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Lighter-Than-Air-Vehicle Design for Adversarial Defense

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Abstract

The Defend the Republic (DTR) competition is a biannual collegiate robotics event in which teams design autonomous lighter-than-air vehicles (autonomous blimps) to capture and score helium balloons into opponents' goals–resembling robotic Quidditch. The competition presents a range of technical challenges, including autonomous operation under strict buoyancy constraints in dynamic, sensor-limited environments. While early team strategies emphasized autonomous scoring, recent developments have introduced adversarial tactics aimed at disrupting opponents. This paper presents the design methodologies and vehicle architectures developed by the Indiana University DTR team for adversarial defense and interference, highlighting three LTA vehicle iterations deployed during the Fall 2023, Spring 2024, and Fall 2024 competitions. Each iteration is discussed in terms of design evolution, operational strategy, and competitive performance, concluding with lessons learned and future development directions.

I. Introduction

At the Defend the Republic (DTR) competition, collegiate teams strive to use their autonomous lighter-than-air vehicle (LTA) vehicles (i.e., autonomous blimps) to autonomously capture helium balloons and score them into the opponent's goals–effectively Robotic Quidditch. Collegiate teams recently involved with this competition have included Arizona State University, Baylor University, Boston University, Drexel University, George Mason University, Georgia Tech, Indiana University, Lehigh University, Penn State University, University of Michigan, Virginia Tech, and West Virignia University. Teams typically meet at a hosting university twice per year to compete in a tournament bracket. Fig. 1 shows an example of a DTR match, with the Indiana University's (IU) 'Swordfish' adversarial defense vehicle seen on the top left of the photo.

Figure 1. Indiana University LTA vehicles (blue) and Baylor University LTA vehicle (red) navigating the game space during a DTR match in November 2023; the IU 'Swordfish' adversarial defense vehicle can be seen on the top left.

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The competition challenge involves designing and controlling robot vehicles with physical constraints that can operate in challenging environments with limited sensing, actuation, and computation capabilities. The major physical constraints on designs are a maximum helium budget of 50 cu. ft. of helium and a maximum negative buoyancy of 100 grams (when inflated). Before the competition, teams perform vehicle design, fabrication, prototyping, embedded development, systems engineering, feedback control, motion planning, computer vision, among many other research and development tasks.[1–13]

During the competition, students aim to have their vehicles capture the neutrally-buoyant goal balloons, and place them through colored, multi-shaped hoops on the opposing end of the playing field. Each game consists of two 30 minute halves and a 20 minute halftime. During each half, there are six five-minute intervals, with 30 seconds for teams to take manual control of their blimps, followed by 4.5 minutes for autonomous flight. Teams can advance through the competition by scoring the most number of points during their one-on-one matches, with different criteria for various point values based on the level of autonomy used to complete a task. However, as the competition progressed over the past several years, teams have shifted their focus beyond simply scoring points to also developing strategies for blocking opponents and disabling their vehicles.

This paper describes the methodologies and resulting interference vehicles developed by the Indiana University Defend the Republic team for adversarial defense, for the Fall 2023,[14] Spring 2024,[15] and Fall 2024[16] DTR competitions. The rest of this paper is organized as follows. Section II introduces the context of the Defend the Republic competition and the motivation for developing an interference vehicle. Section III, IV, and V each describe a different iterations of the the IU interference vehicle design across competition cycles, detailing the system architecture and key design revisions. Finally, the paper concludes with Section VI and VII, presenting lessons learned and discussing directions for future work.

II. Background

Over the past five years, the Defend the Republic (DTR) competition has challenged collegiate teams to design and build autonomous lighter-than-air vehicles capable of capturing helium balloons and scoring them into opponents' goals–effectively robotic Quidditch. In the early years, teams focused primarily on developing reliable autonomous systems for scoring. As the competition evolved, however, teams began to look beyond scoring alone and toward maximizing overall competitive performance. This shift gave rise to two main strategic approaches: enhancing their own scoring efficiency and limiting their opponents' ability to score. As a result, teams have increasingly incorporated defensive tactics—such as blocking opponents and disabling rival vehicles—making the competition more dynamic, strategic, and multifaceted.

During the 2023 Fall DTR competition, George Mason University's (GMU) collegiate team showcased a vehicle composed of a large net wall, called 'Skynet'.[17] The vehicle would be initially deployed to capture the opposing teams scoring vehicles and clear the airspace, with GMU's scoring vehicles following to compete uncontested. Fig. 2 shows the 'Skynet' successfully catching one of the opposing team's vehicles. This approach proved especially effective against teams with smaller fleets, as a single pass from 'Skynet' could effectively neutralize the entire opposing team from the field.

