The University of Texas at Austin
Air Systems Laboratory
The UT UAV Group

The 2010 AUVSI Student UAS Competition

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ABSTRACT

In 2009, the University of Texas at Austin UAV Group entered its Phoenix I UAS in the AUVSI Student UAS 2009 Competition, placing 9th overall. The 2010 competition marks the team's second consecutive appearance at the international level with the premiere of the Phoenix II UAS, an improved version of the Phoenix I UAS. Phoenix II is designed to fly by waypoint navigation in search for ground targets. Using its onboard camera, the system transmits live video to its Ground Control Station (GCS) and processes the imagery, achieving real-time target detection, recognition, and identification.

This paper details the steps taken to design and develop the four major subsystems that comprise the Phoenix II UAS: The Airframe, the Target Acquisition System (TAS), the Avionics, and the GCS. In keeping with last year's tradition, the subsystems were designed in-house from the ground up at the UT Air Systems Laboratory (ASL). The paper begins with a discussion of the mission overview and the design approach taken by the UT UAV Group to satisfy the mission requirements. Next, each subsystem is discussed in detail, describing the methodology behind each design decision and the measures taken to ensure the highest standard of safety. The paper concludes with test and performance analysis of Phoenix II, and outlines plans for future development.

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1.0 INTRODUCTION

1.1 The UT Unmanned Aerial Vehicle Group

The UT Unmanned Aerial Vehicle (UAV) Group is one of three undergraduate student-led groups that make up the Air Systems Lab (ASL) of the Department of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin. The UT UAV Group, founded during the summer of 2006, demonstrated its commitment to undergraduate UAV research with the advent of its first UAV, Murcielago.

The following year, the group took on the challenge of designing Vespertillio, the largest UAV built in the ASL to date. With her 14 ft wingspan and 45 lb gross takeoff weight, Vespertillio was designed to fly a LADAR imaging system. Vespertillio is now an integral part of the department's capstone aircraft design class.

In the fall of 2008 the UT UAV Group decided to design the Phoenix I Unmanned Aircraft System (UAS) in preparation for the 2009 AUVSI Student UAS (SUAS) Competition. The ambitious project involved the design, fabrication, and integration of in-house airframe, image recognition system, and autopilot. The team proudly placed 9th and returned home with high spirits for the 2010 competition.

1.2 Motivation and Purpose

The AUVSI SUAS Competition is a great opportunity for undergraduate engineering students to demonstrate their systems engineering capabilities. Of notable importance are the competition's requirements, which pose a very open-ended, real-world problem.

Consequently, the design space allows everything short of lighter-than-air vehicles. Teams are free to do anything from integrating a set of Commercial Off-The-Shelf (COTS) products, to designing and fabricating the entire UAS. The UT UAV Group is a strong proponent of the latter philosophy.

Quite often, the aerospace industry encourages the use of COTS due to their ability to reduce cost and work load, while still meeting existing system requirements. However, the primary goal of the academic world is to provide engineering students with a strong background in technical and systems engineering skills. Consequently, the design process cannot always be optimized for cost or schedule. Instead, the project must be appropriately balanced between the reality afforded by a voluntary student workforce, aerospace industry norms, and the goals and objectives of an academic engineering institution.

The UT UAV Group recognizes that the path chosen for this project is not be the path of least resistance. However, the team strongly believes that the work described in the subsequent sections provides the ASL with great flexibility in future research and competitions, and that this approach is in accordance with the academic spirit of the University of Texas at Austin.

1.3 Mission Overview

The 8th annual AUVSI SUAS Competition simulates a real-world, low altitude military aerial reconnaissance mission, as dictated by the Statement of Work (SOW). The top-level system requirements provided in the SOW prescribe the mission as follows:

The UAV will takeoff from a designated runway. While manual takeoff is permitted, autonomous takeoff will be awarded bonus points.

Once airborne, the UAV must autonomously navigate through a set of pre-designated waypoints. The waypoints will be provided by the judges in the form of Latitude, Longitude, Altitude (LLA). During this stage of the mission, the UAV will encounter two targets. One of the targets will lie directly below the aircraft, while the second target will lie up to 50° off the vertical from the UAV. The operators will be notified of the location of the latter target prior to the mission.

As the UAV finishes the ingress portion of the mission, it will enter a pre-designated target search area where the it will be free to fly any desired pattern within the allotted altitudes and no-fly zone boundaries. The UAV will provide the operators with enough information to determine a set of target characteristics, which include position, orientation, background color, background shape, alpha-numeric, and alpha-numeric color. The UAV must continue to fly autonomously throughout the search area portion of the mission.

Once the target area has been sufficiently searched, the UAV will be instructed to autonomously follow a pre-designated egress route and land in a the designated landing area. As with takeoff, manual control is permitted for landing, with extra points awarded for autonomous landing. The mission culminates when all transmitters are turned off, and the judges are handed the target list generated by the UAS and the operators. The UAS is given 40 minutes to complete the mission without any loss of points.

The rules state that the UAS should be capable of mid-air re-tasking. This capability includes the option of changing the flight plan and adding or editing an existing search area.

It is also notable that post processing is an admissible design solution for the imaging portion of the mission. However, extra points can be awarded for providing actionable intelligence about one target. This can be done only by providing the judges with all six target characteristics in real-time.

2.0 DESIGN APPROACH AND RATIONALE

Figure 1: The Phoenix II UAV

The Phoenix II UAS, whose airframe is shown in Figure 1, is the next generation of the Phoenix UAS family. The team made a substantial effort to use as much of last year's work as possible, while at the same time improving what was deemed necessary. This resulted in a new design that emphasizes subsystem modularity, reliability, and most importantly, situational awareness and safety.

The following sections describe the lessons learned from the 2009 AUVSI SUAS Competition, the newly derived top-level goals, and the systems engineering approach used throughout the design process.

2.1 Lessons Learned and Top-Level Goals

The 2009 competition was the UT UAV Group's first time competing in the AUVSI SUAS Competition. Naturally, the experience revealed some of Phoenix I's strong points, and even more of its weak points. There are six issues of notable importance that were addressed in this year's design. They are discussed in the subsections below.

2.1.1 Wiring

Phoenix I's excess wiring not only added to the payload weight and volume, but also to Electro-Magnetic Interference (EMI) inside the aircraft. The excess wiring physically impeded maintenance operations, and in some cases, faulty wiring and poorly made connections caused hardware malfunctions. Poor labeling and a large number of connections further reduced the maintainability of the system.

It was determined that a major overhaul of the onboard electronics was necessary. Emphasis was placed on repackaging and shortening wires, as well as generating detailed pin-out diagrams and component flow charts. Producing a reliable hardware base for the software to operate on became a top priority.

2.1.2 Autonomy

From a mission performance standpoint, autonomy was Phoenix I's most lacking quality. After the 2009 competition, the team came to a consensus that there were too many possible problems to pinpoint any one as a cause of malfunctions.

The team concluded that in order for autopilot software testing to commence, the avionics hardware must first be made reliable. This goal was in line with the redesign effort discussed in Section 2.1.1.

2.1.3 Reconnaissance Capabilities

While a great deal of design went into Phoenix I's camera-gimbal system, the capabilities of the payload were somewhat limited. The UAS lacked two important qualities: a slow flight speed, and the ability to stabilize the camera.

Phoenix I's high flight speed was a result of excess system weight, resulting in a much higher wing loading than originally anticipated. Consequently, the team committed to exercising better mass properties practices, drawing on the knowledge of better defined subsystem weights and experience gained from the 2009 design process.

The 2009 team concluded that the ability to stabilize the camera would be one of the most valuable improvements to the UAS. Regardless of flight speed, it was deemed that the camera operator would not be able to efficiently point the camera while having to react to the aircraft's changes in attitude. A decision was made to incorporate this new feature into the system architecture, as discussed in Section 4.3.17.

2.1.4 Payload Accessibility

Payload accessibility problems became evident during the integration of Phoenix I's subsystems. The causes of these problems, Phoenix I's small hatch sizes, were a high wing and a narrow fuselage.

Larger hatch sizes became one of the primary factors in the layout of the Phoenix II airframe. Consequently, the team opted for a wider fuselage and a high mid-wing design.

