SANTA CLARA UNIVERSITY

Departments of Mechanical, Electrical, and Computer Engineering

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I HEREBY RECOMMENT THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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Nicholas Bushnell, and Mike Nicholson

ENTITLED

SHARP Reentry Vehicle Prototype

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE IN **MECHANICAL ENGINEERING**
For Kevin Murray and Whitney Armbrust

BACHELOR OF SCIENCE IN **ELECTRICAL ENGINEERING**
For Kenneth Pirozzoli, Anthony Bucad, and Nicholas Bushnell

BACHELOR OF SCIENCE IN **COMPUTER ENGINEERING**
For Mike Nicholson

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SHARP Reentry Vehicle Prototype

By

Kevin Murray, Whitney Armbrust, Kenneth Pirozzoli, Anthony Bucad, Nicholas Bushnell, and Mike Nicholson

THESIS

Submitted in Partial Fulfillment of the Requirements for the
Bachelor of Science Degree in
Mechanical Engineering, Electrical Engineering, and Computer Engineering
In the School of Engineering
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Abstract

The performance of maneuverable reentry vehicles depends on a fundamental tradeoff between the wing's leading edge radius, material thermal properties and aerodynamic performance. The NASA SHARP program is developing new Ultra High Temperature Ceramic materials to increase the toleration of heat on sharper leading edge wings. The SHARP vehicle has been defined as an experimental test bed to enhance sharp reentry vehicle wings. Our senior design project is an initial step in developing a prototype vehicle of the SHARP test bed.

Acknowledgments

Professor Chris Kitts

As the team's project advisor, Chris gave detailed insight and knowledge to the team to work towards the goals of the project. He was a motivator and organizer for all members of the team, and we appreciate his efforts.

Paul Kolodziej

Our primary contact with NASA Ames, the project was directed towards what he and NASA specified us to do. Paul offered helpful hints to the team with regard to testing and implementing certain design characteristics of the project. He also gave the team a tour of the NASA ARC Jet Facility at Ames where they test Ultra High Temperature Ceramics for space applications.

Pascal Stang

Offered knowledge and hints in regard to CPU programming, sensor and power wiring and integrated system configuration.

Randy Stuart

Acted as the team's high altitude balloon and parachute expert; Randy was ready to help with team with any questions or uncertainties regarding high altitude and recovery applications. He also designed and manufactured the team's balloon release mechanism for the SHARP prototype.

Chad Bulich

Offered the team his home oven for manufacturing purposes, as well as helpful insight from his knowledge in design projects

Steve Nelson

A junior intern for the project team, Steve helped out with random tasks and minute details of the project.

Don MacCubbin

As Machine Shop Manager, Don helped out the mechanical engineers with difficult manufacturing designs and processes.

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1. Introduction

1.1 The Sharp Program

Responsive control and accurate maneuverability of spacecraft is important for today's space programs. When a spacecraft reenters the atmosphere of the Earth, having the ability to manage and fly the vehicle is a primary concern for safe landings while at the same time diminishing risks of reentry missions. The NASA space program currently has 6 landing sites stretching from Spain to Hawaii (reference). Increased maneuverability of current spacecraft designs would allow for both improved reliability during reentry flight, as well as providing a cost effective mechanism in reducing the amount of necessary landing sites around the world. This enhancement of controlled spacecraft can be accomplished by providing wings and control surfaces that conform to traditional aircraft design.

However, this design criterion does not allow for optimum aerodynamic stability and control. In the overall study of aeronautics, it is ideal for an aircraft to have relatively thin, sharp edged wings for smooth, laminar airflow. This provides two important factors, one being to improve the lift of the aircraft, and the other being to increase overall maneuverability of the aircraft as previously stated. Likewise for a spacecraft upon reentry into the Earth's atmosphere, these same traits would be advantageous. Yet given the thermal loading that is seen on reentry vehicles, a more desirable aerodynamic shape must be compromised in order to safely reduce the temperatures experienced on the spacecraft. Empirical testing and physics research has proven that if blunt, rather than sharp shaped designs reenter the atmosphere, than heat will be dissipated more efficiently. An excellent design paradigm for this characteristic of reentry vehicles can be seen in the NASA Apollo Program. The reentry capsules for the Apollo space missions were designed as a blunt cone shape with a high radius spherical section to be the part facing the Earth during reentry. This was designed specifically for the purpose of dissipating heat so that the capsules, as well as the astronauts inside them, would not "burn up" upon reentry. Similarly, on today's space shuttles, the wings are relatively blunt to prevent high thermal loading. On today's space shuttles such as the Endeavour, the maximum wing thickness is 5 feet, leaving a front radius of roughly 2 feet. Such aeronautical properties are not the best for the full potential of space shuttle flight. So given the important design considerations of aircraft aerodynamics, the temperature limitations allow only for current space shuttles to have relatively blunt wings, a property that is not desirable for ideal atmospheric flight.

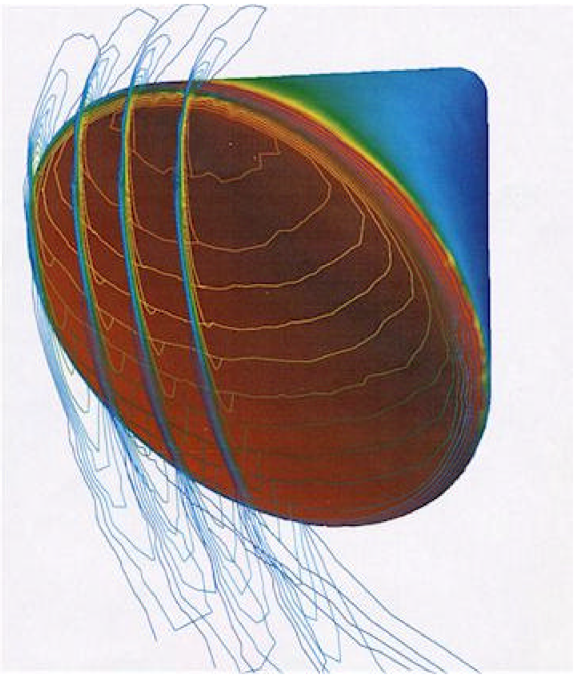


Figure 1.1: Thermochemical Nonequilibrium flow over Apollo reentry capsule

This heat concentration must be taken into account during the design of new spacecraft that will reenter Earth's atmosphere. On current space shuttles, the heat resistant shingles on the front leading edges of the wings can tolerate temperatures up to 3000°F. Confronting these extreme temperatures is vital to space exploration. But just as in any engineering task, the safety and integrity of human life is the primary focus of design and implementation when building a new system for severe conditions. Finding new, innovative, and proven ways to increase the safety of space missions is a topic that reaches the pinnacle of engineering endeavors and motivations. Thermal loading of reentry spacecraft most definitely pertains to this significant role in aerospace engineering.

Better ultra-high temperature ceramics (UHTC's), would be a great asset to increasing the capabilities of spacecraft. Research into thermal protection of spacecraft has been carried out almost exclusively by NASA since the 60's. In recent years, the Thermal Protection Materials and Systems Branch at NASA Ames Research Center have engineered many new UHTC's for spacecraft applications. These new materials have the capability to withstand temperatures of up to roughly 5000°F. The emergence of these new materials has allowed for the possibility of utilizing new leading edge profiles. Testing facilities for these UHTC's include the NASA ARC Jet Division, a sub-branch of the Thermal Protections Materials and Systems Branch in which ceramics can be tested to very high temperatures.

1.2 The SHARP Program

Among the many research projects involved in this area of aerospace engineering, one includes the SHARP program. SHARP is an acronym for Slender Hypervelocity Aerothermodynamic Research Probe and it is a project specifically for research into reentry spacecraft. SHARP is a defined shape by NASA that takes on a wedge-like form to create a sharp leading edge in which materials can be tested in true environmental conditions. The SHARP project was initiated in 1996 to research these new ultra high temperature ceramics along the front leading edge tip of the probe. Currently, NASA has a suitable amount of theoretical and simulated data on the shape of the SHARP vehicle. In Figure 1.1, a CFD model of the SHARP concept is given.

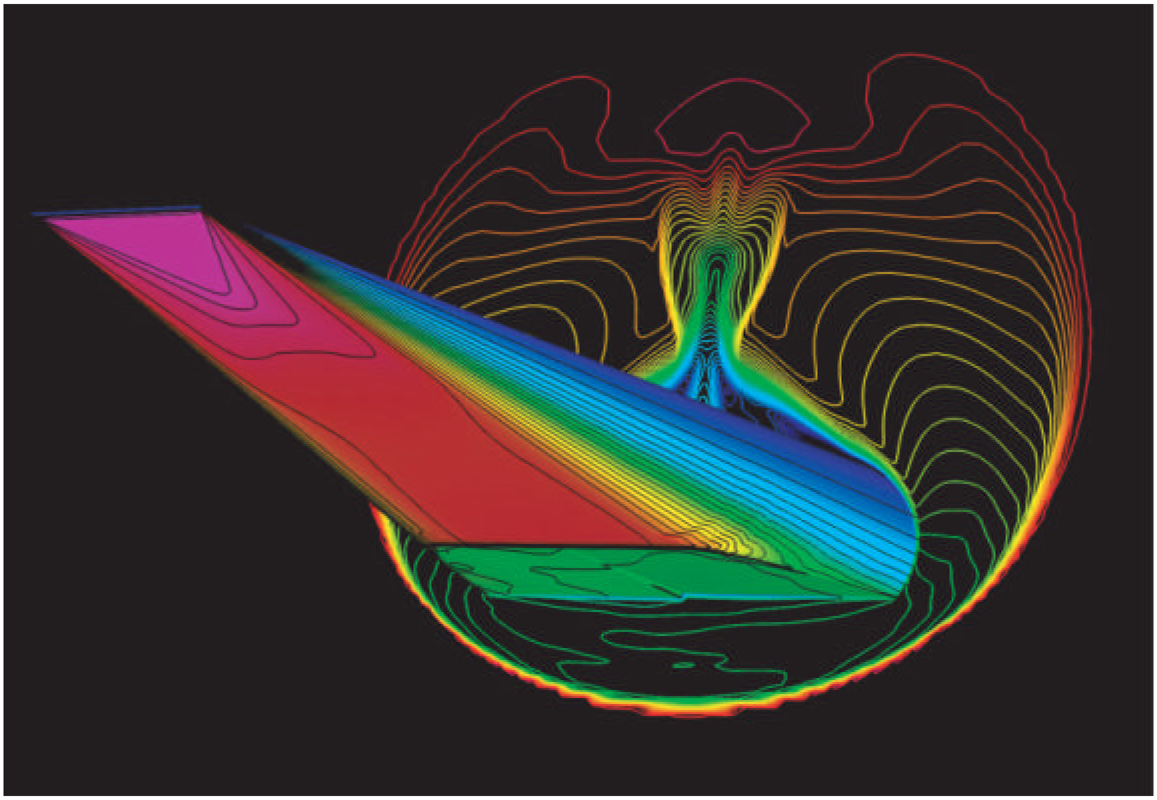


Figure 1.2: NASA Ames, Thermal Protection Materials & Systems Division, SHARP CFD model

There have also been previous attempts in recent years to test the SHARP models in reentry conditions. The SHARP program was initially broken down into two separate teams known as the SHARP B series, and the SHARP S series. The B series focused on a different geometry than the S series. The SHARP B involving a cone shaped prototype, while the SHARP S series were "knife" shaped to introduce wing like structure. The S series was then broken down into two groupings, the S series, which would be continued research conducted by NASA and it's research teams and subcontractors, and the L series, which would be low cost sounding rocket research contracted out to universities and small businesses. The first L series team was assembled in 1997, and was a unified effort between NASA Ames, Wickman Spacecraft and Propulsion, Stanford University, Santa Clara University and Montana State University. Wickman was to develop the sounding rocket to take the SHARP prototype to an altitude of 270,000 ft., Stanford's Space Systems Development Laboratory and Santa Clara University engineered the avionics and data acquisition systems, while Montana State and their Composite Research Group were contracted to build the SHARP structure out of composites and metal alloys. NASA Ames would be the project coordinator. Unfortunately, the sounding rocket failed during the test flight, and the project has since been postponed due to funding limitations.

1.3 The Santa Clara SHARP Senior Design Team

This year's Santa Clara SHARP Senior Design Team wished to make a low cost but compelling contribution to the SHARP program and expand on a relationship with NASA Ames and their research teams. For this project, our goal was to design, build, and test an initial SHARP prototype reentry vehicle capable of collecting data relevant to the natural flight dynamics and pressure distribution related to the unique aerodynamic geometry. In this manner, the team could offer empirical data to compare with researched data and analysis in an effort to better understand the motion of this probe.

Our Senior Design Team is an interdisciplinary team that consists of two Mechanical Engineers, three Electrical engineers, and one Computer engineer. Due to the complexity and variation within the project, our team had to be interdisciplinary to manage and our specified goals. However, because there was no financial support from NASA Ames, as well as a lack of graduate student assistance and advanced facilities, our prototype had to be designed and implemented with limited resources and capabilities. Initially, the team brainstormed numerous ideas such as launching the probe on a sounding rocket, or even using real NASA space shuttle heat resistant tiles. However, these proved to be beyond the scope and aptitude of the team. For the final overall design specifications, the team decided to build a relatively small SHARP prototype for a high altitude test drop. This intuitively meant that our probe would not go into low orbit space, but remain within the atmosphere. Building and implementing this SHARP vehicle is the small role that Santa Clara and the School of Engineering can offer in the larger SHARP program.

2. Project Overview

2.1 Our Part in SHARP

The SHARP team is an interdisciplinary team that consisted of two mechanical engineers, three electrical engineers, and one computer engineer. We came together to build an initial prototype sharp angle reentry vehicle. Because we do not have financial support from NASA Ames, our prototype is not designed to be released from orbit. Rather, the vehicle was designed to be dropped from a high-altitude balloon that would reach a speculated height of 80,000 feet. The altitude that it would achieve is a very cold, low-density, low-pressure region of the atmosphere. These extreme conditions would affect the vehicle's velocity, pressure, and temperature upon descent.

We targeted our goals and specifications to match the limited resources available to the team. As specified by NASA, we constructed a SHARP vehicle capable of doing two primary functions for data interpretation. The first function of our project was to sense and record pressure distribution exerted on the vehicle while it is in flight. This data is currently unknown to NASA, and could be analyzed and interpreted as needed by their engineers and scientists. The other function of our project was to sense and record dynamic motions of the vehicle while in flight. These data, similar to the pressure distributions, are unknown, and could be a great asset to further research in the SHARP program.

Our sponsor also suggested that we provide a control vehicle for our experimental SHARP vehicle. This control vehicle would be of similar geometry to the Apollo reentry capsule so that our data could be compared to a known and extensively studied geometry. However, this would have required us to design and manufacture two vehicles; such a mission would by far exceed our capabilities and funds. Therefore, we focused only on the SHARP vehicle development and left the control vehicle idea for future design teams.

Overall, one of the primary purposes of this project was to show NASA the capabilities that an undergraduate SCU team of engineers obtain. We were eager to provide NASA with relevant data to further advance the SHARP project.

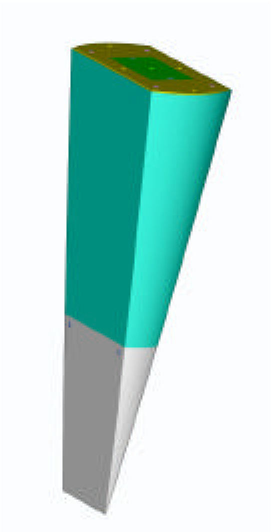


Figure 2.1: The designed SHARP vehicle

2.2 System Overview

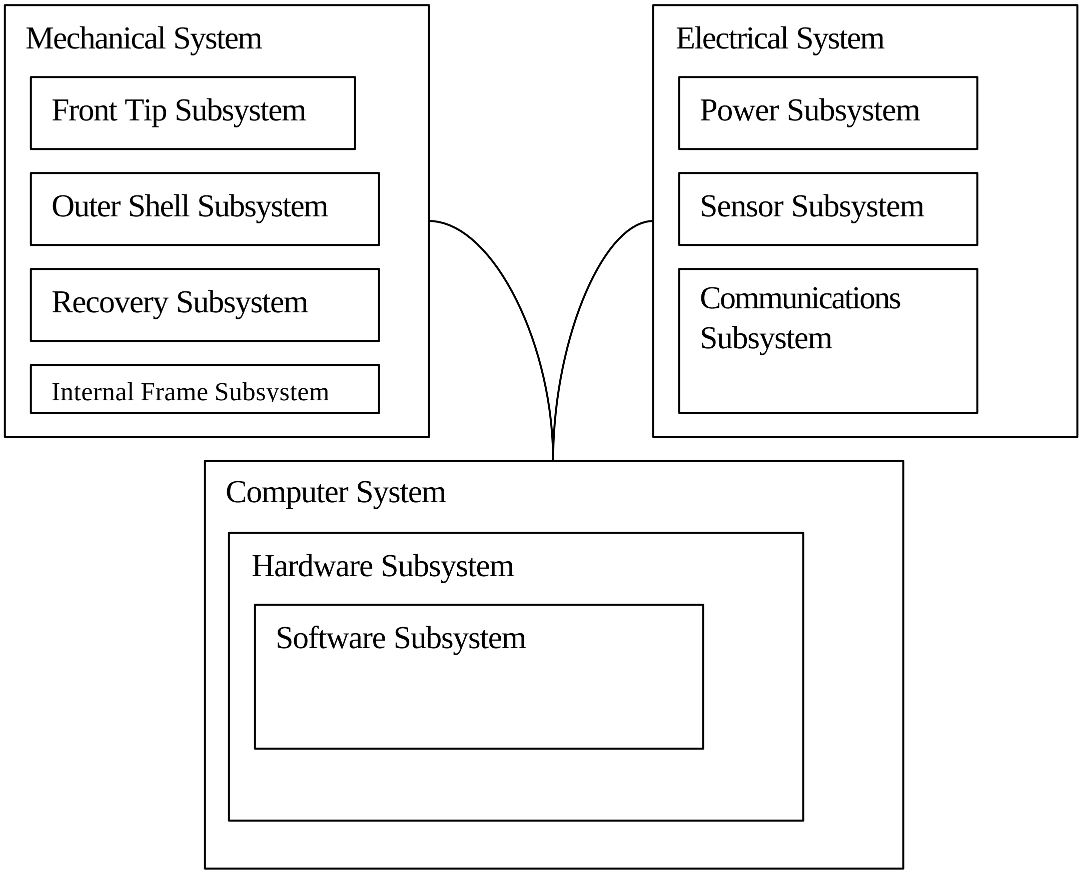


Figure 2.2: System Level Functional Block Diagram

The SHARP project at SCU was partitioned into three primary systems, one for each engineering discipline. Each of these three major systems was then partitioned further into subsystems to aid in design and implementation.

The mechanical system was broken down into subsystems representing the major parts that together formed the vehicle. These consisted of the custom machined aluminum front tip, home oven thermoformed outer shell, acrylic and sheet metal back door, and the parachute based recovery system.

The electrical system was too broken down along the lines of the major components. The power system, which included batteries and power regulation hardware, was of great importance because it supported the other electrical systems including the complex sensor subsystem which included all of the pressure sensors attached to the outer shell and back panel, the accelerometer, the internal temperature sensor, and the very usefull GPS receiver. The communication subsystem also resided in the electrical system and contained an off the shelf HAM radio with a directional antenna.

The computer system acted as a hub between the mechanical and electrical systems. It read and interpreted data from the various sensors, including the GPS, and acted upon other systems in the vehicle such as the parachute based recovery subsystem. For design purposes it was divided into a hardware and software subsystem. The hardware included the microcontroller chip and its supporting proto-board hardware.

2.3 Flight Plan

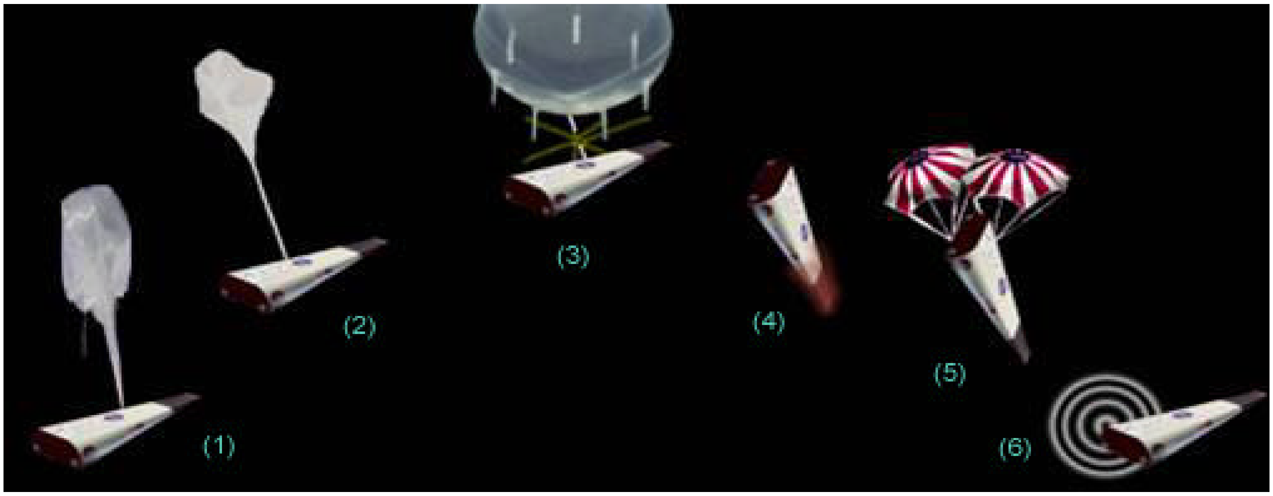


Figure 2.3 Flight plan

Before many parts of SHARP could be designed, a flight plan had to be established. This flight plan consisted of six major phases: power on self test, ascent, release, active descent, parachute release, and recovery. Each of these phases corresponded directly with the phases listed in the software state chart and the electrical power budget.