The new paradigm of 'interference' vehicles required teams to now consider and evaluate responses to various direct attacks on their scoring fleet. Throughout the remainder of the fall DTR competition in 2023, and the following years, Indiana University developed and iterated on a counter for sweeping net designs, eventually creating their own offensive vehicles developed on the same principles. The following three sections are each iteration of IU's developed countermeasures, describing system architecture and operation, and a review of their usage in competition.

The new paradigm of 'interference' vehicles forced teams to consider and develop responses to various forms of direct attacks on their scoring fleets. Throughout the remainder of the Fall 2023 DTR competition and in the years that followed, Indiana University focused on countering sweeping net and other defensive designs, ultimately developing their own offensive adversarial vehicles, developed on similar principle: increasing score differential based limiting their opponents' ability to score. The following three sections details each iteration of IU's defense vehicles, including system architecture, operational design, and a review of their performance in competition.

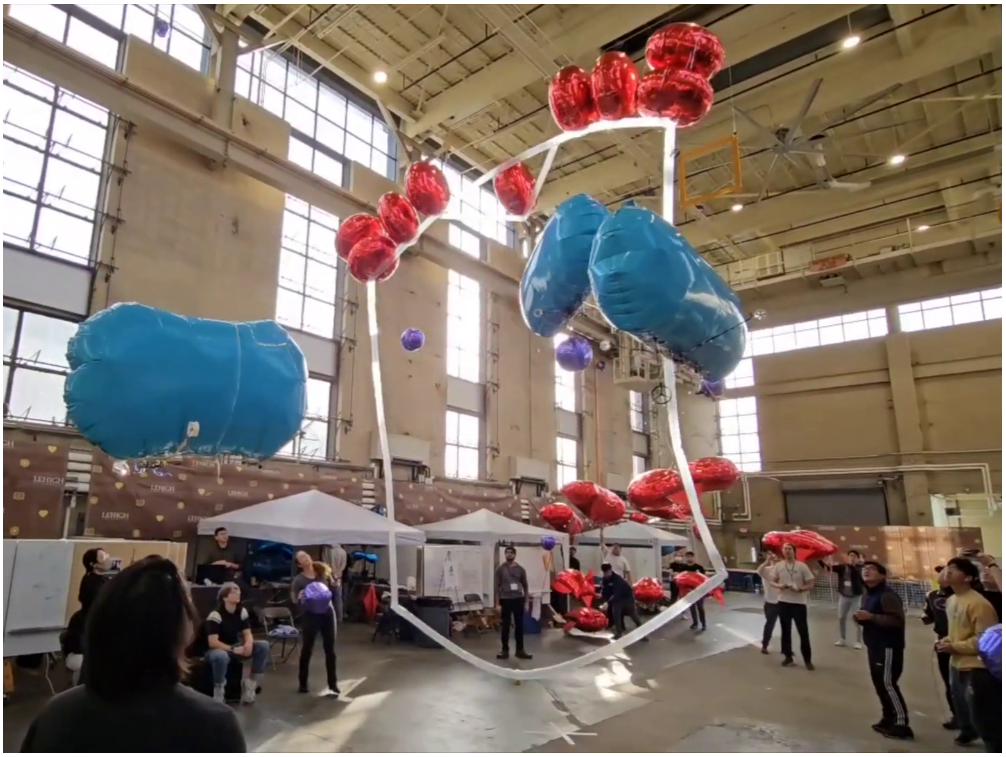

Figure 2. George Mason University's 'Skynet' interference vehicle (red, center) capturing University of Florida scoring vehicles (blue, left) before the George Mason University scoring vehicles (red, back/right) advance [screenshot taken from YouTube[17]].

III. Swordfish

The first iteration of IU's defensive LTA vehicles was named 'Swordfish', which developed directly to respond to GMU's 'Skynet'. The vehicle was built, tested, and completed in two days, using spare parts from the IU DTR team's scoring vehicles. The 'Swordfish' was aptly named after the blunt balsa wood stick protruding from the front of the vehicle, resembling that of a swordfish. Operationally, 'Swordfish' functions as an autonomous 'spear' to push against the 'Skynet' vehicle. More specifically, the'Swordfish' would actively catch the 'Skynet' vehicle using the front-facing protruding balsa stick, and use the thrust of 3 propellers to push the the 'Skynet' backwards, and out of the way.