2.1.5 Operational Functionality

Due to the extensive wiring problems on Phoenix I, system initialization posed a real challenge during flight operations. This became more evident at the 2009 competition, where the system was not allowed to radiate until takeoff permission was granted.

An addition to the avionics subsystem was proposed. The new design would allow the operator to activate Phoenix II's motor and avionics without the need to open up the aircraft's hatches. It would also provide the operator with the ability to bypass any radio transmission in order to ensure that the system is up and running prior to takeoff. This topic is discussed in greater detail in Section 4.3.2.

2.1.6 Situational Awareness

Based on the experience of the 2009 competition, the team decided that the operators need to have better situational awareness.

A redesign of the ground station software was proposed. The new software would feature better graphical depiction of the aircraft and camera states, and reduce the effects of information overload.

2.1.7 Integration and Testing

Phoenix I underwent very few flight tests. While this was a result of time constraints (rather than intent), the system's performance reflected this reality.

While the time constraints leading up to the 2010 AUVSI SUAS Competition are just as challenging as those of the previous year, the team approached the problem by staging the integration and testing process in accordance with the V-Model described in Section 2.2.1. The integration and testing of the Phoenix II UAS was planned such that it would happen at both the subsystem and system levels. This plan was meant to alleviate the inevitable time crunch leading up to the competition.

2.2 Systems Engineering

A systems engineering approach was adopted in the development of the Phoenix II UAS. The following sections briefly explain the process used to implement the lessons learned during the 2009 AUVSI SUAS Competition.

2.2.1 The V-Model

The V-Model, shown in Figure 2, was adopted early on in the design of Phoenix II. Using the concept of operations partially defined by the 2010 AUVSI SUAS Competition, as well as the one used for the Phoenix I UAS, the overall system architecture was determined and top level requirements were derived for each subsystem.

The team proceeded with the detailed design, where the hardware architecture was completed, pin-out diagrams were created for all of the avionics, and the Phoenix II airframe dimensions were finalized. As the design progressed, care was taken to ensure that the paper design would meet the requirements set forth in the earlier stages of the design process.

2.2.2 Requirements Analysis

Once a plan of action was established for the design process, the requirements defined by the SOW were

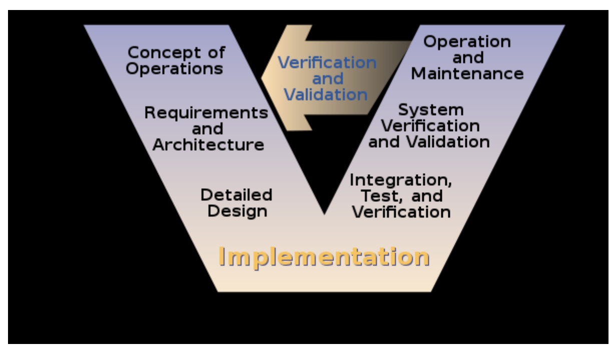

Figure 2: The V-Model
(http://en.wikipedia.org/wiki/V-Model)

broken down to the component level. A list of requirements was made for each subsystem, and a clear correlation was drawn from the component-level requirements to the top-level system requirements that they satisfied.

The process of deriving the component level requirements was driven primarily by the Phoenix I UAS architecture and the lessons learned from the 2009 competition.

2.2.3 Integration and Testing

Utilizing the derived the system and subsystem requirements, a plan for verification and validation was developed to ensure that the quality and capabilities of final product can be assessed.

As the fabrication process comes to an end, the team is working on the second phase of V-Model. This process is discussed in more detail in Section 5.0.

2.2.4 Considerations for Future Designs

Finally, just as the design must incorporate the lessons learned from previous design iterations, good systems engineering involves considerations for future designs. Such considerations were implemented in three forms.

First, a emphasis was placed on modularity. The consolidation of much of the hardware and software improves the systems maintainability and is conducive to future modifications and improvements.

Secondly, the excess processing power onboard the aircraft is reserved for future implementations of an Inertial Navigation System and Kalman Filters. For this reason, the UT UAV Group remains dedicated to designing an in-house autopilot.

Lastly, in recent years the ASL has put in a significant effort to documenting parametric manufacturing data. Throughout the fabrication of Phoenix II, the UT UAV Group remained committed to this effort by weighing components at different stages in the construction process. Additionally, time was taken to document the type of material layering and quantity of Epoxy used for different composite layups.

The data collected during the fabrication process will serve to conserve materials and to build future structures more efficiently. The data will also aid future designs in the process of weight estimation, helping them avoid the Center of Gravity (CG) problems encountered in the Phoenix I design.

3.0 SYSTEM OVERVIEW

The redesign efforts that the ensued were aimed at rectifying the design flaws discussed in previous sections. As a result, the lessons learned from the 2009 competition served as the rationale behind many of the engineering decisions made in the design of Phoenix II. These are summarized in the following sections.

3.1 Airframe

The Phoenix II airframe is designed as a conventional wing-body-tail configuration, as seen in Figure 3. The aircraft's lightweight, composite structure was designed and fabricated in-house, taking advantage of the ASL's extensive experience with composite construction.

Some of Phoenix II's notable design improvements include increased internal volume, better payload accessibility, and larger wing area for slower loiter speeds. Additionally, the wings were lowered to improve the manufacturability of the wing-fuselage junction and to increase the allowable payload access hatch sizes. Lastly, the wings and the horizontal tail are detachable, allowing the airframe to be packaged in a smaller shipping volume than that of the Phoenix I.

3.2 Target Acquisition System

The Target Acquisition System (TAS) is comprised of the image recognition software used to analyze the live video feed and the onboard hardware.

The image recognition software includes the Object Detection Suite (ODS), which detects prospective targets; the Target Position Determination (TPD) algorithm, which calculates target positions; and the Target Analysis Routine (TAR), which identifies the visual target characteristics.

The TAS hardware includes last year's Sony FCB-EX980 video camera, last year's student-designed gimbal, two gimbal servos, and two gimbal encoders.

New to the TAS hardware is the TAS Box which consolidates the Camera Interface Board (CIB), a backup 72 MHz receiver for secondary gimbal control, and the Camera Field Programmable Gate Array (FPGA), or CFPGA. The CFPGA is a elemental in the implementation of the new gimbal stabilization capabilities of the system.

3.3 Avionics

The avionics subsystem of the aircraft is divided into three parts: the Automatic Flight Control System (AFCS), two interfacing components, and the Avionics Access Panel (AAP).

The AFCS houses the Flight Control Computer (FCC), which is responsible for all of the system's autonomous navigation capabilities. The AFCS employs a Global Positioning System (GPS) unit, an Inertial

Measurement Unit (IMU), and an Air Data System (ADS) for sensor feedback. The AFCS also utilizes a 900 MHz wireless modem for communications with the ground. Two interfacing components are used to connect Phoenix II's avionics: the Avionics FPGA (AFPGA) and the Power and FCC Interface Board (PFIB). The AFPGA is used for switching between manual and autonomous flight modes. The PFIB, a new student-designed, six-layer printed circuit board, offers many of Phoenix I's capabilities in a smaller and more reliable form (see Section 4.3.4). The AFPGA, PFIB, and most of the AFCS are housed in the Avionics Box shown in Figure 3.

The AAP, located at the top of the aircraft, allows for easy access to essential flight hardware without the need to open any of the aircraft's hatches. It is used to activate AFCS components and to arm the motor during the initialization stage of the mission. The AAP is used to mitigate the problems discussed in Section 2.1.5.

3.4 Ground Control Station

The Ground Control Station (GCS) is divided into the Mission Operations Console (MOC) and the Target Acquisition Console (TAC). The MOC is responsible for interfacing with the AFCS through the 900 MHz radio link, as well as for relaying information between the TAC and the sensor payload.

The TAC is responsible for displaying the live video captured throughout the mission, and for aiding the TAC operator in target detection and queuing.

Both consoles utilize a map indicating the aircraft's position, flight plan, and camera footprint. This feature is in accordance with the goal of increasing situational awareness.