In the first phase, power on self test (1), the vehicle sat on the launch pad for a few minutes after the balloon had been filled and ran through various diagnostics to ensure that the sensors, GPS, data storage, power supply, batteries, and communication systems were operating specifications. After about five minutes, all the tests completed and SHARP proceeded to takeoff. During ascent (2), the vehicle released from the ground tether and it rose rapidly for about 90 minutes until it reached 80,000ft. At this point, the balloon release mechanism was activated (3). After the vehicle began to fall, as verified by GPS, active descent began (4). During active descent, the sensors sampled at their highest possible rate and information was selectively transmitted down to the base station as well as stored in the onboard flash memory card. This phase lasted only 90 seconds as the vehicle fell as fast as 200 miles per hour. Once these 90 seconds had passed, or GPS reports that the vehicle has reached 20,000 ft, the parachute was released (5). This was an important system which required redundancy at some levels for safety reasons. Once the parachute was released, as verified by a deceleration on the vehicle and GPS, the recovery phase of the mission begins. During this phase, the vehicle retransmitted its GPS location over and over to aid in recovery efforts. Even if the recovery window of an hour was exhausted and SHARP powered down, the last possible location was still known. Also, SHARP took advantage of the slow descent time to retransmit a larger selection of important data to the base station. At the termination of this phase the vehicle was recovered and preparations began for its next flight.

2.4 Major Objectives and Constraints

The first major constraint of the SHARP vehicle was its prescribed shape. The entire purpose of this project was to investigate this unique geometry, but because of this, we had to accommodate all internal components accordingly. The shape itself was of wedge-like geometry, as shown in Figure 2.1, with the leading edge at approximately 10-12 degrees. The other dimensions weren't prescribed exactly, only that the width tapered outward slightly as it went to the back of the vehicle to about 25% greater than the leading edge width. The length was an adjustable variable that could be varied to meet weight requirements. This shape severely limits the amount of workable volume near the front edge.

This was coupled with the second major constraint, the location of the center of gravity. It was desired that the vehicle fall with its sharp edge pointing downward at all times. This required that the center of gravity be as close to the front leading edge as possible and that it stay below the center of pressure. From previous NASA tests on SHARP geometries at various speeds, it was known that the center of pressure was approximately 50% of the length away from the leading edge. This meant we were required to achieve a center of gravity within 5-40% of the length from the tip, with a safety margin. This was somewhat of a challenge because of limited usable volume in the front of the vehicle where the most weight distribution was needed. From this, the first designs of the vehicle were made, which consisted of a solid tip and hollow back to push the center of gravity toward the leading edge. The heaviest components, specifically the batteries, were then placed in the hollow region closest to the tip. The heaviest item that we had to place in the back of the vehicle was the parachute recovery system.

The weight of the vehicle was the most challenging constraint of the project. Because the vehicle was designed to be dropped from a high-altitude balloon, it needed to meet weight requirements imposed by the FAA. The high-altitude balloon requirements specified that anything dropped must be under 6 lb in one release compartment or under 12 lb in two release compartments. It also specified that there could be up to 12 lb or more in one compartment with special permits depending on what weight range the vehicle fell into. In essence, the heavier the vehicle, the more costly and complicated the necessary FAA paperwork. Originally, we were designing the vehicle to be less than 12 lb. However, in the event that we discovered that we could not get the approval for the drop, we didn't want to be completely out of luck. Thus, we had a backup design that met the less than 6 lb requirement. In this, there were fewer sensors that reduced the power requirements and thus the battery size. Also, the front leading edge, instead of being made out of a metal alloy, would be constructed from wood.

The vitality of the vehicle before, during, and after the flight was also a major concern for the success of this project. We wanted to be able to gather useful data pertaining to the dynamic motion and pressure distribution of the vehicle. While this information would be transmitted real time via HAM Radio, the data would also be collected and stored on-board, making the recovery of the vehicle critical. In addition, accurate pressure sensors and accelerometers were critical to the quality of the gathered data along with sensing correct altitudes to initiate the drop and recovery.

The limited funding and high cost of the vehicle were also major constraints. Most of the financial support came from SCU's Robotics Systems Laboratory with the instructions to be as economical as possible. This limited the materials selection for the hardware components, the quality of the pressure sensors and accelerometers, and the facilities to design, manufacture, and test the vehicle. Consequently, the hardware, circuit boards, and system integration were entirely constructed using SCU facilities. Unfortunately, this evoked problems in manufacturing and sensor calibration.

The last constraint of the project was time. There was eight months to design, implement, construct, integrate, and test the vehicle. This goal was definitely a test of our capability to work under time pressure, and in the end, proved to be highly significant.

3. Mechanical System

3.1 Front tip

3.1.1 Introduction

The front tip of the SHARP vehicle was separated as a specific part primarily to enhance weight distribution and the location of the CG (center of gravity). In order that the pressure distribution and flight dynamics of the SHARP vehicle can be tested properly, the probe must remain stable while in flight. Therefore, it is a primary objective to keep the CG as far forward towards the front part of the vehicle as possible. A cone or wedge shape tends to have the CG near the wide part of the geometric object, which is contradictory to the desired properties of the vehicle. Therefore, a front tip made of a relatively high-density material coupled with a low-density aft portion is necessary for proper aerodynamics.

The front tip is the most difficult part of the assembly to manufacture. Ultimately, the three most important factors for creating and building the front leading edge tip of the SHARP vehicle are the shape and sizing of the part, the density of the part, and manufacturability. The form of the front tip is significant in that the prescribed shape of the SHARP vehicle needed to be maintained as specified by NASA. The density is vital as stated previously based on the fact that the SHARP vehicle must remain aerodynamically stable. Finally, the part had to be easy to manufacture and inexpensive with regard to material selection. This then equates to using a material that could be manufactured in the Mechanical Engineering Machine Shop.

3.1.2 Design Selection

The final design selection for the front leading edge tip material was swiftly chosen to be aluminum. The reasoning in choosing this material relates to the fact that all of the design and manufacturing criteria are satisfied. Aluminum is both heavy in relation to the rest of the vehicle, and it has the capability to be readily manufactured in the machine shop. In addition, it is important to note that aluminum was also used by the previous SHARP team for the same reasons of weight distribution. The cost of the aluminum "block" for machining came to $100 as purchased from the Aluminum REM Center.

Another element of key importance in designating the front tip material was it's interface to the rest of the SHARP vehicle. Primarily, this means the front tip's attachment to the internal frame and the outer shell. Two designs for interfacing were investigated. One being that on the back part of the front tip, there be a protrusion to fit within the internal frame, while the other is machining a pocket so that the outer shell can fit inside the pocket of the front tip. It was finally reasoned that in manufacturing the outer shell, the dimensions may not come out to exact specifications. Therefore, it would be easier to design a way to form the outer shell to go within the pocket of the front tip, and this was then implemented.

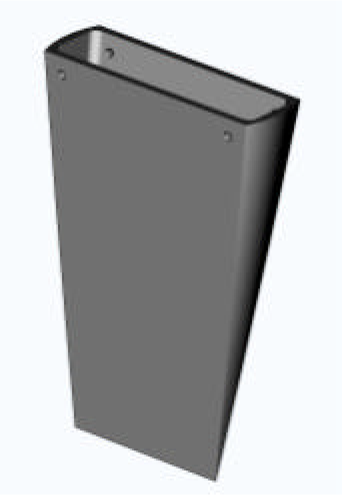


Figure 3.1 Front Tip Final Design

The only other material considered by the Mechanical Engineers of the team for the front tip was carbon steel. Although heavier than aluminum, steel is much more difficult, and holds with it higher risks, when machining. The benefit of extra density of steel did not exceed the detriment in manufacturability of the material.

3.1.3 Analysis

The leading edge tip was proven as a reasonable and successful means to stabilize the SHARP probe. Dimensioning of the part would be difficult, but manageable to the team. It was also important to maintain a smooth surface along the external faces of the front tip for accurate data gathering

3.1.4 Implementation

The implementation of the aluminum front tip was one of the most challenging aspects of the mechanical system. With Aluminum 6061 as the material choice, the front tip had to be machined to exact dimensions. However, the front tip is a highly unconventional form as compared to most other mechanical parts. The general form of the front tip is a flying wedge shape geometry with rounded edges along the sides and a pocket on the back face. The existence of rounded edges and the sharp front edge created difficulties in manufacturing of the part.

The originally purchased aluminum block had to first be machined to the outside dimensions of the part, given from the detailed drawings to be 10.5” x 6.75” x 2.25”. After completion of “squaring” the part (making all sides perfectly parallel and all angles 90°), the pocket was machined during the course of one day. The pocket is 1” deep while maintaining ¼” thickness to the outside of the part.

After discussion of machining the front face angles of the front tip with machining experts, it became evident that it would be necessary to manufacture a fixture for the front tip. This was a large block of aluminum manufactured to hold the front tip in place in order that machining of the angles could take place. Consequently, machining of the front tip had to be temporarily halted to make a fixture. This was eventually designed to have a protrusion into which the front tip could fit firmly, as well as to hold three 3/8” bolts that would attach into the front tip. Dimensions of the fixture are 6.75” x 4” x 3” including the 1” protrusion. Then, the front tip, still in block form, was drilled and tapped to hold these screws, and the fixture was attached.

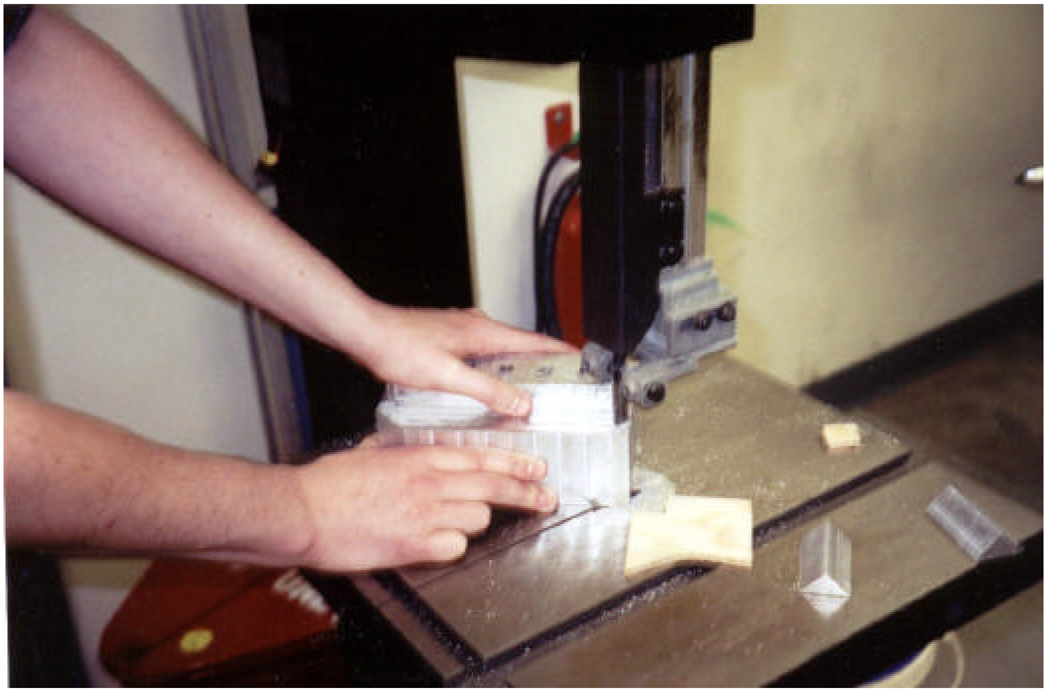


Figure 3.2: Machining Front Tip Fixture

Finally, the angled cuts to the front tip could be completed. Manufacturing of the faces was done carefully, and had to be completed in one sitting to optimize machine shop time. If the angles were not cut in one sitting, than careful mounting of the front tip and fixture would have be done again. The front tip, attached to its fixture, was placed in the milling machine vice at an angle of 6°. This allowed for the cutting of each face with a 2" carbide end mill halfway across the short 2.25" distance of the part. The last layer of aluminum to be removed was done slowly to create a smooth surface finish. In order that the outer shell could be fastened to the front tip, four thru-holes on the pocket edges and perpendicular with the outer faces had to be drilled and chamfered. This allowed for flathead screws to be used in interfacing the outer shell. Flat head screws were used to maintain the smooth surface of the SHARP vehicle. The frontal angle, as stated previously, was finalized at 12°, allowing for a sharp angle while maintaining a reasonable amount of space to provide for internal avionics and components in the aft body of the vehicle.

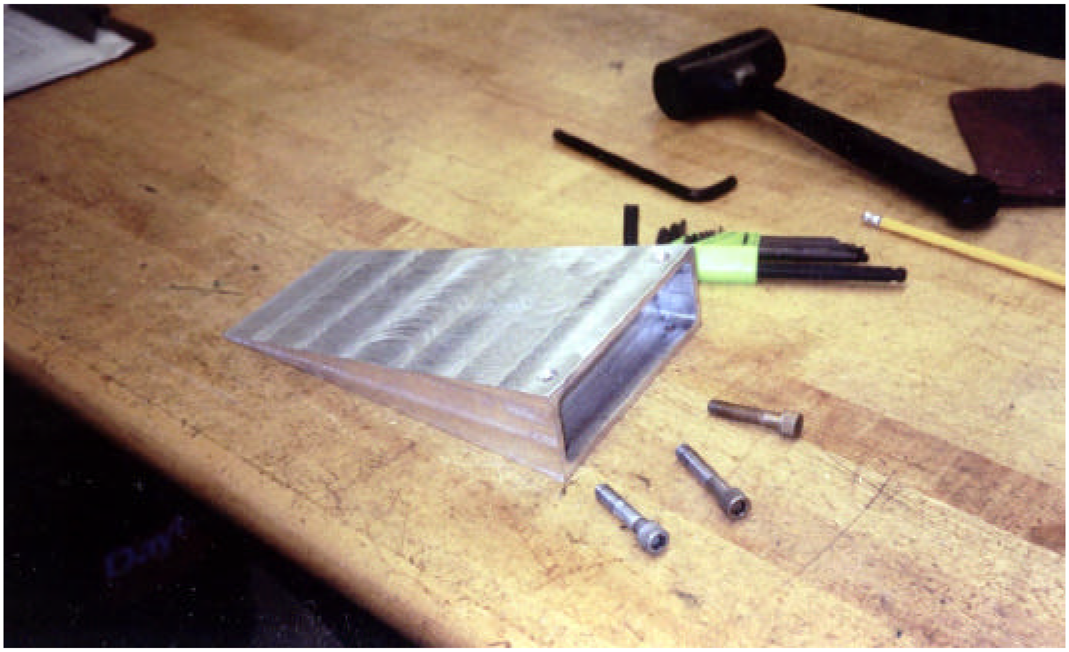


Figure 3.3: Front Tip before rounding of edges

Next, angled cuts had to be completed on the sides that would eventually become the rounded edges of the front tip, also at 6°. However, in continued discussion with experts on machining of the front tip, there were more challenges to be dealt with. Original specifications of the SHARP geometry specified that the edges of the vehicle be rounded to come out tangent with the frontal faces as in Figure 3.4b. This proved to be impossible to manufacture in the Santa Clara Machine Shop. Although a rotary index for a milling machine could have offered a smaller radius than was implemented, an extra fixture would have had to be made, and was not time effective with the project.

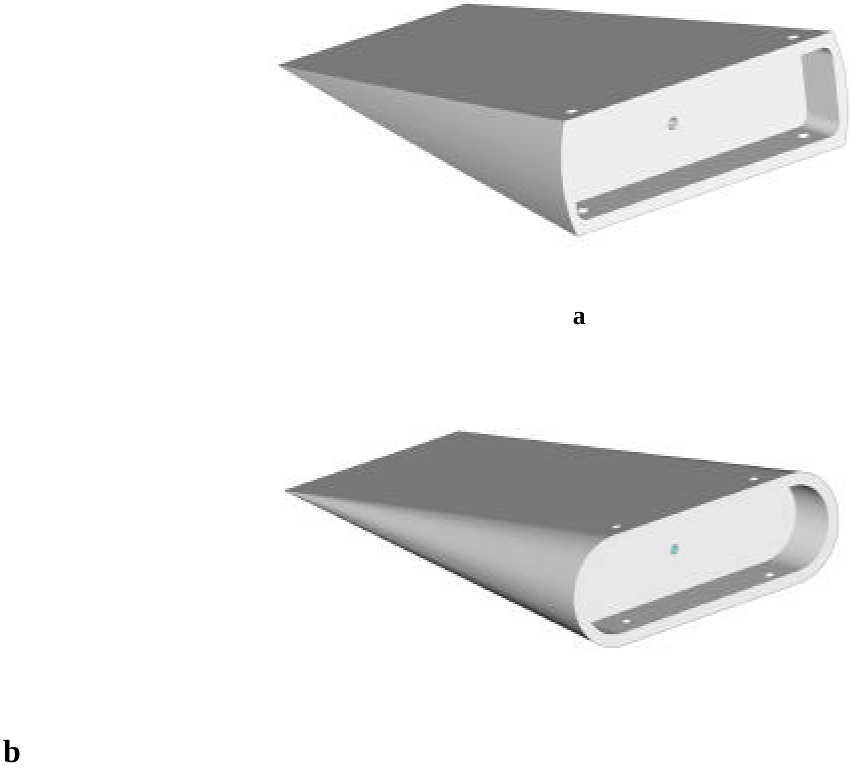


Figure 3.4:
a) Front Tip as manufactured
b) Original prescribed shape

In the end, it was decided by the team and machining experts to round the edges on a lathe. The primary setback to this machining technique was that the front tip edges could only have a radius equal to that of half its outside dimension in the long plane as shown in Figure 3.4a. Therefore, the front tip was machined in this fashion as in Figure 3.5 during the course of one day. Overall, the machining of the front tip took an estimated 30 hours.

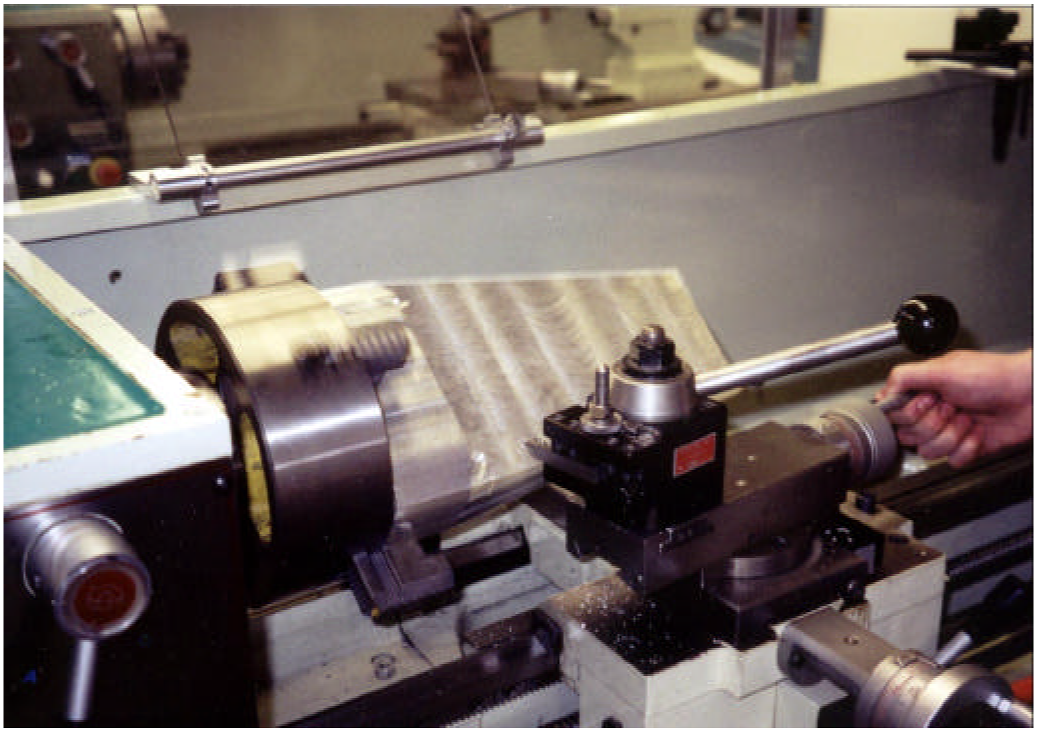


Figure 3.5: Front Tip in lathe machine

Interfacing of the front tip to the outer shell and internal frame was successful. In addition, the central 3/8" tapped hole holds the I-bolt necessary to attach the parachute system.

3.1.5 Testing

The testing of the front tip consisted of measuring for the angle achieved. This is finalized at an angle of 12.2?. This was a reasonable allowable error of the original 12 goal since machining angles is a difficult task (See PDS).

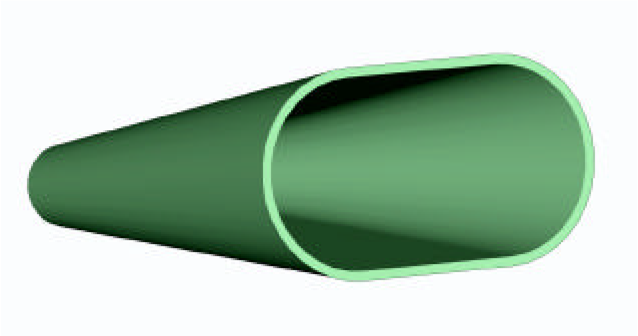
3.1.6 Future Work

Future work on the front tip could include making the side edges rounded to become tangent with the front faces as previously stated. This would be more in conjunction with the actual SHARP form. Different designs could also be devised depending upon the rest of the vehicle.