Due to the gameplay format–30 seconds of manual control followed by 4 minutes and 30 seconds of autonomous-only operation–rudimentary autonomy was implemented, ensuring that the limited manual-control time could be used more effectively with a scoring vehicle. Based on the spare materials available, an Arduino 33 BLE Nano Sense Rev. 2 was used for sensing and computation. Sensor fusion was performed, determining the vehicle's absolute vehicle orientation and altitude, using the onboard Bosch BMI270 6-axis inertial measurement unit, Bosch BMM150 3-axis magenetomoeter, and STMicroelectronics LPS22HB pressure sensor. The 'Swordfish' system architecture diagram is presented in Fig. 3. Two proportional (p) controllers were tuned to maintain a specified altitude and orientation upon initialization. By saving the initial altitude and heading of the vehicle, the Arduino controller was programmed to continuously fly 'Swordfish' forward in a given direction and altitude offset.

After two days of development, 'Swordfish' was successfully deployed against GMU 'Skynet'. As shown in Fig. 4, 'Swordfish' hooked into Skynet's net and redirected its forward momentum, turning the vehicle and pushing it into the wall, effectively removing both vehicles from play. This tactical disruption of GMU's defense, combined with the simultaneous deployment of a manual scoring vehicle, allowed Indiana University to score quickly and without interference.

While 'Swordfish' successfully disabled 'Skynet', several major flaws were revealed. The propellers and motors–repurposed from IU's scoring vehicle–were sufficient to redirect Skynet but lacked the thrust needed to push the vehicle backward effectively. Additionally, constructing the ‘Swordfish’ LTA required substantial materials and build time—-comparable to that of a more advanced scoring vehicle—-raising the question of whether limited resources should be allocated to constructing scoring vehicles or defensive ones. Finally, Swordfish lacked a failsafe mechanism to recover the vehicle if it missed its target or ascended to an unrecoverable height. As a result, the design required a comprehensive overhaul ahead of the next competition.

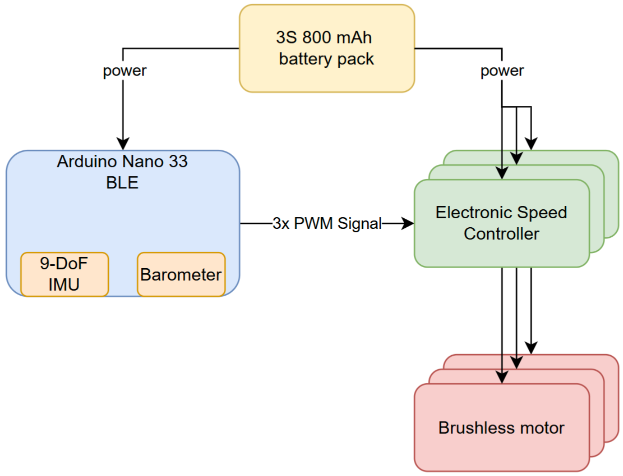

Figure 3. System architecture diagram for the IU ‘Swordfish’ defense vehicle.

Figure 4. The IU ‘Swordfish’ defensive LTA vehicle (red) successfully disabling the GMU ‘Skynet’ defensive vehicle (blue) by successfully redirecting it out of the game play.

IV. Titan

The ‘Titan’ was the second iteration of Indiana University’s interference defense vehicle developed for the DTR competition. This second defensive vehicle evolution was developed over a six-month period between the Fall 2023 and Spring 2024 competitions. The ‘Titan’ was nicknamed after its single large balloon used for buoyancy and its significantly larger, low-pitched, loud propellers, resulting in a lighter, stronger, and louder vehicle.

Fig. 5 shows the new design of the ‘Titan’, with a core architecture resembling Swordfish but stripped of unnecessary supports. The ‘Titan’s’ single large spherical balloon could accommodate a similar payload as the ‘Swordfish’, while reducing aerodynamic drag and helium requirements of the four ‘Swordfish’ coin-shaped balloons. Since nets are the primary capturing mechanism used by all adversary teams, the spear remained the most effective means of engaging with opposing vehicles. Additionally, a new motor configuration was employed, using larger motors to boost thrust for vertical takeoff and for forward differential drive. This setup minimized weight while maximizing upward thrust, resulting in improved overall flight efficiency and endurance.

