SINCHDrone UAV: Preparations for Technology Integration and Testing

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Abstract

Unmanned Aerial Vehicles (UAVs) are steadily growing more popular and accessible in both the commercial and military industries, but today's UAVs are severely limited in their mission capabilities by low flight times. Many commercially available UAV's can only sustain maximum flight times of twenty minutes. Project BANSHEE UAV (Battery as iNtegrated Structure High Endurance Experimental UAV) is a multidisciplinary team of students from aerospace, electrical, computer and mechanical engineering degree paths with the goal of extending the flight time and endurance of UAVs through various battery regeneration and storage techniques. Proposed methods of in-flight battery generation include the replacement of a UAV's upper wing skins with solar panels and lower wing skins with induction coils capable of charging by flying over AC distribution powerlines. The UAV's wing spars will be replaced by electrolyte batteries, which will decrease the overall weight of the vehicle if they prove successful enough to replace the on-board batteries. Project BANSHEE plans to develop and manufacture a SINCHDrone (Solar and Induction Charged ultra-high endurance Drone) UAV VTOL hybrid by modifying a commercial Volantex ASW-28 fixed wing RC airplane with VTOL spars and four quadcopter motors and propellers to be used as a technology demonstrator vehicle which can provide proof of concept of the success of the battery regeneration techniques listed above. Previous years' Cal Poly Pomona BANSHEE student teams initiated and developed the basic concepts and technologies approach for the SINCHdrone In-flight rechargeable UAV concepts. This paper builds on that previous work and discusses further developments in the SINCHDrone structural design improvements, updated baseline endurance testing, and progress in developing the solar cell skin. Once the SINCHDrone has proved the ability to extend the endurance of UAVs Project BANSHEE will begin modification of a commercial Baby Shark hybrid UAV with the same techniques.

Index Terms — Hybrid, endurance, UAV, solar panels, battery, structures, wireless charging, flight testing, technology demonstrator.

1. Introduction

The Solar and Induction Charged ultra-high endurance Drone, or SINCHDrone UAV, will be a technology demonstrator used to study the effectiveness of battery regeneration and structural integration techniques. The design will modify a commercial Volantex ASW-28 fixed wing RC airplane by replacing the upper wing skin with carbon fiber reinforced solar cell skin and the lower wing skin with induction coils, all of which will be integrated into a power management system capable of charging the batteries in-flight while also supplying the power required to maintain stable VTOL and forward flight. A structural electrolyte battery will replace the wing spars for increased energy storage and wing support. According to a research article published in January 2021 by Leif E. Asp, Karl Bouton, et al., "Due to their multifunctionality, structural battery composites are often referred to as "mass-less energy storage" and have the potential to revolutionize the future design of electric vehicles and devices." [1]. Efficient mass-less energy storages can reduce the weight of an electric aircraft significantly, decreasing power usage and increasing endurance. As seen in Figure 1, the reinforced solar cell skin and induction coil will serve a similar purpose as the structural battery, replacing key structural components in the wings to create a more efficient system. These concepts were introduced by previous BANSHEE teams [2], and progress of the technologies will be explained below.

