The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #41307

An Independent Study Course for a Multi-Rotor Design and an Endurance Record

Dr. Stephen Andrew Wilkerson P.E., York College of Pennsylvania

Stephen Wilkerson (swilkerson@ycp.edu) received his PhD from Johns Hopkins University in 1990 in Mechanical Engineering. His Thesis and initial work was on underwater explosion bubble dynamics and ship and submarine whipping. After graduation he took a

Yargo Teixeira Gomes de Melo, York College of Pennsylvania
Alex Suarez, York College of Pennsylvania

Senior Electrical and Mechanical Engineering Student with a background in UAV technologies.

An Independent Study Course for a Multi-Rotor Design and an Endurance Record

This paper presents a student-led initiative to extend the flight endurance of multi-rotor aircraft, guided by a team of instructors. This venture stands distinctly as it targets surpassing the existing world record for flight time in small multi-rotor autonomous aircraft. The investigative approach involved an analysis of the current record-holder's design, focusing on potential improvements in battery technology, motor efficiency, structural design, and rotor blade aerodynamics. Amidst a rapidly evolving drone technology landscape, this endeavor holds promise. The narrative highlights the student's educational journey, supported by testimonials and educational insights from the academic advisors, illustrating the pedagogical value and the innovative potential of hands-on, goal-oriented academic projects.

Introduction

This paper delineates the efforts of an engineering student in advancing the endurance capabilities of small multi-rotor autonomous aircraft, herein referred to as Unmanned Aerial Vehicles (UAVs). This ambitious project began with the innovation in rotor-prop design and advancing through a comprehensive model for predicting UAV endurance. This evolved into a series of aircraft concept generations, ultimately leading to the final design that promises to redefine industry benchmarks.

The realm of small multirotor endurance represents a critical frontier in the development of UAVs, with significant implications across various sectors including search and rescue operations, environmental monitoring, and long-duration surveillance. Enhancing the endurance of these aerial systems is paramount as it directly correlates to their operational efficiency, and effectiveness. With extended flight times, small multirotor can cover larger areas, collect more data, and perform longer missions without the need for frequent landings to recharge or swap batteries. This not only optimizes mission workflows but also ensures that UAVs can remain in the field during critical times when they are most needed. In disaster-stricken or inaccessible areas, for instance, the prolonged airborne presence of a UAV could mean the difference between life and death. Furthermore, increased endurance minimizes the downtime and logistical challenges associated with battery management, thereby reducing operational costs, and enhancing the feasibility of UAVs for continuous, real-time applications. Consequently, pushing the boundaries of small multirotor endurance is not just a technical challenge, but a necessary stride toward unlocking the full potential of UAV technology in serving humanity.

Background

While there are some documentations on breaking world records [1], there does not appear to be any pedagogical efforts to document the process. The projected design predicts a flight endurance of 2 hours and 57 minutes, surpassing the current Guinness World Record (GWR) for electric UAV endurance in the 5-20 kg category by approximately 42 minutes, which stands at 2 hours, 14 minutes, and 23 seconds. UAVs within this category typically exhibit a flight duration ranging from 2 minutes to 45 minutes, contingent upon their size and weight. Notably, the current GWR for an electric multi-rotor UAV is 2 hours, 23 minutes, and 23 seconds within the 5 kg division. Our design endeavors to eclipse the record in the 5-20 kg category [2].

Methodology

Research was conducted in four distinct phases: initially focusing on rotor-prop design; subsequently moving to propulsion selection; followed by the creation and validation of aircraft concepts; and culminating in the final aircraft design. This paper presents a selection of the student's pertinent research, while primarily chronicling the student's developmental journey and evolution throughout the process.

An integral part of this project was to discern, articulate, and measure the learning outcomes achieved by the student. Although the project was driven by an end goal, it expanded the scope of what is traditionally encountered in an undergraduate engineering curriculum. The endeavor highlighted that success hinged not solely on technical acumen but also on the ability to navigate complex interpersonal dynamics and organizational challenges. The student emerged as a leader, addressing numerous unforeseen issues. Securing funding, acquiring specific materials, and garnering support from corporate sponsors and private contributors necessitated significant personal development, to which the student achieved admirably. While cooperative education often cultivates interpersonal skills, this project served as an accelerant for the student's maturation process, particularly in resolving intricate people-related challenges. Beyond the daily technical hurdles, the project was a testament to the importance of fostering cooperation and collaboration, areas in which the student demonstrated considerable growth over the course of the year.

