Purdue IEEE Aerial Robotics

AUVSI Student Competition 2015

Technical Report

Captain, Secretary, AeroMechanical Co-Leads, Electrical Lead, Sponsorship, Technical Writer:
Darius Pang, Ajay Kumar, Sanket Mandhani, Chris Rogers, Michael Malachowski, Anuraag Rajasekhar, Doreen Mbekenga

Faculty Advisor: Professor Steven Pekarek

Team Members

AeroMechanical:

Jon Paul Pepen (AeroMech Co-Lead Fall 2014)
Rahul Bhardwaj
Apoorva Kharche
Jason Kirk
Yash Nain
Richard Rao

Electrical:

Andrew Pensinger (Electrical Lead Fall 2014)
Anthony Goeckner
Patrick May
Karan Samel

Abstract

The purpose of this report is to discuss the various methods used to design an Unmanned Aerial System (UAS) that meets criteria for the 2015 Association for Unmanned Vehicle Systems International (AUVSI) Student Competition. This report follows the process of the development of the UAS including the airframe itself, along with the autopilot and payload systems. The system is designed to return telemetry information during safe autonomous flight and capture images. This objective was reached by implementing our in-house aircraft, flight controller, and a Foxtech camera. After conducting numerous flight tests with the final design, Royal Flush, we conclude that it is flightworthy.

Table of Contents

List of Figures

List of Tables

1. Introduction

This section provides an overview of our team, project objectives and requirements, and initial risks considered.

1.1 Team

The Purdue IEEE Aerial Robotics Committee is comprised of over 17 active undergraduates for the AUVSI 2015 competition. The team consisted of two major groups: Aero/Mechanical and Electrical. Within Aero/Mechanical, CAD, Aerodynamics, Structures, and Propulsion then became sub-teams. The CAD sub-team became very familiar with SolidWorks and 3D modeling, the Aerodynamics sub-team heavily focused on airfoil shape and characteristics, the Propulsion sub-team analyzed the use of gas engines versus electric motors, while the Structures sub-team researched materials to be used, discussed weight placement, electronics stability, and landing gear. The Electrical team developed and created the software and hardware, specifically autonomous flight, flight controller, and the ground control station. This is the team's attempt to participate in the competition in over four years and seeks to demonstrate what they have learned about aircraft design, autonomous features, and the ground control station over the season.

Weekly updates were documented throughout the progress of each sub-team and are provided in the binder, Weekly Notes.

1.2 Objective

The main goal of our system is to return telemetry during safe autonomous flight. What we achieve are listed in the following Section 1.3: Requirements. The requirements are then further expanded upon in Section 2: Analysis of Systems.

1.3 Requirements

At the completion of this project, our system should be able to reach its objective by completing the following requirements listed:

1.3.1 System Requirements

We set our system requirements based on those provided in the 2015 AUVSI SUAS Rules and determined what we are able to achieve given our experience and ability.

- Flight mission length of 15 minutes
- Maintain steady flight at specified altitudes (100 ft. - 500 ft.)
- Takeoff and landing distances under 20 ft.

1.3.2 Flight-Mission Demonstration Requirements

We decided to select a core group of flight objectives as basic set of requirements that our system needed to fulfill. Further support for these objectives along with others was planned to be added after the completion of the system. These were taken from the primary autonomous flight task and thresholds of the search area task listed in the 2015 AUVSI SUAS Rules.

Table 1: Tasks and Objectives Required for Systems

Task	Objective
Takeoff	Achieve controlled takeoff
Flight	Achieve autonomous flight
Waypoint navigation	Capture waypoint in sequence accurate to within 50 ft. and stay within 100 ft. of planned flight path
Landing	Achieve controlled landing
Locate Target	Determine target location within 150 ft.
Classify target	Describe two target characteristics

1.4 Risks & Methods

Risks are always a factor while designing. In this case, our greatest fear and risk for the aircraft itself was that of crashing. (There is also the fear and risk of the aircraft colliding with a spectator, examined in Section 4: Safety). This risk was reduced mechanically by giving our wing a high aspect ratio, thus increasing its capability to fly without power. Additionally, by using tried and true methods and designs, which is discussed in Section 2: Analysis of Systems, we were sure to be able to get the aircraft off the ground.