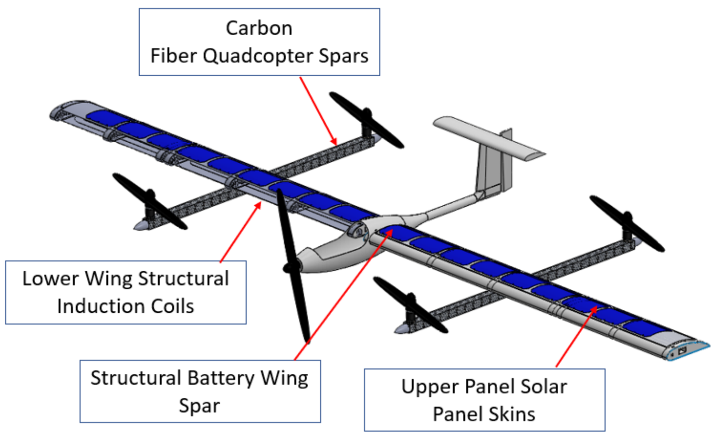

Figure 1 SINCHDrone with Labeled Core Technologies

To satisfy these power and weight requirements, lightweight yet durable materials are needed, making carbon fiber and plastic the ideal material choices. The Volantex has a plastic fuselage and foam airfoils with aluminum wing spars. To reduce weight, the aluminum wing spars are replaced with carbon fiber. Two carbon fiber quadcopter spars are attached to the wings, allowing VTOL and forward flight capabilities. An addition carbon fiber wing wrap will protect the foam wings from crushing. A custom 3D printed motor mount will reduce the drag of the quadcopter spars, while also allowing a secure connection between the spar and quadcopter motors. In addition to landing skids, this will be the basic test bed where different technologies are added or removed to analyze its effect on endurance.

The concept of operations of the SINCHDrone can be seen in figure 2, which shows a civilian application of the UAV. If induction coil charging and solar cells can provide as much energy as the SINCHDrone uses in hover, then start-up for the UAV can be avoided by keeping the SINCHDrone in hover while charging. Power lines and ground charging stations on the way to the target destination supply energy, allowing the SINCHDrone to have a larger operating range.

Another civilian mission profile would include monitoring powerline damage using the SINCHDrone's enhanced endurance, which is explored by previous BANSHEE teams [4].

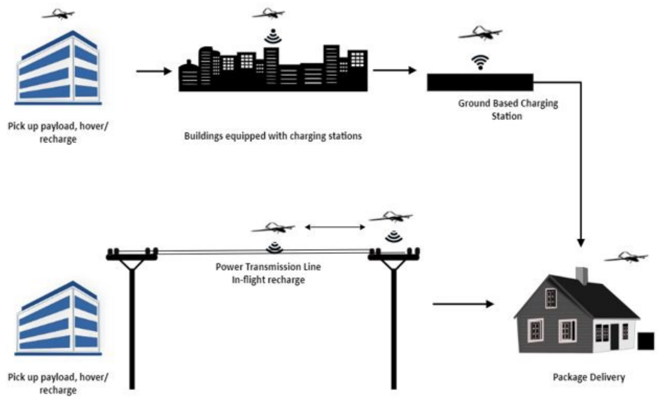

Figure 2 Example Concept of SINCHDrone Mission

The development and testing of the SINCHDrone is described in a 7-phase plan. This plan was initiated and conducted early development by previous BANSHEE teams [5]. Phase 1 and 2 involves conducting endurance tests on pre-existing systems to have a proper comparison of endurance capabilities. The baseline aircraft chosen were the Volantexrc's Volantex powered glider, Storm Racing Drone's Storm 4 quadcopter, and the Foxtech's Baby Shark drone. These endurance times will be used to measure the benefits of the technologies placed on the SINCHDrone. Phase 3 is to design, manufacture and test the SINCHDrone test bed. In phases 4 through 6, technologies will be tested individually on the test bed to analyze their impacts on endurance times. Phase 4 involves testing solar cells strengthened with carbon fiber and laminate as an upper wing skin. In phase 5, the lower wing skin is replaced by induction coils and tested. In phase 6 the structural battery will replace the wing spar and tested for endurance benefits. Phase 7 will be the last test for the SINCHDrone, where all successful technologies will be integrated onto the test bed for final testing.

Phases 1, 2, and 3 are being conducted simultaneously, with different sub teams responsible for them. Ground tests for the Volantex RC Plane and flight tests for the Storm 4 have been completed. The SINCHDrone test bed construction is in progress, with the modifications of the wing spar and wings complete.

2. Senior project course technical description

2.1 Solar Cells

To increase UAV endurance, a combination of increased energy storage and reduced net energy draw are required. Net energy draw can be reduced by generating power while in flight as well as by reducing energy consumption via increased efficiency. Solar wing skins can generate power while in flight. However, traditional applications of this technology commonly increase weight and drag, offsetting some of the benefits of the power generated. Figure 3 shows an updated Volantex-SINCHDrone wing replacement cross-section structural arrangement with a laminated structural solar-cell upper skin, and a copper induction coil (for powerline in-flight recharging) embedded into a composite wing lower skin design. This design aims at reducing the typical wing skin parasitic weight with electrical power-generation and storage electrical components that also have structural properties. To mitigate the parasitic weight and drag caused by the addition of solar cells, we plan to incorporate them into the wing's structure.