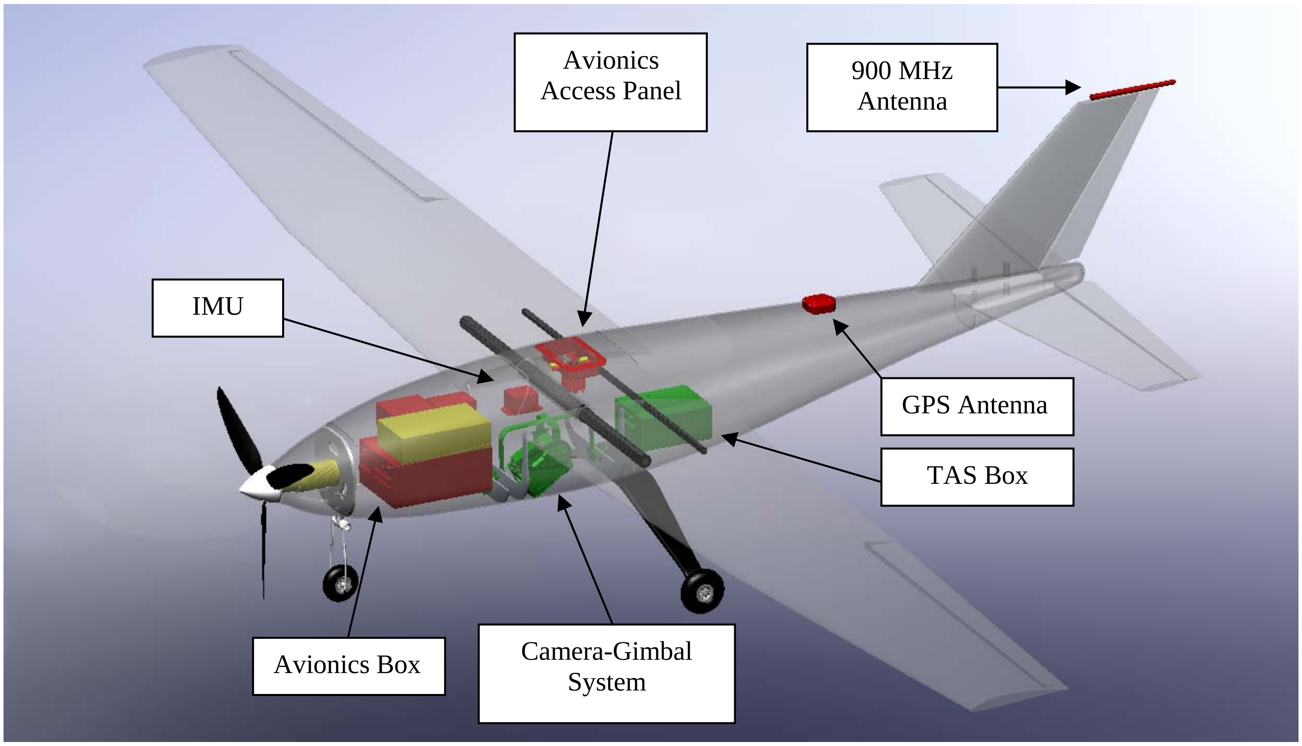

Figure 3: Phoenix II UAV - Subsystems and Components

3.5 Communication Architecture

The Phoenix II UAS employs the communications architecture shown in Figure 4. A 900 MHz radio link is utilized to uplink sensor payload and navigation commands and to downlink telemetry. A 1.2 GHz channel is used to transmit video in real-time. 2.4 GHz and 72 MHz radio channels are employed for backup aircraft and gimbal control, respectively.

Unlike in the Phoenix I UAS, the TAC interfaces with the UAV through the MOC. Consequently, gimbal commands are sent through the AFCS, which is used to stabilize the gimbal.

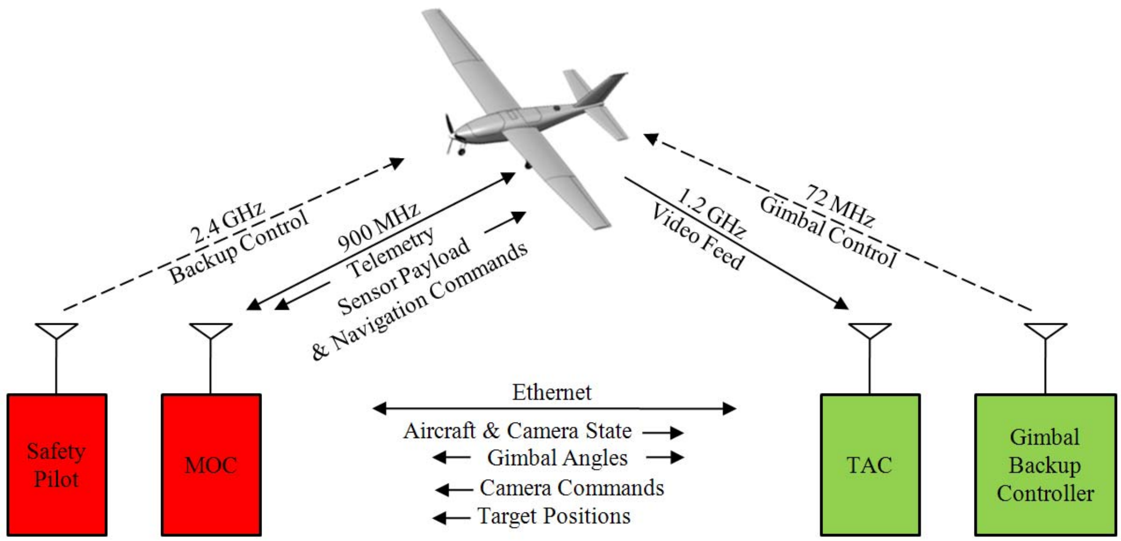

Figure 4: Phoenix II UAS Communication Architecture

3.6 Concept of Operations

The Phoenix II UAS is operated by a team of four. The MOC operator is responsible for managing the flight plan and interfacing with the AFCS. The TAC operator is responsible for controlling the camera and identifying targets. The safety pilot is responsible for flying the airframe, and has the final say on the airworthiness of the aircraft. Lastly, the mission director functions as the coordinator between the MOC and TAC operators, the safety pilot, and the judges, and is ultimately responsible for all decisions pertaining to the mission.

Prior to the mission, the UAS undergoes an initialization procedure. All of the batteries are plugged in and the hatches are sealed. One of the operators activates all of the components essential for initialization via a switch on the AAP. As the system boots up, the MOC is connected directly to the aircraft to bypass the 900 MHz communication link. Initialization is complete once all aircraft and gimbal controls have been checked, and the TAC operator has verified that the camera is outputting a video signal. The MOC and TAC operators then notify the mission director that the system is operational and the airplane is disconnected from the GCS.

Once the judges issue the command, the mission director activates the transmitters, and the aircraft is manually taxied to the center of the runway. The motor circuit breaker is closed once takeoff clearance has been issued, and the safety pilot executes a manual takeoff. The pilot climbs to a sufficient altitude, where control is turned over to the AFCS. The AFCS then proceeds to follow the waypoints as it ingresses towards the search area.

Over the search area, the aircraft executes a series of passes. The TAC operator actuates the camera as necessary in order to identify as many targets as possible. Utilizing the real-time video, the TAC operator is able to provide the judges with actionable intelligence of any target that is fully recognized, pending the approval of the mission director.

The AFCS then proceeds to navigate through the predefined egress route. Finally, as the UAV approaches the designated landing area, the safety pilot assumes control and lands the aircraft.

Once the motor circuit breaker is opened, the aircraft is taxied off the runway, and the TAC operator hands the target list to the mission director for a final review. With the approval of the mission director, the target list is turned in to the judges, the aircraft is powered down via the AAP, and the judges will be notified that the mission has been completed.

Throughout the mission, mid-air re-tasking will be executed by the MOC operator, as instructed by the mission director.

4.0 DETAILED DESIGN

4.1 Airframe

The Phoenix II airframe, shown in Figure 5, is a result of the lessons learned at the 2009 AUVSI SUAS Competition. Though the Phoenix I airframe boasted excellent drag characteristics, stability, handling, and durability, it suffered from CG issues, which ultimately increased both the weight and loiter speed, and limited payload accessibility due to the aircraft's small hatches.

The Phoenix II airframe addresses these issues with a longer nose section for more forward CG placement, larger wing area for slower loiter speeds, and lower wing placement for larger hatches and better wing manufacturability.