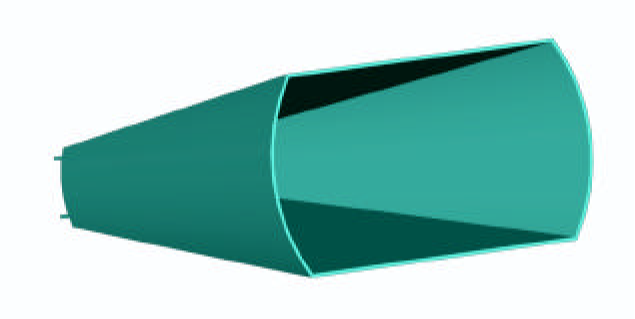
3.2 Outer-shell

The function of the outer-shell was to provide the outer covering for the main body of the vehicle. It was the outer-shell and front tip union that created the prescribed SHARP wedge-like geometry. The outer-shell provided no structural support for the vehicle, only a covering for the internal electronic components. The main objectives of the outer-shell were to be (1) lightweight so that the center of gravity would be as close to the front leading edge as possible, (2) very precise in dimensional tolerances so that the interface between it and the front tip would be perfectly continuous—meaning the interface within 1 cm of perfect alignment, (3) high impact strength to withstand the load exerted when the vehicle landed on the ground, (4) economic because of the tight budget, and (5) easily manufactured within the means of the students.

The shape of the outer-shell was designed to be a continuum of the front tip to produce the desired wedge-shape. Thus, it consisted of a flat surface on the front and bottom and curved edges along the sides. Initially, the sides were shaped as semi-cones as shown in Figure 3.6(a). When the manufacturability constraints of the front tip, as discussed earlier, forced a change to its original shape, the outer-shell geometry had to be modified accordingly as shown in Figure 3.6(b).



3.6 (a)



3.6 (b)

Figure 3.6: (a) Original outer-shell design with semi-conic edges;
(b) Modified outer-shell design to be continuous with front tip

Originally, the outer-shell was designed to be manufactured as one piece out of fiberglass from an outside contractor (see Figure 3.6(b)). This was an option because a single, continuous, thin covering was desirable for a smooth, aerodynamic vehicle profile. However, due to further discussion and research about this method, it was decided that the fiberglass was not the best option for two main reasons. First, fiberglass was heavier than anticipated, and second, the dimensional tolerances upon manufacturing were less than desirable. Considering the entire objective of the SHARP project was to build a vehicle that was of precise geometry and was lightweight, fiberglass was simply out of the picture.

Consequently, the material chosen for the outer-shell was acrylic. This material was selected because of its lightweight and thermo-formable properties. Using this material allowed us to construct it with the aid of a home oven. The shell was constructed out of four main portions: two flat pieces and two rounded edges. To construct the rounded edges of the outer-shell, a mold was formed out of modeling clay. To do this, templates were made for cross sections of the rounded sides, and modeling clay was formed accordingly as shown in Figure 3.7.

Figure 3.7.: Forming the mold using modeling clay and templates

The mold was allowed to dry overnight, and then two small nails were inserted along its centerline. These were used to place the acrylic precisely on the mold where it was needed. The acrylic was cut using a pattern for the side pieces, and small holes were drilled for placement upon the nails. Preliminary experimental tests revealed that the acrylic needed to be heated in the oven at a temperature of about 375°F for about 20-30 minutes for it to become soft and moldable without forming bubbles in the plastic. This was the temperature and time used for the final forming. As shown in Figure 3.8, the acrylic was placed directly on top of the mold and the entire setup was heated in the oven. Once heated, the mold and acrylic were removed from the oven, and with the use of two wooden 2x4's, the acrylic was clamped to the mold and allowed to cool (see Figure 3.9).

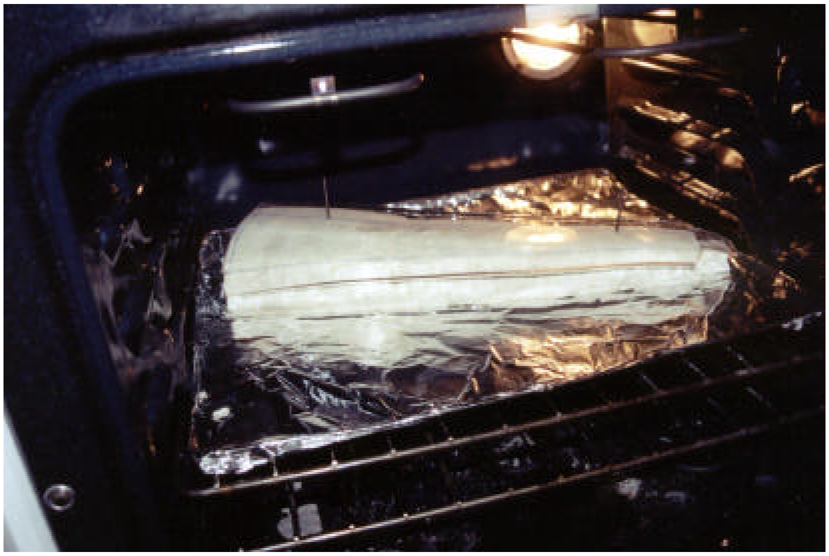
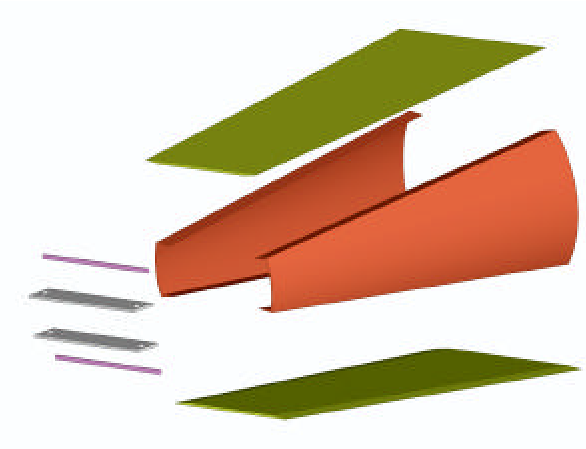


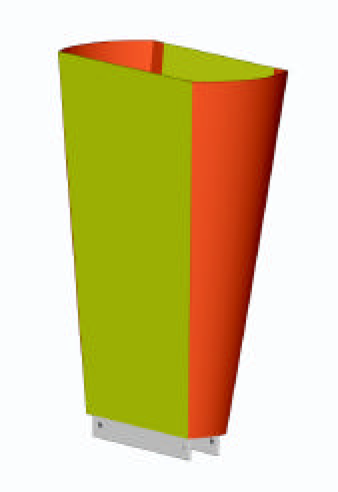
Figure 3.8: Forming the rounded sides of the outer-shell in a home oven

Figure 3.9: The thermoformed acrylic was clamped and allowed to cool

Once the two side pieces were successfully constructed, they were adhered to the top and bottom flat plates using acrylic cement. Once this had been assembled, the adjoined edges were filled in with additional adhesive and then sanded down for a smooth finish. To connect the outer-shell to the front tip, two acrylic plates were adhered to each of the top and bottom plates so as to fit precisely within the pocket of the front tip. The assembly could then be bolted to the front tip. The outer-shell assembly is shown in Figure 3.10.



3.10(a)



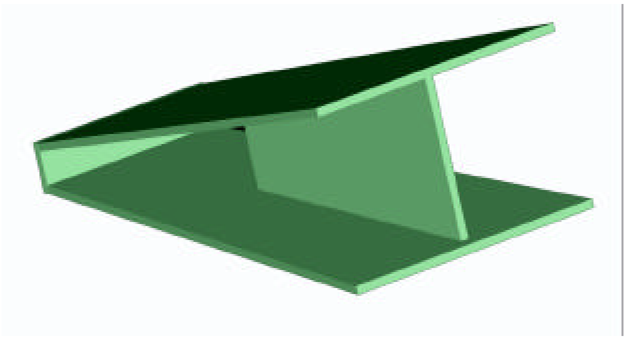
3.10(b)

Figure 3.10: Outer-shell final design: (a) exploded and (b) assembled views

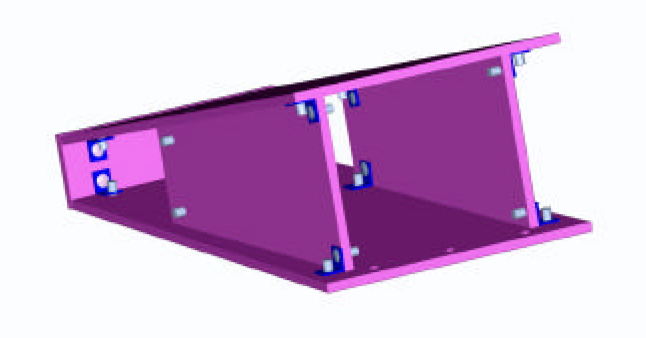
3.3 Internal frame

The purpose of the internal frame was to provide structural support for the vehicle along with housing the electronic components. The frame needed to be as lightweight as possible and allow as much usable internal volume for the necessary electronics. The internal frame was designed to be modular. That is, it should be easily removable from the vehicle for easy access to and maintenance for the electronic components. It was designed to slip into the outer-shell from the backend and connect directly to the front tip. To provide structural support to the vehicle, the frame was tapered in shape, fitting snugly into the outer-shell.

In the early stages of design, the frame was shaped like an I-beam: a top and bottom plate with a single support plate in the middle (see Figure 3.12 (a)). This design was considered at a time when there were conceptually two parachutes in the vehicle. The I-beam design allowed for structural support and the placement of the parachutes on both sides of the support plate. When it was decided that there would only be a single parachute, the internal frame geometry was modified to suit the new specification. Similarly, the internal frame consisted of a top and bottom plate, but rather than only one, a second support plate was introduced.



3.11(a)



3.11(b)

Figure 3.11: (a) Original internal frame design for dual parachute system;
(b) Modified internal frame for single parachute system

As shown in Figure 3.11(b), this produced a hollow cavity in the middle of the vehicle, allowing sufficient volume for the parachute. The support plates were placed parallel to one another, providing usable volume both between the plates as well as outside along the outer-shell wall. The support plates were of considerably shorter length than the top and bottom plates. This was to allow sufficient room for the placement of the batteries, the ATMEL, and the HAM Radio. These were the heaviest of the electronic components, and with the center of gravity location in mind, it was decided that they should be placed as close to the front leading edge as possible. Thus the shorter support plates were introduced to maximize usable volume in this critical area.

As noted previously, the entire geometry of the vehicle had to be modified when the manufacturability constraints of the front tip changed its original shape. This affected the internal frame, but not too dramatically. Instead of having the top and bottom plates of uniform cross sections, they were tapered outward to be continuous with the outer-shell. The support plate’s shape also needed to be modified to correct for the new angle of the wedge.

The material of the internal frame needed to be lightweight, structurally strong to support the vehicle geometry, and with high impact strength to resist any loads exerted from the parachute deployment or vehicle landing. Originally, honeycomb aluminum was chosen for the internal frame. This material is used extensively in aerospace applications for its high structural strength-to-weight ratio. From this and the fact that a significant amount of the material was already available in the lab, honeycomb aluminum seemed to be the ideal option for this application. However, the manufacturability of this material was found to be too complex, requiring the use of a vacuum injector to place metal inserts for all fasteners. This was a necessary tool that the university did not have, so a different material was employed. Wood was decided upon for the final internal frame design. It proved to be an excellent choice: very lightweight, economical, easily manufactured, and structurally strong.

The final design of the internal frame is shown in Figure 3.12. The top, bottom, support, and front plates were all made out of ¼-inch plywood and were connected together at specific points using L-brackets to produce the desired angle between the top and bottom plates. An I-bolt was used to connect the internal frame directly to the front tip. This I-bolt is connected directly to the parachute chords, and its connection directly to the front tip was implemented to produce as little stress on the outer shell as possible upon parachute detonation. Brackets were placed on the back end of the support plates to allow the connection of the backend plate and thus the enclosure of the vehicle.

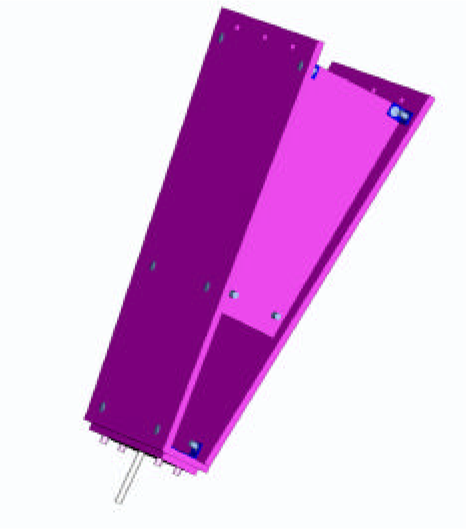


Figure 3.12: Final design of internal frame

Once, the internal frame was manufactured, the usable volume of the vehicle was measured. The usable volume is defined as the volume available inside the vehicle for electronic components. This is the volume inside the outer-shell minus the volume of the internal frame. This was found by measuring the dimensions of the outer-shell and internal frame and then calculating the appropriate volumes. The resulting value was 387.90 in^3 (see Appendices A and H).

3.4 Backend Plate

The Backend Plate of the SHARP vehicle is perhaps the most important mechanical component of the probe with respect to data acquisition and analysis. NASA engineers and scientists know the least about the aerodynamic flow at the aft part of a SHARP vehicle. That is primarily why the Santa Clara team decided to focus on that area of the probe, and place the majority of the pressure sensors in that location. Due to the fact that the frontal surfaces (front tip and outer shell) of the SHARP vehicle must remain smooth, any components of the probe that need to protrude or intrude must be placed on the backend plate. At the same time, the weight considerations of the mechanical design had to be taken into consideration.

The primary NASA contact for the SCU SHARP project specified that 5 pressure sensors be placed on the backend part of the vehicle, with 4 along the centerlines at the top, bottom and each side of the plate, and 1 directly in the center. In the detailed drawing below, 5 holes can be seen in these locations.

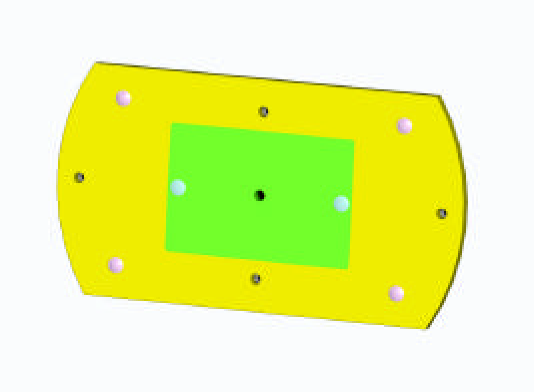


Figure 3.13: Backend Plate with pressure sensor locations at holes

This was the first objective with respect to this part.

Although the backend plate would house many components, at the same time there existed the design criteria of having the least amount of weight near the back. After realizing that pressure sensors would be extremely lightweight (less than 1/10 oz. each), the material selection quickly converged on acrylic, like the outer shell. Sheet metal was the other design consideration, but it was more than was necessary strength and weight. Acrylic is relatively lightweight, but still strong enough to sustain light loads with screws and bolts.

A strong material for the parachute door had to be selected. There were many design considerations for this part. The team came up with ideas ranging from "blowing off" the entire backend plate, to just expelling a container with the parachute in side. The team, on the other hand, sought to find the method that would be the least complicated with the avionics and pressure sensor components. Blowing off the entire backend plate wasn't possible due to wiring and valuable sensing equipment. So, a hinged parachute door was deduced as the most effective mode to do this task. Finally, a material for the parachute door itself had to be selected. Mechanically, if the door was going to be hinged, rationally it would be best to have a "flat" material to blend smoothly with the backend plate. To optimize the strength and flat geometry needed for the door, the team selected thin steel sheet metal of a thickness of roughly 500 microns. This would have to be a fairly strong material to keep the parachute from prematurely releasing.

Implementation of the Backend System had to be delayed until completion of the outer shell. Obviously, it would have been inefficient to manufacture the backend plate, only to find out that it did not interface with the outer shell properly.

Manufacturing of the Backend System was relatively simple. A piece of acrylic was cut to a square shape in the outside dimensions of roughly 10" x 5 3/8". Then the rounded edges were basically "sculpted" using a sander. The square cutout in the middle was done using a ¼" end mill on a milling machine, and a sander to smooth out the edges as seen in Figure 3.13.

The parachute door was made from sheet metal and using a sheet metal cutter. Holes were punched so that the hinge could be fastened to the door and the backend plate itself. A tab was left on the opposite side of the door from the hinge in order that the solenoid release mechanism could "punch" open the door.

The door on the backend system was tested with a parachute release in static conditions to see if it would interfere with parachute deployment. The parachute released successfully. Although this was not completed in true environmental conditions, it showed that it had the potential to be a good system.

3.5 Parachute recovery system

3.5.1 Introduction

The parachute system is crucial in the overall system assembly. The parachute is the solitary means in bringing the SHARP vehicle safely to the ground. It was never the intention of the team to manufacture a parachute, so it was purchased after calculations were performed with respect to terminal velocity and acceptable g loading as seen in the Appendix calculations section. Due to the lack of experience with parachutes on the part of the team, outside expertise was sought in conjunction with internal research.

3.5.2 Design Selection

In order to bring the vehicle safely to the ground along with the data, a design specification for maximum velocity at touchdown was implemented at 20 ft/s. Not only was the effect of material impact on the structure considered, but more importantly, it was vital to protect the data stored onboard. This helped the team to make a clear decision on sizing and material of the parachute. Although a slow decent speed would have been the most desirable, there was a tradeoff with the problem of drift of the falling vehicle. Any more velocity, and the SHARP might fail during impact, and any less velocity would cause the probe to drift too far in the horizontal direction. The parachute had to have the capability to withstand the high loading, and had to take up a minimum amount of volume.

3.5.3 Analysis

After extensive calculations, the team concluded that a parachute diameter of at least 35.5 in or roughly 1000 in^2 would be appropriate (See Appendix A). We also included a factor of safety since the system is critical to success. This selection also seemed to satisfy drift concerns for a reasonable decent speed. From a volumetric standpoint, the parachute occupied a significant portion of the available internal space. It was evident that the parachute would take up nearly 60% of the internal volume.

Shock due to the opening of the parachute was also considered as a hazard to the project. A nylon/Kevlar cord was also purchased to release a significant amount of impact force on the SHARP vehicle. The nylon cord from company specifications, could stretch up to 3 times the unforced length. All calculations on the parachute cord shock were done without taking into account this nylon cord. The nylon cord was manufactured specifically for high mass, high velocity space applications, which coincided well with the project specifications. It was primarily implemented for the overall protection of sensitive onboard equipment.

The parachute is connected to the front tip of the SHARP vehicle through the subassembly. This was done because the impact loading would be too high for the internal frame or outer shell materials. The front tip, being made of aluminum, would have the capability to withstand this loading. A diagram of the parachute subassembly interfacing order is given in Figure 3.14.

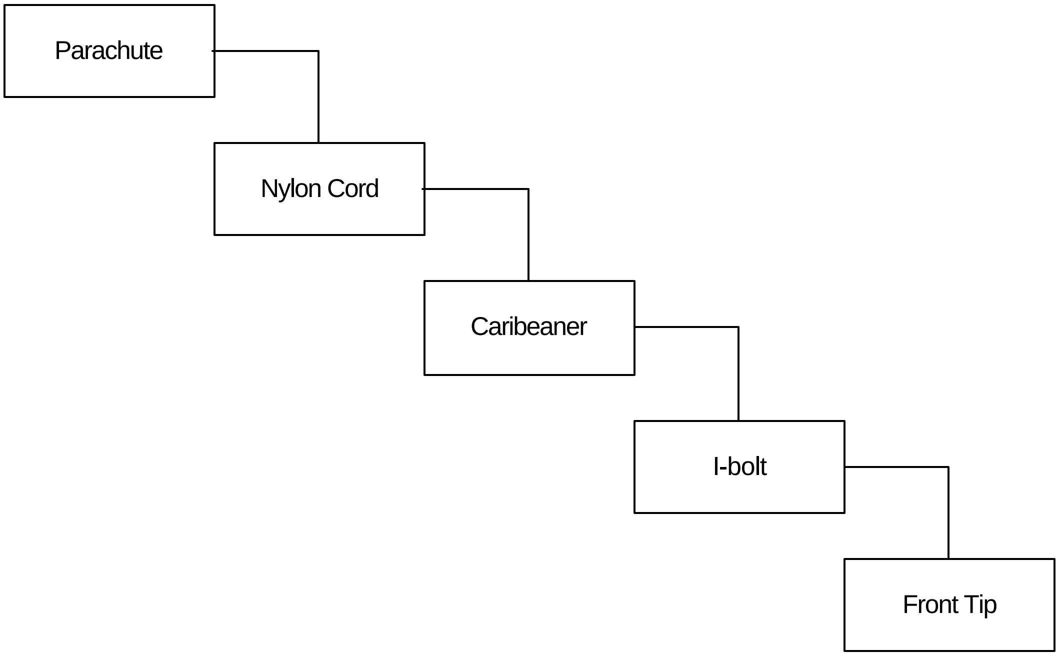


Figure 3.14: Parachute subassembly interfacing connections

The release mechanism of the parachute system was difficult to both design conceptually, as well as manufacture. Initial parachute release mechanism ideas varied from using the explosive power of black powder, to using a drogue parachute. In consulting with outside sources and rocket hobbyists, it was apparent that black powder was the mainstream means in releasing a parachute. However, due to the valuable and sensitive equipment onboard, this idea was scrapped for safety purposes. Finally, the mechanical engineers on the team chose a solenoid to “push” the back door open as the most effective and safest means.