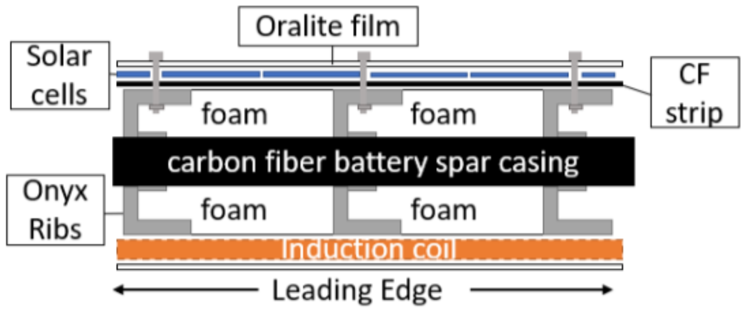

Figure 3 SINCHDrone updated wingspan-wise cross section design uses structural properties of the solar cells, induction coil skins and battery wing spars to reduce parasitic structural weight

Based on inspection of previous solar aircraft, solar cells are commonly attached to the fuselage and upper wing skin of an aircraft or are placed inside the wing with a clear skin. Both approaches disregard the solar cell's inherit strength. We plan to use the cells as structural members, enabling us to use a lighter weight structure elsewhere on the wing. To investigate the feasibility of this concept, work needs to be done in a few key phases. The first phase is to parasitically attach the solar cells to an unmodified aircraft to determine the power generated and if there is any increase or decrease in endurance. Next the endurance needs to be tested with the solar cells attached, but electrically disconnected to determine the effect of the additional weight and drag on the aircraft. These tests will help us establish a baseline to determine if future developments are a success or failure. Next the structural properties of a solar power wing skin need to be determined so that they can be incorporated into engineering calculations to optimize the weight of a new wing using solar wing skin technology. The solar cell wing prototype is shown in Figure 4 and will be tested in the Cal Poly structures lab Shimadzu testing machine in tension and compression to determine its strength to weight ratio benefits versus a parasitic attachment to an existing wing skin.

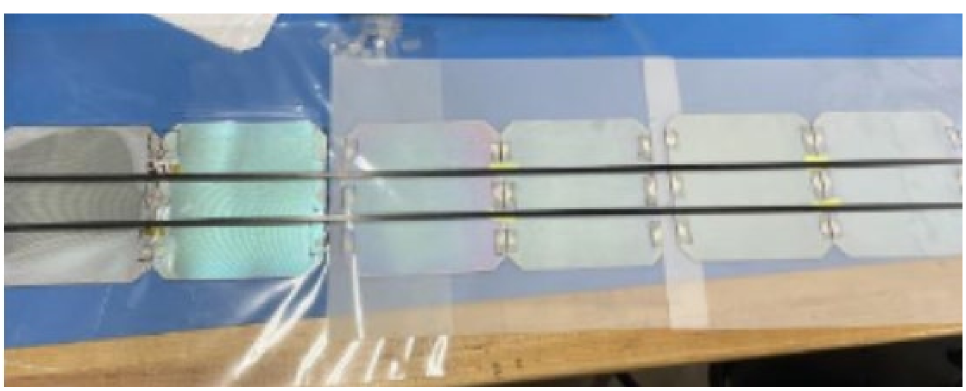

Figure 4 Solar wing skin prototype

Finally, a new wing can be constructed incorporating the solar wing skin, and its effect on endurance can be tested.

2.1 Wing manufacturing

As mentioned previously, to harness the strength of the solar wing skin and other potential range enhancing technologies, a new wing for the Volantex R.C aircraft needs to be created, as seen in figures 5a and 5b. Critically, the structure needs to be able to transfer the tension and compression efficiently to the structural outer skins, easily allow for the incorporation of future structural batteries, and allow for expedient modification of the skins to test different strategies, as well as be manufacturable within the current capabilities of the manufacturing sub team.