The following section discuss the details of the new Phoenix II airframe with regards to structures, aerodynamics, stability, and propulsion.

Figure 5: The Phoenix II Airframe Under Construction

4.1.1 Structures

4.1.1.1 Fuselage

The fuselage of the Phoenix II UAS, although significantly larger than that of Phoenix I, was constructed in a similar fashion using a fiberglass mold. Three layers of Kevlar were used to ensure a lightweight and durable fuselage that would protect the payload in the event of a crash. Key structural areas such as the motor mount, wing and empennage joints, and landing gear mount were reinforced with carbon fiber. The hatch size were determined by accessibility requirements. Additionally, the hatches were made from carbon fiber reinforced fiberglass to save weight.

Foam-Kevlar bulkheads were added to increase rigidity and to provide mounting surfaces for the camera gimbal assembly and avionics.

4.1.1.2 Wings

The wings were constructed from CNC-cut 1.3# EPP foam cores. Each wing was composed of two panels. Carbon fiber spars tubes were placed in the inboard wing panels, and were anchored to fiberglass and carbon fiber ribs. Carbon fiber spar caps were added to the top and bottom surfaces of the wing, and were joined together via a fiberglass shear web. This resulted in an I-beam structure that spanned the wing.

Each wing was sheeted in two layers of Kevlar for added torsional rigidity and durability.

4.1.1.3 Empennage

The conventional empennage was constructed in a similar fashion. However, since the vertical and horizontal tail surfaces experience smaller loads, they were reinforced to a lesser degree, foregoing the fiberglass shear web and thick carbon fiber spar caps.

While the vertical tail was permanently mounted to the fuselage, the horizontal tail can be removed. This design feature allows for better shipping characteristics when compared to Phoenix I, and allows the larger Phoenix II to be packaged in a smaller rectangular volume.

4.1.2 Aerodynamics

4.1.2.1 Airfoil Selection and Planform Sizing

Based on its excellent flight performance at low Reynolds numbers, and proven performance on the Phoenix I UAV, the PSU 94-097 airfoil was selected as the wing airfoil for the Phoenix II airframe. NACA 0012 airfoils were selected as the empennage airfoils.

In order to attain slower flight speeds, a larger wing area and span was deemed necessary. The wing span was increased to 10 ft, and the planform was changed to a two panel straight tapered wing to increase both area and wing efficiency. The wing area was increased by approximately 35% increase from that of the Phoenix I UAV.

4.1.2.2 Drag Build-up and XLFR5 Analysis

The parasite and induced drag of the airplane were calculated using both a component build-up method and XFLR5. The resulting drag polar was used to estimate in-flight performance. The Phoenix II UAS has a predicted cruise speed of 39 mph and a loiter speed of 28 mph. The maximum L/D was estimated at approximately 14.

4.1.3 Stability and Control

A detailed stability analysis was performed to determine key stability coefficients that would be used to tune the AFCS. Using a number of analytical methods, the aircraft's neutral point was calculated and used to determine the desired CG location. Current CG estimates indicate that Phoenix II can easily achieve a static margin of 21%. Extra payload room

4.1.3.2 Control Surface Sizing

For ease of construction and actuation the ailerons were sized to span the outboard portion of the wing at 20% chord, while the rudder was sized to span the entire length of the vertical tail at 25% chord. Inheriting a redundancy feature from Phoenix I, the Phoenix II airframe has two elevators, each controlled by a separate servo. Each elevator is cut at the 28% chord line.

4.1.4 Propulsion

4.1.4.1 Motor

Moto-calc was used to determine an appropriate propulsion system for the Phoenix II UAS. With a maximum power rating of 1900 W (2.1 HP), the Hacker A60-20S brushless electric motor proved most suitable for the Phoenix II propulsion requirements.

4.1.4.2 Batteries

Phoenix II utilizes 10, 8000 mAh Li-polymer battery cells connected in series. This battery configuration was chosen based on its previous performance on the Phoenix I UAV.

4.1.5 Payload

The Phoenix II fuselage is notably more spacious than that of its predecessor. Also notable, is the rearrangement of the payload location. The camera-gimbal system has been moved forward, ahead of the main landing gear, resulting in a more favorable CG position, as well as better camera visibility.

4.2 Target Acquisition System

Responsible for aiding the TAC operator with target detection and acquisition, the TAS is capable of real-time target detection and analysis.

Like all Phoenix II UAS components, the TAS was built in-house and specifically designed to solve the problem set defined by the 2010 AUVSI SUAS Competition.

4.2.1 Goals and Objectives

Section 3.5.3 of the 2010 AUVSI SUAS Competition rules state that the system shall detect target locations within 250 feet, in addition to identifying two visual target characteristics.

The UT UAV Group outlined a number of personal goals, in addition to those set forth by the competition rules.

4.2.1.1 Software Goals

Because Phoenix II lays the foundation for years of future development, the UT UAV Group emphasized the importance of software modularity and maintainability. To increase the level of autonomy of Phoenix II, the team aimed at designing a simple and intuitive user interface controlled by a single operator. As a safety measure, the operator would function inside the target acquisition loop.

4.2.1.2 Hardware Goals

In implementing the lessons learned discussed in Section 2.0, the team aimed at making the TAS hardware as compact, modular, and reliable as possible. Additionally, the design of the hardware had to incorporate the new camera stabilization feature.

4.2.2 Software

The TAS software is a full-fledged, real-time target detection suite employing novel image processing methods to accomplish the high demands of contemporary military reconnaissance missions. The software was written in LabVIEW 2009, and utilize the NI Vision Library in the composition of image processing algorithms. In addition to the robustness of NI Vision, LabVIEW simplifies the hardware and network interaction of the TAS with the remaining subsystems.

The TAS is run on the TAC in real-time by interfacing with the camera through wireless transmission. The

TAC communicates with the AFCS through the MOC. Section 4.4.4 describes the data links in detail.

The following subsections outline individual software components of the TAS. The command chain of the full system is deferred to Section 4.4.5.

4.2.2.1 Object Detection Suite

The ODS handles the initial object detection by processing the raw color image obtained from the camera. The ODS employs a three-stage approach. First, the image is segmented into clusters based on information in the saturation plane, followed by a threshold to produce a binary image. Next, the binary image undergoes noise removal. Finally, a connected component labeling (CCL) algorithm is used to label clusters as objects, recording pixel position information.

4.2.2.2 Target Position Determination

The ODS provides object positions in pixels relative to their parent image. Although this is useful for comparing objects located in the same snapshot, it does not afford a basis of comparison throughout the mission. A number of practices exist for converting the relative pixel position of an object to an absolute geodetic position. When the camera is pointing at the ground, it is often sufficient to simply assign an object the location of the UAV at the time of detection. However, this crude estimation fails when the camera is not oriented properly. The use of a dual-axis, gimbal-mounted camera further complicates the estimation process.

The Phoenix II UAS employs the student-developed TPD algorithm in transforming an object's position from a camera-based reference frame to an absolute LLA position. Table 1 lists the five primary reference frames that map an object's position to an absolute reference frame.

Table 1: TPD Reference Frames

Target-Aligned (TRG)
Camera-Fixed (CAM)
Body-Fixed (Body)
Aircraft-Fixed Local Navigation (NAV)
Ground-Fixed Local Navigation (GFLN)

The angles required to traverse the five reference frames include the three aircraft attitude angles (roll, pitch, and yaw), the gimbal roll and pitch angles, and the camera screens azimuth and bore-sight angles. Other factors that influence the conversions including camera zoom, lens distortion, and camera resolution.

By utilizing the theory behind the TPD algorithm, the TAS provides the capability to transform TRG positions computed by the ODS to LLA positions in the GFLN reference frame. Additionally, the TAS employs the reverse functionality, enabling the TAC to perform reverse targeting with *a priori* position information.

4.2.2.3 Object Filtering

To accomplish real-time object detection, the TAS sacrifices some performance for speed. Unfortunately, this fundamental design tradeoff often results in high false detection rates. Additionally, there is a high likelihood of detecting an object that is not relevant to the mission objectives, such as a runway or tree.

