

SHARC

Stable Handling Aerial Remote-controlled Cargo-testbed

T.J. Chace, Chris Ellerhorst, Eli Grun, Luke Hartwig, Kim Kroh, Shawn Kruse, Andrew Mohler, Matt Olson, and Brian Taylor
University of Colorado, Boulder, CO, 80309

Sierra Nevada Corporation (SNC) is an electronics-based engineering company that specializes in research, development, manufacturing, and logistical support. The aviation unit within SNC is currently developing a tactical, unmanned aerial system (UAS). The UAS consists of an air vehicle, a ground control system, and a variety of electronic sensor payloads. These payloads are nearing completion and are awaiting successful flight tests aboard the air vehicle; however, the vehicle is still in development and requires a large logistical footprint for flight testing. This has lead SNC to request a low cost, easy to operate, and reliable unmanned aerial vehicle (UAV) on which to test their sensor payloads prior to integration with the full-scale UAS. There is currently not a UAV on the market that is capable of meeting the customer requirements while being compatible with their payload module, thus presenting the challenge of developing a unique design solution to the specific needs of the company. From this need stems a set of project requirements that were given to a group of aerospace engineering students at the University of Colorado at Boulder with the objective to design, build, test, and verify a UAV to mechanically and electronically interface with the SNC payload module. This paper describes the design, manufacturing, integration and testing plans for the production of a UAV with specifications that meet these objectives. The aircraft has been named the Stable Handling Aerial Remote-controlled Cargo-testbed (SHARC).

Nomenclature

AAA	=	Advanced Aircraft Analysis
C.G.	=	Center of Gravity
COTS	=	Customer Off-the-Shelf
GPS	=	Global Positioning System
HP	=	Horse Power
IMU	=	Inertia Measurement Unit
LB	=	Pounds
MGTW	=	Maximum Gross Takeoff Weight
MMC	=	Multi-Memory Card
PCM	=	Pulse Code Modulation
PSI	=	Pounds per Square Inch
RC	=	Remote-Controlled
SNC	=	Sierra Nevada Corporation
SHARC	=	Stable Handling Aerial Remote-controlled Cargo-testbed
UAS	=	Unmanned Aerial System
UAV	=	Unmanned Aerial Vehicle
USB	=	Universal Serial Bus

I. Introduction

A team of nine aerospace engineering students at the University of Colorado at Boulder is developing a low cost and reliable UAV for the Sierra Nevada Corporation. In order to ensure compatibility with SNC's sensor payload package, the customer provided the team with a specific set of requirements. First, the aircraft must have a fixed-wing configuration without exceeding seven feet in any dimension. Next, it must be capable of carrying the provided 15 pound payload and have a maximum gross takeoff weight no greater than 55 pounds. Furthermore, it should be

capable of achieving at least a 60 knot dash speed with a maximum 45 knot stall speed, both while operating at a 6,000 foot density altitude. The aircraft is also required to provide 12 volts DC power at 10 amps to the sensor payload for at least 20 minutes. These requirements were the drivers for the design and construction of a UAV to best meet the customer’s needs for stable and reliable payload flight testing at a low cost.

II. System Architecture

Three main aspects of this design are novel and presented challenges to the SHARC team in the design of the air vehicle. The first, and possibly the most challenging, is the location of the payload. Historically, cargo-carrying aircraft had their payload located near the center of gravity (c.g.). For this design, the payload must be located at the nose of the vehicle which, given the size and shape of the payload, prevented the serious consideration of many aircraft and landing gear configurations. In addition, the forward location of the payload presented challenges in balancing the aircraft.

Second, the dimensional footprint requirements presented many challenges. For the aircraft to remain within a seven by seven foot square, fuselage length and wingspan limitations were imposed. Fuselage length limitations, coupled with the placement of the payload, dictated the locations of many of the aircraft components to ensure a stable aircraft center of gravity. Given the weight of the aircraft, the wingspan limits made wing and control surface design very difficult when attempting to achieve both controllability and lift.

Finally, the ratio of the payload weight to the maximum gross takeoff weight of the aircraft was very high; this necessitated an optimized minimum mass design throughout.

The concept of operations and flight profile, Figure 1 and Figure 2, respectively, for this vehicle is similar to that of other UAS designed to carry scientific or engineering payloads. First, the aircraft is transported to the flying field where it is assembled, mated to the payload, and pre-flight checks are performed. It then undergoes flight operations under radio commands from a ground station. It is during this phase that the payload is tested for 20 minutes. Following cruise, the aircraft descends, lands, and is disassembled and de-mated from the payload. The aircraft is transported back to storage while the payload is given back to its customer for data acquisition and analysis.