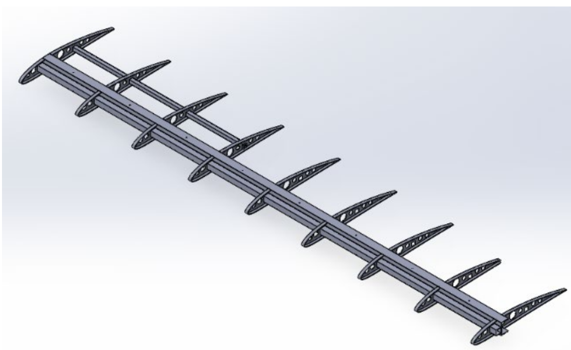

Figure 5a New wing sub-structure design allows wing skins to be interchanged for testing different concepts

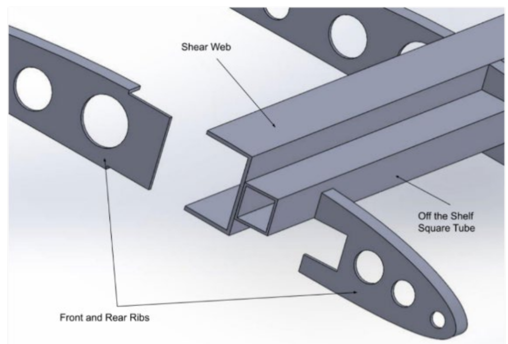

Figure 5b Detailed view of carbon-fiber spar assembly and 3-D printed Onyx carbon-fiber reinforced nylon rib attachment will use epoxy bonded components

The c-shaped shear web transfers the bending load to the structural skins, its wide flanges allow for firm skin attachment, and an even distribution of load. We plan to manufacture this component using a carbon fiber epoxy infusion, we determined that compared to 3d printing, or fiberglass construction this method would yield the highest strength to weight ratio while still being manufacturable. The off the shelf square tube is planned to be another carbon fiber component, which in the future has the potential to be augmented or replaced by structural battery technology. Finally, the wing ribs are planned to be 3-D printed Onyx carbon-fiber reinforced nylon in a two-piece construction to ease manufacturing, reducing weight, as well as to facilitate easier replacement in the event of damage. The wide flanges on the wing ribs allow for easy attachment and modification of the structural wing skins.

2.3 VTOL Motor Mount Design

The criteria for designing a motor mount to be utilized in the SINCHDrone quad copter electric motors relied heavily on weight and existing vehicle geometry: because the SINCHDrone is to utilize the Volantex model fuselage and wingspan, the length of the booms is predetermined with some simple calculations.

The VTOL Boom selected by the Structures & Manufacturing team was a 30mmx30mm square carbon fiber spar at variable length. To be best suited for vertical flight, it was necessary that the length of each VTOL Boom be equivalent to twice its x-axis distance from the drone's center of gravity such that a downward projection of the assembly be square in its dimensions. This layout enables the center of the quad copter total thrust vector to be vertically aligned with the vehicle center of gravity, to prevent a moment arm that would produce thrust-pitch coupling.
The spar had a set mounting distance 410 mm away from the vehicle's CG; thus, the motors would need to be located 410 mm away from the mounting point (midpoint) on each spar.
The Motor mount Subassembly consists of 6 main elements: a carbon fiber spar, mounting insert, insulating plate, U2216 KV800 Motor, nose insert, and Storm4 prop. Because the only load-bearing structure is the spar itself, the decision was made to utilize 3D printing to manufacture the mounting and nose insert, while the insulating plate would be laser cut lightweight balsam wood, as shown in Figures 7.

