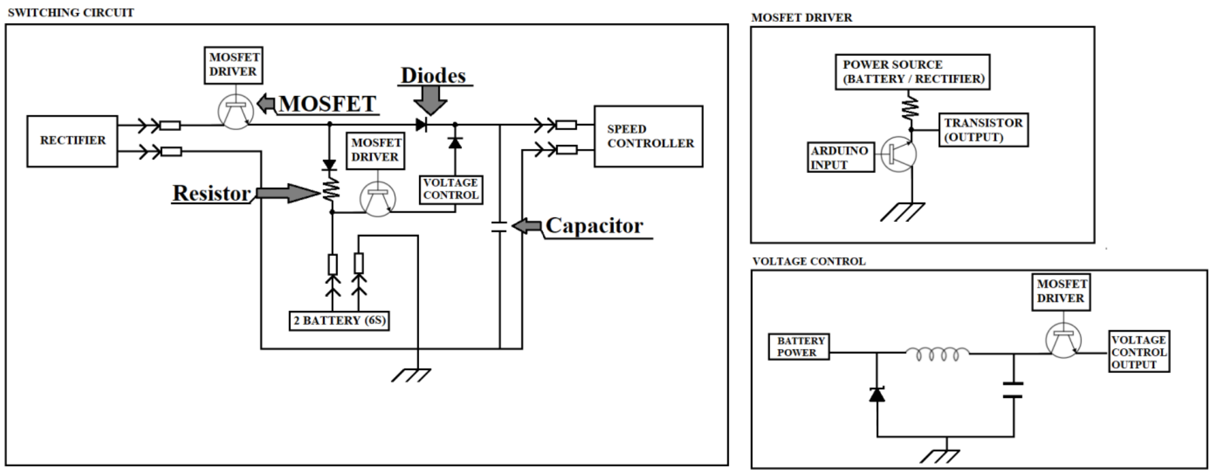


Figure 1. Switching circuit for power management system.

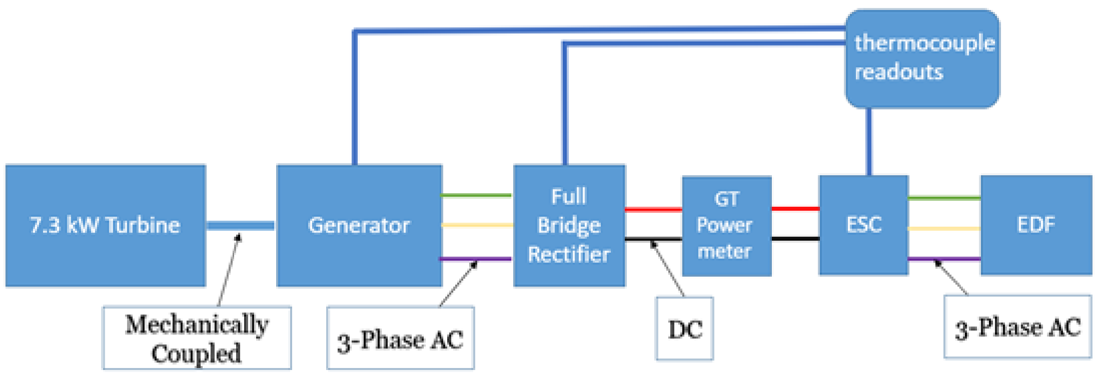


Figure 2. Flow chart of the turboelectric system with measurement instrumentation.

Decommissioning Guide

ECEN 4024/MAE 4374

A report written by Andrew Cobb and Maxwell Lewis, in conjunction with members of MAE 4374

Table of Contents

After The Semester is Finished

Where should it be stored?

All equipment, including all mechanical and electrical equipment, test benches, university tools, and other equipment purchased but not used this semester due to the SARS-CoV-2, and the project re-scoping that followed should be stored at Richmond Hill, an OSU laboratory building off-campus. All the work done this semester was performed in that facility, and the turboelectric lab work will continue to be performed in the same areas by the graduate students and future undergraduate design teams.

Does it need to be taken apart?

As of right now, none of the equipment should be taken apart because next semester's design team will continue to do research and build on current progress. Further testing is to be performed by graduate students over the summer, so present test setups should remain as so.

Are there any precautions that should be taken when disassembling or moving it?

For the 7-kilowatt system, the Mugin is fragile and relatively bulky when it has the engine, generator, and other electrical components in it. Since there are many components that are modular and can be removed, it is encouraged to remove:

- All electrical components
- The engine and generator, optionally removing the coupler
- The propeller. When reassembling, **ENSURE the propeller is facing the correct direction.**

- The battery/batteries. When not in use, they should be stored in a bag or container aptly rated for the type of battery.