Design and Development

In the design and development phase of the GWR-attempt multi-rotor aircraft, the research had the potential to explore a spectrum of scholarly aspects such as rotor-prop design, aircraft mass, and the optimization of component efficiency. The strategic choice to prioritize the propulsion system, specifically the synergy between the rotor-prop and motor, was pivotal. The prevailing hypothesis was that surpassing existing records would require in-house creation of a bespoke rotor-prop. To this end, various airfoils were scrutinized with Airfoil Tools, evaluating their Coefficient of Lift (Cl) against the Angle of Attack (α), and the Coefficient of Drag (Cd), to establish the Cl/Cd ratio over a range of α. This analysis was complemented by calculating the Reynolds number (Re), a ratio between inertial and viscous forces, to benchmark multiple airfoils.

Following the selection of an optimal airfoil, a rotor-prop was engineered to incorporate this profile, integrating a varying chord length to ensure a uniform Re along the blade span. This prototype was produced using 3D printing technology with Polylactic acid (PLA) and subsequently treated with MonoKote plastic shrink wrap for finishing. It was during this process that the limitations of the institution's manufacturing resources became evident, guiding the decision towards a composite rotor-prop as the most effective solution for this project.

Throughout this process, the student leveraged his expertise in drone racing and design to navigate the project's trajectory. Faculty guidance was instrumental, offering a dialogue that fostered informed decision-making and encouraged the application of theoretical knowledge to practical challenges, such as discussions on aerodynamics of the blades as well as possible movement-induced vibration failure modes.

Iterative design process for the multi-rotor aircraft

To determine the optimal propulsion system for the aircraft, a comprehensive Excel spreadsheet was developed to evaluate various motor and rotor-prop pairings. The comparative data was sourced from thrust stand data provided by the manufacturers. Due to instances of unreliable data from UAV motor producers, the selection of manufacturers was narrowed to T-Motor [4] and VertIQ [5], both of which are esteemed within the UAV industry.

The spreadsheet was designed to process multiple inputs: throttle percentage, voltage, thrust, current, weights of the motor, electronic speed controller (ESC), and rotor-prop, as well as the estimated weight of the remaining components (EWRC), including smaller electronics and the frame, and the number of motors. These variables were crucial in identifying the most efficient, lightweight, and appropriately sized combinations for the aircraft.

After evaluating several options, those propulsion systems promising the longest endurance were further analyzed on a secondary spreadsheet to fine-tune battery selection. In this phase, instead of calculating the battery weight remaining, it was pre-determined based on the weight of the tested battery combinations, which were chosen according to the specifications of the *Foxtech*[1] Diamond Series Semi-Solid-State Li-ion Battery [6]. The battery configuration was capped at 6s to manage the costs associated with chargers for higher capacities. Furthermore, actual battery capacity ratings were utilized rather than estimates based on mass. Verification was conducted to ensure the generation of sufficient thrust for flight.
Flight duration was calculated if the resultant thrust was positive; otherwise, it was designated as zero hours. Another criterion was the aircraft's weight, which had to be under 20 kg. Any combination exceeding this weight was disregarded. Using this meticulous approach, an appropriate propulsion system was selected.

The conceptualization process began with brainstorming, generating various configurations inspired by prior observations of diverse multirotor designs. Initial assessments were made based on perceived complexity, which often correlates with increased weight. Concepts that met the preliminary criteria were further scrutinized using a MATLAB program developed to quantify the advantages of each configuration. This analysis included calculating the required thrust per motor to achieve equilibrium and estimating flight times at various angles of the aircraft's orientation to gravity. Additionally, the design process incorporated recommendations for overlapping and coaxial rotor-prop configurations from the research by M. Ramasamy [7].