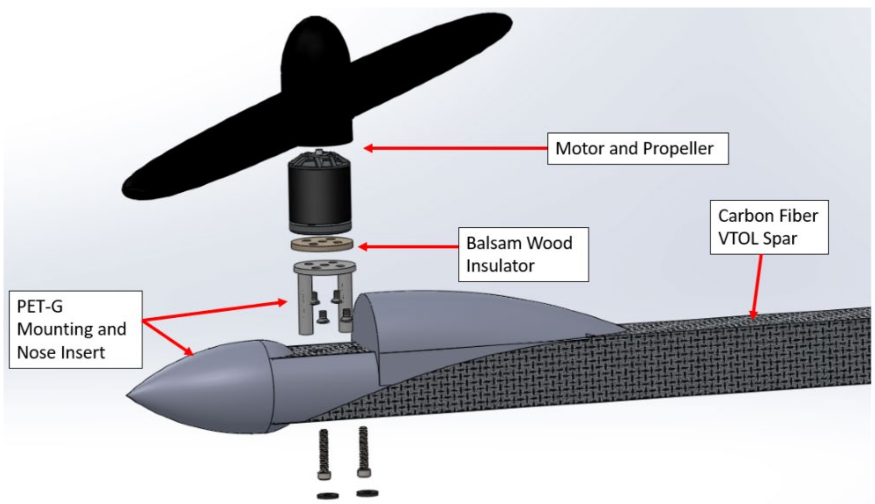

Figure 7 VTOL Motor Subassembly Exploded View with Labeled Materials

Because the mounting insert is constructed of low-density plastic, there was concern that the operating temperature of the motor during vertical flight would destroy the structure and thus the implementation of an insulating plate was created to separate the contact surfaces. The geometry of the balsam wood plate is easily adapted for bulk machining operations such as laser cutting and easily replaced by removing the 4 M4 bolts that attach the motor to the mounting insert.

To reduce any vibrations caused by vortices from being shed (Strouhal vortices) from the cylindrical profile of the motor in forward flight, a flare modification was designed to the existing nosecone insert: the trailing end of this part is resin cured to the surface of the spar and because it does not interfere with the other assembly structures will remain as a permanent addition.

2.4 Endurance testing

The motivation for the data collection of the Volantex-ASW has been the focus on endurance and power evaluation of the drone. The end goal of the data collection is to measure the baseline flight time endurance of the Volantex-ASW prior to modification and to work around that endurance time or increase its longevity while amassing a feasible amount of payload. The collection of the data involved an onboard autopilot or CPU (Pixhawk) which controls the aircraft and records the power draw as well as the remaining capacity of the battery. The Pixhawk acts as a guide where if given a specific flight plan and having been calibrated it will fly autonomously until it has followed all the given instructions. All the data, flight plans, and ins and outs of the given aircraft will be accessed through a software called Mission Planner. Due to major repairs being needed for the Volantex this semester as well as other underlying conditions, ground tests have been done in place of flight tests for the endurance testing so data may be skewed.

When flight plans do resume to their normal procedures, we will be using a manual takeoff where the pilot will help with takeoff and once at speed, the Pixhawk will take over. Flying the drone to 100ft for emergency recovery if needed. The drone will follow a circular radius of 200ft where it will loiter in that constant turn until the battery reaches a minimum level of 11.1v where it will land as seen in Figure 8. When the LiPo batteries are at 11.1v, the Volantex single propeller motor automatically turns off, so that is the criteria where the battery storage capacity is considered "empty". The associated time it takes for the battery to discharge from fully charged to 11.1v is identified as the "endurance" of the flight.

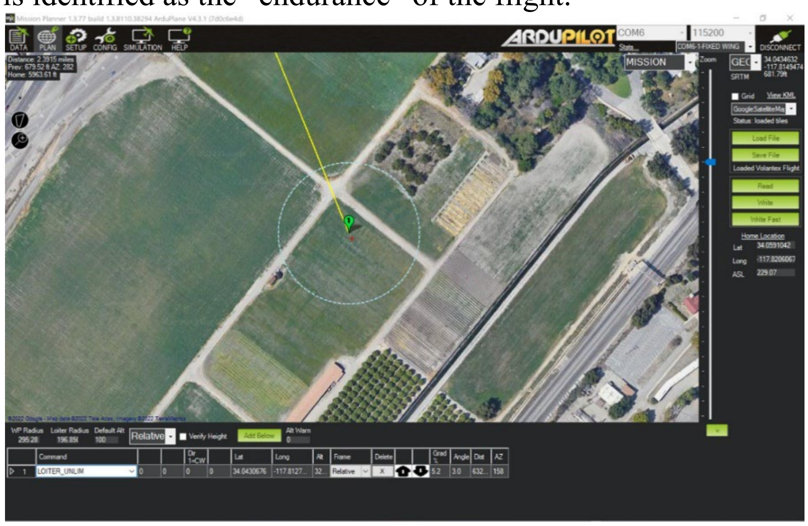

Figure 8: Missionplanner/ArduPilot Volantex-ASW Flight Path

Before performing any kind of actual flight, the Volantex-ASW must pass a predetermined pre-flight checklist. The pre-flight checklist being an overall run-through of the aircraft before an actual flight can be made. This check is run by the pilot flying the aircraft as well as the flight test lead to mitigate any risk before a flight and to ensure a successful test flight. Listed below is the checklist with every single tick needing to be marked by the pilot during inspection before declaring it to be flight worthy.