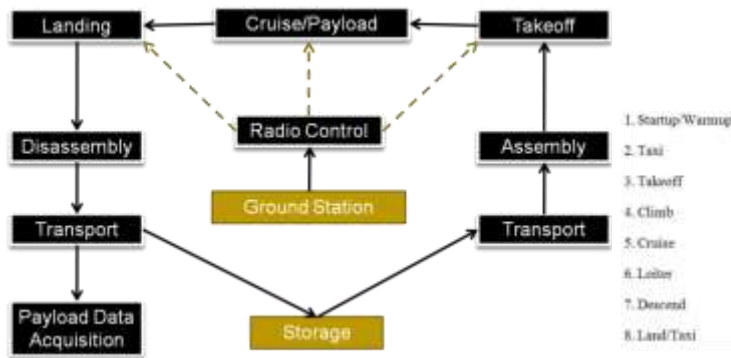


Figure 1: Concept of Operations

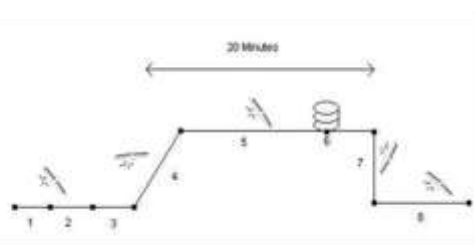


Figure 2: Flight Profile

Figure 3 is a depiction of the functional block diagram for this vehicle. It should be noted that for the student-delivered aircraft, the payload section will be modified to allow data storage and gathering to verify that the aircraft meets all requirements. This payload has “plug and play” capability with the aircraft and can be replaced by customer payloads after customer delivery. The verification payload will include an Inertia Measurement Unit (IMU) coupled with a Gumstix computer to measure and record linear and rotational acceleration in all three axes. In addition, the payload will have a pitot-static and Global Positioning System (GPS) to measure, record, and transmit to the ground airspeed, ground speed, and altitude. Finally, a temperature probe will use outside air temperature to convert altitude to density altitude to allow verification of requirements.

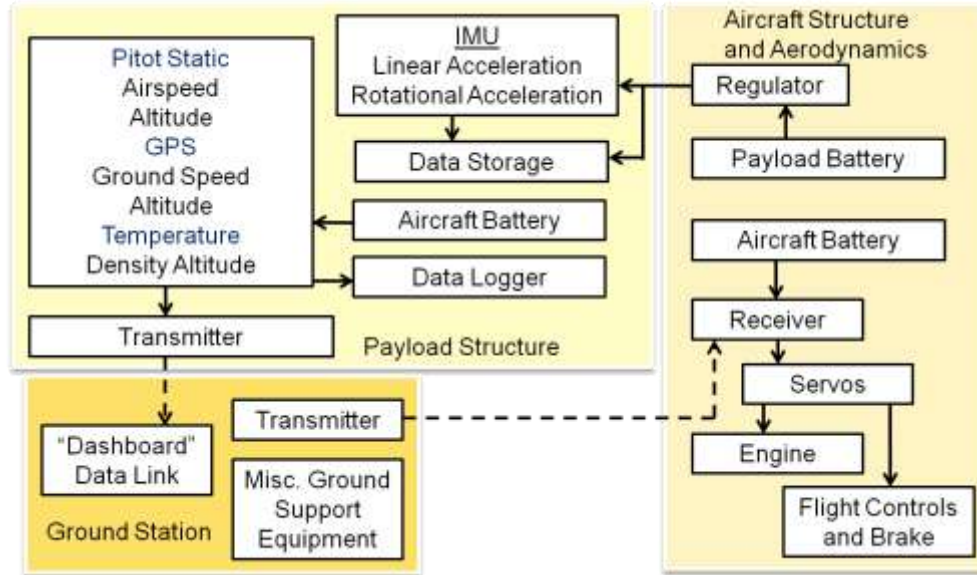


Figure 3: Functional Block Diagram

III. Vehicle Design

A. Aerodynamics

The customer requirements for a stable, easy to fly aircraft with the constraints of a 7'x7' footprint and 55 lb Maximum Gross Takeoff Weight (MGTW) were the main drivers for the aerodynamic design. Intensive research, analysis, and trade studies were performed in order to determine the best layout for this unique unmanned aircraft. A traditional aircraft configuration with wings in the front and tail in the back was chosen because of its known stability and handling characteristics. Further design and analysis was then performed using Advanced Aircraft Analysis (AAA) software ⁽¹⁾. This software allows the user to input the desired takeoff weight and flight profile and design the aircraft around such parameters. Using this software, the appropriate dimensions of all lifting surfaces and control surfaces were determined and initial models of stability were obtained. While this software provides a good estimate of the aircraft's flying qualities, it is not without limitations. Many of the design elements within the model are considered only estimates. In addition, because of the scale of this aircraft, it will often fly in a low Reynolds number regime, which is difficult to analyze.

While a traditional configuration was chosen for the aircraft, there are many unique aspects that challenged the aerodynamic design of this project. The customer required that the payload package be mounted in the front of the aircraft, unobstructed from any aircraft system. Preliminary center of gravity calculations, along with mechanical interference from the payload, forced the selection of a high wing mount. The payload configuration also eliminated the possibility for a standard tractor propeller. Instead, the propulsion system needed to be mounted in the back of the aircraft such that it would not interfere with the payload. The major consequence of such a unique configuration is that all of the major weight components are located in the extreme front or extreme rear of the aircraft. This led to a very high moment of inertia in the pitching direction. After stability models were analyzed on the aircraft, it was determined that the chosen configuration would be very difficult to trim at steady level flight due to its poor pitching stability.

The first step in correcting the pitching moment obstacle was to increase the area of the horizontal tail. This would produce more negative lift on the tail and counteract some of the pitch down moment caused by the heavy payload in the nose. The consequence of the increased horizontal tail area was a reduction in overall lift of the aircraft. To overcome this obstacle, a canard was added in order to increase the lift of the aircraft and improve pitching stability. The dimensions of these surfaces were carefully determined to produce an effective design that could produce the required lift at reasonable takeoff speeds and be trimmed in steady level flight. Finally, the length of the front landing gear was adjusted such that the aircraft would have an effective angle of attack of three degrees on the runway. This will allow for more lift to be generated on takeoff to ensure the aircraft will get off the ground without exceeding the runway distance since the aircraft is unable to rotate on takeoff due to the aft location of the propeller.

Due to the limitations of certain design tools used on this project, the flying qualities of the aircraft were verified with additional analytical methods. The lift, drag, and stall characteristics were scrutinized with computational fluid dynamics software called PowerFlow⁽²⁾. This software runs a solid model of the aircraft through a simulated airstream and outputs a visual representation of the resulting flow, along with quantitative lift and drag analysis. This process was used to fine-tune the design with respect to stall characteristics. In addition to numerical modeling, a scale model of the aircraft was tested in a wind tunnel at various speeds and angles of attack to once again verify the theoretical flying qualities. Figure 4 shows the prototype used in the windtunnel to help validate theoretical models.

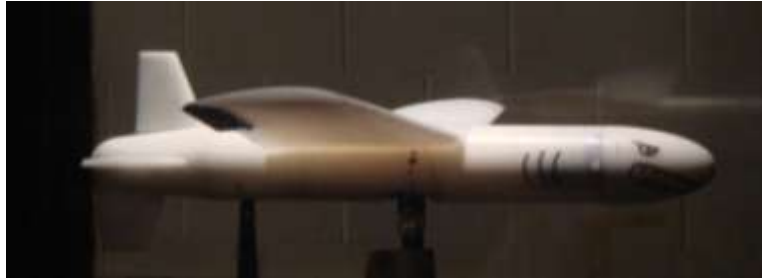


Figure 4: Windtunnel Prototype

B. Tail Configuration and Landing Gear

Tail configurations were analyzed while consciously de-coupling them from gear location and engine mounting. Many tail configurations exist including a low horizontal stabilizer, T-tail, mid mounted tail, V-tail, H-tail, conventional inverted tail, and inverted V-tail. A low horizontal stabilizer would be desirable from a weight standpoint; however, T-tails, H-tails and mid-tails both have increased structural requirements over a low-tail. A V-tail will likely not be used because that configuration to have decreased directional stability over a conventional vertical stabilizer. An inverted tail may be beneficial; it would provide beneficial yaw-roll coupling, because rudder deflection would add to roll in the same direction instead of opposing the roll. An inverted conventional tail was chosen based on trade studies conducted.

Given the constraints of a nose payload and rear engine buried in the fuselage, landing gear configuration options were severely limited gear configurations considered for the SHARC aircraft included tricycle, bicycle, or tail-dragger styles. Payload location eliminated the option of a traditional tricycle gear and propeller clearance requirements eliminated a tail dragger. It was determined that the only option was a gear without the ability to rotate on takeoff or landing. It was also determined to use the inverted tail as a location for a rear main gear since this would be more aerodynamically efficient. The considered options for the front gear were a buried nose gear in the fuselage or a nose gear on a strut. Both these options would result in a bicycle gear configuration with the requirement of outriggers at the wing tips. In addition a dual main gear mounted on the fuselage or dual gears mounted from the wings were considered and would not require outriggers.

Due to length constraints on the landing gear, the inverted vertical tail sizing was limited. From initial sizing estimates, it was clear that additional tail area was needed. To remedy this problem, an additional vertical tail was placed above the fuselage. Figure 5 shows the final tail, landing gear, and payload configurations attached to the fuselage.

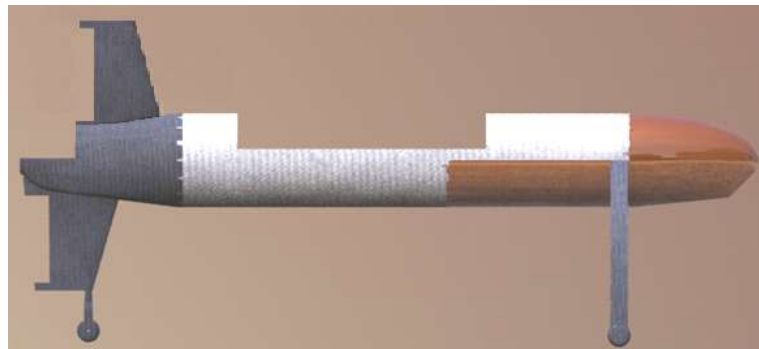


Figure 5: Tail and Landing Gear Design

C. Propulsion

The selection of the propulsion system and configuration for the SHARC platform was a consequence of the mission performance requirements as requested by the customer, SNC. As relating specifically to the propulsion system, it was required that the aircraft be able to takeoff within 350 feet at an altitude of 5,300 feet, dash at a speed of 60 knots, and cruise at 6,000 feet density altitude

It was from these parameters that the engine and propeller selection were driven, as will be described later. Additional requirements stated that the aircraft be: a) propelled by an internal combustion engine and b) that the electronics payload must be in the most forward section of the aircraft. As a result of these two latter constraints, the overall configuration of the aircraft was directly defined.

Having an internal combustion engine requires that liquid fuel be used in the system and in order to mitigate a shift in the c.g. with time, the fuel tanks must be placed at the “dry” c.g.. Coupling this design complication with the stated requirement that the payload bay must rest at the nose of the aircraft, the engine configuration was narrowed to two options. The first would be to mount one engine on each wing in a tractor configuration so as to provide symmetric thrust, while the second would be to mount a single engine at the aft of the aircraft in a pusher configuration. As it turns out, the prior design was removed as a consequence of reduced stability properties and complicated integration concerns. By placing a single engine at the rear of the aircraft, the ability to balance the c.g. of the aircraft so as to provide a positive static margin (and therefore advantageous longitudinal stability characteristics) would be obtainable by counteracting the large payload weight at the forward aircraft section. Additionally, a single engine reduces the concern over asymmetric thrust, complicated internal wing structure fuel line integration, as well as overall cost and time demands for verifying and testing engine performance. As was mentioned previously, by placing the engine at the aft of the aircraft, the fuel tanks could be placed within the internal structure of the aircraft at the center-of-gravity without the complication of a more forward c.g. location that would have been a consequence of wing-mounted engines. Therefore, the overall propulsion system configuration had been determined within the initial requirements of the customer.

One must look at the performance requirements of the customer to make the final selection of the engine and propeller for the SHARC system. It was determined through AAA⁽¹⁾ software that a power requirement of 8 HP would be required of the propulsion system to meet the design-driving takeoff condition. As budget and time constraints do not allow for typical UAV projects to develop engines to meet their specific performance needs, projects of this scale are subject to the current market of remote-controlled (RC) engines. After compiling a database of the available market engines, an outlier was discovered which would provide more-than-sufficient power (11 HP) at a reasonable weight of 4.2 lbs. Other engines on the market at this weight provide no more than 6 HP but, as expected, the consequence was in the overall price of the engine. However, strategic design decisions have to be made and in order to ensure the success of the propulsion system the cost was not considered prohibitive. It was concluded that the BME Extreme 115cc engine would be selected, as the excess power provided by this engine would overcome additional and unquantifiable power requirements. It is well known that RC engines are rated at sea-level conditions as this allows for the determination of maximum performance specifications. Unfortunately, as the SHARC project was based in Boulder, CO (5,300 ft altitude), it was expected that there would be power losses as a result in a density decrease which would reduce the effective engine power to an approximated 9.2 HP. This value was still above the required power prediction for takeoff and the residual power was assumed to be adequate to overcome the additional drag induced by the fixed landing gear that could not be estimated in AAA⁽¹⁾.

The BME Extreme⁽³⁾ 115cc engine manufacturer suggested that a 30 inch diameter by 10 inch pitch propeller with two blades be used at an engine speed of 6100 RPM to generate a static thrust of nearly 90 lb. However, as a consequence of the tail-dragger landing gear with a rear-mounted engine in a pusher configuration, the maximum propeller diameter allowable was 24 inches. Therefore, by matching engine loads in order to produce the same static thrust of the suggested system, a three-blade propeller with a 24 inch diameter and an 18 inch pitch was selected. This was a unique propeller design that could not be bought off-the-shelf; instead, this propeller design would require custom manufacturing. Fortunately, this design could be manufactured by XOAR Intl⁽⁴⁾, thereby completing the overall configuration of the SHARC propulsion system such that the customer performance and integration requirements could be met. This design would also satisfy the various design needs as constrained by the overall aircraft configuration. A picture of this engine from the manufacture’s website is shown in Figure 6



Figure 6: BME Extreme Engine

D. Payload

The payload of the aircraft will consist of various measurement sensors that will measure and record the aircraft's altitude, airspeed (via pitot-static tubes), outside air temperature, tri-axial accelerations and tri-axial rotational rates such as the yaw, pitch, and roll. This sensor package will consist of two different systems: an inertial measurement system and a flight data recording system. The data received from these sensors will help to verify the overall stability of the aircraft. Figure 7 shows the location of the payload with respect to the aircraft.

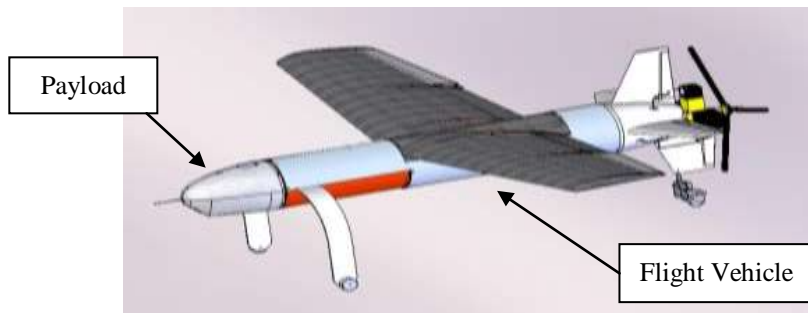


Figure 7: Location of Payload

The inertial measurement system will include an off-the-shelf IMU from Microstrain, Inc.⁽⁵⁾ This unit will measure tri-axial acceleration and the tri-axial angular rates of the aircraft. These data will be recorded at a sample rate of 100 Hertz by running through a program on a Gumstix Linux computer and saved to a 2 Gigabyte Multi-Memory Card (MMC) card. This MMC card will then be able to be inserted into a computer for post-flight analysis and will ultimately help to verify stability of the aircraft by comparing collected data with previously created stability models. Figure 8, below, shows how each sensor will be located inside the payload shell.

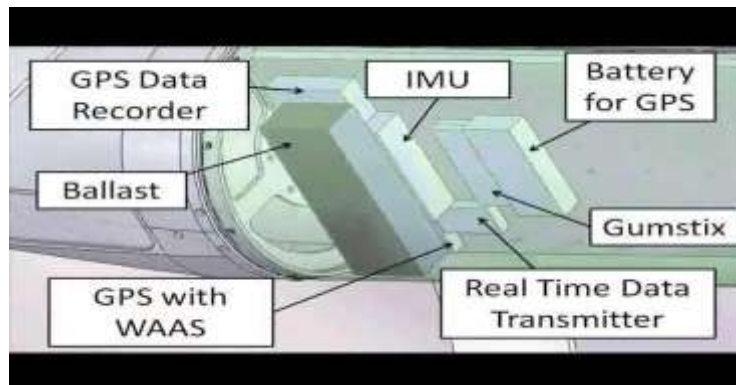


Figure 8: Layout of Payload Sensors

The flight data recording system will be purchased from EagleTree Systems⁽⁶⁾ and will consist of a flight data recorder, a GPS unit, a pitot-static tube system, a wireless transmitter, and a dashboard receiver. Data collected from the GPS and pitot-static systems will be able to be transmitted down to the ground station, via the wireless transmitter and receiver, where the team will be able to view real-time measurements of the aircraft while in flight. The system comes with user-friendly software that will be downloaded onto a laptop computer so that the team on the ground will be able to view the simulated cockpit of real-time data of the aircraft. This will be extremely helpful for the pilot in that he will be able to know the aircraft's altitude and speed during takeoff and landing. Figure 9 is a flow diagram of the EagleTree flight data system.

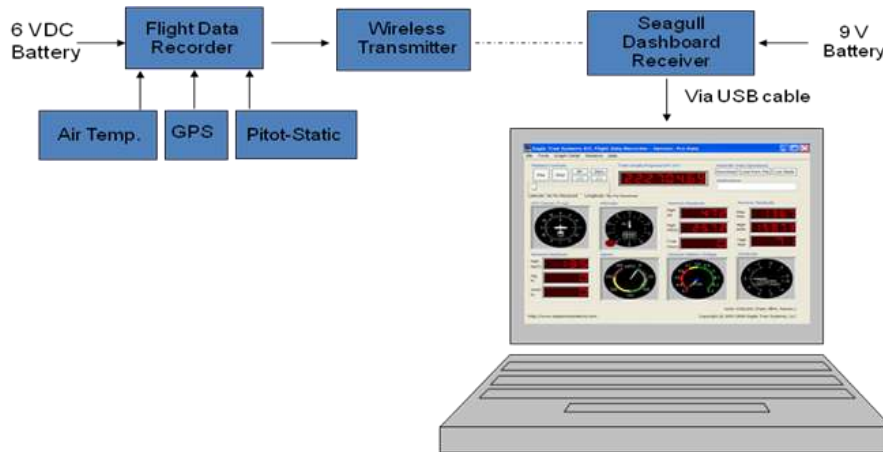


Figure 9: Diagram of EagleTree System

IV. Final Design

A. Vehicle Design Overview

The final design of the flight vehicle consists of a pusher-engine configuration, high-mounted wing, inverted and upright vertical stabilizers, as well as an immobile canard. Two main gears are located on the forward section of the fuselage, while the tail-dragger rear gear is mounted to use the inverted vertical tail as a fairing to reduce drag. This configuration is depicted in Figure 10.



Figure 10: Aircraft Design Overview

Inside of the flight vehicle are systems to provide fuel to the engine, power to the payload, servos for flight control, and all respective mounting systems, including mounts for the payload and wing shown in Figure 11.

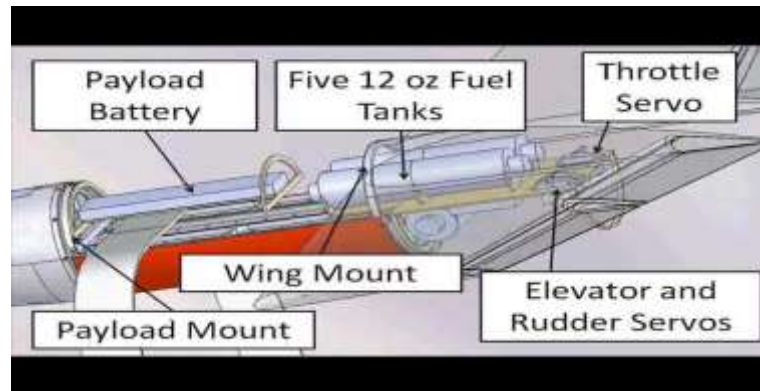


Figure 11: Flight Vehicle Interior

On the underside of the flight vehicle mounts are the receiver, receiver battery, and payload power regulator along with an additional payload mount seen in Figure 12.

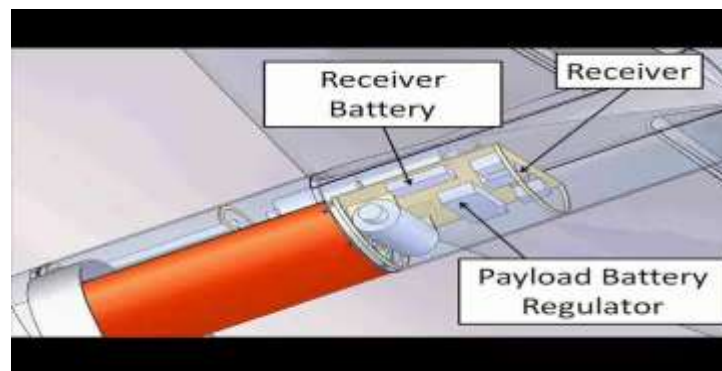


Figure 12: Receiver Hardware and Payload Power Regulator

B. Ground Support

The ground support for the air vehicle includes systems to start the engine, charge batteries, fuel the vehicle, and communicate during flight operations. This equipment includes two 12 V batteries to power the engine starter and the battery charger. All of the aircraft power circuits are designed to be charged and armed via switches and plugs on the skin of the aircraft so that no disassembly is required. In addition, a Pulse Code Modulation (PCM) transmitter will transmit commands to the aircraft and the EagleTree Dashboard ⁽⁶⁾ will allow the ground crew to view the altitude and airspeed of the vehicle in real-time.

Once at the flying field, a crew of two will check the range of the transmitter and receiver by driving the fuselage of the aircraft to the maximum expected distance from the transmitter. Then a control surface movement check will be performed, as well as a check of correct transmission of the EagleTree Dashboard ⁽⁶⁾.

Next, the aircraft fuselage is returned and using bench-top power, the payload is turned on to acquire a GPS signal. While one crew member works with the payload, the other plugs the wing servos into the receiver and attaches the wing via six screws on the wing mounts. Next, the payload is removed from bench top power and the payload to aircraft power connection will be established followed by mechanical mounting. The aircraft is then fueled and the status of the batteries is checked to ensure a full charge. The aircraft is brought to the runway and the transmitter and receiver are turned on once again. With the pilot at the transmitter, the engine is started followed by the payload battery. If all indications are nominal, the aircraft takes off and undergoes flight testing with one crew member piloting the vehicle from the transmitter and the other supporting by calling out information provided by the EagleTree Dashboard ⁽⁶⁾.

As stated previously, the EagleTree Flight Dashboard System ⁽⁶⁾ will be purchased in order to measure altitude, airspeed, air temperature, and GPS locations of the aircraft. The system is capable of wirelessly transmitting the data

down to the Dashboard at the ground station in real-time. The flight system will need to be powered for a short time on the ground so that the GPS unit is given sufficient time to determine its location and to get warmed up. Once the aircraft has taken off, the Dashboard will begin to receive data from the on-board transmitter. The Dashboard itself will be connected to a laptop computer via a Universal Serial Bus (USB) cable and with the necessary EagleTree software ⁽⁶⁾ installed, the team will be able to view a simulated cockpit of the aircraft with its current, real-time data. These flight data will also be recorded to the Flight Data Recorder onboard the aircraft. Therefore, post-flight analysis of the flight will be achieved by removing the Data Recorder from the aircraft and downloading the file onto the laptop.

On descent to landing, airspeeds and altitudes will be called out to the pilot from the EagleTree ⁽⁶⁾ crewmember. Following landing, the engine will be stopped and the batteries powered down. The aircraft will then be disassembled and readied for storage, while the payload can be returned.

C. System Requirement Overview

From the detailed analysis performed at the subsystem level, expected build-to specifications were derived. These are compared directly with the respective design-to specifications for the system level requirements in Table 1. This allows a presentation of the expected capability of the SHARC vehicle to exceed requirements.

Table 1: System Level Analysis

Parameter	Design-To specs	Build-To specs
Footprint	84 x 84 in	75.8 x 84 in
Empty Weight	40 lbs	35 lbs
Stability	Appropriate derivatives	Level 1
Lift	55 lbs	156 lbs at max lift
Fuselage Bending	$\sigma_{Yield} = 70,000$ psi	366.6 psi at 3 g
Wing Bending	$\sigma_{Yield} = 70,000$ psi	3500 psi at 3 g
Rear Landing Gear	Survivable +4 g landing with crosswind	Verified through design and prototype testing

Notice that in this case, empty weight is defined as the MGTW with the payload removed. This was used as a method of comparison because the weight of the payload is defined to be fifteen pounds, including added ballast when necessary to ensure that this weight is met; therefore, the only uncertain weights are those located within the flight vehicle. It is estimated that the flight vehicle will weigh thirty-five pounds, giving a weight margin of thirteen percent.

Level 1, 2 or 3 stability standards are an indication of the stability of the flight vehicle, where Level 1 represents the highest level of stability offered through FAR certification standards. The SHARC vehicle is predicted to achieve Level 1 Dutch roll stability. It was also determined that the SHARC flight vehicle is longitudinally stable with a static margin of about seventeen percent, as well as being stable in the spiral mode and statically stable in sideslip.

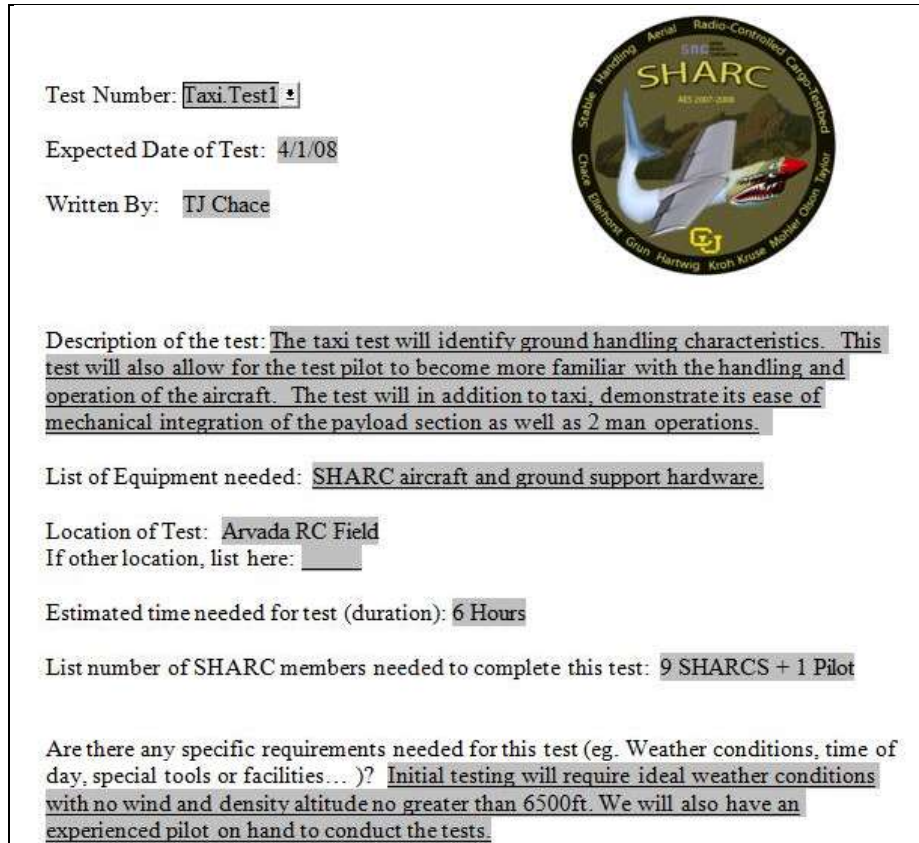
Structural requirements were for survivability at flight loads of +3/-2 g. The maximum expected stress on the fuselage and wing are 366 psi and 3,500 psi, respectively. This gives large factors of safety considering that both have a yield stress of 70,000 psi. The fuselage is a customer off-the-shelf (COTS) product used to reduce manufacturing time. The wing design may be adjusted in the future to save weight and allow for more structural stress, although any design changes would be minor and would only affect the structure of the wing and not the aerodynamics or flight dynamics.

The rear landing gear was the major critical component identified during the Preliminary Design Review ⁽⁷⁾ due to its unique configuration and design. The entire landing gear on the flight vehicle is required to survive a +4 g impact as well as forces created by landing without correction during crosswind conditions. The impact requirement deals primarily with buckling of the landing gear while the crosswind requirement produces a lateral point load due to frictional forces at the point where the gear and pavement meet. The design in place for the SHARC aircraft has been verified through analysis and was also prototyped for testing purposes.

V. Verification

A. Test Plan

The steps used to create the overall testing plan began with the project level, system level, and subsystem level requirements. Having defined requirement numbers, the documentation of each test could begin. A testing matrix, outlining testing numbers, could be established to corresponding requirement numbers, ensuring that all requirements would be fulfilled. Once these testing numbers were completed, they were re-organized so that they could be achieved in parallel with appropriate subsystem or component testing. Utilizing the new testing matrix, with corresponding testing numbers to subsystem or component, the responsible individual for that subsystem or component could fill out a testing form, shown in Figure 13.



The form is titled "Sample Preliminary Test Form" and contains the following fields and text:

- Test Number: Taxi Test 1
- Expected Date of Test: 4/1/08
- Written By: TJ Chace
- Description of the test: The taxi test will identify ground handling characteristics. This test will also allow for the test pilot to become more familiar with the handling and operation of the aircraft. The test will in addition to taxi, demonstrate its ease of mechanical integration of the payload section as well as 2 man operations.
- List of Equipment needed: SHARC aircraft and ground support hardware.
- Location of Test: Arvada RC Field
- If other location, list here:
- Estimated time needed for test (duration): 6 Hours
- List number of SHARC members needed to complete this test: 9 SHARCS + 1 Pilot
- Are there any specific requirements needed for this test (eg. Weather conditions, time of day, special tools or facilities...)? Initial testing will require ideal weather conditions with no wind and density altitude no greater than 6500ft. We will also have an experienced pilot on hand to conduct the tests.

The form also features a circular logo for SHARC (Stable Handling Aircraft) with the text "SHARC ALL 2007-2008" and "Radio-Controlled Cargo-Rescue". The logo includes a list of names: Aerial, Stable Handling, Radio-Controlled Cargo-Rescue, Chris, Robert, Glenn, Harwig, Krah, Kruse, Robert, Owen, Taylor.

Figure 13: Sample Preliminary Test Form

The test engineer would then interpret the information on the form to determine the resources and required materials to successfully run the test. The tests that will have to be performed involve aerodynamics, flight dynamics, structures, electronics, propulsion, and payload. In aerodynamics testing, the team has already performed a wind tunnel test to help determine the aircraft's performance. After manufacture and assembly of the entire aircraft, slow and fast taxi tests will be performed, followed by an actual flight. There are multiple flight tests that will be performed, ranging from very short flights to longer flights, determining specifics of the handling qualities of the aircraft. The structural components of the aircraft will be tested upon the completion of each component. The landing gear will be drop tested to landing impact scenarios, as well as the fuselage accompanied by all landing gear components. The wings will undergo wing bending tests to failure to determine the airworthiness of the main lifting devices. In addition, the propulsion system must be verified for the required thrust at takeoff and cruise conditions as well as for fuel consumption, which will be done using a Dynamite engine test stand. During these tests, the payload electronics and aircraft electronics will be tested to ensure the aircraft can gather sufficient data to compare with the initial stability models and that the aircraft will have sufficient power and control during flight. Upon completion of all the tests described, a system level and project level inspection will be done to fulfill all the requirements.

To ensure each test is carried out properly, a test card is provided as a procedure and reference guide. The test cards were compiled from the initial test form (Figure 13). Figure 14 shows a sample test card. The test card is interactive, allowing for the individual(s) running the tests to record observations and outcomes for reference. The results of the tests are then documented and are used to support compliance with all the requirements outlined for this project.

Wind Tunnel Test Card: 45 Knots		
Task	Observations	Outcome
Ensure prototype is mounted securely to mounting hardware at zero angle of attack		
Run wind tunnel to simulated 45 knots and save 10 data points and record initial chamber temperature		
Set prototype to -5 degree angle of attack and record 10 data points		
Return to 0 angle of attack and record 5 data points		
Set prototype to +5 degree angle of attack and record 10 data points		
Set prototype to +10 degree angle of attack and record 10 data points		
Set prototype to +15 degree angle of attack and record 10 data points		
Record last wind tunnel chamber temperature and shut down		

Figure 14: Sample Test Card

References

1. *Advanced Aircraft Analysis Version 3.2 (Software)*. s.l. : DARcorporation, 2006.
2. PowerFLOW (Software). s.l. : EXA company, 2007.
3. **BME Engines**. BME Engines. [Online] [Cited: 12 1, 2007.] <http://bmeengine.com/gfx/e115/2.jpg>.
4. **XOAR International**. [Online] [Cited: 12 14, 2007.] <http://www.xoarintl.com/props/ma/PJI.html>.
5. MicroStrain Microminiature Sensors. *MicroStrain: Orientation Sensors-Wireless Sensors*. [Online] [Cited: 10 10, 2007.] <http://www.microstrain.com/>.
6. PRO/UAV/JET PRODUCTS. *Eagle Tree - R/C Telemetry UAV...* [Online] [Cited: 10 30, 2007.] <http://www.eagletreesystems.com/UAV/uav.html>.
7. **Chace, Todd, et al**. *Preliminary Design Review*. ASEN, University of Colorado. Boulder : s.n., 2007.