Funding

Securing sufficient funding posed a considerable obstacle for this endeavor, as the project's scope encompassed the incorporation of cutting-edge technologies, state-of-the-art manufacturing processes, and specialized materials, all of which demanded a substantial financial investment. Despite receiving a portion of the necessary funds from faculty-allocated

[1] Foxtech: https://www.foxtech.com/

budgets, there remained a significant shortfall to cover the expenses needed to design, construct, and obtain a solution within the allotted one-year timeframe. This financial gap necessitated proactive fundraising efforts on the part of the student, who, through diligent outreach to former cooperative education employers and various industry contacts, managed to obtain sponsorship, thus ensuring the continuation and support of this innovative project.

Results

While the definitive outcomes of this student-led world record attempt will not be available by the time of this paper's publication, the findings are expected to be presented at the ASEE 2024 symposium, marking this endeavor an ongoing scholarly pursuit. The student has ambitiously set out to challenge three distinct records, with the focus currently on the endurance record due to its foundational significance for subsequent achievements. The performance is partly attributable to the choice of components; however, the educational emphasis has been on the design process and the selection of materials. This project serves as a practical lesson in engineering optimization, where the student is tasked with balancing the selection of robust yet lightweight materials to push the boundaries of what is achievable with multi-rotor aircraft. The final presentation will provide a comprehensive overview of the design, encapsulating the learning journey and the innovative outcomes of this academic venture.

Discussion

The significance of this project extends beyond the enhancement of our collective understanding of multi-rotor aircraft endurance; it has become an invaluable educational odyssey for both the faculty and the student involved. The experiential learning and the journey itself have emerged as paramount, offering profound insights into pedagogical benefits and student development that eclipse the importance of the final outcome. Recognizing the transformative impact of this hands-on research experience, we are including testimonials that capture the personal and professional growth witnessed during the project. These narratives, contributed by the student at the heart of the research and the two professors guiding him, reflect the symbiotic relationship between teaching and learning, and the profound influence of mentorship in shaping future engineers. This testament serves to illustrate the integral role that such projects play in academic growth and the cultivation of expertise in a specialized field.

Incorporating a scaling element into future projects is a viable consideration. In the current scenario, the student had independently conceived the idea and completed substantial preliminary work before seeking faculty guidance. Although capstone drone students received encouragement to contribute and participate, there was a noticeable lack of strong interest in joining the project. We advocate for an organic growth model for such initiatives, favoring a bottom-up rather than top-down approach. Nonetheless, the concept of a collaborative team endeavor for such projects remains both possible and advantageous, offering the opportunity for a group of students to engage collectively rather than placing the responsibility on an individual student.

The Gallup-Purdue Index identifies six pivotal experiences that contribute to post-collegiate success in work and life:

- Engagement with professors who ignite a passion for learning,
- The perception of professors caring about students as individuals,
- Mentorship that motivates the pursuit of aspirations,
- Involvement in long-term projects,
- Opportunities to apply classroom learning in real-world settings, and
- Participation in diverse extracurricular activities.

In the context of this independent study, the project notably addressed the first four criteria and the last. The student interacted closely with faculty who fostered excitement in learning and provided personalized support. The endeavor itself served as a significant project spanning several semesters. Furthermore, extracurricular involvement was implicit in the project's outreach for funding and support. Regarding internships, our institution's curriculum includes multiple cooperative learning experiences, which complement the practical applications inherent in this project. Thus, the student's attempt to break a world record encapsulated the essence of the Index's experiential learning components, serving as a catalyst for professional and personal development.

Student Testimonial

During the elementary and middle school book fairs, the most sought-after book was the Guinness Book of World Records. My friends and I would always skim through the pages to discover the coolest and weirdest world records, sparking my desire to break a Guinness World Record. With the talent and knowledge gained over the years, I now aim to push the envelope further and advance drone technology to its maximum extent. Therefore, I aspire to fulfill my childhood goal of breaking a Guinness World Record in the near future.

Faculty Testimonial

As a new Engineering Professor with a focus on aerodynamics, I was eager to support Alex in his goal to break the world record in drone flight. Alex, a student with a strong interest in drones, reached out to me for advice on optimizing his drone's aerodynamics and how to avoid flutter. His independent approach to learning and applying complex principles, particularly in fluid dynamics, was notable. This collaboration was an opportunity to apply academic knowledge to a real-world challenge, and as new faculty, working with someone as independent and driven as Alex made my job easy. My involvement in Alex's project was driven by a shared interest in aerodynamics and the chance to guide a student in achieving a significant technical milestone, and made me gain significant appreciation for independent student-led research.