Date:__________

Pre-Flight Checklist ~ Volantex

Sign below when all items have been checked off.

Flight Lead:____________________ Test Pilot:____________________

- ☐ All items below have been checked before flight.
  - ☐ Aircraft RC connection is stable and normal. (Connection of pixhawk to controller)
  - ☐ Both aluminum spars have been mounted to support wings. (2 spars)
  - ☐ Wings have been clipped on properly.
  - ☐ Rudder has been mounted properly to the vertical stabilizer.
  - ☐ Check all servo horns have been hooked to the designated control surface.
  - ☐ The propeller is in the normal direction and is fastened.
  - ☐ Check that all control surfaces have been reset to their original position.
  - ☐ Check LiPo is fully charged and functional. (3s = 12.6V)
  - ☐ Aircraft voltage is normal. (Check through Mission Planner)
  - ☐ Check that all control surfaces have inputs.
  - ☐ Check CG and Control Surface Directions.
  - ☐ Check Modes. (Stabilize, RTL, Manual)
  - ☐ Throttle Check
  - ☐ The compass is toward the right direction.
  - ☐ No warnings from the ground station.
  - ☐ The remote controller power is normal and is fully charged.
  - ☐ Make sure the antenna on the controller is properly set up.
  - ☐ Data connection strength is normal.
  - ☐ Upload and double check the route being used.
  - ☐ Double check fail safes.
  - ☐ Ground device recording is up and on.
  - ☐ Height setting of Return Home Point is normal.
  - ☐ Out of control/out of range Return-to-Launch setting is normal.
  - ☐ Try to take off and land, make sure the direction-correct and direction control are normal.

Figure 9: Pre-Flight Checklist

The baseline ground test of the Volantex-ASW was conducted on December 1st, 2022, inside Building 13 High Speed Wind Tunnel at Cal Poly Pomona. The test lasted from 4:00pm to 6:30pm. The Volantex-ASW was motor was turned on or "forced armed" due to the wings having been removed from it as it would not be flying (ground test). Mission planner was used for the force arm by using the bottom left UI and clicking force arm.

Since a ground test was conducted, which is a test where only the motor is run, almost all the pre-flight checklist requirements did not have to be followed as well as flight plans due to the aircraft being held in place on the ground. Different throttle percentages were used in the ground test where the battery was run until it hit its nominal voltage and was replaced for the next throttle group. The LiPo (3s 2200mAh 11.1V) was run from its maximum capacity of 12.6V (4.2V per cell) to 11.1V (3.7V per cell).

The first test run was at 100% throttle with a full LiPo (3s 2200mAh 11.1V) battery at 12.6V (maximum capacity). The endurance time at 100% throttle was 4 minutes 26 seconds where it had a power draw of 0.072Ah. In figure 10, the Voltage (green) and Current (red), the voltage of the battery was an initial steep drop until maximum current (11.12A) was reached. The battery voltage then decreased in a rather linear way until it hit the failsafe of 11.1V. Looking at the initial draw and strain on the battery, having the throttle at 100% is not ideal for maximizing the endurance time.

