Integration of a Structural Battery into a Fixed Wing Drone

Principal Investigator: Daniel Fistos, UNCA Sophmore, dfistos@unca.edu, 850-284-3039

Subject Matter Experts:

Dr. Ralph White, Professor at University of South Carolina,white@cec.sc.edu, 803-777-3270

Dr. Joshua Gray, Professor at University of South Carolina, jgray@mailbox.sc.edu, 803-513-7054

Dr. Paul Coman, Professor at University of South Carolina, comanpt@cec.sc.edu, 803-777-9478

Core Team Members:

Christina Johnson - NASA Postdoctoral Program
Daniel Fistos - University of North Carolina at Asheville
Nathalie Reid - New York University
Abu Islam - University at Buffalo
Courtney Hundrieser - University of North Alabama
Alexander Rielage - University of Cincinnati
Kelechi Osueke - Virginia Tech
Margaret Wielatz - University of Florida
Qiang Han - University at Buffalo
Sayan Shil - Stony Brook University

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Abstract

Batteries are often bulky and can add significant weight to one portion of the aircraft. If we can decrease the weight, and distribute it more evenly throughout the aircraft, the structural requirements will change. Structural batteries allow us to decrease and redistribute that weight. The theoretical models for structural batteries have improved significantly in recent years, alongside the advancement of lithium-ion batteries. Currently, structural batteries are theoretical and are not yet ready to be applied to unmanned aircraft technology. Alongside our Subject Matter Experts, Dr. Paul Coman, Dr. Ralph White, and Dr. Josh Gray at the University of South Carolina, we propose to advance the TRL of theoretical structural batteries by designing a fixed-wing drone that can function with the current state of the art structural

battery. Each team member will have an opportunity to develop modeling skills for this project, either for the battery or a fixed-wing drone design that uses a structural battery. The minimum metric for success of our project will be successfully modeling a working drone that has the structural battery integrated. Having the drone match the performance of a commercially available drone of the same class is the ultimate goal. This proposal focuses on advancing technology while having students working alongside experts to develop a specific set of advanced modeling and writing skills that will be useful for our future careers in STEM.

Technology Merit and Workplan

Rapid advancements in science and aviation technology have notably changed drone technologies, which have core implications in relevant fields. Yet there are still significant obstacles that prevent the widespread adoption of drone technology. Two primary obstacles are power storage systems with limited nameplate capacity (total current or power output) and drones with limited weight tolerance. Currently, most drones are powered by lithium-ion(Li-ion) batteries. Li-ion batteries are efficient, generating greater nameplate capacity than other types of batteries. However, a Li-ion battery constitutes approximately 25% of the overall weight of a drone. Increasing the power supplied to a drone requires a bigger battery or more cells, which results in an increase in the drone's weight. This, in turn, would increase the vehicle's energy and power consumption (Wang et al, 2021). This proposal discusses a new battery technology to reduce the weight of a battery without sacrificing battery nameplate capacity. Moreover, this technology will enable drones to carry a greater load capacity. As this technology becomes more widely used, drone commercial applications may increase, resulting in drones with higher carrying capacities.

In order to accomplish this objective, we propose furthering the development of structural battery technology. Specifically, this proposal examines the current state, development, and integration of structural battery technology for drones. This proposal provides the information and plans necessary to develop a model of an improved battery and drone within a one-year timeframe to further structural battery technology for the eventual use in physical drones. Although this proposal is primarily focused on drones, further research can be conducted to optimize it for large-scale aviation and automobile applications.

Structural batteries can be classified into five different categories based on their degree of integration (Kühnelt et al, 2022). Type 0 is the lowest degree of integration, and refers to a device with separate structural elements and batteries. This is what standard Li-ion batteries are classified as. Type IV consists of the highest degree of integration in which there is a fully integrated system where the material in the structure acts as an energy storage device. While there has been research dedicated to each degree of integration, Type IV batteries are the least developed. Two different approaches have been proposed for developing a working model. The first approach is a coaxial approach that consists of an electrolyte layer on a carbon fiber core with a matrix made of cathode material (Kühnelt et al, 2022). The second approach is the layered approach, which involves using carbon fibers as the anode material, coated carbon fibers as the cathode, and a thin layer of electrolyte material (Kühnelt et al, 2022). Although research has been conducted for Type IV integration, no working full cell structural battery has been created.