Students frequently approach faculty members with proposals for projects they wish to undertake as an independent study or specialized course prior to graduation. These projects often stem from a desire to conduct material tests or delve deeper into a subject briefly touched upon in a previous class, yet not explored extensively. Typically, we facilitate the student's research, granting them considerable leeway to pursue their intellectual curiosities. The institution generally provides the necessary resources, and such scholarly pursuits prove advantageous for both the students and faculty members.

The study in question, however, was distinctively more ambitious than usual. Additionally, the student involved was a national-level drone racing competitor with a wealth of experience in drone technology. Consequently, this project has evolved into something significantly greater than I had initially envisioned. While the outcomes of the record-breaking attempts remain uncertain, I am confident in the student's potential for success, or at the very least, to approach the existing records closely. This endeavor has enriched my own research as well as the institution's contributions to the field of drone technology.

Conclusion

In closing, this paper has chronicled a pedagogically driven, student-led endeavor to elevate the flight endurance of multi-rotor aircraft, aimed at surpassing the existing world record for autonomous flight duration in this category. While the project's objective is centered on technical innovation, the core narrative has been the educational journey undertaken by the student, as directed by a supportive team of instructors.

The investigative methods adopted in this research scrutinized the design of the reigning record-holder's aircraft, with a particular focus on enhancing battery technology, motor efficiency, structural design, and rotor blade aerodynamics. Although the ultimate outcome in terms of record-setting will not be known until post-publication, the paper predominantly addresses the pedagogical insights gleaned throughout this process.

The pedagogical implications of this project are manifold, illuminating the value of learning through doing. The student's engagement with real-world engineering challenges, supplemented by the advisory team's insights, has provided a rich tapestry of learning experiences that exemplify the power of applied research in an educational setting. This paper's conclusion is not simply a tale of technical ambition but a testament to the transformative nature of goal-oriented academic projects in cultivating not only engineering acumen but also fostering a deeper appreciation for the learning process itself.

We posit that by allowing students to pursue dreams and activities they are passionate about, the learning experience is greatly enhanced. This symbiotic engagement benefits both student and instructor, reinforcing the notion that when educational pursuits align with personal passions, the potential for learning and innovation is boundless.

References

[1] Performance Drone Works, "Longest duration flight of an electrically powered prototype multirotor/drone (5 - 20 kg)," Guinness World Records, 18 March 2022. [Online]. Available: https://www.guinnessworldrecords.com/world-records/679489-longest-duration-flight-of-an-electrically-powered-prototype-multirotor-drone-5 . [Accessed 14 December 2023].

[2] Paterson, Sam, et al. "Design and development of the Sunswift eVe solar vehicle: a record-breaking electric car." *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 230.14 (2016): 1972-1986.

[3] Airfoil Tools, "Airfoil Tools," 2023. [Online]. Available: http://airfoiltools.com/. [Accessed 14 December 2023].

[4] T-Motor, "T-Motor The Safer Propulsion System," 2023. [Online]. Available: https://uav-en.tmotor.com/. [Accessed 14 December 2023]

[5]VertIQ, "Thrust Data," VertIQ, 2023. [Online]. Available: https://www.vertiq.co/thrust-data. [Accessed 14 December 2023].

[6] Foxtech, "Foxtech Diamond Series Semi-Solid-State Li-ion Battery," Foxtech, 2022. [Online]. Available: https://www.foxtechfpv.com/foxtech-diamond-6s-22000mah-semi-solid-state-li-ion-battery.html. [Accessed 14 December 2023].

[7] M. Ramasamy, "Measurements Comparing Hover Performance of Single, Coaxial, Tandem, and Tilt-Rotor Configurations," in *AHS 69th Annual Form*, Phoenix, AZ, 2013

[8] Microsoft Word, Google Sheets and ChatGPT were used to check Grammar and Style of this document.