However, during the development period, it was found that due to the vehicle’s unique design and resulting aerodynamics, it lacked fine flight control during high speed flight. Due to the reduced frontal drag, increased motor power, and reduced drive motor torque arm, steering in the yaw axis was hard to controlled and undamped. The overcompensation of power resulted in overly sensitive controls, resulting in a vehicle that was as imprecise as it was powerful. However, interestingly it was found that with the increased power from larger propulsion system, the human pilot could provide enough thrust to flip the vehicle around completely in the air–effectively performing an Immelmann turn, which was unheard of for DTR LTA vehicles. The manual flight performance of the aircraft motivated the vehicle to remain manually piloted for the Spring 2024 DTR competition, with effort being increasingly allocated towards scoring vehicle development. Fig. 6 presents the system architecture diagram for the ‘Titan’, notably replacing the Arduino-based autonomy system with a radio control receiver for manual-only operation.

During the 2024 Spring DTR Competition, the ‘Titan’ defensive LTA vehicle was only deployed in between matches as a technology demonstrator. A notable amount of attention was drawn to the vehicle by other DTR teams, specifically towards its powerful thrust and loud presence. While unsuccessful in engaging with opposing team’s vehicles, it’s high speed and aerobatic demonstrations seemed to serve as a form of strategic intimidation, motivating adversary teams to not deploy all their LTA vehicle in matches against the IU team. Therefore, the next revision’s focus was on maneuverability and low cost, in order to address growing numbers of vehicle’s in opposing team’s fleets. Despite it’s shortcoming, ‘Titan’ had proved its viability as a low-cost and resource efficient deterrent, whether or not it could be precisely controlled.

Figure 5. The IU ‘Titan’ defensive LTA vehicle.

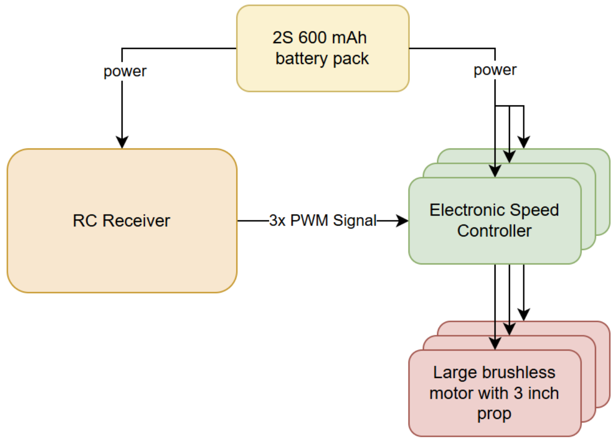

Figure 6. System architecture diagram for the IU 'Titan' defense vehicle.

V. Witch

During the Spring and Fall 2024 DTR competitions, the 'Witch' LTA vehicle was developed and refined as the third evolution of IU's defensive interference vehicles. Nicknamed for its broom-like appearance and flight behavior, the 'Witch' is shown in Fig. 7. The 'Witch' design was guided by three core principles: (1) speed and maneuverability, (2) low cost, and (3) thrust.

First, the vehicle needed to be fast and agile enough to track down and engage opposing vehicles within the 30 second manual control windows during each period. Given its speed and maneuverability, the 'Witch' could be quickly deployed and prevent opponents from scoring manually during these brief periods.

Second, the vehicle had to be cost-effective. To compete with teams deploying larger fleets, the 'Witch' was designed to be economically scalable–with sufficiently low cost, opposing teams could be effectively neutralized with an uncontested field for Indiana University to score. The low-cost design also allowed IU to preserve resources for constructing scoring vehicles.

Third, the interference vehicle required significant thrust capability to disrupt an opponent vehicle's motion. The vehicle interference operation was revised such that the LTA would provide an upward thrust to place the adversary vehicles on the ceiling rather than forcing the vehicle backwards. This prevented opposing team's from recovering their vehicles, and reduced the high forward thrust requirement (which created the yaw instability which made the 'Titan' hard to fly). Incorporating lessons from the previous iterations, the 'Witch' used a combination of both the differential drive propellers and motors from the 'Swordfish', and a stronger vertical thrust propeller and motor and reduced frontal-drag design from the 'Titan'. To further increase the maneuvering stability, a tail was added to reduce unwanted heading drift, allowing the vehicle to fly straight unassisted. The 'Witch' differential drive system also mirrored that of Indiana's scoring vehicles, maintaining control system consistency across the fleet.

The simplified system architecture, with no onboard autonomy, resembled that of a basic remote-controlled aircraft, a refined version of the 'Titan'. As a result, 'Witch' was a ultra-lightweight, low-cost, and reliable, suitable for operation even by inexperienced pilots. A wiring diagram of the system is shown in Fig. 8, illustrating the minimal components required for functionality.

During the Fall 2024 competition, 'Witch' successfully engaged with at least one target in every match it was deployed. Minor revisions included the utilization of small hooks, resembling fishing hooks, to keep the spear vehicle locked into a target. Overall, the third revision of Indiana University's interference vehicles achieved its goals in speed, cost, and impact, marking the conclusion of major spear-based interference development.

Figure 7. The IU 'Witch' defensive LTA vehicle.

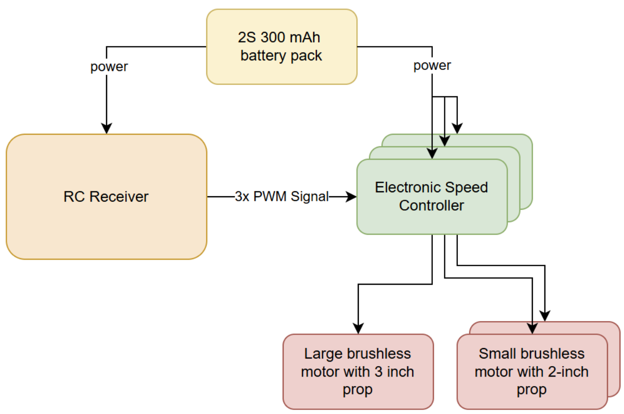

Figure 8. Witch Vehicle Wiring Diagram

VI. Lessons Learned

The development of adversarial defense and interference vehicles for the Defend the Republic (DTR) competition by the Indiana University team provided several valuable lessons that can be applied to future adversarial aerial platforms and competitive environments. The rapid development of the 'Swordfish' vehicle in just two days demonstrated the importance of quick prototyping, and each subsequent iteration, from 'Swordfish' to 'Witch', built upon the lessons learned from previous designs, allowing for continuous improvement and adaptation to new challenges.

The initial incorporation of rudimentary autonomy in 'Swordfish' was a valuable learning experience but revealed limitations, which highlighted the necessity of maneuverability as well as speed. The 'Titan' provided lessons on the connections between speeds, maneuverability, and aerodynamic properties. Without a sufficient balance of these characteristics, the interference vehicle could not succeed. The 'Witch's' success with a simple, manual control system showed that a straightforward approach can be the most effective. It's design focused on being low-cost and scalable, which proved crucial in out-performing competing fleets, allowing IU to gain a strategic advantage by rapidly deploying vehicles.

The evolution of the interference vehicles was driven by the need to counter evolving opponent strategies, such as the 'Skynet' introduced by George Mason University, necessitating a response and the design of specific solutions to address these challenges. The choice of materials and physical design significantly impacted the performance of the vehicles; the Witch's use of an aerodynamic tail to resist yaw drift and the incorporation of small hooks for better engagement demonstrated the importance of system design in achieving desired performance.

VII. Future Work

The success of the Witch vehicle in the Fall 2024 Defend the Republic competition provided valuable insights and a solid foundation for future development. Moving forward, the Indiana University team aims to build upon these lessons and explore several key areas to maintain and enhance the team's competitive edge.

The IU team plans to further explore the usage of alternative attack vectors, including hooks as an independent interference mechanism. By expanding the range of interference capabilities, other teams must use more resources to further develop countermeasures. Additionally, correct propeller and motor selection was shown to be vital prompting further testing and optimization of the vehicles' propulsion systems.[18]

As the DTR competition culture promotes autonomy, future revisions will explore the usage of basic lightweight autonomy such as off-board image processing and computation.[19] Finally, as a part of autonomous coordination efforts, inter-vehicle communication will be considered for target selection. By allowing vehicles to communicate, lower-computation adversarial vehicles can be strategically directed by fewer, more expensive, high-computation (scoring) vehicles.

References

[1]Messinger, S., *Modeling, Adaptive Control, and Flight Testing of a Lighter-than-Air Vehicle Validated Using System Identification*, Master's thesis, The Pennsylvania State University, 2022, Master's Thesis.

[2]Mathew, J. P., Karri, D., Yang, J., Zhu, K., Gautam, Y., Nojima-Schmunk, K., Shishika, D., Yao, N., and Nowzari, C., "Lighter-Than-Air Autonomous Ball Capture and Scoring Robot – Design, Development, and Deployment," *arXiv preprint arXiv:2309.06352*, 2023.

[3]Mendoza, A., Lovelace, A., Potter, S., and Koziol, S., "Sensor Fusion Image Processing for Autonomous Robot Blimps," *2023 IEEE 66th International Midwest Symposium on Circuits and Systems (MWSCAS)*, 2023, pp. 312–316.

[4]Simmons, J., Lovelace, A., Tucker, D., Mendoza, A., Coates, A., Alonzo, J., Li, D., Yi, X., Potter, S., Mouritzen, I., Smith, M., Banta, C., Hodge, R., Spence, A., and Koziol, S., "Design and Construction of a Lighter than Air Robot Blimp," *2023 ASEE GSW*, No. 10.18260/1-2-1139-46327, ASEE Conferences, Denton, TX, June 2024, https://peer.asee.org/46327.

[5]Xu, J., D'antonio, D. S., Ammirato, D. J., and Saldaña, D., "SBlimp: Design, Model, and Translational Motion Control for a Swing-Blimp," *2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, IEEE, 2023, pp. 6977–6982.

[6]Li, K., Hou, S., Negash, M., Xu, J., Jeffs, E., D'Antonio, D. S., and Saldaña, D., "A Novel Low-Cost, Recyclable, Easy-to-Build Robot Blimp For Transporting Supplies in Hard-to-Reach Locations," *2023 IEEE Global Humanitarian Technology Conference (GHTC)*, IEEE, 2023, pp. 36–42.

[7]Santens, L., D'Antonio, D. S., Hou, S., and Saldaña, D., "The Spinning Blimp: Design and Control of a Novel Minimalist Aerial Vehicle Leveraging Rotational Dynamics and Locomotion," 2025.

[8]Xu, J., Vu, T., D'Antonio, D. S., and Saldaña, D., "MochiSwarm: A testbed for robotic blimps in realistic environments," 2025.

[9]Nojima-Schmunk, K., Turzak, D., Kim, K., Vu, A., Yang, J., Motukuri, S., Yao, N., and Shishika, D., "Manta Ray Inspired Flapping-Wing Blimp," *arXiv preprint arXiv:2310.10853*, 2023.

[10]Dantsker, O. D., "Design, Build, and Fly Autonomous Lighter-Than-Air Vehicles as a Project-Based Class," AIAA Paper 2024-4375, AIAA Aviation Forum 2024, Las Vegas, NV. 2024.

[11]Dantsker, O. D., "Integrating Unmanned Aerial Systems into the Intelligent Systems Engineering Curriculum," Paper 2024-1185, Congress of the International Council of the Aeronautical Sciences, Florence, Italy. 2024.

[12]Taylor, C. and Dantsker, O. D., "Lighter-Than-Air Vehicle Design for Target Scoring in Adversarial Conditions," AIAA Paper 2024-3896, AIAA Aviation Forum 2024, Las Vegas, NV. 2024.

[13]Taylor, C., Widjaja, M., and Dantsker, O. D., "Remotely-Processed Vision-Based Control of Autonomous Lighter-Than-Air UAVs With Real-Time Constraints," AIAA Paper 2025-1344, AIAA SciTech Forum 2025, Orlando, FL. 2025.

[14]Lehigh University, Swarms Lab, "Defend The Republic Fall 2023," `https://sites.google.com/lehigh.edu/dtr2023b/home`.

[15]George Mason University, Patriot Pilots, "Defend The Republic Spring 2024," `https://www.sparx.vse.gmu.edu/`.

[16]Indiana University, Aerospace Systems Lab, "Defend The Republic Fall 2024," `https://www.iu-dtr.com/`.

[17]GMUBlimpSquad, "GMU Braitenberg Blimps with a giant skynet at DTR competition in Nov 2023." https://www.youtube.com/watch?v=rOjwytXUIUQ.

[18]Cox, B., Dantsker, O. D., and Deters, R. W., "Propulsion System Testing Instrumentation for Multi-Rotor and Lighter-Than-Air UAVs," AIAA Paper 2025-0252, AIAA SciTech Forum 2025, Orlando, FL. 2025.

[19]Widjaja, M., Taylor, C., Meighan, A., and Dantsker, O. D., "Viability of NPU-Equipped SBCs for Real-Time Onboard Vision Autonomy on Lighter-Than-Air UAVs," AIAA Aviation Forum 2026, Las Vegas, NV. 2025.