To mitigate such issues, the TAS employs a filtering algorithm to help reduce the number of false detections. The 2010 AUVSI SUAS Competition rules explicitly define minimum and maximum target dimensions. By exploiting this knowledge, and by using information available from the ODS, detected objects are filtered based on their GFLN-computed size and aspect ratio. Objects that do not fall within the bounds of mission target specifications are discarded.

4.2.2.4 Target Analysis Routine

The TAR consists of software tools designed to identify the visual characteristics of targets. The TAR operates on a small subset of the camera image, cropped around a recognized target.

<u>4.2.2.4.1 Color Recognition</u>

The color recognition method employs the same three-stage design as that of the ODS; however, the input image to the color recognition routine is significantly smaller. This allows for more robust image processing, yielding very accurate results.

The target image is segmented using the k-means clustering algorithm. Using $k = 3$, this results in three binary images, referred to as image segments. Intuitively, one of the image segments will contain the pixels pertaining to the background shape, one will contain the alphanumeric pixels, and one will contain the pixels outside the target. Figure 6 shows a typical output of the image segmentation.

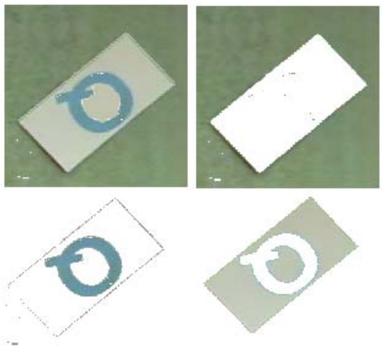

Figure 6: k-Means Image Segmentation

After noise removal and CCL, the area of each closed-polygon segment is computed. The segment with the largest area is declared the border segment and discarded. The segment with the second-largest area is declared the shape. The remaining segment is declared the alphanumeric. The RGB color values of the shape and alphanumeric segments (obtained from the *k*-means routine) are assigned a color name based on a 32-color look-up table.

4.2.2.4.2 Shape and Alphanumeric Recognition

Rather than approach shape and alphanumeric recognition from the traditional pattern-matching approach, the UT UAV Group developed a novel method capable of analyzing an arbitrary polygon, provided it is included in a pre-compiled library.

The shape and letter perimeter pixels are obtained from the image segments output by the color recognition routine. For each perimeter pixel coordinate, the distance to the polygonal centroid is computed and plotted against its counter-clockwise angle from the X-axis. The periodicity of the signal is exploited by performing the autocorrelation, and the magnitude is normalized. The resulting signal, referred to as the signature, is translation, scale, and rotationally invariant. Figure 7 and Figure 8 show the process for generating the signature of a star.

Large libraries of stock shape, letter, and numeric signatures were constructed during the testing phase. After the signature generation, the least-squares difference of each stock signature to that of the signature of interest was computed and sorted. The signature was declared to match the stock signature with the smallest least-squares error. Libraries of stock shape and alphanumeric signatures are kept separate to reduce computation requirements. The following stock shapes are currently supported:

- *Circle*
- *Equilateral Triangle*
- *Hexagon*
- *Oval*
- *Plus*
- *Right Triangle*
- *Star*
- *Thin Triangle*
- *Diamond*
- *Half Circle*
- *Octagon*
- *Pentagon*
- *Rectangle*
- *Square*
- *Thick Triangle*
- *Trapezoid*

The advantage of the shape and alphanumeric recognition routine is that the addition of new, arbitrary shapes and fonts requires little overhead.

4.2.2.4.3 Orientation Analysis

The orientation of the target is currently only partially autonomous. The TPD algorithm is used to draw a North-facing vector from the center of the target. It is left in the hands of the TAC operator to determine the target's closest matching orientation.

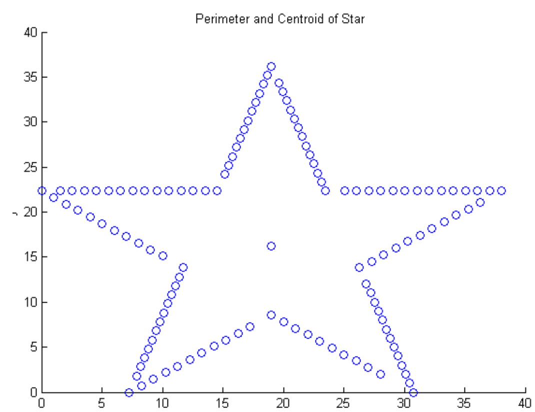

Figure 7: Perimeter and Centroid of Star

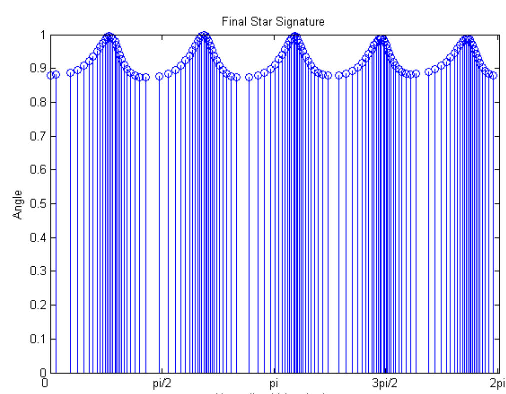

Figure 8: Star Signature after autocorrelation

4.2.3 Hardware

The TAS hardware includes the CIB to interface with and power the camera, the CFPGA to switch between backup and stabilized control, a 72 MHz receiver for backup control authority, and, of course, the Sony FCB-EX980 video camera. Additionally the system employs two high torque servos to actuate the gimbal, and two magnetic, absolute encoders. These are used for gimbal position feedback, and are an improvement over Phoenix I's relative encoders because, in the event of a power failure, they do not lose their reference. The TAS Box, which houses most of the TAS hardware components, and the camera-gimbal system are shown in Figure 9.

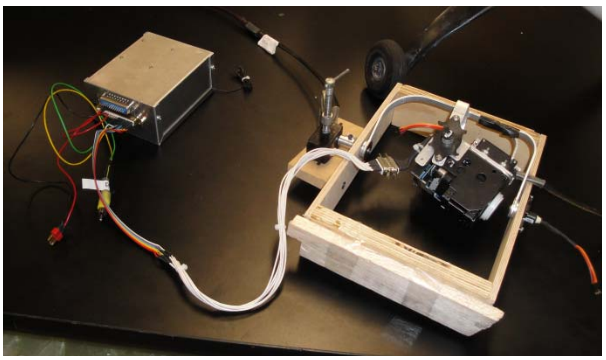

Figure 9: TAS Hardware Components

4.3 Avionics

As stated before, many of the avionics components have been consolidated into the Avionics Box, seen in Figure 10. These components

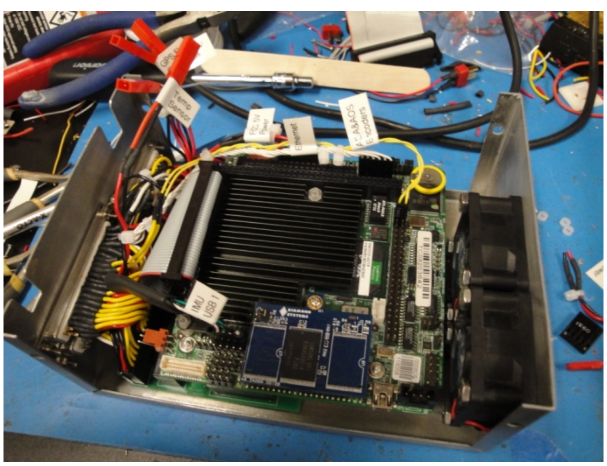

Figure 10: The Avionics Box

4.3.1 Automatic Flight Control System

4.3.1.1 Flight Control Computer

The FCC is a Diamond Systems Athena II Single Board Computer. It houses a 800 MHz processor and 256 MB of RAM. The FCC provides the UAV with a complete embedded PC and the circuitry necessary to perform data acquisition. In terms of data storage, the Athena II is capable of using a 2.5 Inch hard drive, a CD-ROM, or a 4 GB solid state storage module, the latter of which is employed on Phoenix II. The computer offers an Ethernet interface for programming and networking, as well as four USB ports, and four RS-232 serial ports. In the current configuration, all communication ports are utilized.