A general trend in structural battery research is that as the degree of integration and energy density increases, the quality of the mechanical properties decreases (Kühnelt et al, 2022). Researchers at the Chalmers University of Technology have developed a structural battery with an energy density of 24 Wh/kg and a stiffness of 25 GPa (Asp et al, 2021). This research demonstrates that structural batteries are moving toward being competitive with conventional battery technologies. The research demonstrated its tentative multifunctionality with an increased energy density and improved mechanical performance from previous research developments. Based on this research, further improvements of structural battery technology is promising.

The current state of the art has few examples of any practical applications of a structural battery. We will address this by using an established model of a current state-of-the-art structural battery and gather information about some of the electrical properties of the battery (ex: voltage per kilogram). This information will then be used to create a theoretical model of a working prototype of a small drone with this battery integrated into it.

One of the major technical challenges for this project is the integration of the battery with the structure. There have been no studies posted about the effects integrating a structural battery would have on the mechanical properties of an aerospace composite body. For instance, if structural batteries were to be placed on the wings of a drone, we would have to evaluate how the wings would handle the added load and if they would still be able to work at normal efficiency. We would get around this by placing the battery in the fuselage.

Additionally, we could likely face possible safety challenges incorporating structural batteries into drones. Thermal runaway begins when the heat generated within a battery exceeds the amount of heat that is dissipated to its surroundings (see Comen et al, 2017). If the cause of this excessive heat creation is not remedied, the condition will worsen. Internal battery temperature will continue to rise - causing battery current to rise - creating a domino effect. The rise in temperature in a single battery will begin to affect other batteries in close proximity, and the pattern will continue, thus the term "runaway." We would have to make sure that wherever the structural battery is incorporated into the drone, it is not susceptible to high temperatures, as this could result in thermal runaway. By gathering information about the thermal properties, we will be able to have a more accurate estimate of how to incorporate the battery. Two other major technical challenges of the project are balancing the structural efficiency with battery efficiency, and obtaining a high degree of multifunctionality. Since the current structural battery technology is still in the beginning stages of development, other specific challenges that may be encountered are still unknown.

The first task of the work plan is to find the electrical parameters of the battery. We will first focus on learning the COMSOL modeling software which has been recommended by our SMEs (Cai & White, 2011), along with the structural mechanical and battery modules. We have set aside 50 days to complete this. We will use the next 21 days to model the battery with the parameters from the state-of-the-art battery supplied by the SME. Then, we will test the model with COMSOL in order to find the energy density per kilogram, the voltage per kilogram, and the charge-discharge cycle per kilogram. The first two parameters are expected to take 14 days to find, with one being found by the engineering team and the other by the science team. The last will take 10 days since both teams will be working on it. The data will be analyzed and then reported to both the SMEs and NASA. We will have a schedule margin of 18 days with 11 days to write the report.

Our second task consists of concluding how all of these properties will change under some of the most extreme temperatures recorded on earth. We have used Death Valley (56 C) and Antarctica (-56 C) as our benchmarks. We expect this to take 27 days with a schedule margin of 12 days. We will have 15 days to write and submit the report. The Science Team will focus on -56 C, and the Engineering team will focus on 56 C.

The results from the previous two tasks will give us the constraints forced on the drone parameters (size, thrust provided by propeller, etc.) for our fixed-wing drone model. We have decided that we will take 25 days to build the model, 12 days to test its stability and weight, 8 days to optimize its stability and weight, 7 days to test its flight time, and 14 days to write and submit the final report detailing the performance parameters that we have tested for this drone model compared to the data from existing commercially available drones. Both the Science and Engineering teams will be working on this. We have set aside a schedule margin of 13 days for this task. See Gantt Chart in the Project Management section for further clarification. Currently, NASA has explored the use of small drones in conjunction with rovers. This model that we will develop could contribute significantly to that exploration.