1 Introduction

For years, remotely-controlled aircraft have captured the interests of hobby enthusiasts of all ages and skillsets, combining ease of operation with a multitude of designs available as kits, templates, or ready-made models. For students at the university level, however, who have had exposure to flight principles like aerodynamics, dynamics, and fluid mechanics, scale aircraft provide a unique opportunity to translate that theory into a physical application at relatively low costs, allowing students to explore untested design concepts and construction ideas in an environment that celebrates challenges and mishaps as an opportunity to learn.

It is this concept that inspired the 2014 senior design capstone project for which students were tasked with working cohesively as a team to construct viable aircraft, complete with useable control surfaces, guided by their knowledge of aerodynamics concept and the skills of seasoned pilots. Steered by a mission mandate requiring that each aircraft be designed to climb to as high an altitude as possible in ten seconds before performing an unpowered glide back down to the cruising altitude, the four students of DBC Industries, referred to herein as the Team, created an aircraft colloquially referred to as, ``The Flappy Bird", a minimalist airframe designed to climb quickly while also allowing the craft to glide for long periods of time. This report details the design and construction process of the final vehicle and also analyzes the results of preliminary flight testing, permitting a comparison of predicted vehicle maneuverability and the observed capabilities during flight.

2 Mission and Design Proposal

The stated mission for this design project consists of three phases of aircraft flight operation. The aircraft must first take off, solely under its own power, and maintain low altitude, level flight. From there, it must begin to climb as fast and as high as it can over a ten second interval and level off at the top of its ascent. After circling at the new altitude and verifying its stability, the aircraft will perform an unpowered glide back to its original altitude, with the area of focus centered on the rate of descent during that glide.

The primary design driver for this mission profile was aircraft weight. Weight savings were gained from efficient design of the wing and fuselage structures to eliminate excess material weight. A low weight helped with both of the main objectives of the mission, climb and glide. For climb, a low-weight structure did not tax the fixed-thrust propeller motor as much as a heavier aircraft would on vertical ascent. On the gliding descent as well, a lighter aircraft experienced a more favorable descent gradient than heavier variants using the same lifting surfaces.

The secondary design driver was a high lift-to-drag (L/D) ratio. High performance in this area will promote a low descent rate during the gliding phase of flight, allowing the aircraft to remain aloft for an extended period of time. In this design, the glide performance was deemed the mission phase in most need of optimization and, as such, the choice of the two primary design drivers centers around the aircraft performance characteristics that will lead to the best glide performance.

1

There are a few key physical features on the proposed aircraft that served as main drivers towards the desired mission objectives. The main wing has an aspect ratio of 7, leading to a total wingspan of 5 feet, 6 inches. The high aspect ratio contributed to a low wing loading during descent which was favorable for glide performance. The wing was mounted high on the fuselage to afford the aircraft increased roll stability during flight.

3 Figure of Merit Analysis

Although this design was ultimately constrained by the requirements of the mission statement, a determination of favorable attributes for an aircraft of this type was conducted using a figure of merit (FoM) analysis. An FoM analysis is part of a design approach that is used to select components that form an aircraft’s structure in an efficient and objective manner. Although the analysis cannot produce design dimensions, it can provide a numerical point of comparison between different variations of airframe components under consideration. As Table I shows, physical and performance characteristics are evaluated across a rating system between 1 and 5, with larger numbers representing a greater importance to the design drivers. The row totals are then summed and each characteristic is assigned a bias percentage which determines its overall priority in the final design.

Table I: Figures of Merit for Aircraft Performance

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Weight | High L/D | Size | Ease of Construction | Stability & Control | Payload | Row Totals | Bias |
| Weight | 0.00 | 4.00 | 4.00 | 4.00 | 4.00 | 5.00 | 21.00 | 23 % |
| High L/D | 2.00 | 0.00 | 4.00 | 4.00 | 3.00 | 5.00 | 18.00 | 20 % |
| Size | 2.00 | 2.00 | 0.00 | 2.00 | 2.00 | 2.00 | 10.00 | 11 % |
| Ease of Construction | 2.00 | 2.00 | 4.00 | 0.00 | 1.00 | 3.00 | 12.00 | 13 % |
| Stability & Control | 3.00 | 3.00 | 4.00 | 5.00 | 0.00 | 4.00 | 19.00 | 21 % |
| Payload | 1.00 | 1.00 | 4.00 | 3.00 | 2.00 | 0.00 | 11.00 | 12 % |

Once the design biases have been set, the figure of merit analysis was conducted on each of the possible component configurations considered for the final design. Table II illustrates the process for the main wing selection. Unlike Table I, component analyses ratings are based on each configuration’s benefit or detriment to the stated design drivers, with larger numbers representing more beneficial performance. These rankings are

2

based on research into each possible configuration with special care taken to identify the strengths and weaknesses of each design. To finally determine the most appropriate component variation for the mission profile, a weighted average of the figures of merit for each configuration was tabulated, appearing on the bottom row of the matrix. Matrices for each of the other component analyses are located in Appendices A-D

Table II: Wing Design Matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Monoplane | Biplane | Tandem Wing/Canard | Flying Wing/Blended Body | Winglets | Bias |
| Weight | 4.00 | 3.00 | 3.00 | 5.00 | 5.00 | 23 % |
| High L/D | 3.00 | 4.00 | 3.00 | 3.50 | 2.00 | 20 % |
| Size | 3.00 | 1.00 | 3.00 | 4.00 | 5.00 | 11 % |
| Ease of Construction | 5.00 | 2.00 | 2.00 | 1.00 | 5.00 | 13 % |
| Stability & Control | 4.50 | 3.00 | 2.00 | 1.00 | 1.00 | 21 % |
| Payload | 3.00 | 3.00 | 3.00 | 1.50 | 3.00 | 12 % |
| Column Average | 3.81 | 2.85 | 2.66 | 2.81 | 3.33 |  |

The results of each analysis were not entirely unexpected given the common history of these types of aircraft. Table II shows that the single wing is the most advantageous wing configuration because of its low weight and relative ease of construction. Beyond those, it also boasts a high level of stability and average scores in all of the remaining categories, highlighting it as the best possible configuration.

Scoring highly in the same categories as the wing, the conventional tail also logged a markedly higher score than its competitors. Historical data comparisons show that the conventional tail has the lowest weight of the three variations in the category and, due to its right angle mounted design, scores well for ease of construction as well.

The final component selection of note is that of the landing gear. Historically, the three wheel trike configuration has a heavier under-mount system than other options such as the skids and tail gear which would suggest that it would conflict with the primary design driver of weight. In this instance, however, the additional stability gained over other gear options provided enough justification to the team to prioritize stability over weight. In addition to stability advantages, the trike gear also provides the aircraft with a more forgiving structure on which to land and takeoff. The three wheel configuration elevates the underbelly off the ground and provides some level of shock absorption during landing, preventing damage to the fuselage or lifting surfaces.

3

4 Predictions from Spreadsheet Analysis

In addition to the figure of merit analysis, the provided aircraft design spreadsheets were used to determine finite numerical dimensions for each of the airframe components as well as providing some insight into the forces acting on the vehicle during flight.

Our empty weight is expected to be around 1.5 pounds, leading to an estimated takeoff weight of approximately 3.7 pounds which is a typical weight based on previous senior design aircraft. This figured is based on a preliminary weight estimate consisting of 2 pounds of aircraft control and monitoring equipment and a vehicle structure factor of 0.4.

Perhaps one of the most important factors for determining the aircraft’s ability to perform well within the mission constraints is the wing loading as it is an integral factor in the aircraft’s climb and glide performance. As mentioned previously, glide performance is the mission phase in most need of optimization and, as such, the wing loading on the vehicle was determined based on performance during descent, during which a low wing loading is desired. True to form, assuming a glide from 1,400 ft ,assuming a ground elevation of 729 feet in South Bend, the wing loading during glide would only amount to about 0.81 lb/ft2, or approximately 13 oz/ft2, a wing loading that will surely help contribute to satisfactory glide performance.

Given these flight characteristics and data culled from previous design planes, the final climb rate of the aircraft was given a best-estimate of 1,100 feet per minute although that number is expected to decrease in flight testing due to the structure weight of the high aspect ratio wing. Over the stated ten second time interval, this climb rate allows a gain in altitude of approximately 200 feet. Assuming the unpowered glide will begin at this altitude, it is estimated that the aircraft will lose 2.5 feet of altitude every second and take approximately 73 seconds to return to its original cruising altitude. As before, this glide rate assumes ideal flight conditions and is expected to diminish somewhat during flight testing. At the moment, the vehicle exhibits a lift-to-drag ratio of approximately 26 which falls within the average value for light cruise aircraft. Over the design and construction process, however, various drag reduction methods will be explored to increase this value. Control for the aircraft will be accomplished using two outboard ailerons, a rudder placed on the vertical tail, and a single elevator that occupies the entire trailing span of the horizontal tail plane. Once properly sized, these elements should provide sufficient control for the vehicle in flight.

Each spreadsheet used in this analysis is attached at the back of this report in the order of completion. Due to the constraints and requirements of this remote controlled aircraft, the engine and flap spreadsheets have been omitted. Please note the following as well: The takeoff and landing spreadsheet is not representative of the values expected during either phase of flight and quantities cited in both the refined weight and stability

4

analyses are rough estimates and will be updated throughout construction with actual values.

5 Detailed Design

The aircraft wing was the most challenging, and arguably most important, aspect of the design. The wing aspect ratio had to be small enough for decent climb and performance large enough for decent glide performance. The wing had a final span of 5.5 feet and an aspect ratio of 6.7. The compromise between these two decisions made it such that design team had to innovate in other areas of the design in order to be a truly competitive aircraft, rather than an average one. That is the reason why weight was such an important factor in the success of this plan.

The fuselage and wing had to be strong enough to withstand the high stress of take off and landing while also light enough to be competitive. For this reason, a rectangular carbon fiber rod was chosen as the main structural element of the fuselage. It was meant to take most of the stress in flight and as the backbone of the fuselage and tail assemblies. Weight savings were gained from the need for less material due to the functionality of the carbon fiber rod. The fuselage was approximately cylindrical, tapering off in roughly a cone at the trailing edge. It housed most of the internal electronics, aside from two aileron servos and a pitot tube in the main wing. The propeller mounted to a thick bulkhead at the flat leading edge of the fuselage.

The main landing gear was attached directly to the carbon fiber rod within the fuselage. Since the main landing gear experiences the most stress of any other component, it was beneficial to transfer that energy to the strongest part of the aircraft. It was also reinforced with plywood around the edges of the connection to prevent the gear from torqueing off of the carbon fiber tube. The aircraft was made a tail dragger to decrease weight and improve take-off performance. A small wheel was attached directly to the rudder to reduce the amount of mechanical linkages. This negligibly reduced the ground control of the aircraft but improved weight characteristics, which was more desirable for the given mission profile.

The tail was of conventional design placed on a boom tail. One of the concerns for this type of design was the twist of the boom tail. This was counteracted with a double thick carbon fiber rod as well as double thick ply for stiffness of the assembly as a whole and individual material, as well. A custom bracket was designed for the attachment of the tail surfaces to the carbon fiber. Each surface had two anchor points to prevent twisting and was held in place with epoxy. The elevator and rudder control surfaces were large enough for sufficient control of the aircraft and had no flutter or twist in-flight.

The design employed a 1.25 horsepower motor, capable of providing approximately 3.5 pounds-force of thrust. This gave a final thrust-to-weight ratio of 0.7. This motor powered a 13-inch propeller with an 8-inch pitch. The main wing was mounted atop the fuselage and bolted on, utilizing hatches to access internal components. This high wing configuration contributed to roll stability, as indicated in conceptual design. For further details on the design, see the attached CAD drawings.

6 Results

The results were calculated from a combination of the two runs. The average flight speed was 34.2 mph. The maximum and minimum flight speeds attained were 52.8 and 20.0 mph respectively. The maximum climb rate was 22.6 ft/s and the average was 19.3 ft/s. The minimum glide rate was -7.7 ft/s and the average was -8.6 ft/s. From the observed results and the predicted ones, the success factor was calculated to be 3.7. The ideal success factor was 15.8.

7 Discussion

Overall, this aircraft performed very well for the given mission profile. The aircraft was designed such that it balanced the climb and glide portions of the flight in an efficient way. The design team decided that the most important factor for a balanced design was reducing the total weight. This proved to be a correct decision when compared to other designs with the same mission profile. The thrust to weight ratio of the aircraft was approximately 1. This allowed the plane to climb at a much faster pace than competitive aircraft, giving it more time to glide.

8 Conclusion

Overall, this aircraft performed very well for the given mission profile.