4.3.1.2 Global Positioning System Unit

The GPS unit onboard the Phoenix II UAV is responsible for measuring the position and velocity of the UAV in the Earth Centered Earth Fixed (ECEF) reference frame. Manufactured by Ublox, the AEK-4T uses both the National Marine Electronics Associations and binary protocol to communicate messages at a rate of up to 4 Hz. The GPS unit uses one of four USB ports to communicate with the FCC.

4.3.1.3 Inertial Measurement Unit

The IMU is used to determine the aircraft's attitude. The Phoenix II UAV makes use of a MicroStrain 3DM-GX2 IMU. The 3DM-GX2 is a tri-axial, temperature compensated IMU, which has an internally built Extended Kalman Filter that can correct for gyro drift in both the vertical and horizontal planes. The FCC reads Euler Angles directly out of the IMU via a dedicated USB connection. Therefore, no direct use is made out of the accelerometer data.

4.3.1.4 Air Data System

A Microbotics SPA 20422 ADS is used to determine the airspeed and altitude of the aircraft. Airspeed is measured by a differential pressure transducer that is connected to static and total pressure ports, while altitude is measured by an absolute pressure transducer that is connected to a static pressure port. Additionally, the ADS measures air temperature data through a temperature sensor located on the wing. The board interfaced with the FCC via one of the four available USB ports.

4.3.1.5 Wireless Modem

The Phoenix II UAS utilizes the Digi XTend-PKG 900 MHz RS-232/485 RF Modem. The wireless modem is capable of data rates up to 115 kbps, and is used for wireless communication between the MOC and the FCC. The XTend-PKG is integrated into the Avionics Box and communicates with the FCC through one of the four USB ports.

4.3.1.6 Autopilot Software

The AFCS employs an in-house, multi-threaded C program that is run in a QNX hard real-time operating system. A state machine is used to determine which threads are executed at different stages of the mission. Currently, only two states have been completed: the idle and cruise states. The idle state will be employed when the aircraft is stationary and can be used to ensure sensor functionality before a flight. The cruise state is in effect at all times between takeoff and landing and is capable of receiving and following waypoints, as well as executing camera and gimbal commands and control. The AFCS is not yet capable of Automatic Takeoff and Landing (ATOL).

4.3.1.7 Gimbal Stabilization Software

The gimbal stabilization algorithm is a new addition to the UAS. Stemming from one of the most important lessons learned from the 2009 competition, it was intended to improve the camera operator's ability to maneuver the camera. Utilizing the same theory employed by the TPD algorithm (described in Section 4.2.2.2), it calculates the gimbal angles necessary to stabilize the camera. The stabilization routine then negates the aircraft's movements using a closed-loop feedback controller, the TAS servos as actuators, and the TAS encoders for sensor feedback.

Through a series of additional calculations, the stabilization algorithm is capable of tracking GPS ground locations. This is done by computing the gimbal reference angles from the aircraft's GPS location.

The algorithm allows the operator to alternate between stabilized, GPS-hold, and manual control modes at any point in time. In both the stabilized mode and GPS-hold, mode the operator's gimbal commands are superimposed onto the stabilization commands calculated by the AFCS. Therefore, the operator is able to actuate the gimbal without any impedance from the computer.

4.3.2 Avionics FPGA

Just like the CFPGA mentioned in Section 4.2.3, the AFPGA is a Microbotics Inc. SSC. It provides the safety pilot with the ability to switch from manual to automatic flight with the flip of a switch. Unlike in Phoenix I, the AFPGA in Phoenix II connects directly to the PFIB to reduce wiring weight.

4.3.3 Power and FCC Interface Board

The PFIB, shown in Figure 11, is the greatest contributor to the consolidation of the Phoenix I avionics. The six-layer printed circuit board was designed by the UT UAV Group in PCB123 specifically to solve the wiring and power distribution issues encountered during the 2009 competition.

Compared to Phoenix I's avionics, the PFIB does not implement any new circuitry. However, it does offer a more compact and reliable alternative to Phoenix I's messy wiring, while providing control over four more servos, resulting in a total of eight controllable servos. The PFIB is divided into the power distribution circuit, the FCC interface, the AFPGA interface, and the failsafe control circuit.

4.3.3.1 Power Distribution Circuit

The power distribution circuit provides power at 5 and 12 Volts. Both voltages are available in the initialization and flight operational modes described in Section 4.3.2. The circuit allows the user to select the desired voltage/mode combination for up to 16 components. This is done by soldering jumpers to the power configuration matrix, shown at the bottom left of Figure 11.

Four 10 Amp relays are used to turn power on and off. While the relays can handle a relatively high current, very little current is required to close them, thereby ensuring that the IOM and FOM (which control the relays) experience minimal current loads. Additionally, the relays are not wired in series, thereby ensuring that if any one of them were to fail, the other three would be unaffected.

4.3.3.2 FCC Interface

The PFIB maps four serial connections to the FCC via a 40 pin ribbon wire cable. The serial connections include the portion of the ABIC used to bypass telecommunication during the initialization phase, the CIB communication link used to send zoom commands to the camera, the CFPGA communication link used to control the camera gimbal, and the AFPGA communication link used to control the aircraft in autonomous mode. In addition, two FCC LEDs are mapped to the AAP via the FCC interface to indicate the status of the FCC during initialization.

4.3.3.3 AFPGA Interface

The AFPGA interface is a high density DB44 connector that links the AFPGA directly to the PFIB. Nine servo inputs are routed into the AFPGA, one of which is used to control the automatic to manual switch. The AFPGA outputs eight servo signals that are linked either to the FCC serial communication link (in automatic mode) or to the servo inputs (in manual mode). This safety feature has been thoroughly flight tested on Phoenix I and saved the airframe on a number of occasions.

4.3.3.4 Failsafe Control Circuit

The failsafe control circuit is the most important safety feature on board the Phoenix II UAV. In the event of a complete avionics power failure, the circuit employs four relays to bypasses the AFPGA, and automatically restores control authority to the safety pilot. Since the 2.4 GHz receiver and airframe servos are on an independent power supply, the aircraft remains controllable and can be landed safely.

4.3.4 Avionics Access Panel

The AAP's notable features include the Initialization and Flight Operational Mode Switches (IOM and FOM), the motor circuit breaker, the Avionics Box Interface Connector (ABIC), and access to the 900 MHz and composite video signals.

The IOM and FOM allow the operator to set the UAV in either initialization or flight mode. Using the PFIB, the components included and excluded in each mode can be configured ahead of time. Currently, the IOM activates all components except for the transmitters, which are activated by the FOM. It is notable that both switches have two poles for added redundancy. The poles are wired in parallel, and have LEDs that indicate their conditions.

The motor circuit breaker is a major improvement over last year's system, which employed a fuse to arm the motor. Rated for 50 Amps, the circuit breaker operates like a button, and can be easily reset (rather than replaced) in the event of an overload. Additionally, the location of the circuit breaker (see Figure 3) allows the operator to arm and disarm the motor from behind the propeller, safely out of the way of the propeller disk.

The ABIC allows the operator to communicate with the onboard electronics without removing them from the aircraft. The ABIC includes the FCC Ethernet connection, an FCC RS-232 serial link that can be used to bypass radio transmission during initialization, and the programming ports to the AFPGA and CFPGA.

The AAP is yet another example of the increased safety and functionality built into the Phoenix II UAS. It also proof that the lessons learned from the 2009 AUVSI SUAS Competition were fed back into the design process, at a technical and operational level.