Make sure that when you are removing the components, you are comfortable using an electrical screwdriver and/or other power tools. Most everything is screwed into a wooden frame or velcroed together.

For the 5 and 13 kilowatt systems, since those are on a test bench with handles, all you need to do is carefully lift with proper lifting technique (lifting with your knees, not your back etc.) and ensure that you have a clear path for movement. It is generally recommended to have at least three people to move it because there are two people needed for the bench, and one person for doors. Considering all equipment is already at Richmond Hill, nothing should need to be moved.

Are there any consumables that will need to be thrown away?

There is nothing that will need to be thrown away. The only consumable is jet fuel, but that has a special cabinet outside of Richmond Hill that will remain locked when not in use.

Are there special instructions for disposing of waste?

If a battery needs to be disposed, discard it as hazardous waste, except for the LiPo batteries. For the LiPo batteries, discharge the battery while in the bag down to 1 V per cell or lower, and afterwards soak the battery in a tub of saltwater with a lid (does not need to be airtight) for at least two weeks (1/2 cup of salt per gallon of water). After soaking for the allotted time, the LiPo battery may be discarded with normal trash. **Note: if the battery is damaged, do not attempt to discharge the battery before soaking.**

At Project End of Life

What can be salvaged?

Mechanical Equipment:

KingTech engines (3). Engines should be sent for maintenance every 25 hours of run time. There are several motors of varying sizes used for the project, all of which are to be retained by the lab for possible future use in projects. All hardware (bolts, nuts, etc.) can be stored at Richmond Hill for later use by other projects. All modified raw materials (i.e. machined plates) should either have direct use in other small engine projects or be easily modified for reuse.

Electrical Equipment:

Major electrical equipment including conductors, microcontrollers, and motor speed controllers are to be retained by the lab for potential use in future projects.

What can be recycled?

Mechanical Equipment:

Metal plating and railing (steel and aluminum) that cannot be repurposed can be sent off as scrap metal. This is expected to be less than 5 pounds of scrap metal.

Electrical Equipment:

LiPo Battery, capacitors, diodes/rectifiers and MOSFETs. These components can be put into any common recycling bin and collected.

<u>Should some parts be thrown away?</u>

Mechanical Equipment:

No mechanical components should be thrown away. See recycling section above for more information.

Electrical Equipment:

No electrical components should be thrown away. See recycling section above for more information.

<u>Any special procedures for disposal?</u>

Mechanical Equipment:

Scrap metal is to be sorted and taken to local metal recycling center (such as Northern Oklahoma Metals).

Electrical Equipment:

LiPo Battery - Discharge completely, deliver to appropriate recycling center

All electronics - should be delivered to local E-waste center for safe and ethical handling/disposal

Maintenance Manual

ECEN 4024/MAE 4374

A Manual written by Andrew Cobb and Maxwell Lewis, in conjunction with members of MAE 4374

<u>Table of Contents</u>

Identification of components that do or do not require maintenance

Components that DO require maintenance	Components that DO NOT require maintenance
Turboprop Turbine Engine	Rectifiers
Motors/Generator	MOSFETS
Diodes	Solder Joints
Propellers	Conductors
Electrolytic Capacitors	Arduino
Start-up code for Arduino	Passive Heatsink

Intervals of Maintenance by Component

1. **Electrolytic Capacitors** - Every 45,000 to 50,000 hours (approx. every 5 years) or upon noticeable bulge of the lead-end of the capacitor.[1]

2. **Start-up code for Arduino** - Depending on the circumstances, a change in firmware might be needed. There is no specific time frame for this maintenance.

3. **Diodes** - After any over-current event that occurs during the life of the system.

4. **Motors/Generator** - Motors need a few routine maintenance checks that vary from weekly to annually. Refer to the next section for specific times frames for each maintenance routine.[2]

5. **Turboprop Turbine Engine** - Service every 25 hours of run time.

6. **Propellers** – Propellers do not have any regularly scheduled maintenance; however, they should be inspected before each flight or test. Refer to the "Propeller" section below for information on inspecting the propeller.

Instructions for Maintenance by Component

1. **Electrolytic capacitors** - Desolder capacitor from the system and replace the capacitor. Electrolytic capacitors are not repairable, so they must be entirely replaced. Ensure the system is completely turned off, and the capacitor has had at least 5 minutes to discharge entirely before soldering. If there is a noticeable bulge near the leads, immediately shut down the system, allow for discharge, desolder and replace. Discard capacitors immediately after replacing them.

2. **Arduino start-up code** - When an update needs to be pushed out, ensure that you have the Arduino connected to the computer with the provided USB cable. Ensure the sketch is uploaded via the IDE. Then remove the cable from the Arduino and reconnect to the system for use.

3. **Diodes** - Should be replaced in the event of an over-current event as the junction is damaged and likely destroyed. Once the system has shut down entirely, desolder the diode and remove it from the circuitry.

4. **Motors/Generators** - There are several recommended maintenance routines performed at various times for motors. See the list below for procedures and time frames.

    A. **Temperature** - The motor should run below 75℃. Use an infrared thermometer to read the internal temperature while running the motor. In most cases, a motor needs to be replaced if it operates above that temperature. This operation should be done **weekly.**

    B. **Vibration** - Vibration checks can be done using any vibration measuring device such as a vibration pen. The manufacturer can usually fix the vibration. Vibration should be below 5 mm/s, and that test can be performed **every 3 months.**

    C. **Lubrication** - Lubrication needs to be applied to the electric motor bearings periodically, dependent on the size of the motor. For the motors used in this project, **every 6 months is recommended.**

D. **Binder Bolts -** Ensure that the bolts anchoring the motor to the frame are tight. Tighten them should be performed every **3 months or if there is noticeable looseness in the bolts.**

E. **Alignment** - Whether the motor is being used to generate electric power or to drive a propeller, alignment checks with a coupler need to be performed **every 6 months**.

F. **Cleanliness** - The exterior should be wiped down thoroughly **once a week**. The internal copper windings should be cleaned annually.

5. **<u>KingTech Engines</u>** - To ensure the safest operation and get the most extended life out of your KingTech engine, it should be sent to KingTech to receive an overhaul service after every 25 cycle hours. The service is done by following the instructions on the KingTech website under the "Service Request" tab (1). If there are any questions regarding this process, please refer to the KingTech website or contact KingTech directly at by emailing kingtechturbines@gmail.com or calling 1-626-793-4677. The process involves:

A. **Packing the engine for shipping** – When sending in a turbine, please make sure it is in a plastic bag and that the ECU and engine clamp are included, also consider including components in the following order of importance, should they require to be examined ECU, Fuel pump, Solenoid valves, and Complete wiring harness. Do not send the FOD screen and battery.

B. **Service Request Form** - Please print, fill out, and include this form in the box, Service Request Form, service will ONLY commence when this form is included. The form can be found in the "Service Request" tab of the KingTech website (2).

C. **Ship the packet** - Ship the packet to "KingTech Turbines 289 S Santa Anita Ave Pasadena CA 91107 United States".

The maintenance performed by KingTech will include:

- Turbine dismantling
- Replace of bearings and other components determined by technical staff

(1) http://www.kingtechturbines.com/products/index.php?main_page=page&id=2

(2) http://www.kingtechturbines.com/doc/service.pdf

- Balance correction
- Cleaning of injectors and chamber
- Turbine assembly
- Test and adjust if necessary

6. **<u>Propellers</u>**:

A. <u>Inspection of the Blades</u>

To be carried out every day

1. Clean the blades.
2. Perform a visual inspection of the blades looking for:
   a. Level of erosion on the leading edge of the blade.
      A small amount of erosion is normal and not critical.
   b. Cracks in the structure of the propeller.
   c. Damage in the paint.
      If any damage occurs the paint must be fixed immediately.

B. <u>Propeller Maintenance</u>

If the inspection of the propeller results in a concern, consult the manufacturer.

C. <u>Removal of Propeller</u>

1. Disconnect the aircraft battery.
2. Loosen the four M4 bolts located on the aft side of the propeller.
3. Remove the M4 bolts, aluminum disk, and propeller.
4. Store the propeller, parts, and bolts in a safe place to prevent damage.

D. <u>Installation of Propeller</u>

1. Disconnect the aircraft battery.
2. Align the four bolt holes on the propeller with the four threaded holes on the motor.
3. Place the aluminum disk on the outside of the propeller and align the bolt holes.
4. Install the four 3 in. M4 bolts by threading them into the motor.
5. Tighten the M4 bolts using a similar torque.

Works Cited

[1] "**Capacitors Age and Capacitors Have an End of Life**." Emerson Network Power, 2008. http://www.repeater-builder.com/tech-info/pdfs/replacing-capacitors-from-emerson-corp.pdf

[2] Azly, Ditulis Rahmad. "**Maintenance Schedule Of 3-Phase Motor**." *My Electrical Diary*, 22 Dec. 2018, https://diary-of-electric.blogspot.com/2018/12/maintenance-schedule-of-3-phase-motor.html