Given the lack of human input while the plane is in autonomous flight, a manual override that is toggle-able from the ground was installed to allow for operator control of the aircraft. This mitigated the risk of unexpected autonomous flight patterns.

2. Analysis of Systems

Our system is made up of six different sub-systems. In this section, the function and requirement of each sub-system is examined in detail.

2.1 Airframe

Our aircraft is designed as a conventional fixed wing-fuselage aircraft with a standard empennage, front mounted motor, and tail wheel landing gear. As an inexperienced team, we decided to model our craft after a proven design and then optimize it for safety and stability. The design for the fuselage was initially based on the fuselage of the Cessna 152 and was only slightly modified to become less angular and have wider walls to provide better support for the wing and electronics bay. Continuing with our strategy of using tried designs, the wing form is a rectangular planform wing with a NACA 4412 airfoil. The airfoil was precision cut on a CNC wire cutter and contains carbon fiber rods embedded in the lower surface to provide additional structural support. Over the course of the prototypes, we modified the wing to meet our goal of a safe and stable flight; the wingspan has changed from 8 feet to 6 feet and the respective chord length from 8 inches to 9 inches.

In the industry, many propeller planes use front mounted motors for better efficiency and aerodynamic stability. Furthermore, in our case it enabled us to move the center of gravity closer to the center of lift and thus increasing the stability of the craft.

2.2 Autopilot System

The autopilot system is a custom solution that has been developed by our team. After looking at various existing autopilot solutions, our team determined that developing our own system had two benefits. First, this will allow us to better understand its functions. Second, as our system grows, permit for a more simplified design approach in the future, as opposed to one that not only involves creating new hardware and software for additional desired functionality, but also having to integrate it with a third party system.

Our solution consists of a custom designed printed circuit board that contains the majority of the electrical hardware used in the system. This hardware consists of the following:

- 3-axis Gyroscope
- Accelerometer
- Magnetometer
- Altimeter
- Airspeed Sensor
- Temperature Sensor
- GPS module

The board houses the AVR microcontroller that interfaces with all of these sensors and carries out the majority of the autopilot logic. Additionally, the board contains an XBee Pro S2 2.4 GHz modem that communicates with an identical modem on the ground station.

In the interest of safety, the manual override system was designed to be separate from the main processor. This system consists of a discrete multiplexer IC's that switch the servo signal source between the microcontroller and the external R/C receiver. A separate AVR microcontroller on the board reads an output on the R/C receiver that is controlled by a switch on the R/C transmitter, and determines whether or not to enable manual override. In the event that the dedicated override microcontroller experiences a failure, the multiplexers default to enabling manual override.

2.3 Data Link & Data Processing

The data link for sending telemetry data to and receiving mission data from the Ground Control System is implemented using a pair of XBee Pro S2 2.4 GHz modems. Both modems have a transmit power of 63 mW (18 dBm), with the modem on the UAV using an omni-directional antenna with a gain of 8 dBi and the ground station using a higher gain 12 dBi omni-directional antenna. The data is formatted for use with a custom protocol developed by our team in order to minimize the amount of necessary bandwidth. The video data link is currently implemented using a third party 5.8 GHz video transmitter and receiver and monitored manually. The R/C link used by the safety pilot is also implemented using a commercial Spektrum 2.4 GHz system.

2.4 Payloads

Our aircraft carries relevant electronics inside a dedicated bay within the body of the fuselage, as well as a bottom mounted camera with a gimbal system to be used for image capturing.

2.5 Ground Control Systems

The Ground Control System consists of a laptop computer running a custom application which interfaces with the UAV over the XBee wireless data link. The application displays received UAV telemetry data and displays the position of the UAV on a map. The application allows for sending of desired waypoints to the UAV. In addition, the GCS has a separate LCD display for monitoring the video link.