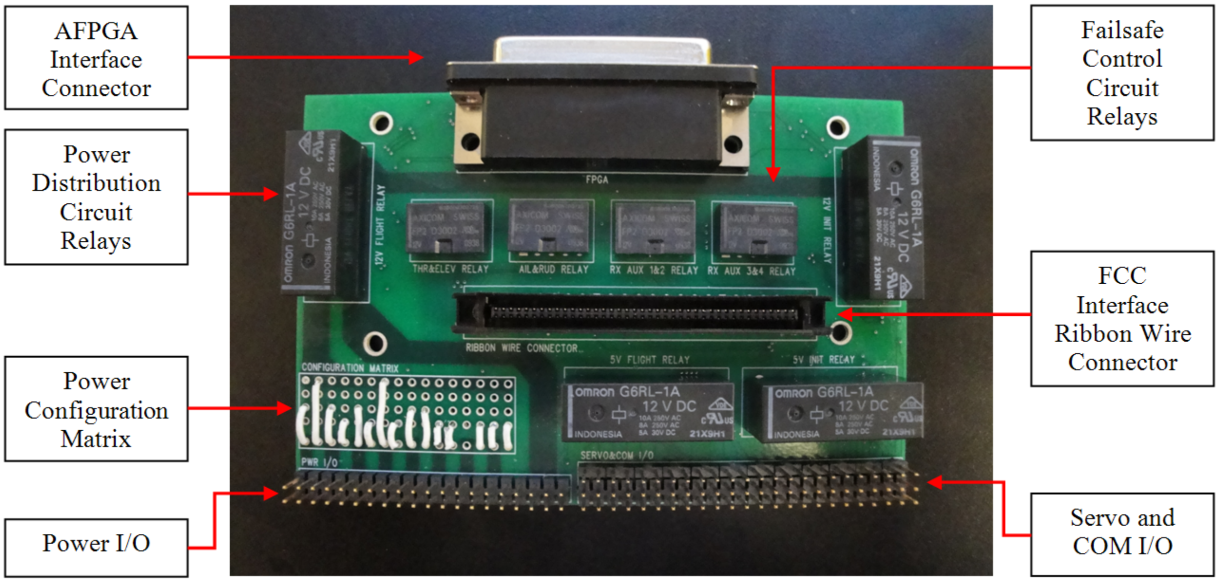

Figure 11: The PFIB

4.4 Ground Control Station

4.4.1 Description

The GCS provides an interface between the operators and the UAV. The GCS is composed of two consoles designed to perform specialized tasks. The MOC serves as the communication hub of Phoenix II, and is responsible for interacting with the AFCS. The TAC performs all functions related to the payload sensor, including target detection and camera control. Each console is controlled by a single operator. The design of the GCS reflects standard military operations, where core UAS functions and payload tasks are separated and independently controlled.

4.4.2 Computer Selection

In order to select the computers for the GCS consoles, TAS computation requirements and the availability of required peripherals, such as 1394 Firewire and serial port connections, were considered. Because the bulk of the TAS and GCS design and testing was performed on Dell Precision desktop computers, they were selected as viable candidates for the GCS. Although the desktop computers lack the portability of their notebook counterparts, their increased computational power and durability are far more valuable.

4.4.3 Software Design

All major software elements of the GCS were programmed in-house by the UT UAV Group. The software is written in LabVIEW 2009 and provides the console operator with the ability to interact with the components of the UAS through a graphical user interface (GUI).

4.4.4 Mission Operations Console

4.4.4.1 Description

The MOC is the central component of the GCS and serves as the main point of contact with the UAV. The MOC performs a number of tasks, including relaying information and commands to and from the TAC and UAV, controlling waypoint navigation, and providing the operators with situational awareness.

The MOC operator controls the MOC through the graphical interface, depicted on the left side of Figure 12. Critical UAS information, such as the aircraft's attitude, airspeed, and altitude, is continuously transmitted to and displayed on the MOC.

The map display on the MOC shows satellite imagery of the mission area with a number of overlays to increase situational awareness. These overlays include a UAV location and heading marker, UAV ground track, flight plan waypoints, camera view footprint, and the position of targets identified by the TAC.

The MOC has the capability of re-tasking the UAV during the mission by allowing the operator to add, remove, and modify individual waypoints.

4.4.4.2 Safety Considerations

The design of the MOC emphasizes safety by providing the operator with a high level of situational awareness and by employing measures for recovering from loss of communication. The former is achieved through the newly designed GUI and the overlays mentioned in the previous section. The latter is made possible through the ability of the AFCS to guide the UAV even in the absence of communication. As mentioned before, a final layer of safety is provided by the safety pilot's ability to regain control at any time.

4.4.5 Target Acquisition Console

4.4.5.1 Description

The TAC is responsible for payload control and image processing. By employing the TAS, the TAC is able to perform real-time target detection and analysis, in addition to stabilized and manual sensor control. The decision to design the TAC in-house follows the overall philosophy of the UT UAV Group, and affords the group with a large degree of freedom in implementing the design.

The TAC GUI can be seen on the right side of Figure 12. The majority of the screen real-estate is dedicated to the camera view, which displays a live video feed. The TAS uses unique identifiers to classify regions of interest within the camera view. The unique shape and color of each indicator ensures the operator's ability to distinguish potential targets and already detected targets.

4.4.5.2 Operations

According to Johnson's criteria, a region of interest must pass through three stages in order to be marked as a specific target. The criteria defines Detection as discerning an object from the background, Recognition as discerning an object as a target, and Identification as classifying a target.

Figure 12: The Ground Control Station - The MOC on the Left and the TAC on the Right

Throughout the autonomous flight stage, the TAS autonomously searches for objects (i.e. the detection stage). An object autonomously detected by the TAS is marked on the TAC camera view with a red oval, providing the TAC operator with a visual cue that detection has occurred. Although detection positively correlates with recognition, the ultimate decision to recognize an object as a target (i.e. the recognition stage) is left in the hands of the operator. This provides an additional layer of safety against false recognition and identification, a potential error that may have catastrophic implications in combat situations.

After a detected object is recognized as a target by the TAC operator, it is marked on the TAC camera view with a blue rectangle. The recognition event automatically triggers the TAR, leading to identification. The target's image, geodetic position, and critical characteristics are recorded in an accessible database and appended to a tabular file.

Targets previously recorded in the database may not be autonomously detected by the TAS in all future frames due to a number of reasons, such as low visibility. In order to assist the operator with these false negatives, existing targets are converted from the GFLN reference frame to the TRG reference frame and marked with green rectangles. This reverse-targeting provides the TAC the unique capability to display expected locations of targets with *apriori* knowledge.

4.4.5.3 User Interaction

The TAC operator interacts with the TAC through a Logitech Dual Action gamepad. The gamepad caters to the TAC design, allowing a single operator to simultaneously control the TAS software and hardware. Figure 13 shows the distribution of key functionality provided by the gamepad. Camera and gimbal control is distributed on the right side of the gamepad. The left side of the gamepad is reserved for software interaction; specifically, the operator controls a crosshair on the TAC Camera View by moving the left joystick. The object can be recorded as a target through point-and-click functionality.

Figure 13: Gamepad Button Functions

4.4.5.4 Safety Considerations

Regardless of the level of sophistication of an autonomous target detection system, the results of the system must be carefully reviewed to minimize inaccuracies. The TAC operator fulfills this purpose by maintaining the final decision on an object's match as a target. A number of fail-safes are in place to assist the TAC operator with incorrect identification.

For example, previously identified targets are kept in a list accessible by the TAC operator. The operator may review targets during or after the mission and remove any wrongly selected targets. Additionally, the operator can select false negatives by override the autonomous target analysis using a designated button on the controller.

4.4.6 Ground Control Station Communication

The UAV, the MOC, and the TAC communicate with one-another through the data links depicted in Figure 14.

The AFCS communicates with the MOC through the 900 MHz wireless modem mentioned in Section 4.3.1.5. This telemetry link exchanges critical UAS information between the two systems, including information critical to the TAC.

The MOC and TAC are connected by Ethernet, sharing data through LabVIEW's Data Communication Toolbox. The TAC sends recognized target positions to the MOC, as well as camera and gimbal commands to the AFCS (via the MOC). In return, the TAC receives updates on the aircraft and payload state.

Because no direct connection exists between the TAC and the AFCS, all camera and gimbal information is relayed through the MOC, resulting in potential synchronization errors. To mitigate this risk, the payload state is transmitted down from the AFCS, rather than inferred from the operators inputs. For example, if the operator changes the camera zoom to a new value, the new zoom level will not be used in the TPD algorithm until the AFCS confirms that the camera has changed zoom levels.

Lastly, the video feed transmits live video data from the UAV directly to the TAC via a 1.2 GHz connection. This allows for real-time reconnaissance capabilities and the collection of actionable intelligence.