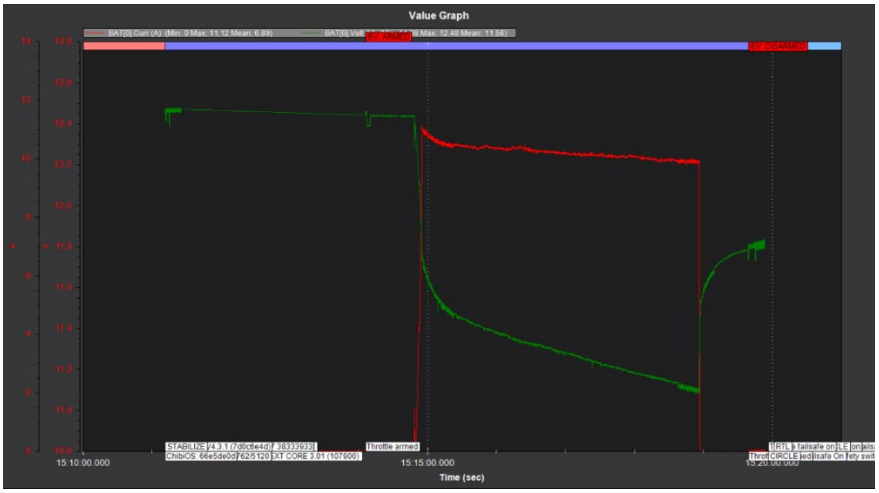

Figure 10: Ground Test 100% Throttle – Volantex-ASW propeller motor showing the LiPo battery discharge over time; voltage in green and current in red

The second test run was at 75% throttle with a full LiPo (3s 2200mAh 11.1V) battery at 12.6V (maximum capacity). The endurance time at 75% throttle was 9:48:27 where it had a power draw of 0.039Ah.
The third test run was at 50% throttle with a full LiPo (3s 2200mAh 11.1V) battery at 12.6V (maximum capacity). The endurance time at 50% throttle was 26:17.83 where it had a power draw of 0.023Ah.
The fourth test run was at 30% throttle with a full LiPo (3s 2200mAh 11.1V) battery at 12.6V (maximum capacity). The endurance time at 30% throttle was 20+ minutes where it had a power draw of 0.0015Ah. Due to a time constraint while testing, a full test till battery death was not achieved, but a predicted time of around 46 minutes was calculated. The assumption of the time could be determined by calculating the average voltage drop and as well as the draw rate on the battery to determine the estimated endurance time when it is run at 30% throttle.

3. Outcomes

In the process of designing and manufacturing the SINCHDrone, the team has acquired hands on experience in creating and conducting flight tests, constructing and testing composites, and repairing damage on composite UAVs. In addition, the team did research into safely using epoxy and resin with carbon fiber and the safe charging discharging of Lipo batteries. Students learned how to pilot software such as ANSYS, Solidworks, and Ardupilot in the design or testing of a new aircraft. The project also allows students of different majors and backgrounds to work together on a multidisciplinary project, facilitating conversations and transfer of ideas to design and manufacture the SINCHDrone and related technologies. The team also gained experience in producing written reports on the work they have done, as seen in a paper they wrote earlier this year [3]. These hands-on learning opportunities will be expanded in the spring of 2023 as the project progresses through the SINCHDrone development phases.

4. Conclusion

The BANSHEE UAV team is ready to explore the combination of in-flight battery regeneration technology and structural integration of load-bearing electrical generation and storage components to reduce parasitic weight through the SINCHDrone test bed, in the spring of 2023. The team has designed various modifications to the Volantex to create the SINCHDrone, including new wings and motor mounts. In addition, the reinforced solar skin design allows for in flight charging while reducing the parasitic weight of the upper skin. The skin is removable allowing for future testing. Endurance tests of the Volantex and Baby Shark give baseline data, power draw of the motors and batteries' voltage data. These are essential in the analysis of the regenerative technology's efficiency and prepares the team for future testing of technologies that will extend the endurance of UAV aircraft. Also, a Foxtech Baby Shark E-VTOL UAV aircraft has been purchased to be modified with the proven technologies demonstrated on the SINCHdrone testbed, as a final technology demonstrator. The team plans to continue with the 7 phases of development to complete the SINCHDrone technology demonstrator during the spring of 2023, and beyond.

6. Acknowledgement

The authors would like to acknowledge the financial support of Lockheed Martin, AFRL and ROBOTIS Inc., which have provided funding for the purchase of equipment for experimentation, with an emphasis on long-term items to be used by the team for years to come. The authors would also like to acknowledge the Cal Poly Pomona SPICE Grant, Mr. Mark Bailey, and Mr. Tristan Sherman.

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