2.6 Mission Planning

The custom GCS application designed by our team allows the creation of a list of waypoints, each with specified desired airspeed and altitude. Because the UAV will be manually taken off and landed, before and after executing the mission, manual override is switched off/on by the safety pilot in order to control the plane.

3. Test & Evaluation of Results

3.1 Prototypes & Modeling

Before finalizing on our system, a few prototypes were designed. This section focuses on our prototypes specifically, their shortcomings and how they were improved.

3.1.1 Prototype 1 (Wilbur)

Wilbur was the first prototype built. Starting from the CAD stage, it was noted that the center of gravity was behind the center of lift; however we believed it would be within acceptable bounds. Below, Figure 1 displays the Solidworks Model of this prototype.

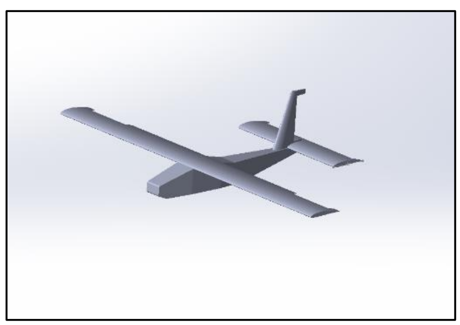


Figure 1: Solidworks Model of Prototype 1 (Wilbur)

After the first flight, other issues with the craft were discovered. First, we found the wing flexed beyond safety conditions. Next, we found that our heat dissipation system was not enough to prevent electrical hardware from overheating. Figure 2 presents Prototype 1 (Wilbur) before its first flight.

Figure 2: Prototype 1 (Wilbur) for Flight 1

After adding tension cables to reduce wing flex, another test flight (shown as Figure 3) was conducted. Here, we learned that our calculations for motor power draw were incorrect. The motor was drawing more current than our system was capable of handling. During the landing, which was conducted without power, the landing gear bent on impact.

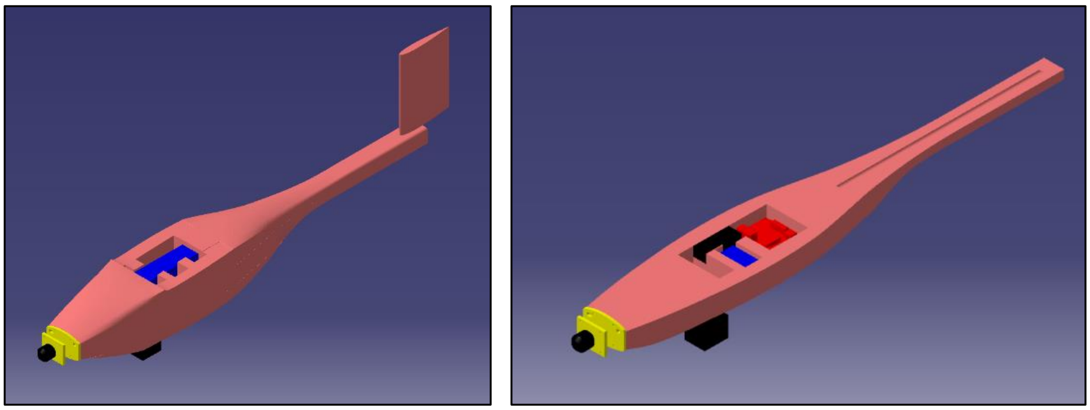
Figure 3: Prototype 1 (Wilbur) for Flight 2

3.1.2 Prototype 2 (Genie)

For the second prototype, we improved the overall strength of the design by adding more carbon fiber and incorporating thicker walls for the electronics bay. We also improved the center of gravity by moving more of the payload forward and reducing the overall weight of the tail. Servos were moved closer to their respective control surfaces for greater control in the air. We also improved precision of the work by fabricating Prototype 2 on a CNC Gantry using a new model created in CATIA V5. Experimentation with a heat shrink plastic was also done.

In order to ensure that we did not have power consumption and heat dissipation issues, Prototype 2 (Genie) included air inlets in the nose that directed air into the electronics bay and out the tail section. We rigorously tested several props for current draw and power delivered to ensure that we did not exceed maximum current draw while maintaining minimum power output.

Suspension to the landing gear to make landings smoother and prevent permanent damage, as had occurred on Wilbur's second flight, was implemented as well. Figure 4 displays the fuselage without the wing, horizontal stabilizer, and landing gear. Figure 5 shows the middle layer of the fuselage with all internal hardware (Flight controller, battery, and camera) accounted for. Figure 6 displays Prototype 2 (Genie) before its flight.



Figures 4, 5: Prototype 2 (Genie) CAD Model & Internal Cavity

Figure 6: Prototype 2 (Genie) Before Flight

Unfortunately, due to an error in wing fabrication, the wing resulted in having a longer chord than designed. Additionally misplacement of carbon fiber reinforcements caused a structural failure along the center line of the aircraft during a test flight. The damage on the aircraft can be seen in Figures 7-9 below.

Figure 7, 8, & 9: Prototype 2 (Genie) After Experiencing Error in Wing Fabrication

3.1.3 Prototype 2 Repaired (Royal Flush)

Prototype 2R was constructed using salvaged parts from Prototype 2. The tail was made shorter and extensive repairs and redesign to the nose were performed. We adjusted for the longer chord by reducing wing span to 6 ft. and adding an extra carbon fiber rod for support along the center line. Additionally a new nose was fabricated as it was irreparable; this also allowed us easier access to the battery. The Prototype 2R is given in 3.2 Final Design Specifications as Figure 10: Prototype 2 Repaired (Royal

Flush).

Royal Flush has now flown for many flights without significant incident. We are confident that it is a safe and reliable aircraft that will perform well during flight demonstration.

3.2 Final Design Specifications

Below is Figure 10 and the final design for our system followed by Table 2 which displays the system's specifications.

Figure 10: Prototype 2 Repaired (Royal Flush)

Table 2: Specifications of Final System

Measurement	Value
Length	50 in
Wingspan	6 ft.
Wing Area	4.5 ft^2
Wing Sweep	0 deg
Aspect Ratio	8
Tail Height	16.5 in
Weight	7.14 lbs.
Motor	NTM Prop Drive 35-35A 1400Kv/550W

4. Safety

Throughout this project, the safety of the team, aircraft, and those around the aircraft was always considered. Because of this, safety features have been used since the beginning of the project. This section looks at the safety procedures implemented in the operation and design of our aircraft along with safety risks around our labs and what steps were taken to prevent undesired consequences.

4.1 Operation & Design

Our aircraft was designed partially as a glider with a high aspect ratio so that in case of motor failure it would still be controllable and could be landed safely. Additionally, a manual override system was included to allow the operator to bypass the autopilot system and take control of the aircraft in case of emergency.

4.2 Safety Risks

Throughout the manufacturing phase, the team sought to prevent injuries and reduce inherent risks in using tabletop and industrial sized machines. First, working with insulation foam proved to be difficult because any cutting or sanding down produced small foam particles that made for an unsafe working environment. Masks filtering the air were utilized whenever we worked with the aforementioned foam. In addition, the use of the vertical band saw, gantry, and laser cutter at a university sponsored lab were only permitted to users who had read the manuals and passed safety tests; ensuring we understood how to operate the power tools with employee supervision.

5. Conclusion

This report has discussed our team's methodology in solving a complex problem. Not only were we able to analyze, design, create, and demonstrate a system with specific requirements and under time constraint, but we also were able to document the process. While working on this project, we learned that a simpler design is easy to revise, revisions are necessary, and communication between sub-teams and groups is paramount. Things we will do differently in the future include finding a simpler manufacture process and design, creating more rapid prototypes, and forming a better platform for inter-team communication.

Our system would not have been possible without our generous sponsors; thank you all for your contributions. Our sponsors, along with AUVSI, enable us to practice and improve our engineering skills and increase our interest in unmanned system careers and technologies.

Sponsors