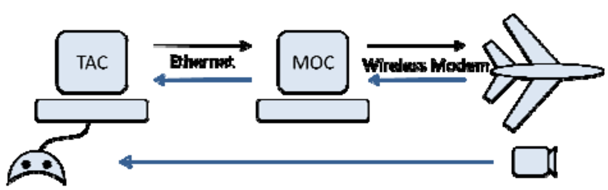

Figure 14: Phoenix II UAS Data Links

5.0 TESTING AND PERFORMANCE

The UT UAV Group adopted the V-Model to organize and task each phase of the UAS design. After outlining, designing, and building each subsystem, the team is entering the testing phase. This involves both component-level and system-level integration and testing.

5.1 Component-Level Testing

5.1.1 Airframe

Prior to any fully integrated flight tests, the airframe will undergo test flights to prove its airworthiness. The flights will include extensive testing of stall characteristics, steep turn and climbs performance, and handling qualities.

5.1.2 Target Acquisition System

5.1.2.1 Software Testing

The modular design of the TAS software proved conducive to a component-level testing environment and improved the maintainability of the code. Each segment of the TAS was tested independently, as detailed by the second phase of the V-Model.

5.1.2.2 Hardware Testing

Several hardware tests were executed in order to ensure seamless integration with the TAS software. For instance, in developing the TPD algorithm, the camera was calibrated for distortion through regression analysis, resulting in improved target position estimation.

A stabilized gimbal test is planned in the near future, and will test the integration of the TAC, MOC, AFCS, and gimbal system. The test will first be conducted on the ground, and will then be repeated during flight testing. The test will also investigate the performance of the backup 72 MHz gimbal controller.

5.1.3 Avionics

Avionics testing will be primarily concerned with checking that all of the wiring is connected properly, and that EMI is not disrupting the system. Additional ground and flight tests are required to fully evaluate the capabilities of the AFCS.

5.1.4 Ground Control Station

Several steps have been taken to improve the testing capabilities of the GCS during the ongoing development of the UAV.

For example, the TAC is equipped with a network switch to enable offline testing independent of the MOC and UAV. When the network switch is off, the operator supplies synthetic data to model the aircraft state, and the camera is connected directly to the TAC. Similar functionality is employed in the MOC to test the operator's interaction with the GUI.

5.2 System-Level Testing

Time constraints allowed for minimal flight testing on the Phoenix I UAS. While Phoenix II is under a very tight schedule, the system level testing will be much more productive in the last weeks leading to the competition. This is primarily due to the staged approach adopted early on in the design process.

5.3 System Performance and Autonomy

Although Phoenix II has not yet reached the level of autonomy aspired by the UT UAV Group, significant progress was achieved. **Error! Reference source not found.**Table 2 compares the level of autonomy of Phoenix I and Phoenix II, where the red check marks indicate manual operation, the orange check marks indicate semi-autonomous operation, and the green check marks indicate fully autonomous capabilities. The future outlook of the UAS autonomy is encouraging.

Table 2: System Autonomy Comparison

Functionality	Phoenix I	Phoenix II
Takeoff and Landing	✔	✔
Waypoint Navigation	✔	✔
Target Recognition	✔	✔
Target Location	✔	✔
Target Color	✔	✔
Target Shape	✔	✔
Alphanumeric Color	✔	✔
Alphanumeric	✔	✔
Orientation	✔	✔

6.0 CONCLUSION

The UT UAV Group took upon a very ambitious project in preparation for the 2010 AUVSI SUAS Competition. Originally, the design plan called for using the Phoenix I airframe so that more focus could be placed on integration and testing. However, as the problems were identified, it was quickly determined that there were too many design flaws. A decision was rendered to redesign the airframe and avionics.

In doing so, the team made every effort to put the work done on Phoenix I to good use. Examples of this can be seen in the use of the same camera-gimbal system, the same avionics components, and a similar (but improved) airframe.

As a consequence of the work load required to complete this project, and due to time constraints, the system has not been tested extensively. However, the team is confident that the Phoenix II UAS is a significant improvement over Phoenix I. Additionally, the team feels confident that the Phoenix II UAS will not have to go as drastic an overhaul as did Phoenix I.

The team is looking forward to the competition and expects to perform better than it did in 2009, demonstrating higher levels of functionality and autonomy. The UT UAV Group is also looking forward to next year, where the system is expected to undergo less design changes and more extensive testing.

7.0 AKNOWLEDGEMENTS

The Phoenix II UAS project required a considerable amount of effort many fronts. The final product of this ambitious project is the result of a team effort that required months of hard work. The author would like to thank a number of individuals to whom the team is especially indebted:

First and foremost, the team is grateful to Dr. Armand Chaput for his role as a technical advisor and mentor, as well as for his support of the team's efforts. Dr. Chaput's commitment to the education of undergraduate systems and design engineers is invaluable to the UT UAV Group and the Air Systems Lab.

Many thanks go out to Dr. Philip Varghese, Chairman of the Department of Aerospace Engineering and Engineering Mechanics, and Dr. Robert Bishop for their help in financing the project.

As with any project in the Air Systems Lab, the team is indebted to Mark Maughmer II for his technical knowledge and help in manufacturing the aircraft. His help throughout the year included many late nights in the lab and ensuring that construction material was always available. Mark will also serve as the team's safety pilot at the 2010 AUVSI SUAS Competition.

A number of team members deserve special thanks for their consistently strong work ethic and dedication to the team:

Jonathan Tamir, who served as the Target Acquisition System lead, deserves much of the credit for the work done on the image recognition software. He spearheaded much of the software design effort, took initiative, and did so under very little guidance. In addition to his efforts throughout the year, Jonathan was one of two primary contributors to the journal paper, which would have never been completed without his work. Should he except the position, the team will be lucky to have him as a team lead next year.

Akber Patel, who led his Design, Build, Fly (DBF) team to 11th place among 69 teams, joined the team in late April. In that time, his persistent work ethic proved elemental in finishing the construction of the airframe. Simply put, the airframe would not have been completed without his leadership. As Akber begins his career, he will surely leave the same impression on his future colleagues and coworkers as he did on this team.

Vishnu Jyothindran, who led UT's other DBF team (that placed 4th), dedicated many hours to programming the Mission Operations Console. Vishnu also helped out in the editing and proofreading of the journal paper. Without Vishnu's help, the Ground Control Station would not have been completed.

The team is particularly thankful for the work of graduate students Jorge Alvarez, Hector Escobar, and Sergio Rodriguez who were a tremendous help in the design and programming of the avionics hardware and software. Their passion for the field of navigation and control is clear in every word of Spanish they speak (and have helped this author learn a considerable amount of Spanish).

Thanks to Travis Weaver for his role as a first year leader of the avionics team. Throughout the year he made substantial efforts and took initiative to document and organize much of the extensive work that was done.

The team could not have completed the project without the of the following people:

Justin Kizer for his leadership during the fall semester and for his help with early construction efforts, the External Advisory Committee presentation, and the journal paper.

Ivan Davydychev and Chockalingam Viswanathan for their committed work on the Target Acquisition System software.

Leonardo Franco and Marlan Kingsley for their dedicated work in the construction efforts leading to the completion of the airframe.

David Taken for his work in constructing the antenna array for the ground station.

Jansen Jewell and Wiley Moseley for their help with construction efforts throughout the year.

Pablo Cortez and Alexis Avram for their support as electronics advisors.

Lastly, many thanks to all of the other members who participated in the project throughout the year.

8.0 LIST OF ABREVIATIONS

AAP	Avionics Access Panel
ABIC	Avionics Box Interfacing Connector
ADC	Analog to Digital Converter
ADS	Air Data System
AFCS	Automatic Flight Control System
AFPGA	Avionics FPGA
ASL	Air Systems Lab
ATS	Antenna Tracking System
CCL	Connected Component Labeling
CFPGA	Camera FPGA
COTS	Commercial Off The Shelf
FCC	Flight Control Computer
FPGA	Field Programmable Gate Array
GCS	Ground Control Station
GFLN	Ground-Fixed Local Navigation
GNC	Guidance, Navigation, and Control
GPS	Global Positioning System
GUI	Graphical User Interface
IMU	Inertial Measurement Unit
MOC	Mission Operations Console
NAV	Aircraft-Fixed Local Navigation
ODS	Object Detection Suite
SBC	Single Board Computer
SOW	Statement of Work
TAC	Target Acquisition Console
TAR	Target Analysis Routine
TAS	Target Acquisition System
TPD	Target Position Determination
TRG	Target-Aligned
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle