Research Aircraft Optimization from Generated Requirements For Use In AIAA DBF Competition

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The aerodynamics division for SPAROW is currently generating design matrices for various aircraft design parameters that are supported by the requirements and main scoring factors of merit from past AIAA Design Build Fly competitions. As the team is mainly composed of underclassmen, this research into past competitions and choosing optimal design parameters is serving as training to build up the knowledge base of aerodynamics and overall aircraft design choices. The overall goal, alongside competing in the 2025 AIAA DBF competition, is spending the semester of 2024 gaining hands-on experience with UAH wind tunnels and working on four optimized designs based on the generated decision matrices. To validate the design choices, simulations will occur to visualize the drag profile of the 4 designs, and subscale model testing will occur in the wind tunnels to validate the computer simulations.

I. Introduction

SPAROW is a student team within the University of Alabama's Space Hardware Club. The team's goal is to compete in the American Institute of Aeronautics and Astronautics's (AIAA) Design Build Fly (DBF) competition in 2025. The team is primarily composed of underclassmen, with over seventy percent of members being freshmen or sophomores. Because of the young demographic, SPAROW decided to forgo attending the 2024 competition and focus on expanding knowledge and building skills of new members.

SPAROW is split into three main divisions: aerodynamics, integrated systems, and structures. The aerodynamics division is composed of five first year students and one third year student. In order to build a knowledge base for the younger members, the aerodynamics division decided to research past AIAA DBF competitions and create three model planes based off of requirements generated from the past competitions. The goal was to expose all division members to the format and scoring of the competitions, as well as an understanding of aerodynamic properties and of different types of aircrafts.

II. Past Competition Research

Research into past AIAA DBF competitions was centered around the scoring and flight complications. Research into how the designs were scored led to three general themes of the competition being identified: transportation capabilities, speed of craft, and endurance capabilities. Each competition did have its own individual objectives and scoring system. This allows each competition to parallel some real world issues, ranging from dropping medical supplies mid-flight to maximizing passenger capacity to maximizing speed alongside payload weight. Each competition is split into three flights. The first flight is almost always a three lap flight to ensure the aircraft's ability to fly the course and land safely. This flight is almost always scored as a flat number, often 1 point for completion. The second flight begins to incorporate the aspects of that year's broad theme. The second flight often incorporates a type of timed lap speed or some other single variable test. The third flight embodies the theme fully and requires the plane to optimize the most important aspects of the competition. This requires teams to find the best combination of weight, speed, carrying capacity, or another capability in order to score well. The aircraft must complete a successful landing in order to get a score for the mission. There is often the ability to reattempt the flight, although failure to land can lead to damages and affect the aircraft's ability to perform the mission.

This research allowed the aerodynamics division to realize the primary ideas present throughout most competitions. Each year the course itself is the same: a simple track style loop with a radius of 1000 meters, with a

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small 360 degree turn half way through the backside of the loop. The aircraft must always start halfway along the long stretch of the track. The ability to successfully transport a payload is present in all years studied.. The payload configuration, weight, and scoring values vary from year to year. Required size and dimensions of the aircraft also change yearly, with limitations on wing span, aircraft weight, or fuselage length. Speed also proved to be a very prominent factor, with timed laps almost always being factored into at least one mission score. This creates the need for speed. Often speed is scored by comparing the aircraft's lap time to the fastest lap time in competition. The larger the gap between the nominal and fastest lap time, the lower the total score. The final major focus is endurance. There is often some need to be able to travel at a high speed for an extended period of time. While this does require speed, endurance also factors into this ability. Without the efficiency of endurance modifications, an aircraft may struggle to hold such a high speed for an extended time. The aircraft will be a radio controlled (RC) aircraft with limited battery; it will not have the long range capabilities of normal aircraft. This understanding of previous competitions allows for the aerodynamics division to design aircrafts that will be suited to each type of possible competition without knowing the challenges for the 2025 competition.

III. Requirement Generation and Sensitivity Analysis

The requirements generated centered around parameters from the past competitions. Some parameters stayed constant from year to year, so those were implemented across all aircraft types. Others were more specific to the scope of the year's specific competition. These parameters were studied and used to create realistic requirements for each aircraft. These requirements were put into a system requirements document (SRD).

Figure 1 is an example of the SRD for the transportation aircraft. Many requirements were base requirements for AIAA's DBF competition that were consistent over several years.

Module Tag	Division Tag	ID	Requirement
Transportation	Structures	SRD.C.S.1	The aircraft shall weigh less than 55 pounds
Transportation	Structures	SRD.C.S.2	The internal payload bay must be easy accessible
Transportation	Structures	SRD.C.S.3	All payloads and supporting equipment must be properly secured
Transportation	Structures	SRD.C.S.4	Flight prep time prior to fly must be less than 5 minutes
Transportation	Aerodynamics	SRD.C.A.1	The aircraft shall not be configured as a rotocraft
Transportation	Aerodynamics	SRD.C.A.2	The aircraft should not make use of lifting gas of any kind
Transportation	Aerodynamics	SRD.C.A.3	No form of externally assisted take-off is allowed.
Transportation	Aerodynamics	SRD.C.A.4	Must be able to succesfully land
Transportation	Aerodynamics	SRD.C.A.5	Must be able to carry a minimum of 32 oz.
Transportation	Aerodynamics	SRD.C.A.6	Must be able to internally carry a payload of minimum 50 in^3
Transportation	Aerodynamics	SRD.C.A.7	Must be able to carry payload 3 laps within 5 minutes
Transportation	Aerodynamics	SRD.C.A.8	Must take off within 60ft runway
Transportation	Aerodynamics	SRD.C.A.9	Wingspan cannot exceed 60in
Transportation	Integrated Systems	SRD.C.IS.SE.1	Must be propeller driven
Transportation	Integrated Systems	SRD.C.IS.SE.2	Must be electrically powered with an unmodified over-the-counter model electric motor
Transportation	Integrated Systems	SRD.C.IS.SE.3	Must have externally available switch to turn on radio control system

Fig. 1 Transportation SRD

There are four classifications in the SRD. The first is the module tag which labels the aircraft type to which the requirement applies. The second is the division tag which labels the division to which each requirement is most applicable. The ID is a label given to each requirement that allows members to recognize how the requirement was derived and the number of requirements per division. Every ID starts with SRD, then the next letter is either a C, meaning that the requirement was derived from past competitions; F, meaning the requirement is a rule set by the Federal Aviation Association; or I, meaning it is an internal requirement. The next letter represents the applicable division, and the final number represents the item number of each requirement within its division.

Using the SRD, three sensitivity analysis scripts were developed in Matlab to visualize the effects of changing different parameters of the aircraft. The scoring equations from previous competitions were used to create general scoring parameters for each aircraft design. The sensitivity analyses use these generated equations, along with data from past competition winners, to plot the effect a change in a certain parameter has on the overall score for the aircraft.

A. Transportation Aircraft

The transportation requirements were split into two categories: weight of payload and internal capacity. The weight requirement was generated by averaging the minimum required payload weight for transportation competitions and comparing that value with the maximum payload weight carried for each year. The requirements were closer to the maximum weight carried as the goal is to prepare the team for scoring well at the competition. The internal carrying capacity requirements were generated using a similar method.

Figure 1 shows that optimization of the plane weight will yield the highest change in score. The weight of the payload, along with the number of passengers, representing the internal carrying capacity, will have less of an effect on the score. This knowledge allows the aerodynamics division to focus on specific aspects of the aircraft design and create an aircraft that will perform well in competition.

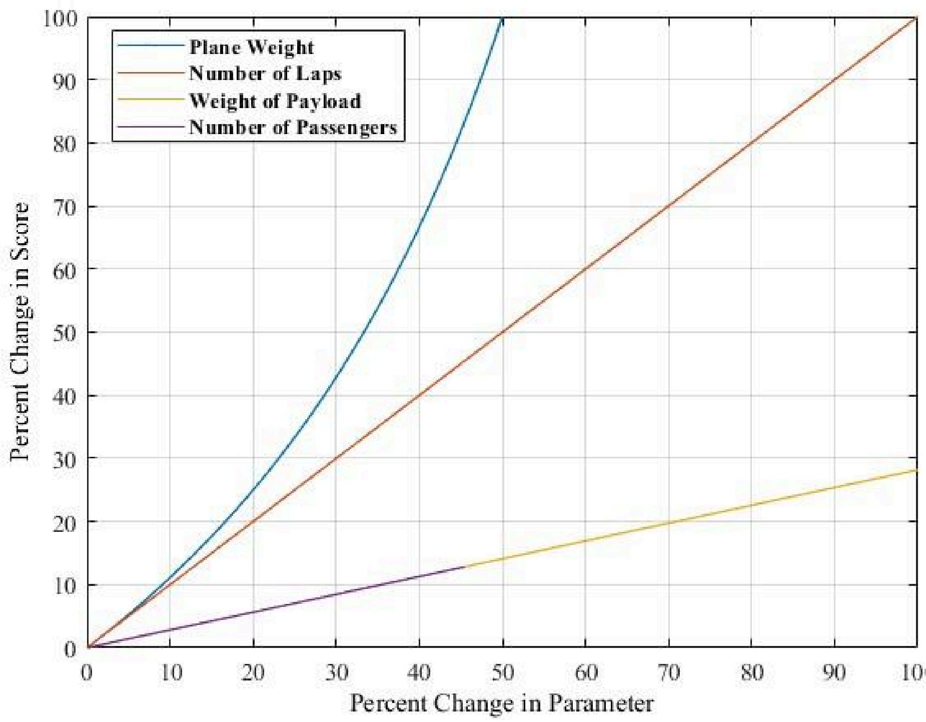

Fig 2 Transportation Aircraft Sensitivity Analysis

B. Speed Aircraft

The requirements generated for the speed aircraft were generated based on previous speed-based DBF competitions, as well as the performance of the winners of these competitions. Speed competitions were typically scored involving a ratio of a nominal plane weight to the minimum plane weight that competed and a ratio of a nominal lap time to the minimum lap time. The minimum plane weight and lap time from each competition were averaged, and this value was used as the best performance values in the calculation of the score.

The consistent parameters in the scoring of speed-based challenges were plane weight, time taken to complete one lap, and number of laps completed within a five minute time frame. Figure 2 is the graph produced by the speed-based sensitivity script.

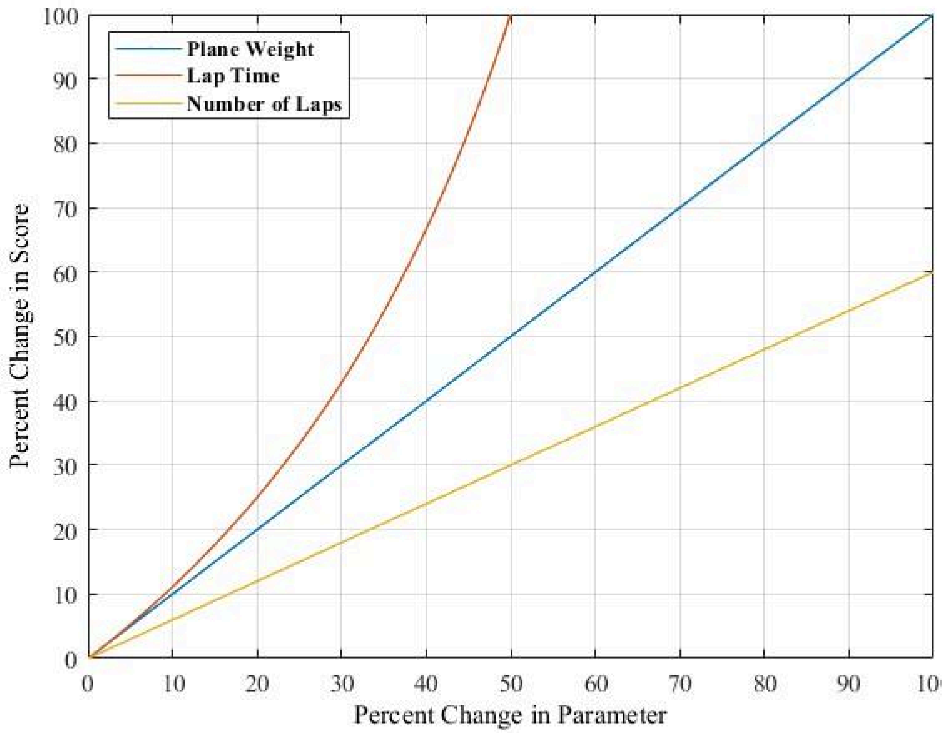

Fig 3 Speed Aircraft Sensitivity Analysis

C. Endurance Aircraft

The endurance aircraft scoring equations were based on battery weight, the payload weight the aircraft could carry for three laps, the maximum theoretical flight time, and the remaining battery percentage after a five minute flight. In past competitions, endurance was rarely tested on its own. Typically something else like transportation or speed would also factor into the score. Because those categories were already covered in the previous two aircraft designs, the endurance craft scoring was based solely on parts of past competitions that dealt with endurance or efficiency. This created a need for a greater understanding of what was expected of an endurance aircraft and which capabilities could be deemed the most important.

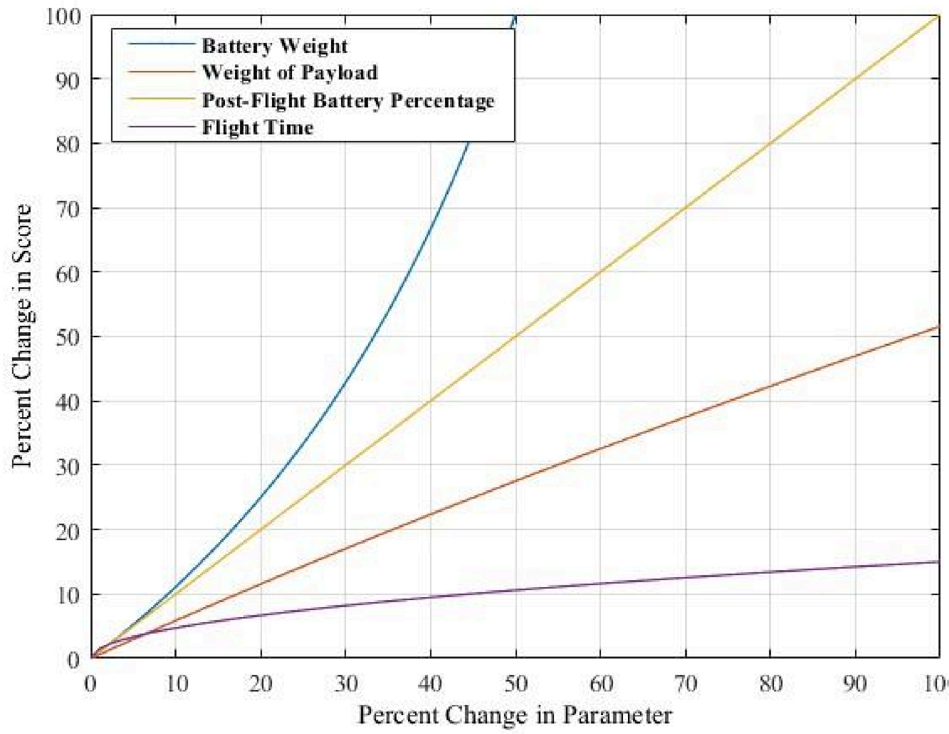

Fig 4 Endurance Aircraft Sensitivity Analysis

IV. Design Development

In the interest of developing aircraft design knowledge for the three most commonly themed aircraft challenges found from the past competition research, the Aerodynamics division of the SPAROW project is focusing on the development of three types of aircraft. The three designs are each an attempt to develop an optimal aircraft based on each derived mission's sensitivity analysis results. The three aircraft types chosen to be designed were a transportation type aircraft, an endurance/efficiency type aircraft, and a speed type aircraft.

The first step was to generate design matrices that would allow for a qualitative analysis of different options for design parameters for each aircraft type. Below, table four, shows the template created and used for the design matrices.

Table 1: Design Matrix Template

Design Aspect:	Option A	Option B	Option C
Wing Type:			
Payload Capacity: (Dry mass vs total			
Control Features			
Cross Section Profile			
Airfoil Type			
Wing Size			
Stability			

Each member of Aerodynamics was expected to fill out table four and at a subsequent meeting the Aerodynamics had decided on the best design parameters for each type of aircraft.

The transportation type aircraft prioritizes maintaining a greater than one lift to weight ratio while minimizing the aircraft mass in favor of increasing the carrying capacity mass for the cargo. This is being done by making the wings as large as aerodynamically possible to ensure maximum lift to account for the excess weight from the cargo. Due to the increased mass of the aircraft, the control features are being designed to encourage positive static stability to discourage any possibility of the pilot having to overcorrect input controls during flight.

The endurance type aircraft is similar to the transportation aircraft in that it prioritizes a high lift to weight ratio but it also prioritizes a minimum drag profile as well. The goal with the endurance type aircraft is to minimize the battery consumption used during flight by minimizing the drag force that opposes the thrust force vector. This is currently being done by reducing the front facing cross section of the aircraft to reduce the wage drag and research is being done into different materials for the outer “skin” layer of the aircraft into what material would be optimal for reducing skin friction drag.

The speed type aircraft follows a unique design consideration. The aircraft is being design with minimal room for cargo transport and the fuselage is being streamlined with the idea of thinning the front facing cross section of the aircraft. Efforts for this aircraft are focused on the wing development. This was chosen to be the focus due to the nature of needing to significantly reduce the drag produced but also still needing to generate enough lift to take off from land.

V. Design Testing

The University of Alabama in Huntsville, Mechanical and Aerospace Engineering Department has granted the Aerodynamics team of the SPAROW project access to utilze the on campus open return wind tunnel for model testing between March 25th and April 1st. Direct Lift and Drag force measurements will be taken using a force balance device along with a pressure wake survey to collect as much data as needed. The testing procedures as of document submission have not been drafted and will be made during the Month of March.

Alongside wind tunnel testing, the Aerodynamics team is developing their skills of Computational Fluid Dynamics (CFD), learning basic boundary setups and fluid behaviors on multiple commerical softwares such as Ansys Fluent, Autodesk CFD, and OpenFoam softwares. The data collected from running the CFD simulations on the designs will serve as the proof of concept to validate the designs into actual development phase.

VI. Conclusion

Designing a competition RC plane requires a large amount of research and planning to generate an effective and high scoring design. This will all lead to the eventual striving to design a competition aircraft ready to fly in the 2025 AIAA DBF competition. In documenting and delving deep into the research and understanding of the competitions and of RC plane characteristics and design, we hope to form a knowledge base for future UAH SPAROW members and to create a continuing knowledge base from people being able to pass it down. Due to the youth of SPAROW as a project, this passing down for future groups will be massively important in furthering the project into being a strong, annual competitor in the AIAA DBF competition.

VII. Acknowledgements

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