3.5.4 Implementation

The parachute implantation has been successful up to this point. The activation of the solenoid is dependent upon the completion of the Electrical assemblies. The solenoid requires a high voltage, high current spike in order to release the parachute.

Due to the extreme conditions that the parachute will see upon release during flight, there was no available way to simulate that environment. Therefore, implementation can not be completely assessed until the flight. The static properties of the entire parachute system, however, fully met the design specifications (See PDS). A minimum amount of volume was used, while maintaining a release mechanism and a safe means to bring the SHARP vehicle to safety.

3.5.5 Testing

Testing of the parachute was completed in order that the ultimate yield stress of the parachute cords could be examined. This was focused primarily on the momentum change at the point of parachute deployment as it is falling through the atmosphere. This point of release is specified for optimum safety at 15,000 ft so that the probe has enough time to slow it's speed, while at the same time minimizing the amount of drift.

In order to test the integrity of the parachute, the instantaneous momentum change had to be calculated. Since mass remains constant the entire duration of the drop, the calculation relied solely on velocity. The velocity change was then calculated to go from 265 ft/s to 20 ft/s. However, it was soon realized that these impact conditions were virtually impossible to simulate in a test. Therefore, the team fell back on the idea that if ¼ of the momentum is calculated, than each cord of the parachute could be tested individually for strength, since the parachute came with 4 cords.

The crude test involved simulating a means to create an instant momentum shift. The easiest way to create this scenario was to drop heavy objects from a specific height while connected to a rope by using gravitational potential energy to create kinetic energy. Simulation of the momentum shift could then be completed by using a weight of 22 lbs at a height of 30 ft. This provided the ¼ momentum change, and the test was completed on the third floor of the Santa Clara University parking structure (See Appendix A).

3.5.6 Future Work

The parachute system, as far as the mechanical assembly of the probe is concerned, must still undergo a significant amount of work and improvement. The release mechanism, up to this point, has not had sufficient testing to be used in an actual high altitude test drop. Simulating these conditions will be very difficult for any team that wishes to continue this project. The electrical system for the solenoid power must also be engineered to give enough power to open the back door holding the parachute back.

4. Electrical System

4.1 System Overview

The goal of the electrical system of SHARP was to create a system to monitor accurately the flight environment the prototype would be tested. As seen in our block diagram in Figure 4.1, SHARP consisted of seven component subsystems.

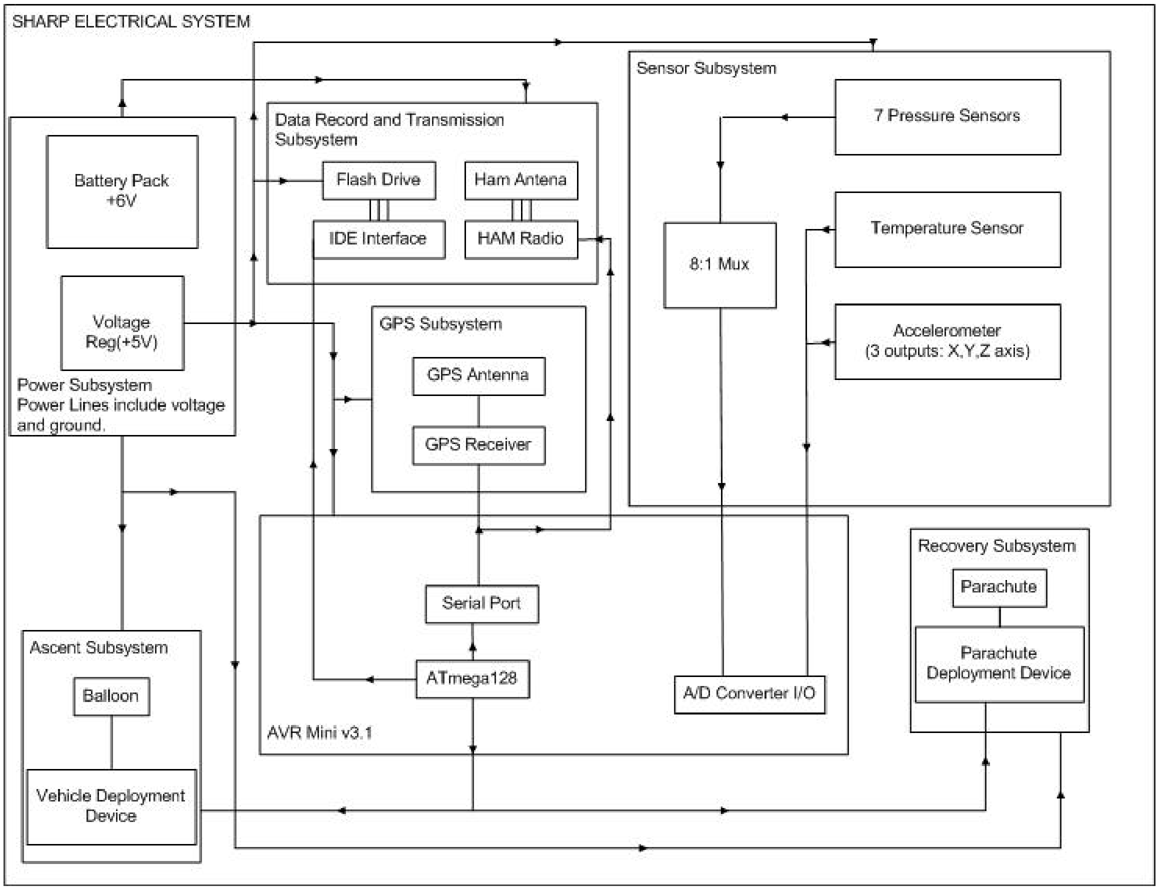


Figure 4.1 SHARP internal electrical subsystems.

Out of the seven subsystems the Atmel AVR mini board with the Atmel Atmega 128 processor was the centerpiece and orchestrated all the data and positioning information that would be transmitted to the ground station.

The sensor subsystem was critical for delivering flight data. The subsystem consisted of one accelerometer, one temperature sensor and 7 pressure sensors. The seven pressure sensors were sent through an 8:1 multiplexer which allowed sampling pressure one point at a time on the prototype. The GPS subsystem is used to track and operate flight plan phases accurately through the data transmission and storage subsystem. This system would allow for on-board flash card storage of the flight data and positioning as well as real time data to a ground station via HAM radio.

The ascent subsystem consists of a balloon drop mechanism currently in development by Randy Stuart, our balloon expert. The recovery subsystem includes a parachute deployment system developed by our group to allow for safe recovery of the prototype.

The power subsystem consists of batteries and a voltage regulation system that allocates 5V to the sensor and GPS subsystems. The other subsystems will use power straight from the battery pack.

The electrical system of SHARP is developed for both low temperature and low pressure conditions with the added factor of limited funding and available space on the prototype to house these components. The results of these products and integration will be explained in the upcoming sections.

4.2 Power System

4.2.1 Overview

The power system of SHARP was designed to accommodate each subsystem's needs. A quality power system not only provides adequate power for the duration of the test flight but the system must sustain the required current and voltage for the approximate two and a half hour flight. Constraining the capability of the system were two main factors: one being the lack of space that would house the battery system and two, the temperature that SHARP would be operating in. To decide on a system and proper batteries, first, a power budget (see Appendix I) was created mocking our desired flight plan. The budget allowed us to gauge energy capacity that needed to power SHARP for the length of the flight. This is illustrated in Figure 4.2.

***all values represent a max power needed**			
Components	**V(v)**	**I(ma)**	**P(w)**
Ham Radio(transmit)	6	1100	6.600
GPS	5	100	0.500
Accelerometer 1	5	1.66	0.0083
Pressure Sensor	5	10	0.050
Parachute deployment	6	3000	18.000
Balloon Drop Mechanism	6	3000	18.000
AtmelAVR mini board	5	8	0.040
Temp Sensor	5	0.158	0.00079
Miscellaneous	5	0.001	0.000005
Totals			**43.199**
	Power Required(mwh)		
Battery Supply:	**16316.13548**		

Figure 4.2 Estimated Power Budget

The estimated power is considered over the span of an entire test flight. Based on these values batteries were chosen, and then a voltage regulation system was then developed to provide accurate voltage of 5 volts to the on board sensors and GPS system. The voltages, both regulated and unregulated with a common regulated ground were connected to a power bus that allowed for power transfer to all subsystems aboard the SHARP prototype.

4.2.2 Design Selection

From our power budget we determined that we needed approximately 16,316 mAh of energy capacity to provide for SHARP for that time. This powers everything, including the HAM radios. We needed at least 6V for the HAM radio so we decided on a total voltage of 6V for our batteries. We also did not want to use rechargeable batteries for our flight, as energy capacity is less over a sustained amount of time. Since we needed primary (non-rechargeable) batteries that worked both for the energy needed and the temperature characteristics we chose Lithium Batteries. The AA sized battery worked properly from temperatures of -40 degrees Celsius to 80 degrees Celsius. Each battery produced 1.5 volts and had energy of 2900 mAh. From our values in the budget we decided to arrange the batteries with the arrangement of four, four cell batteries arranged in parallel configuration for a total 16 batteries. This provided us with 6V and approximately a total energy supply of 11600. While this was not sufficient for the complete system, we originally did the calculations intending on using the provided HAM radio battery.

Regulation was a key factor to the power system. We wanted to maintain a constant voltage supplied to the sensors so readings would be accurate throughout the flight. Since the sensors all required approximately +5V DC the chip we chose for regulation was National Semiconductor's LM2594-adj. This was an adjustable switching regulator where the voltage could be set to any nominal voltage depending on the arrangement of the circuitry. The chip provided .5A max of current which would be adequate for our sensor and GPS circuits. After completing calculations (see data sheet) for the voltage regulation circuit we designed it for 5.14 volts DC. Figure 4.3 illustrates the schematic for the circuit.

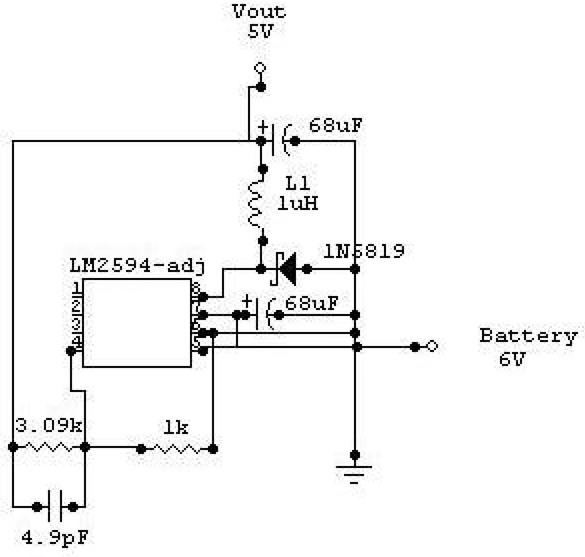


Figure 4.3 Voltage regulation circuit diagram.

A switching regulator was chosen because the sensors used on board had very high impedance. This allowed for the regulator to adjust the current to supply an appropriate voltage to each sensor. Our first option was to use a linear regulator to provide +5 volts to the sensors, but due to the high impedance nature of the sensors that was not feasible.

4.2.3 Implementation

The fabrication of power system consisted of three phases: housing of the batteries, creation of the voltage regulation system and assembling of the power bus. Once the lithium batteries were chosen we needed to make sure they were able to fit into the internal frame of SHARP. Battery cases were bought, with wire adapters. The cases held 4 AA batteries in series configuration. Using four of the battery packs we were able to connect the all the positive terminals together and all the negative terminals to replicate our design. Two of the packs were taped together using electrical tape. Each set of the two packs were places on either side of the parachute hook where they fit tight into the internal frame.

The voltage regulation system design was first implemented on the prototyping bread board. The circuit on the bread board was hooked up to the DC power supply at first to get the approximate value. Using the DC power supply at 6 volts, the regulated voltage was approximately +5.13 volts. Once this value was checked with our design, the regulation system was hooked up to the battery pack. Using AA alkaline batteries for testing, we measured a value of +5.13 volts. Once are values checked out with the design values, we then completed a final circuit that was soldered on a square of proto-board. The final product is pictured in Figure 4.4 and when connected to the battery back provided a +5.13 voltage.

The power bus was created using the same type of proto-board that the regulator circuit was soldered on. The power bus had wires for all the components, including a +6V line for the parachute and deployment subsystems, a +5.13 V line for the GPS, sensors and compact flash drive. There was also a regulated common ground that was provided from the regulator circuit. As for powering the Atmel AVR board, the battery pack was connected directly to the board through an adapter plug. The Atmel had a LM7805 linear adapter which took the battery voltage and created a +5V signal.

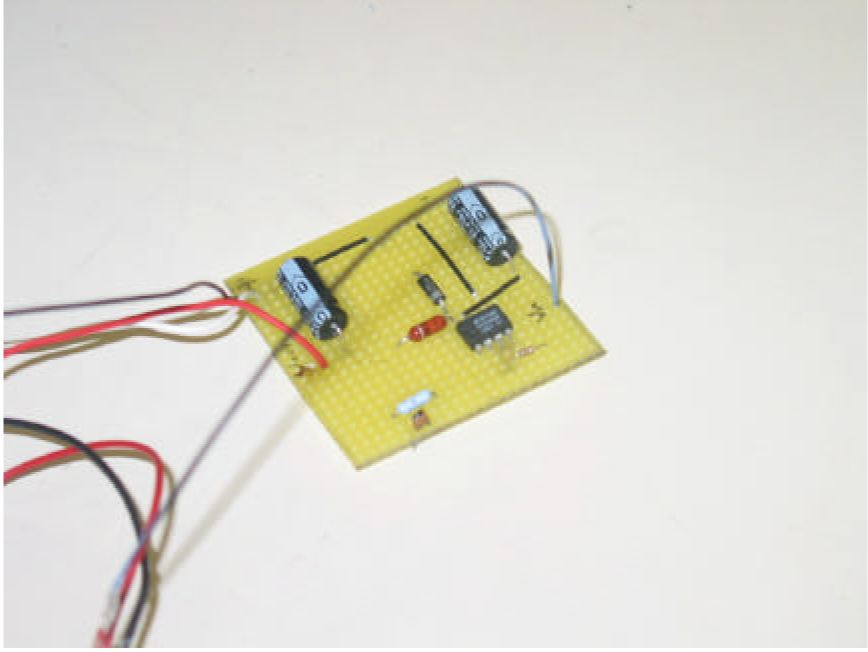


Figure 4.4 Voltage regulation circuit

The battery pack provided an initial voltage of 6.32 volts measured by a multi-meter. This is more than the +6V in the design but the voltage will drop due to the length of the flight.

4.2.4 Testing

Testing for the power system consisted of testing the load that the regulator supplied. Ideally, based on the specification sheet the regulator could provide a maximum current of .5 amperes. To test this load, various low ohm resistors were connected to a breadboard. The regulated power was connected to the breadboards bus, along with the ground. From there multiple resistors were added until either the chip or the components became too warm. Figure 4.5 illustrates our results. As the load drew approximately .43 amperes the chip became warm, but still provided the required voltage. We did not load more resistors after that due to the fact we did not want to destroy the chip.

total resistance(ohms)	Voltage provided(V)	current drawn(mA)	comments
10,000	5.13	0.512	
1000	5.13	5.1	
100	5.13	50.3	resistors begin to warm
47	5.13	109	resistors still warm
23.5	5.13	215	chip heats a little
15.67	5.13	326	
11.75	5.13	436	chip too hot

Figure 4.5 Load testing of Regulation system

While the results didn't max at .5 amperes, we were still able to connect our accelerometer, temperature sensor and GPS subsystems to the power supply and we received a constant 5.13 volts supplied to the system.

4.2.5 Future Work

Future work on the power subsystem will include for groups to come: a stable power source for the HAM radio transmission, a test with all components connected that will last for the duration of the test flight and a test with the high drain subsystems such as the recovery and deployment system. The most important power test is the flight plan test, where the system would do a run through for 2.5 hours allowing checking if it would operate for that amount of time. Another test is a low temperature test operated under extremely low temperatures that will affect SHARP. These tests and implementations will be completed by the next SHARP group that takes over this yearly project.

4.3 Sensor System

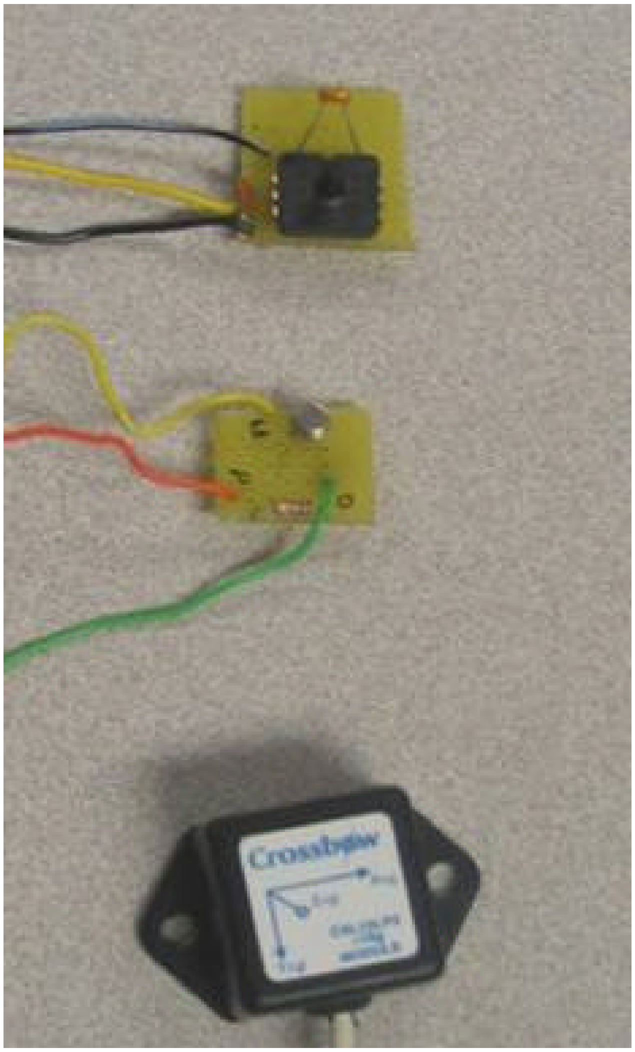


Figure 4.6: Samples of the onboard sensors (from top to bottom):
Pressure sensor, Temperature Sensor, Accelerometer

4.3.1 Overview

Sharp required three primary sensors: pressure, temperature, and acceleration. Each sensor needed to meet certain guidelines that the customer had in mind and specifications for our anticipated flight conditions. We will be testing each sensor for their features, anticipating each will function properly for their requested specification. Assuming they all meet the criteria, we will then proceed with calibration and finally integration.

4.3.2 Sensor Selection

There were many factors that played an important role in our decision for each sensor, one being size. We had to fit our whole electrical system inside our vehicles' inner shell. In the beginning of our design we noticed that our Ham Radio, GPS Transmitter, and Batteries, or power supply, would take up the majority of space so we had to find the most efficient yet smallest sensors possible. Other factors that influenced our decision were mass and cost. We wanted our vehicle to weigh less than 12lbs and had to do this with a small budget. Little funding was obtained, so money had a huge influence on determining what sensors we could purchase. This was very difficult because while researching individual components, we noticed that as size and mass got smaller the price of the sensor increased. However, the obstacles we faced when purchasing components, taught us how to be creative and economical.

4.3.2a Temperature Sensor

The temperature sensor we decided to use for Sharp was the LM135. There were many reasons this particular sensor was chosen over other sensors. One was because unlike other sensors the LM135 has a linear output. There are many applications for this particular sensor. The LM135 operates over a -55°C to +150°C temperature range which is an ideal range for our anticipated flight conditions. Also the low impedance and linear output make interfacing to readout or control circuitry especially easy. The schematic of the temperature circuit and its spec sheet are located in the appendix.

4.3.2b Accelerometer

Sharp's accelerometer was the Crossbow CXL. We chose a tri-axial accelerometer to obtain the velocity in a 3-dimensional range at any point in time. The wide dynamic range, has excellent frequency response, operates on a single +5 VDC power supply, and is easy to interface to standard data acquisition systems. Also, the Crossbow Series with its standard 5-pin female connector proved to be highly flexible and its low mass cable prevents disruption to provide accurate data transmission. Its entire spec sheet and schematic are located in the appendix.

4.3.2c Pressure Sensor

Our pressure sensor was a XFGN model made by Fujikura that has a surface mount package, whose circuit needed few additional components. Each sensor had a voltage level output with an on-chip amplification and temperature compensation feature. The range for this particular sensor was 0-25 kPa making it an ideal sensor for our project, and the fact that it was very inexpensive made our selection process even easier. It had a voltage output of 0-5 Volts with an accuracy range of +/-5 degrees. The final circuit and its spec sheet are also located in the appendix.

4.3.3 Implementing and Testing

The LM135 had a metal can package with a three-pin layout; positive terminal, negative terminal, and an adjustment pin. Its dimensions were 1x1x1 inch and had a mass that proved to be negligible, conditions that were ideal for our project. This sensor was very precise and was easily calibrated. Operating as a 2-terminal zener, the LM135 has a breakdown voltage directly proportional to absolute temperature at +10 mV/°K. With less than 1W dynamic impedance the device operates over a current range of 400 µA to 5 mA with virtually no change in performance. When calibrated at 25°C the LM135 has typically less than 1°C error over a 100°C temperature range.

Once we completed wiring up the LM1335 to a breadboard, we began to test and calibrate. From the spec sheet, we saw that the output of the device (calibrated or uncalibrated) can be expressed as:

$$V_{OUT_T} = V_{OUT_{T_0}} \times \frac{T}{T_0}$$

where T is the unknown temperature and To is a reference temperature, both expressed in degrees Kelvin. By calibrating the output to read correctly at one temperature the output at all temperatures is correct. Nominally the output is calibrated at 10 mV/°K. We hooked it up to an oscilloscope and the first reading we got from the sensor was approximately 2.7 Volts that we calculated to be 295 Kelvin, room temperature. We tested the output voltage to see it vary by using a hair dryer to see its voltage increase, or by applying ice packs to the circuit to see the output voltage decrease. Once we knew the sensor worked, we calibrated it for accuracy, soldered the final circuit to a plastic soldering board, and integrated it with our microcontroller.

Sharp’s accelerometer was the CrossbowCXL. It had a high temperature standard package and it contained a .75 x 1.875 x 1 inch case. Together with an 8” lead and a 5-pin female connector the whole device weighed under 1.62 oz. Other reasons we chose this particular accelerometer rather than its competitors was because of the fact that the CrossbowCXL Series accelerometers are low cost, general purpose, linear acceleration and/or vibration sensors available in ranges of ± 4 g, ± 10 g, ± 25 g, ± 50 g, and ± 100 g. The sensing element in this sensor is a silicon micro-machined capacitive beam. The capacitive beam is held in force balance for full-scale non-linearity of less than 0.2 %.

The Crossbow accelerometer was fairly easy to implement and calibrate since it supplied a 5-pin female connector for our microcontroller. Once again, since our sensor gave out a voltage level output, we hooked it up to an oscilloscope to see its amplitude vary. Since it's a tri-axial accelerometer, by moving it side to side we were able to change its x-axis velocity and the by moving it perpendicular to the x-axis we were able to see the change in its y-axis velocity. By flipping it over and moving it up and down, we noticed a change in its z-axis velocity. By observing the output voltage through an oscilloscope, we were able to interpret its sensitivity using this equation given:

$$VOUT = [VS/2 + (\text{SENSITIVITY X } VS/5 \text{ X ACCEL})]$$

This particular sensor had a +/- 200mV sensitivity with a range of +/- 10G's, and ideal accelerometer for Sharp.

We had a total of 7 pressure sensors, five on the back plate and one on each of the sides of the internal frame. It had a voltage output of 0-5 Volts with an accuracy range of +/-5 degrees. Our pressure sensors were extremely hard to implement because we did not have a sufficient test environment to test and to calibrate them. The XFGN pressure sensors we purchased have a range of 0-25kPa and operate in an environment that is less than 1 atmosphere, ideal features for our anticipated flight conditions. While waiting for a test bed, we completed the sensor circuit and later actually soldered all seven sensors, making it easy to mount and integrate with the vehicle.

4.3.4 Future Work

Now that we have a sufficient test bed to obtain an environment of 1 atmosphere, the next group should have no trouble testing and calibrating each soldered pressure sensor. We left long leads for the Vout pin on each sensor, hopefully making it easier for the next group to test. Also with this newly provided environment, future groups should consider testing the temperature sensor and accelerometer in it to see the how big of an effect low pressure has on each sensor. Another test future groups should consider is a low temperature test with each sensor. Our anticipated flight temperature gets as low as -70 degrees Celsius and together with a non-insulated vehicle may cause data to be very inaccurate.

4.4 Communication and Positioning

4.4.1 Overview

Location tracking of SHARP will be done by a Trimble ACE, GPS system, which is internally mounted in our vehicle. The GPS information, along with all of our sensor readings (i.e. pressure sensor, temperature sensor, and accelerometers) is then transmitted via a Kenwood TH-D7AG HAM radio, in packet form, to our ground station where the information is then received by a second HAM radio. The Kenwood TH-D7AG radios are an FM dual-band (144/440 MHz) handheld transceiver equipped with a built-in 1200/9600 baud TNC compliant with AX.25 protocol.

4.4.2 Design Analysis

The position coordinates of the vehicle received at the ground station can be used to get the exact location on the vehicle in relation to the base station through the use of simple software, which can be downloaded for free. The software we found to fit our needs is simply titled INVERSE. What this software essentially does is take the coordinates given by the GPS, and the coordinates of our ground station (which ideally is stationary) and calculates the angle and azimuth between the two. These coordinates are needed for two reasons, first of all we need to know the location of the vehicle at all times so we know where to point our receiving antenna in order to get the best signal. Secondly we are going to have to track down the vehicle after it lands, and assuming it will be greatly affected by wind, both on the accent and on the decent, the vehicle is most likely to be some distance away from where it started.

Our HAM radio communication system was primarily chosen for its simplicity. The HAM radios allowed us to transfer all of the data we needed at the same time, allowed us to transfer that data over the required distance and only required a simple HAM radio license for their use. Modifications to the HAM radios only consisted of switching out the stock antennas with ones more suited to our needs in this project.

The transmitting antenna located on the HAM radio inside the SHARP vehicle was a shorter, stub, omni-antenna. This shorter, stub antenna was chosen over the original, longer whip antenna for a better transmission signal pointing downwards. The shorter the antenna the less gain it has and therefore more of the signal will be passed downward (if you are holding the antenna straight up) instead of having the signal go radially outward. For most HAM radios use of these longer antennas are desired because the receiving radio is usually horizontally a distance away. The SHARP vehicle in our case is traveling vertically upwards and for the most part will be directly above our receiving antenna, which is why it is desired that our antenna have a low gain and project the signal down.

The receiving antenna at our ground station radio was a large, directional, yaggi antenna. The directional antenna gives us a much better received signal then we would be able to get from an omni-antenna at the ground station. The directional antenna concentrates more of the received signal on a smaller area and therefore will have a higher gain, and better received signal.

4.4.3 Implementation

Implementing the HAM radio into our vehicle was not too complex. The needed transmission data is all run through the microcontroller and is then transmitted via the HAM radio. Once activated, the radio transmits all of the data from the sensors. A separate power source is needed to power the HAM radio on-board the vehicle as most of our sensors only take a 5-volt power source. Implementing this separate power source was not difficult though and only required the use of voltage regulator for the sensors. The original plan was to simply use the battery that came with the radio, but a decision against that was made for a few reasons. First of all that battery was fairly large (about the same size as the radio itself) and secondly it was decided that the use of only a single power source would create less chance for error, and would integrate our system better and more efficiently. Even without the HAM radio battery pack mounting the HAM radio on-board the vehicle was still a concern. The radio is the largest piece of hardware on-board, and space was a big concern as the size of our vehicle was fairly limited. In the end mounting the radio didn't cause any problems and we were able to find enough room within the vehicle for the radio and antenna.

4.4.4 Testing

Through field tests and theoretical analysis of the Link equation(eq. 4.1), we found that because of our transmitting power, receiving power, choice of antennas, and due to the fact that the test is to be conducted in a open space with no obstructions, we will have a very strong, and stable communications link. The Link equation gives an idea of the received power taking into account the transmission power, free space loss, receiving and transmitting antenna gains, and losses due to obstructions. Obstructions blocking the path between the two antennas can create many harmful effects to a signal. Reflections due to an obstruction will simply redirect the signal, ruining the line of sight

$$P_r = \frac{P_t G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2}{L}$$

P_r , P_t are receive and transmit powers in watts

G_r , G_t are receive and transmit antenna gains

d is the distance between transmitter and receiver in metres

L is the attenuation along the transmission path

λ is the wavelength

figure. 4.7: Link equation

transmission and resulting in either a weaker signal or no received signal at all. Multi-path due to obstructions can distort that signal and create many problems. Luckily our test has to be done in an open area, not just for these reasons above but also due to safety reasons, so when analyzing the Link equation the only loss that has to be taken into account is free space loss.

A simple field test helped with our choice of antennas and gave us an idea of just how good our communications link was. Our test was quite simple and was done mainly to find out how much room for error we had in pointing our directional antenna and which, of two transmitting antennas would be more powerful. In our field test the two radios were approximately 8 miles apart. For the first part of the test we had the receiving, directional antenna pointed directly at the transmitting radio and had the transmitting radio aligned so that the antenna was pointing straight up. We then transmitted a short signal and were able to judge the received signal strength from a signal strength meter built right into the radios. Then, keeping the transmitting antenna in the same position we rotated the receiving antenna 45 degrees and transmitted again. Lastly we turned the receiving antenna anther 45 degrees so it was now 90 degrees off, and transmitted again. For the second part of the test we rotated the transmitting antenna 45 degrees downward and then repeated the above steps for part one. For the last part of the test we rotated the transmitting antenna another 45 degrees so that the bottom of the antenna was pointing directly at the receiving antenna, and then repeated the steps for part one again. We did this entire process for two transmitting antennas, one was the stub antenna that we eventually chose to use and the other was a longer antenna with greater gain. Our results for the antenna we chose are summarized below (tables 4.1 and 4.2).

Transmitting Antenna (Degrees from LOS)	**Receiving Antenna (Degrees from LOS)**	**Signal Strength (Max signal = 9)**
0	0	9
0	45	7-9
0	90	7-9
45	0	9
45	45	9
45	90	9
90	0	9
90	45	9
90	90	7

Table 4.8: HAM radio transmitting at high power

Transmitting Antenna (Degrees from LOS)	**Receiving Antenna (Degrees from LOS)**	**Signal Strength (Max signal =9)**
0	0	9
0	45	8-9
0	90	9
45	0	7
45	45	5
45	90	7-9
90	0	5
90	45	5
90	90	5-7

Table 4.9: HAM radio transmitting at low power

We were able to find that there was some variation in the received signal. The worst case was when we had the directional antenna pointed 90 degrees away and the transmitting antenna pointed straight up. There were variations in the data when the HAM radio was transmitting between high and low power, but the changes were not drastic and we did expect a drop in the received signal strength when the transmitting power was lowered. Although this case was the worst we were still able to receive the data unflawed and were getting a pretty solid signal. This test gave us a lot of confidence in our communications link, showing to us that even with poor positioning of the directional antenna because of our entire communications system we would not be risking a communication drop.

4.4.5 Future Work

Future work includes testing the Trimble GPS in coordination with the INVERSE software. Work has to be done to make sure the software gives accurate coordinates for the vehicle as it's moving, and to ensure it can process the information at the needed rate. Along with the testing of the software, some sort of measuring device (along the lines of a large scale compass) must be constructed. This gives a means of accurately moving the receiving antenna to the coordinates received from the GPS and software. Sufficient testing has been done on both the receiving and transmitting antennas. No further testing is required for the antennas as long as there are no drastic changes in the test drop plan.

5. Computer System

5.1 Introduction

At the center of the SHARP vehicle, both physically and logically, resides the computer system. At the lowest levels, the SHARP computer system is responsible for the gathering of information from the various sensors onboard, maintaining knowledge of and reporting the location of the vehicle, and operating the release and recovery mechanisms. As a result of these responsibilities, the computer acts as a hub between all other major systems within the vehicle. Since the computer acts as the hub, no other system can function properly without it, placing the computer very high in importance. To complicate this further, the computer system is also the most dynamic system on the vehicle and must respond gracefully to various emergency situations including the loss of operation of other parts of the vehicle; however no system exists to recover from a computer failure, and as a result the quality in this system must be as close to perfect as possible. The design decisions leading up to development represented this goal of great quality in both the hardware and software components of the computer system.

The computer system overall has many important constraints. The computer has to survive at very low temperatures, as well as great changes in acceleration and vibration upon parachute release. Furthermore, it must accomplish all of its basic functionality using only the minimal power available.

It was decided early on that separation in design and implementation between the hardware and software subsystems would achieve these goals with the greatest ease and efficiency. As a result they are presented here in separate subsections.

5.2 Hardware Subsystem

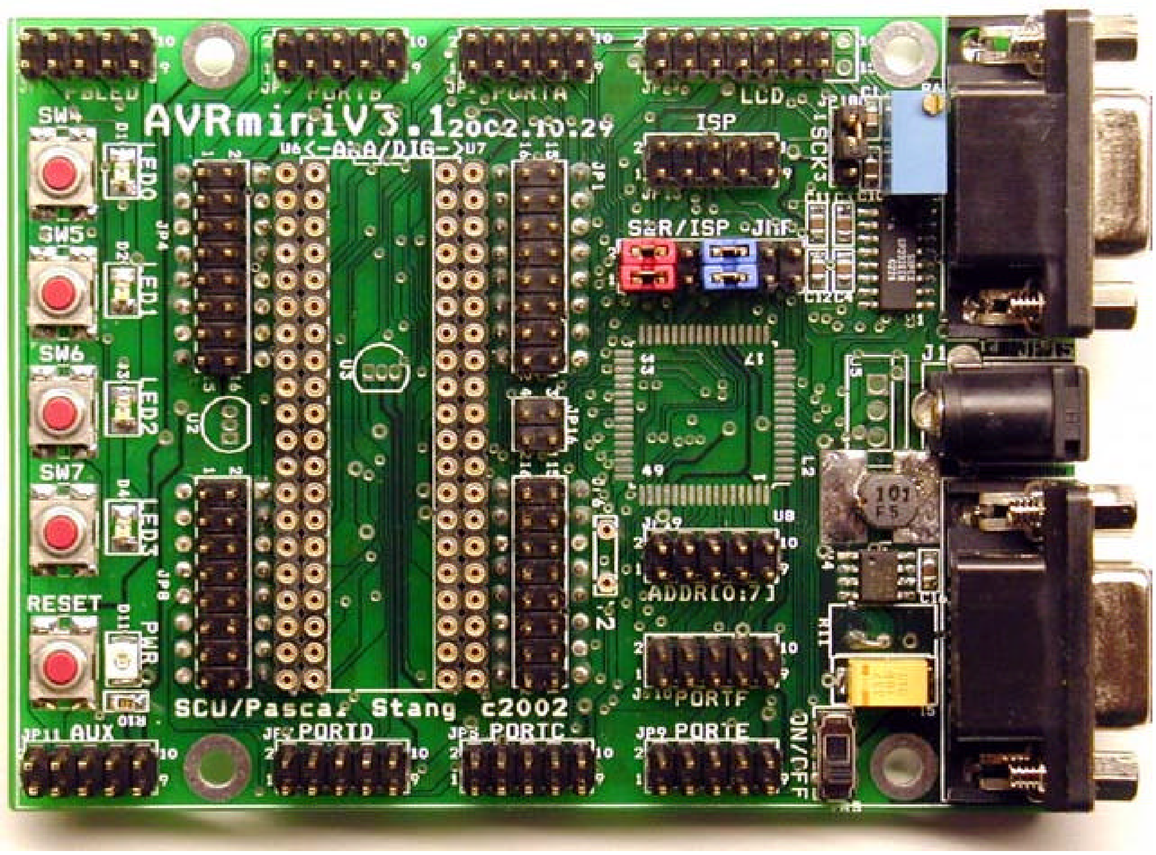


Figure 5.1: AVRMini Proto-board

The hardware subsystem had two major parts: the Atmel AVR microprocessor and the circuit board on which it is mounted. The hardware solution decided upon was a single central Atmel microcontroller supported by external flash ram for data storage. It was mounted on an AVRMini 3.1 development board, with an integrated power regulation system.

The single central microcontroller was picked over an array of specialized ASICs and microcontrollers, because a single microcontroller uses less power and leaves fewer things to go wrong. Also, having a central computer aids greatly in the programmability and resulting flexibility of later projects using the same equipment. The Atmel chip was picked over the many other brands because members of the team were already experienced with the line of microcontrollers.

Within the family of Atmel microcontrollers, many were available. Some had less functionality, but more software support, while others had cutting edge performance, but were more difficult to use. In the end, the Atmel Atmega 128 microprocessor was chosen. It has dual serial UARTs, a built in 10 bit 8 input analog to digital converter, numerous digital input-output ports, and can run at frequencies up to 16MHz. In the final implementation, the UARTs were used to communicate with the GPS and HAM radio, the digital ports were used to control parachute and vehicle release, and the built in analog to digital converter was used to read data from the various onboard sensors.

The AVRMini 3.1 development board was chosen for the flight vehicle as well as development. This board’s integrated power supply allowed for the power of the microcontroller to function independently of the rest of the vehicle. This allowed the microcontroller the ability to monitor the power state of the rest of the system and react accordingly.

Two major design decisions were made during the hardware design: the choicse of the Atmel Atmega 128 chip, and the choice of the AVRMini 3.1 board. The Atmel Atmega 128 chip was specifically purchased due to its technical capabilities in spite of the fact that less software support existed for it within the RSL environment. The technical abilities were decided to be more important because success required them. If a lesser microcontroller had been used, more complex switching schemes would have been needed such that multiple devices could share one UART. Also, its higher maximum frequency would allow the development team to be able to add more software functionality with only the change of a single clock crystal. In the end, the decision to use the Atmega 128 was clear.

The more difficult dilemma was that concerning the board on which to mount the Atmega 128 chip. The AVRMini 3.1 development board was chosen as the flight board, rather than separate flight electronics, for several reasons. Since the design verification occurred on the AVRMini board as the software was developed, much testing was done already. This eliminated the need to do as extensive software testing would be required for new hardware circuitry. The power draw of the AVRMini board was greater than custom circuitry would be, however this power loss was justified because it allowed the Atmel to monitor the power of other systems onboard the vehicle independent of its own power source. This gave the Atmega more time to react in the case of a power failure. The final major issue considered was temperature. The custom circuitry could be built out of components all designed to operate at the very low temperatures that the SHARP vehicle would encounter at drop altitude. This became less of an issue once it was decided that thermal coupling would be sufficient to keep most of the important electronics on the vehicle functioning during flight.

The testing conducted on the hardware portion of the computer system consisted mainly of expected usage testing. This consisted of running the software on the hardware while it was connected to various sensors to verify that the hardware did indeed function properly. Due to lack of simulation equipment and facilities no temperature or pressure testing was conducted on the hardware to guarantee proper functioning in extreme cases.

Later sharp teams can build upon this modular hardware system easily. The majority of future work focuses on quality assurance and testing. To begin with, a simulation microcontroller should be developed in parallel with the continuing development of the primary avionics microcontroller. Since they will have the same pin configuration, the simulation microcontroller would be able to simulate any possible set of inputs to the primary microcontroller. This would allow exhaustive simulation testing of everything from failed components, to slow power failure of the main power supply due to temperature drop. Furthermore, testing should be conducted with the other electrical components integrated in pressure or temperature chambers to the point of failure. This would realistically simulate possible unexpected failures that may occur that the computer hardware would be forced to recover from.

5.3 Software Subsystem

5.3.1 Introduction

This data collection, storage, transmission, and recovery will be the job of the software subsystem. The low cost Atmel AVR microcontroller is directed by the software to collect the data from the various array of sensors, as well as GPS location data, and record all of this data onto flash memory, and transmit critical data back to the base station. The software subsystem will meanwhile manage events such as the detachment from the balloon and the parachute deployment. It will also be the only intelligence available to react to failures in other systems on the vehicle in a graceful manner. If the computer system is the logical hub of sharp, then the software subsystem is the logical hub of the computer system.

5.3.2 Design

During the design analysis phase, various standard analysis exercises were conducted to determine the requirements of the software subsystem to the greatest extent possible. This was the most vital component of the software life cycle. The first exercises conducted included system stories and their translation into a system state chart in coordination with the SHARP flight plan and electrical power budget. See appendix L for these system stories.

Requirements Analysis:

- Transmit data at maximum rate allowed by transmission device
- Capture data and store data at maximum rate allowed by sensors and recording device
- Meet hard deadlines including release of module from balloon and deployment of parachute
- Maintain continuous contact with base station

Subsystem Specifications:

- Inputs
  - Air pressure and temperature readings over the duration of a high altitude descent
  - GPS data from module
  - Acceleration readings from onboard accelerometers
- Intermediates
  - Knowledge of module’s location and altitude
- Functions
  - Store only pertinent data
  - Transmit only critical data
  - Release from ascent vehicle
  - Deploy recovery system
  - Transmit location after landing
- Outputs
  - Pertinent data signals sent to nonvolatile storage device
  - Critical data signals sent to transmitter
  - Signal sent to release device
  - Signal sent to recovery system
  - Location data transmitted to base station

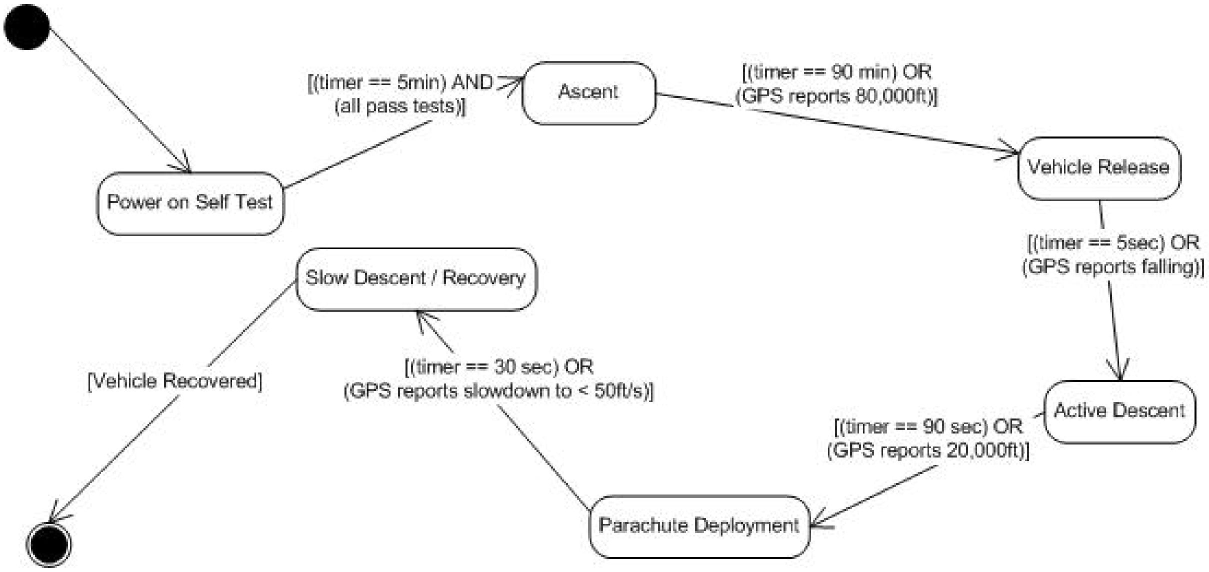


Figure 5.2: Subsystem state chart

By the end of the design analysis phase it was evident that although initial requirements could be known, they would be very volatile and fluid throughout the software subsystem development. This was an obstacle that none of the other disciplines on the project would have to deal with, and as a result raised the risk associated with the software development significantly. Special precautions would have to be taken to ensure that rework risk was dealt with.

The main software design of the computer system is very significant to the function and maintenance of the project. If the system errors on the side of function, some part of the system will fail to function, possibly by missing a hard deadline, and disaster will result; however, if the failure is on the side of maintainability the project will still appear to be a success until the next group attempts to take it to the next level and finds a mass of spaghetti code. To find a balance between these two extremes, three options were considered for the software architecture of the system: object oriented, multithreaded sequential, and straight sequential.

Object oriented architectures, even in simple embedded systems, have been very popular since the 1980s for their strong positives in maintainability and development. This system could be very easily objectified from the functional block diagram and development would be very fast, and modular. Also, testing is much easier with this system. However, the limited CPU cycles of the embedded microcontroller almost completely eliminate this option. Even though it does run C++ code well, the overhead that comes with objects at all is far too high for this project. For this reason object oriented is not a viable architecture.

The next logical option is sequential code with multiple threads. This would allow the system to manage a transmission thread while it simultaneously manages a disk writing thread. This would also be fairly easy to develop. Threads could be terminated or spawned upon state changes of the overall system, and they could use shared memory easily with minimal need for semaphores and other protection code. However even the overhead of a context switch may be too much. Also with only one CPU installed, true simultaneous execution, which is what would be necessary, cannot be attained. Also, testing of such a system is very difficult because the order in which instructions are executed cannot be predicted. A deadlock between any two threads would result in disaster.

The final option, which is usually the hardest to improve and maintain is a simple program of sequential code. This would have the lowest overhead and would allow for maximum data collection. Also, with proper documentation the maintenance it can be scalable and manageable.

5.3.3 Design Analysis

The design architecture phase of the SHARP software subsystem progressed naturally from the design analysis. An architecture had to be developed that was easy to change, easy to test, and efficient. This was a difficult set of requirements to deal with. As a result, for the decision of design architecture, the decision matrix was used. Sequential code won the contest, just ahead of object oriented architecture. This will allow for maximum efficiency, which is the most important requirement of the project, as well as adequate testing, which is equally important. Both the sensors and the transmitter can be easily utilized to their maximum abilities. The hard deadlines can also be easily met since only simple switching code is required to execute them. This simple switching code will be very easy to test completely.

This was the architecture selected for this system due to its raw efficiency. It will be made up of sequentially executed blocks of code each corresponding to a phase. They will be separated by condition statements to determine when the phase switch is to occur. If even greater speed is required the code blocks can be written in assembly fairly easily yielding extremely high performance out of slow a microcontroller. This will also allow us to utilize a lower power microcontroller thereby saving battery weight or energy for increased transmission time.

5.3.4 Implementation

As a result of the design architecture decided upon, the implementation lowered in risk and became much easier than the alternative options; however, significant risk still had to be dealt with. To respond to this risk, a development process was picked specifically to deal with fast changing requirements. Only one development process exists that is designed to handle significant changes in requirements at any time, and that development process is eXtreme Programming. Coincidentally, it is known to work well on small projects; however I was still not sure it was best. I applied the decision matrix again to ensure that this was the right development model for the project. It was put up against various development models I had used in classes previously. These development models include the chaotic method, most commonly used in programming labs, the iterative development model, taught in many programming labs, and the eXtreme Programming model, which worked very well in one programming lab.

The matrix yielded eXtreme programming as the victor in this small competition. As a result this development model will be used. The milestones are fairly clearly laid out, so the initial planning will be simple. Weekly meetings also suggest a weekly development cycle may be a good idea. See Appendix E for a further description of the eXtreme Programming plan including a list of milestones and their component tasks.

In eXtreme Programming there are four variables, one of which must not be fixed. These four variables are quality, time, effort, and features. Quality is obviously fixed, since any failure will result in failure to the entire project. Time is relatively fixed as well, since the project must be completed at the end of the winter quarter. Effort is as well fixed since I was the only engineer developing the software system. The only variable remaining is features. Features that can be implemented later in the project include performance improvements and more advanced communications algorithms. Also pushed on to the backburner at this point was the secondary microcontroller test bed.

The actual development proceeded in parallel with the electrical system development. This allowed design verification to be conducted as the software was developed and also allowed any changes to be made before the impact of such change became great. The time spent properly choosing a process and using it to the fullest extent possible paid off at this time.

5.3.5 Testing and Quality Assurance

The software system was tested at the same time as the hardware portion of the computer system. The various sensors and other electrical systems were connected to the microcontroller and the system was run as a whole. Special software prototypes were developed that compressed the phases of the flight, or ignored some completely. This allowed the testing to be conducted in a timely fashion and only of the functions in question. This testing was by far inadequate for a flight, but proved suitable for design verification purposes.

5.3.6 Future Work

Much remains to be done in the software portion of the computer system. Future groups may wish to demand more stability in software system requirements as requirement fluctuation proved to be the most difficult part of the software system. This will be more feasible for future projects because a majority of the design work has already been completed. In addition to this, the next software team should devise pure software methods for testing various functions of the vehicle. This would allow even faster testing than the simulation microcontroller described in the hardware section.

6. Other Issues

With an engineering project of this magnitude the focus can't be made just on the work of the project. In any engineering endeavor certain issues will arise that are effected by a project. In this section some of these issues will be explained in relation to the SHARP project.

6.1 Social

SHARP has the potential to be a very high profile project. As with any space program project there is an effect on not only those involved with the project but those people of the country or countries where the module is produced. These projects create excitement among the society and stimulate the job market. SHARP has the potential to improve immensely the safety and performance of our space explorations. By changing the aerodynamics and using ultra-high temperature tiles this will vastly decrease chances of disaster on re-entry. With less disaster and turmoil there will be more support from citizens, politicians, etc., to endorse space programs.

6.2 Political

Since NASA is a government funded organization, SHARP must be politically driven. By developing a prototype of a re-entry vehicle using SHARP technology, we created an example and evidence that could be used to get proper funding from government agencies to increase awareness of the space program. With this, further research could be done on SHARP and other space related projects to advance knowledge of our space system. If community interest in SHARP and NASA is heightened, lobbyists and the voting public will see to it that politicians in favor of improving our space program are elected.

6.3 Economic

Funding for our project was contributed from the research grants that Professor Kitts has obtained. With a project with high complexity such as SHARP, funding will become a huge issue. In the initial prototype sensors, materials and testing will be affected due to the funding, but with a proposed test flight and prototype, NASA could become a sponsor and contributor to the Santa Clara University division of SHARP.

6.4 Health and Safety

Safety and health are key problems in developing our prototype. While we are not preparing a test flight in space, we are planning on doing a balloon drop in the desert. Here arises a problem: we are dropping from approximately 80,000 ft and the leading edge of the vehicle is metal and very sharp. If the parachute does not open it becomes a flying weapon that could cause serious injury to any bystanders including ourselves. If we want to drop we have to go through rigorous quality assurance. Since the liability is high, FAA forms were completed to make sure that it is not only legal but safe to continue with testing.

6.5 Manufacturability

Manufacturing of our vehicle was a very difficult problem especially for our mechanical engineers. Constructing the front tip and the outer shell were very long and arduous processes that they had to deal with. If we had adequate funding, we could ideally have had the front tip and outer shell professionally created. While we haven’t dropped the vehicle yet, this lack of perfection in manufacturing the tip and outer shell will affect our dynamic data. As for the electrical side of manufacturing, we would have most likely created PC board circuitry instead of the soldered circuits we created for the sensor and power systems. With more knowledge and funds we could have produced a more efficient wiring system inside of SHARP that would allow for optimal space consumption.

6.6 Sustainability

With any prototype, it is not expected that it will be used for a long duration. Our SHARP prototype is designed to get further funding, not to be the final design for mass use. We anticipate improvements, including; added sensors, higher quality sensors, video capabilities, and flaps added to the shell to increase control of the ship from the ground station. Also, unknown new technology that could ultimately replace SHARP's design could be in development.

6.7 Environmental Impact

Our project has no immediate environmental effect, but if future versions of SHARP are funded, the use of resources to create these vehicles could have a small impact. The materials are used to manufacture the vehicle will ultimately influence the environmental impact it has such as the aluminum shavings from manufacturing the tip and the fumes from the acrylic cement used to create the shell.

6.8 Usability

Usability is not a key factor with our product. The persons using our technology would be scientists, researchers and astronauts all of whom would be technically proficient in the design and uses of our vehicle. As for our prototype, the ground stations consisting of a laptop and antenna will be used to track our prototype and to collect data. The wiring housing inside SHARP is easy to remove allowing for access to change and update the components and wiring aboard the prototype.

6.9 Lifelong Learning

This project taught us lifelong learning on several levels. First, we learned the value of our education as undergrads when entering the project. Much of the preliminary research and analysis was using knowledge from previous engineering classes, teaching us that the classes build upon one another. Secondly, our SHARP project is a small portion of NASA's SHARP project, making research of their previous work essential before starting to design our own vehicle. Also, we have the hopes of our vehicle contributing to the overall SHARP project, making subsequent vehicles/experiments more valuable because of the previous work of which they are based.

6.10 Compassion

The overall purpose of the SHARP program is to make space travel safer by further advancing reentry vehicle development. While our part in SHARP is a very small factor in the overall purpose, we have provided NASA a testing vehicle with which they are able to obtain useful empirical data. Our contribution for the project was essentially voluntary considering we received no funds from NASA, the primary customer. We did this project to develop ties between the university and NASA, hoping that NASA will recognize the value of undergraduate engineering teams, and consequently, benefiting future senior-design teams financially.

6.11 The integrated nature of engineering, math, and science topics

Because the purpose of the project was to obtain and record data pertaining to pressure distributions and dynamics of the vehicle, an extensive amount of physics theory was used to analyze the flight. This physics theory included fluid mechanics, and general dynamics. On several occasions, we were referencing old text books from past general engineering classes, and were happy to be getting some use out of them. Math, of course, was used frequently throughout all applications, and very heavily in the moments of inertia calculations of all vehicle parts. To say the least, the project definitely acted as a culminating experience to an entire engineering educational program.

6.12 The importance of building prototypes

The most important lesson that we learned from building a prototype of the vehicle is that the manufacturing process is always a lot more time consuming than expected. A full-scale prototype of the vehicle housing, front tip, frame, and parachute was made after the first two months of design. By making it full-scale, we saw how much limited internal volume we had to house the electronic components, and made us rethink some of the small design details. The prototype taught us the importance of extensive preliminary design in an engineering project. The more early detail design, the easier the manufacturing process becomes.

7. Summary and Conclusion

7.1 Summary

In conclusion, the SHARP team at Santa Clara University took on the difficult task of designing, building, and testing an initial SHARP L prototype reentry vehicle capable of collecting data relevant to the natural flight dynamics and pressure distribution related to its unique aerodynamic geometry. This was accomplished without graduate student assistance, and on a limited budget. This work involved special focuses in each of the disciplines making up our SHARP team.

The Mechanical Engineers on the project were given a set of physical constraints including the ideal shape of the vehicle as well as direction in which it should fall. From this small data set a vehicle was designed that not only had a proper aerodynamic geometry, and properly located center of gravity, but also was manufacturable with great cost effectiveness in a relatively short time frame. This was accomplished by partitioning the module into the mechanical subsystems of the front tip, outer shell, internal frame, backend plate, and parachute recovery subsystem. The front tip was machined in house out of a solid block of aluminum, while the outer shell was thermoformed out of acrylic in a home oven over hand made clay molds. The internal frame was constructed out of aviations oldest frame material, wood, to save weight and manufacturing costs, the back end plate, constructed largely out of the same acrylic used to form the rest of the outer shell, was designed to finish off the geometry and mount the most critical sensor array in the vehicle while still allowing room for a parachute release, and finally the parachute recovery system, designed using prefabricated, off the shelf components, was designed and tested to withstand even the harshest shocks of deployment.

The electrical system had different set of important constraints including the very low temperatures and pressures of upper atmosphere flight, the extremely low power consumption required for weight saving reasons, and of course the limited funding felt by every member of the project. The power system was required to use affordable, off the shelf components to power the various electronics on the vehicle. This was further complicated by the sub-industrial temperature ranges that the vehicle would be exposed to at altitude and the limited power budget. The power supply had to operate at extremely high efficiency. Also, the onboard sensors, many of which would be directly exposed to the environment, must gather accurate data with minimal energy and financial impact. This was accomplished through in depth searching for the best possible component available. Furthermore, the sensor system was additionally responsible for many of the health monitoring capabilities of the vehicle including battery temperature. Communication and positioning presented difficult design decisions as well. The SCU Robotics Laboratory supplied radios that had already been tested on other projects at very high altitudes. The SHARP team was then responsible for determining the optimal antenna configuration and location that would allow communication to the base station which could be a on the order of thirty miles away using minimal electrical power. Link equations and real world testing in the local mountains proved adequate to select proper antennas and guarantee a satisfactory communication link to the base station.

The onboard computer system, which acted as the hub between the other two systems, required great care in engineering due to the fact that it was required to handle possible failures of other systems gracefully. This meant that it could have no error itself or this graceful recovery could be compromised. It was responsible primarily for the gathering, storage, and transmission of collected data as well as operation of vehicle recovery and release systems and secondarily for health monitoring and emergency mitigation. The hardware portion of the computer system was selected due to familiarity and cost effectiveness, consisting of an Atmel Atmega 128 microcontroller chip coupled with an AVRMini 3.1 proto-board. It allowed the reuse of design modules and source code from previous school projects. On the other hand, the software portion of the computer system presented no immediate financial cost and therefore was designed to adapt to changes in other parts of the project. This allowed for maximum financial flexibility of the other systems on the vehicle. Such flexibility of a software system at its very roots, the external requirements and input specifications, was no trivial task. Focus was placed on quality assurance through rigid process. eXtreme Programming was chosen early on due to its ability to adapt to changing requirements and input specifications without disastrous results. The software was then implemented alongside the electrical system to minimize rework required due to requirements change.

7.2 Conclusion

With the completion of these systems, the first year of the SHARP project at SCU concluded; however the story does not end there. Much was learned over the duration of the project. The mechanical engineers learned that outsourced components, such as the planned fiberglass outer shell, may not always be the best. It was also learned that manufacturability resources do limit the design such as the shape of the front tip. From the electrical standpoint it was learned that testing should be considered from the beginning as problems were encountered when it came time to test and calibrate the pressure sensors. The computer engineer learned that no matter how much effort is put into requirements variation management, it still poses too much risk to allow. Just as a bridge must be given extremely precise requirements before it is to be designed, so too much a software system be given requirements before design or coding is to begin.

With the knowledge of these and other lessons learned under their belts, a new team of students will continue the SHARP project at SCU next school year. This year's team has left suggestions for the next team to continue the project. These future work products include a front tip to be machined with more rounded edges that are tangent to the flat surface, and a mechanism or method to properly test the parachute and recovery systems without risk to the vehicle. Also, suggestions from the electrical engineering discipline include integration testing of the entire electrical system over the duration of a simulated flight. This simulation should include realistic pressures and temperatures that the SHARP vehicle would experience during the real flight. Then too, further work needs to be completed to efficiently integrate the HAM radio into the rest of the onboard controlled power system. Lastly, the computer engineer recommended to next years group that a second AVRMini board coupled with an Atmega128 chip could be used to simulate every single output of the specified electrical system. This would allow extensive and exhaustive testing of every possible failure and mission contingency.

In the end, the first year of the SHARP project was a success. The module was designed, constructed, and tested to a great extent. It should also be noted that an ongoing relationship between NASA and the SCU robotics laboratory concerning the SHARP mission has been initiated and will be sure to continue for many years. Many lessons were learned and future suggestions passed on to later teams. The SHARP project is sure to be an exciting and productive project at Santa Clara for years to come.

References:

SHARP Overview – Montana State University – SHARP Structure Group
www.coe.montana.edu/me/faculty/cairns/ sharp/overview%20left.htm

SHARP: Thermal Protection Optimization – NASA ARC Jet Facility
http://asm.arc.nasa.gov/projects/sharp/pl12.shtml

White, Frank M. Fluid Mechanics, 4th Edition. McGraw-Hill Companies. Boston: 1999.

Appendix A: Detailed Calculations

Terminal Velocity @ 80,000 ft & 15,000 ft

$p = 0.406\,\text{psi} = 2.8\,\text{kPa}$ $\quad$ $T = 221\,\text{K}$

$$\rho_{\substack{air \\ 80{,}000\,ft}} = \frac{p}{RT} = \frac{2800\,\text{kPa}}{(287\,\frac{m^2}{s^2K})(221\,K)} = 0.04415\,\frac{kg}{m^3} = 1\cdot 10^{-4}\,\frac{slug}{ft^3}$$

$$A_{cs} = (9.8\,in) \times (5.25\,in) = 51.45\,in^2 = .405\,ft^2$$

$$V_t = \sqrt{\frac{2\,m\,g}{C_D\,\rho_{air}\,A_{cs}}}$$

$C_D = 0.8$
(reference)

$$V_{80{,}000} = \sqrt{\frac{2\,(12.5\,lb)}{(0.8)(1\cdot 10^{-4}\,\frac{slug}{ft^3})(.405\,ft^2}} = 1000\,ft/s$$

$$V_{15{,}000} = \sqrt{\frac{2\,(12.5\,lb)}{(0.8)(.0011\,\frac{slug}{ft^3})(.405\,ft^2)}}$$

$\rho_{\substack{air \\ 15000\,ft}} = 0.0011\,\frac{slug}{ft^3}$

$$= 260\,\frac{ft}{s} = 180\,mph$$

Parachute Area

PDS ⟶ 20 ft/s   Assumed 1.6

$$v_t = \sqrt{\frac{2mg}{C_D \rho_{air} A}}$$ solve for A

$$20 \text{ ft/s} = \sqrt{\frac{2(12.5 \text{ lb})}{(1.6)(.00237 \frac{\text{slug}}{\text{ft}^3})A}}$$ A = 17 635 ft

Purchased   A = 60 in. diameter

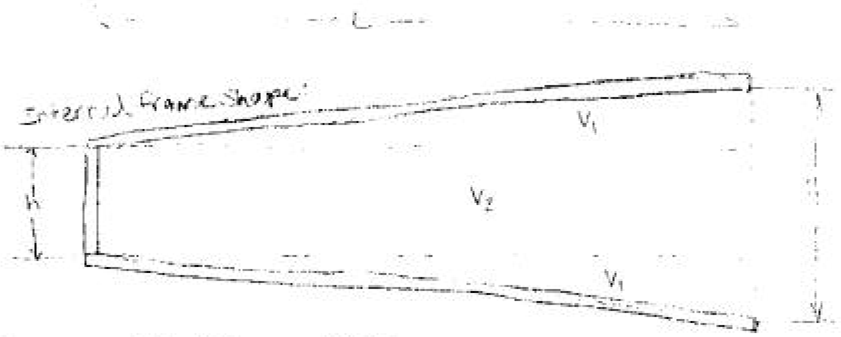
$= 30 \text{ in}^2 \pi = 2850 \text{ in}^2$

$= 19.6 \text{ ft}^2$

Implement factor of safety

Usable Volume

= volume inside vehicle that can be used for placement of electronic components



internal usable volume = $2V_1 + V_2$
(between support plates)

measured values:

$H = 4.74$ in
$h = 1.47$ in
$L = 15.10$ in
dist. between support plates – $w = 5.23$ in

$$2V_1 = L\left(\frac{H-h}{2}\right)w = 15.10\left(\frac{4.74-1.47}{2}\right)(5.23) = 129.12\ in^3$$

$$V_2 = Lhw = 15.10(1.47)(5.23) = 116.09\ in^3$$

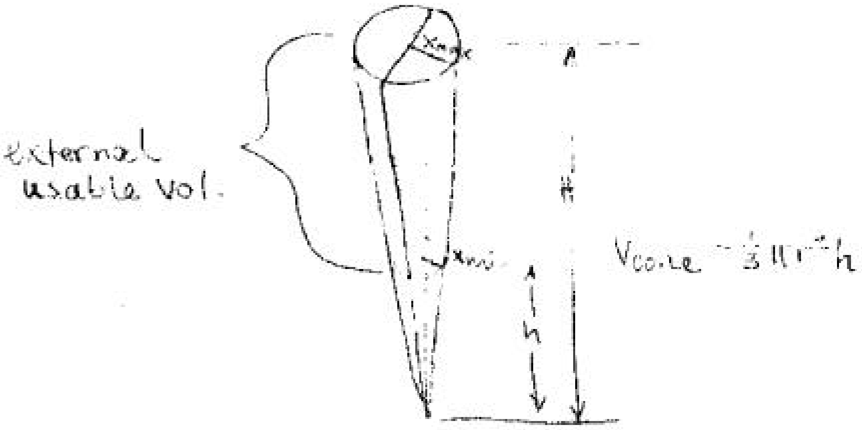
Internal usable vol = 129.12 + 116.09 = $\underline{\underline{245.21\ in^3}}$

External usable space = volume inside outer shell but outside frame

X_{max} ~ far end of vehicle
X_{min} ~ closest towards leading edge

measured values: $X_{max} = 2.29$ in
$X_{min} = 0.27$ in

Approximate volume by two cones: 2 side, 1 cone segment



measured values: $H = 26.13$ in
$h = 10.54$ in

$$\text{ext. } V = \frac{1}{3}\pi(X_{max})^2 H - \frac{1}{3}\pi \cdot X_{min}{}^2 h$$
$$= \frac{1}{3}\pi\left[(2.29^2)(26.13) - (0.27)^2(10.54)\right]$$
$$= 142.69 \text{ in}^3$$

Total Usable Volume = 142.69 + 245.21

$$\boxed{= 387.90 \text{ in}^3}$$

Parachute Drag Force and Drag coefficient

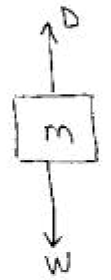
Trial	Height	time	velocity
1	30 ft	2.00 sec	15.00 ft/s
2	30 ft	1.97 sec	15.23
3	30 ft	[illegible]	16.21
4	20 ft	0.96 sec	20.83

Using Trials 1–3: ave. time = 1.94 sec
ave. velocity = 15.48 ft/s

$$\boxed{D = \tfrac{1}{2} c \rho A V^2}$$

D = drag force
c = drag coefficient
ρ = air density = 1.2255 kg/m³
A = effective cross-sectional area = .2827 m²
v = velocity

FBD



$$\Sigma F_y = (ma)_{net} = D - W$$

$$a_{net} = \frac{V - V_0}{t} = \frac{15.48 - 0}{1.94} = 7.98 \text{ ft/s}^2$$

$$m = \frac{13.5}{32.2} = 0.419 \text{ [illegible]}$$

$$(ma_{net}) = D - W$$
$$D = (0.419)(-7.98) + 13.5 \text{ lb}$$
$$\underline{D = 10.16 \text{ lb}}$$

$$D = \tfrac{1}{2} c \rho A V^2$$
$$c = \frac{2D}{\rho A V^2}$$

V = ave. velocity = 15.48 ft/s
A = .2827 m² = 19.63 ft²
ρ = 1.2255 kg/m³ = .002378 slug/ft³

$$c = \frac{2(10.16 \text{ lb})}{(.002378 \frac{\text{slug}}{\text{ft}^3})(19.63 \text{ ft}^2)(15.48 \text{ ft/s})^2}$$

$$\boxed{c = 1.82}$$

Parachute Chord Testing

$V_0 = 180\text{ mph} = 264\text{ ft/s}$ $m_0 = m_f = 13.5\text{ lb}$

$V_f = 20\text{ ft/s}$

change in momentum:

$$\Delta P = mV_0 - mV_f = m(V_0 - V_f)$$
$$= (13.5\text{ lb})(264 - 20)$$
$$= 3294\text{ lb}\cdot\text{ft/s}$$

***Parachute consists of 4 chords:** 1 chord has $\frac{1}{4}$ load

1 chord: $\frac{\Delta P}{4} = \frac{3294\text{ lb ft/s}}{4} = 823.5\text{ lb}\cdot\text{ft/s}$

To test: drop height = 30 ft

$$V_0 = \sqrt{2gh}$$
$$= \sqrt{2(32.2\text{ ft/s}^2)(30\text{ ft})}$$
$$V_0 = 43.95\text{ ft/s}$$

$V_f = 0$

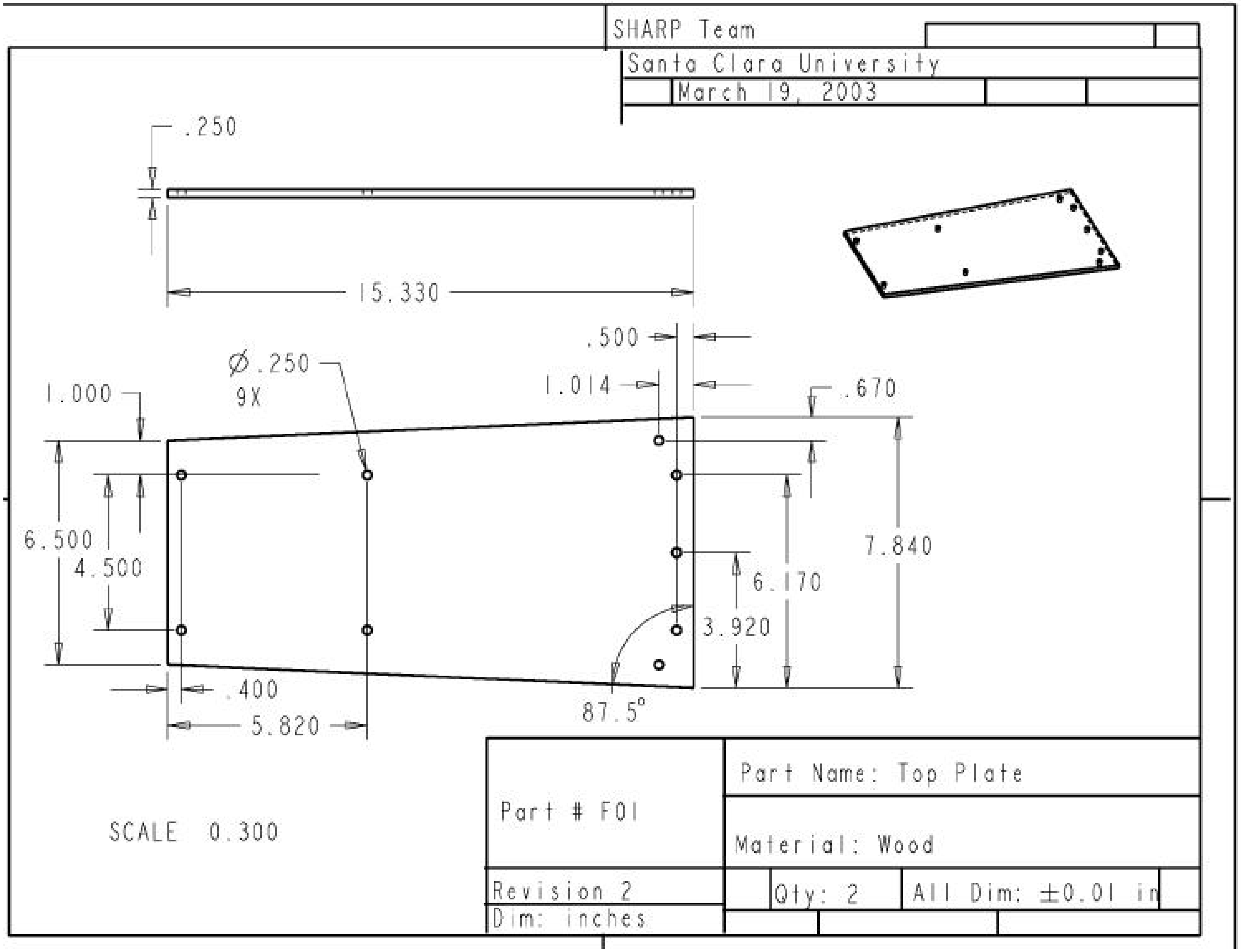
$$m = \frac{\Delta P}{\Delta V} = \frac{823.5\text{ lb}\cdot\text{ft/s}}{43.95\text{ ft/s}}$$

$\boxed{m = 18.7\text{ lb}}$ ~ necessary weight of object dropped off of parking structure

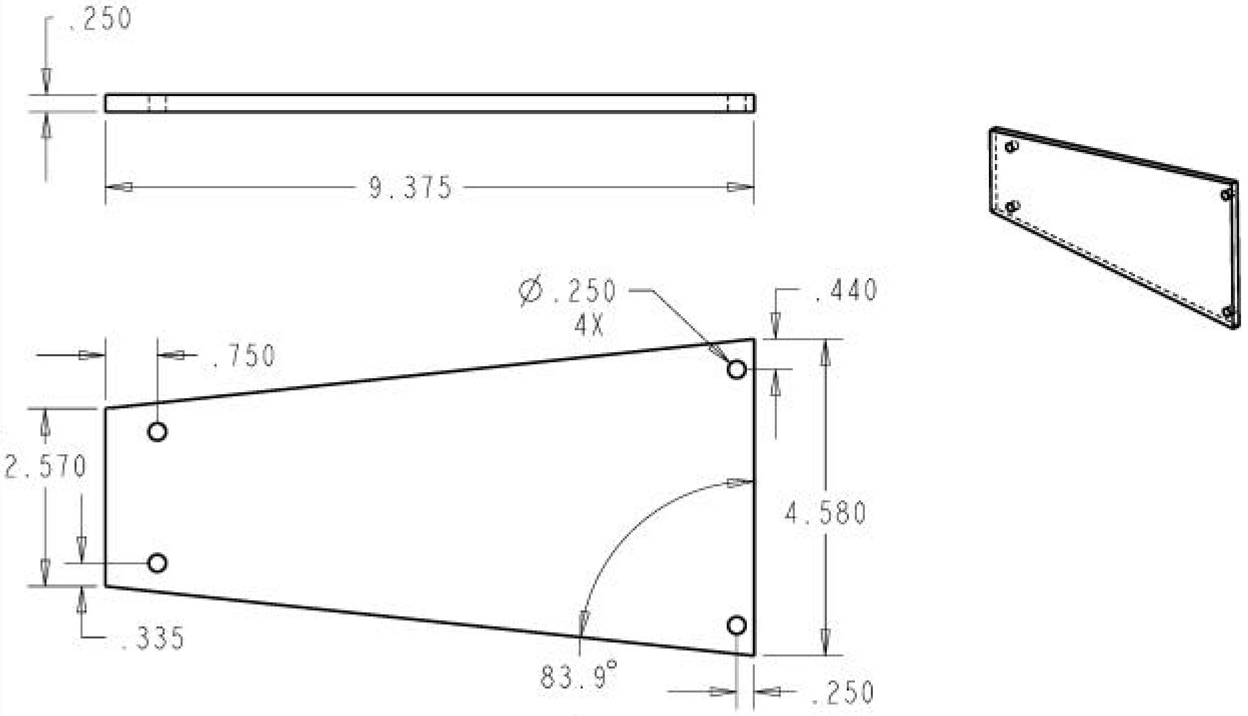
Appendix B: Detail Drawings

Designed/Manufactured Components

Subsystem	Component Description	Part #	Qty	Material
Internal Frame		**FA1**	**1**	
	Top plate	F01	2	Wood
	Support plate	F02	2	Wood
	Front plate A	F03	1	Wood
	Front plate B	F04	1	Wood
Outer Covering		**CA1**	**1**	
	Top shell	C01	2	Acrylic
	Side shell	C02	2	Acrylic
	Shell-tip A	C03	2	Acrylic
	Shell-tip B	C04	2	Acrylic
Leading Edge		**LA1**	**1**	
	Front tip	L01	1	Aluminum
Back End		**BA1**	**1**	
	Back plate A	B01	1	Acrylic
	Back plate B	B02	1	Acrylic
	Door	B03	1	Acrylic

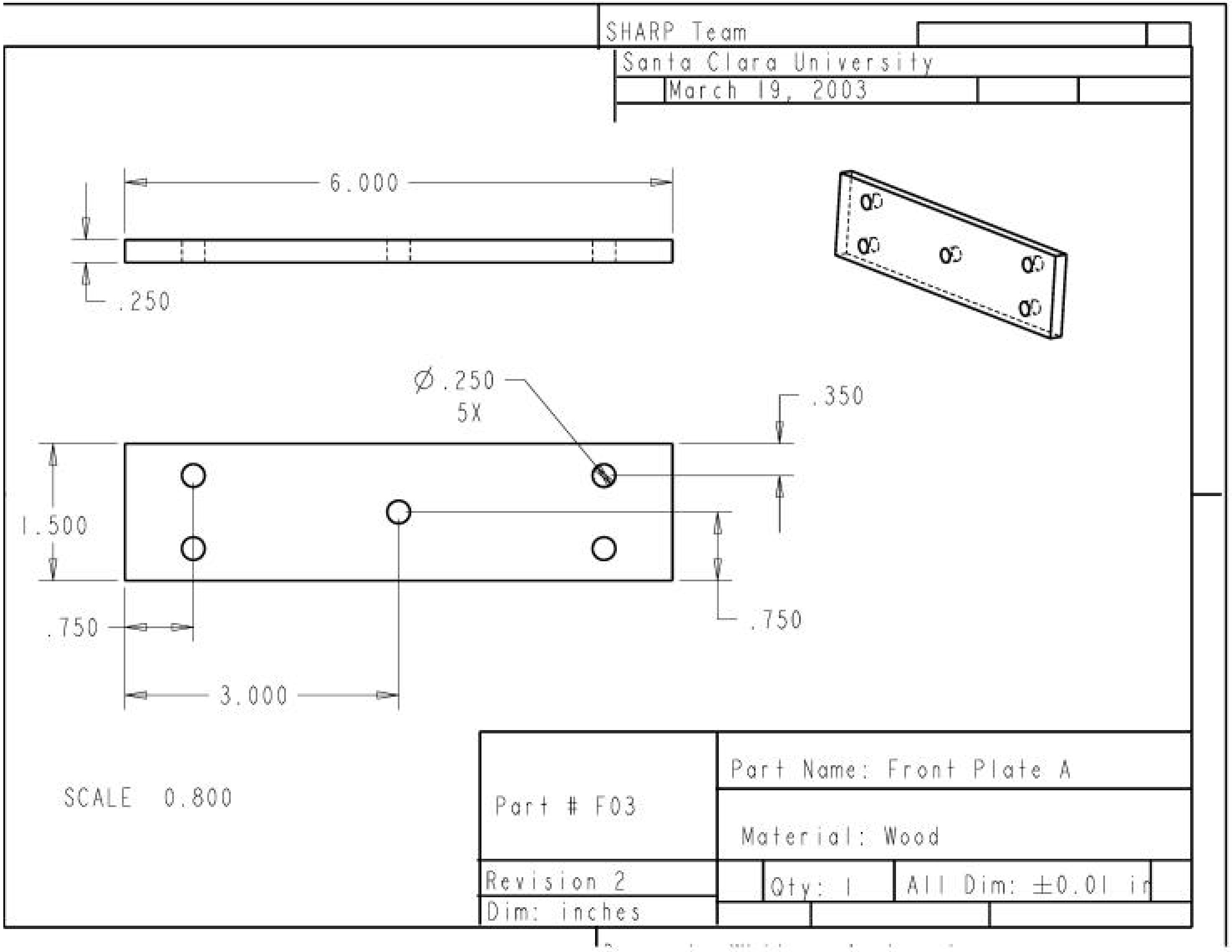

SHARP Team
Santa Clara University
March 19, 2003
.250
15.330
.500
1.014
.670
Ø.250
9X
1.000
6.500
4.500
6.170
7.840
3.920
87.5°
.400
5.820
SCALE 0.300
Part # F01
Part Name: Top Plate
Material: Wood
Revision 2
Dim: inches
Qty: 2
All Dim: ±0.01 in

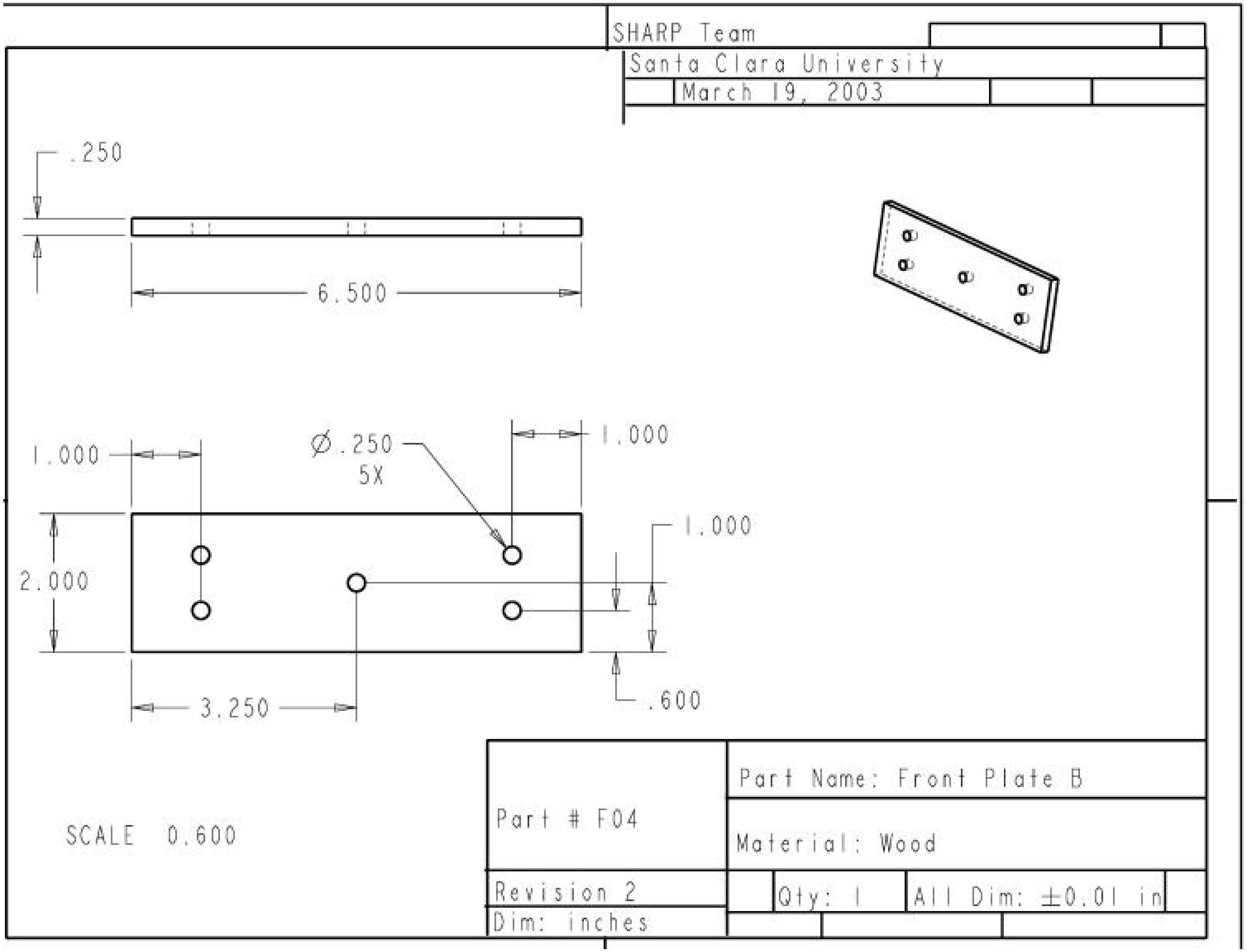
SHARP Team
Santa Clara University
March 19,2003



SCALE 0.500

Part # F02	Part Name: Support Plate
	Material: Wood
Revision 2	Qty: 2
Dim: inches	All Dim: ±0.01 in

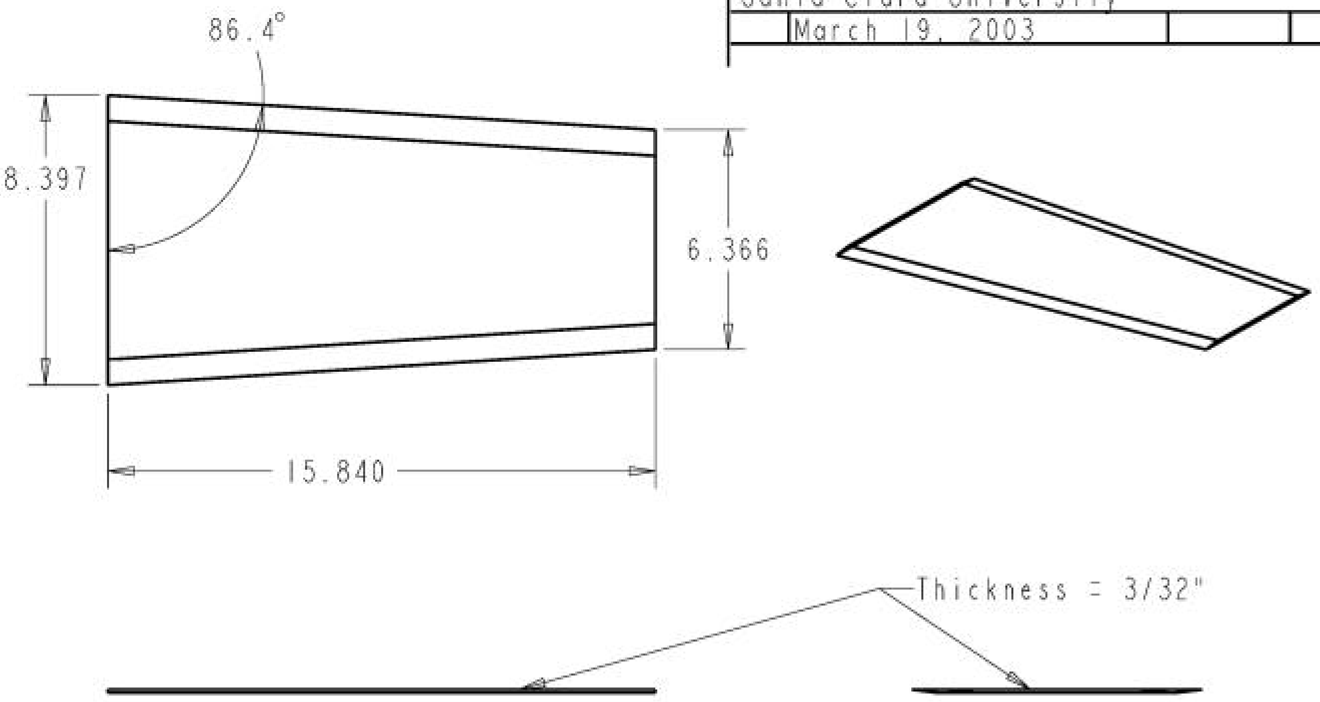

SHARP Team
Santa Clara University
March 19, 2003
6.000
.250
Ø.250
5X
.350
1.500
.750
.750
3.000
SCALE 0.800
Part # F03
Part Name: Front Plate A
Material: Wood
Revision 2
Dim: inches
Qty: 1
All Dim: ±0.01 in


SHARP Team
Santa Clara University
March 19, 2003
.250
6.500
1.000
Ø.250
5X
1.000
1.000
2.000
.600
3.250
SCALE 0.600
Part # F04
Part Name: Front Plate B
Material: Wood
Revision 2
Dim: inches
Qty: 1
All Dim: ±0.01 in

SHARP Team

Santa Clara University

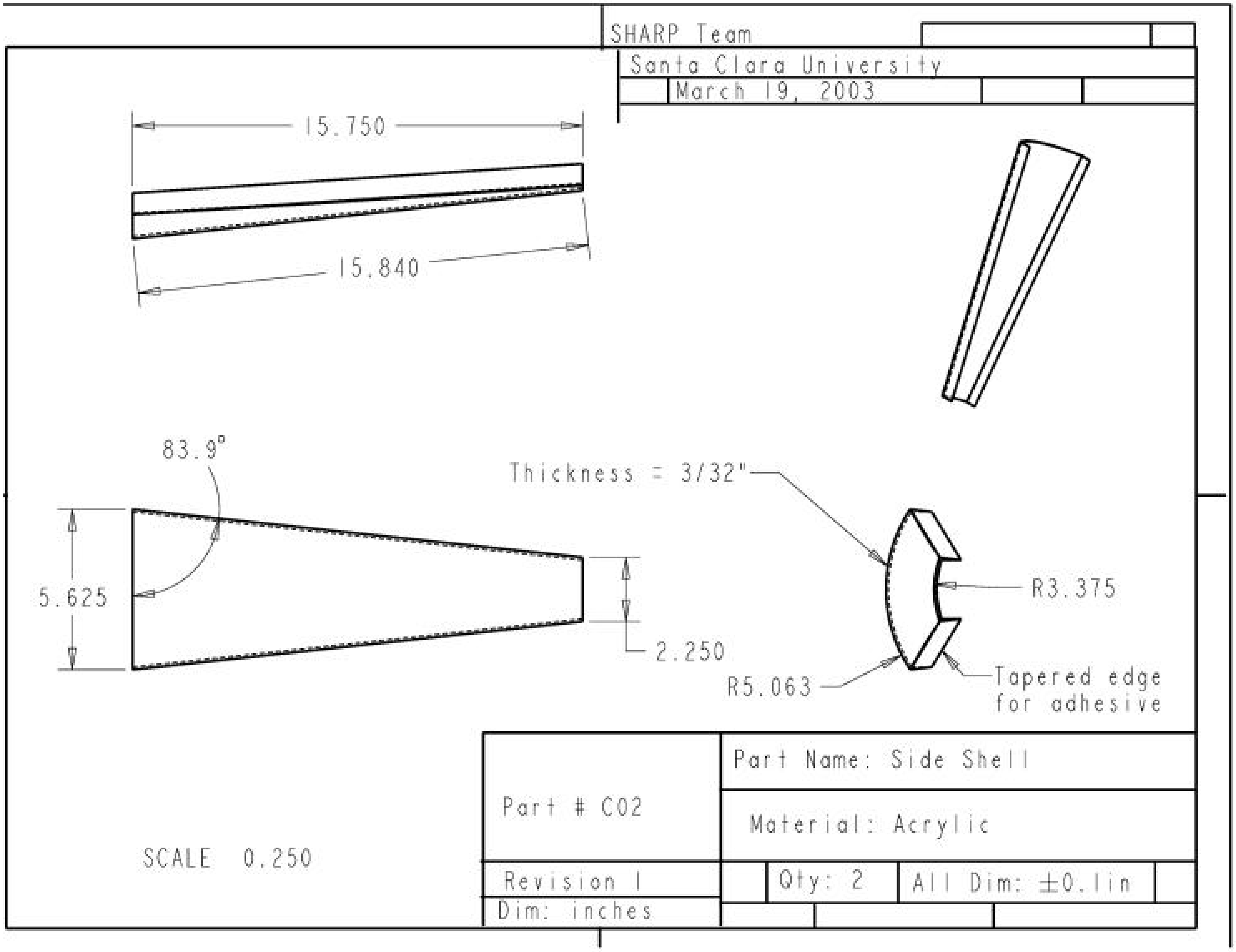
March 19, 2003

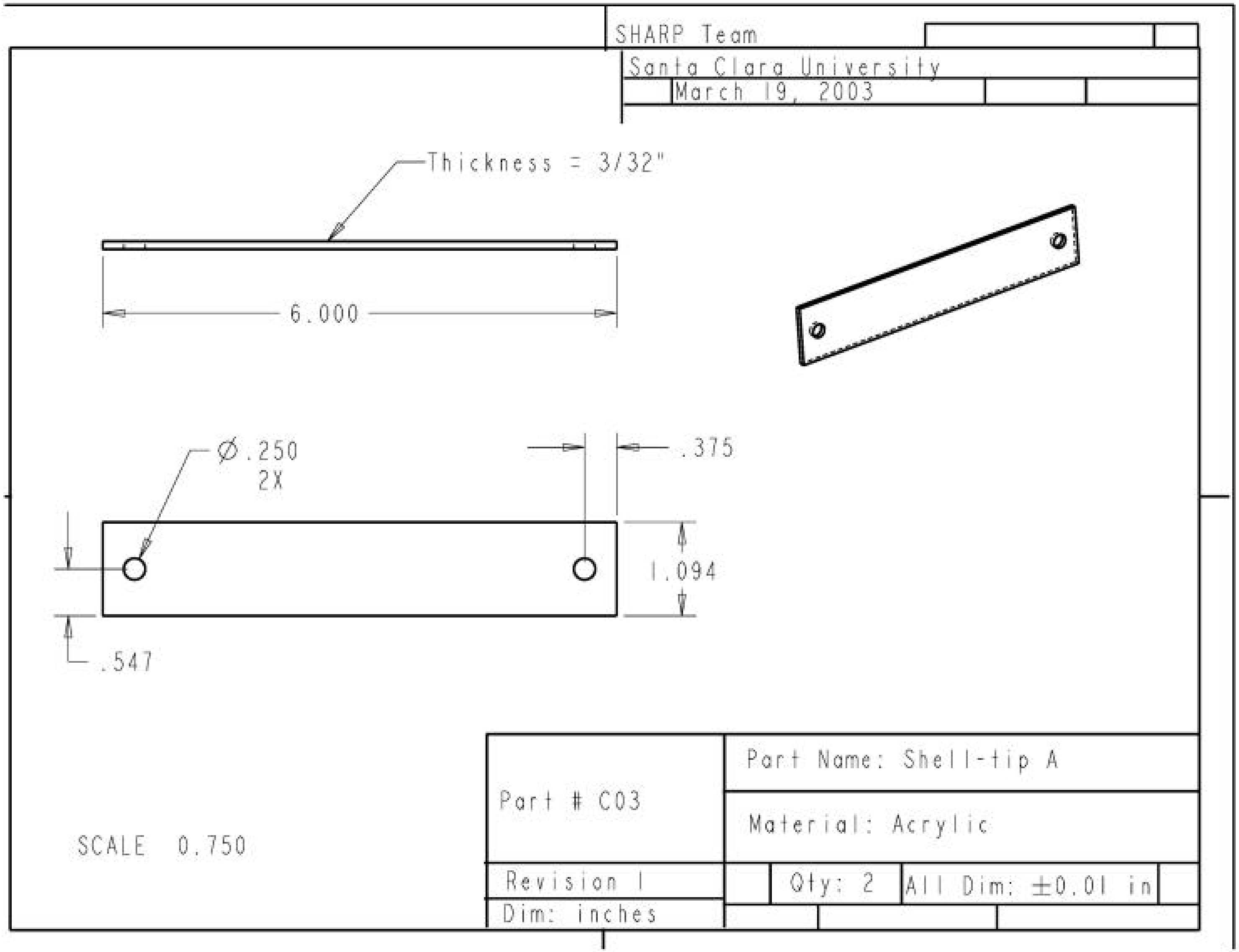


*Slightly tapered edge for adhesive

SCALE 0.250

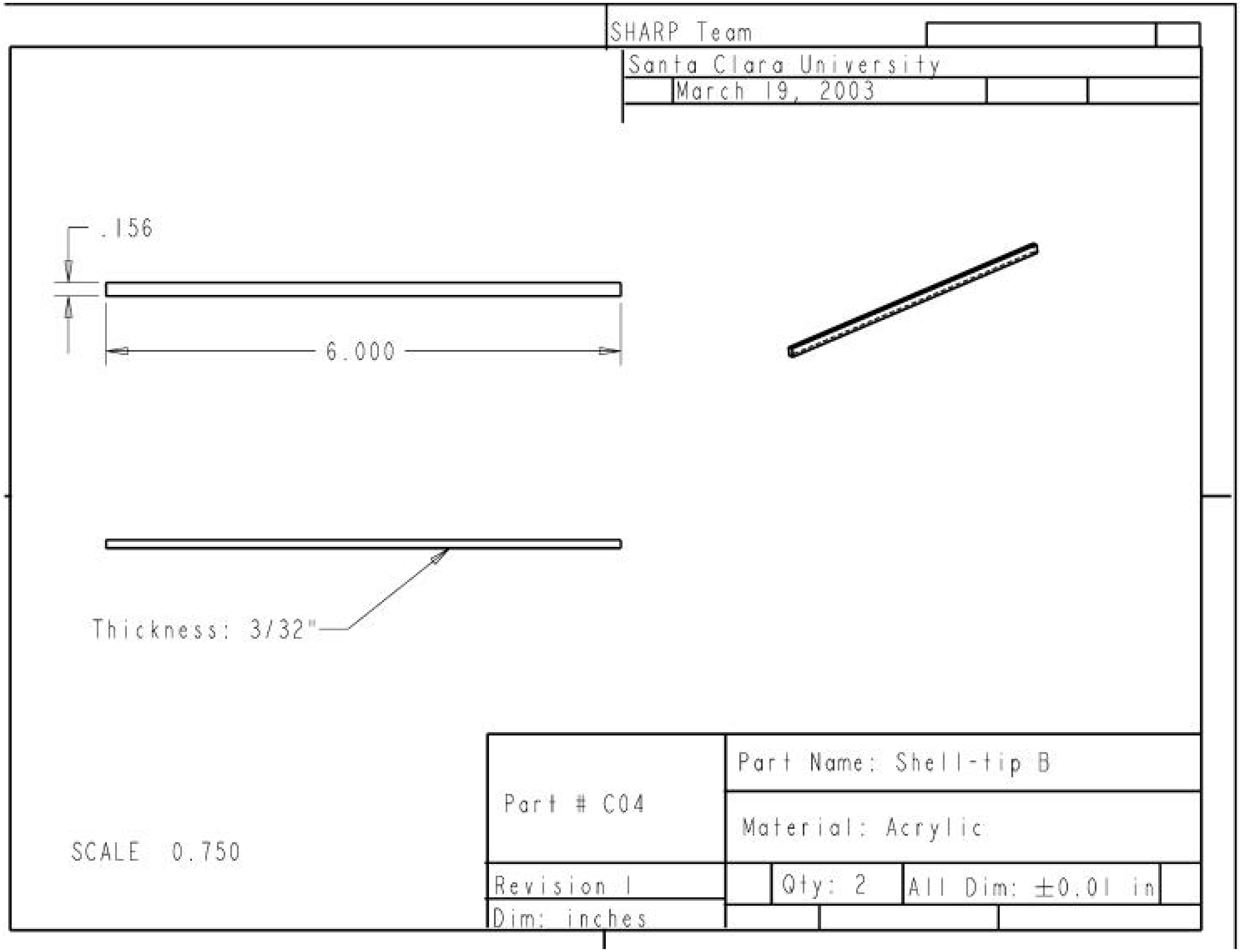
Part # C01	Part Name: Top shell Material: Acrylic
Revision 1	Qty: 2 All Dim: ±0.01 in
Dim: inches	


SHARP Team
Santa Clara University
March 19, 2003
15.750
15.840
83.9°
5.625
2.250
Thickness = 3/32"
R3.375
R5.063
Tapered edge for adhesive
SCALE 0.250
Part # C02
Part Name: Side Shell
Material: Acrylic
Revision 1
Dim: inches
Qty: 2
All Dim: ±0.1in

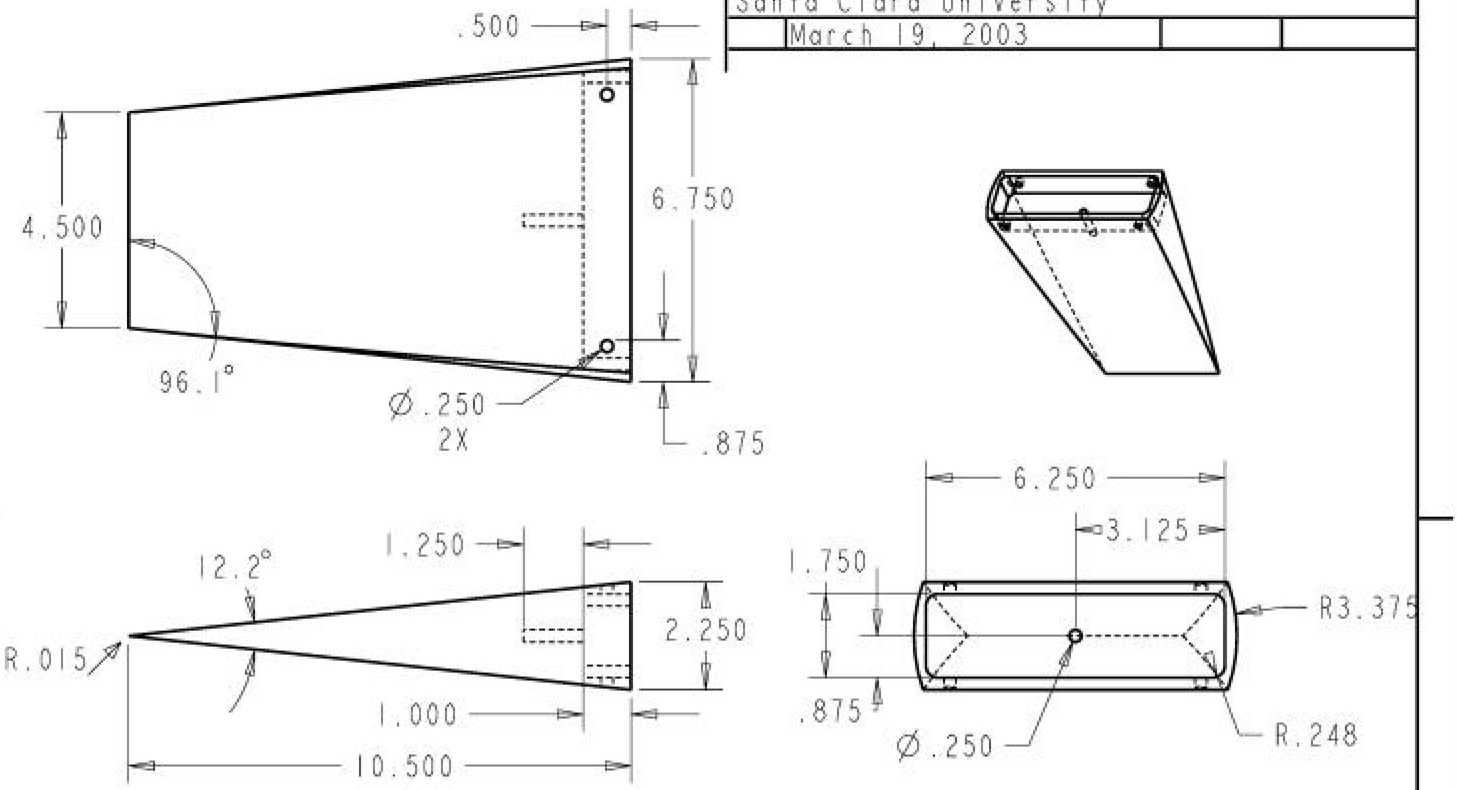


SHARP Team
Santa Clara University
March 19, 2003

Part # C03
Part Name: Shell-tip A
Material: Acrylic
Revision 1
Dim: inches
Qty: 2
All Dim: ±0.01 in

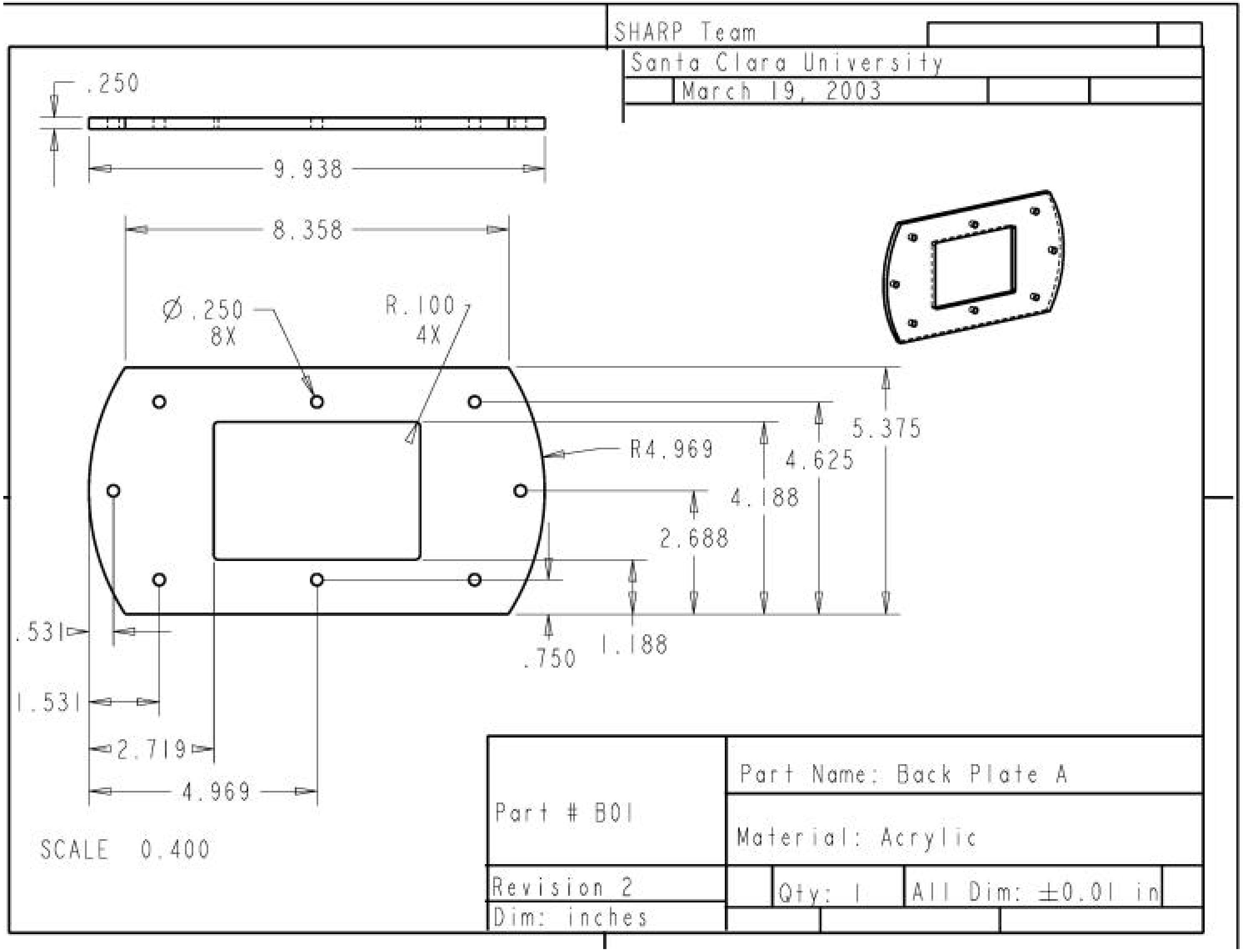

SHARP Team
Santa Clara University
March 19, 2003
.156
6.000
Thickness: 3/32"
SCALE 0.750
Part # C04
Part Name: Shell-tip B
Material: Acrylic
Revision 1
Dim: inches
Qty: 2
All Dim: ±0.01 in

SHARP Team
Santa Clara University
March 19, 2003



SCALE 0.350

Part # L01	Part Name: Front Tip Material: Aluminum 6061
Revision 2 Dim: inches	Qty: 1 All Dim: ±0.01 in



SHARP Team
Santa Clara University
March 19, 2003

SCALE 0.400

Part # B01

Part Name: Back Plate A

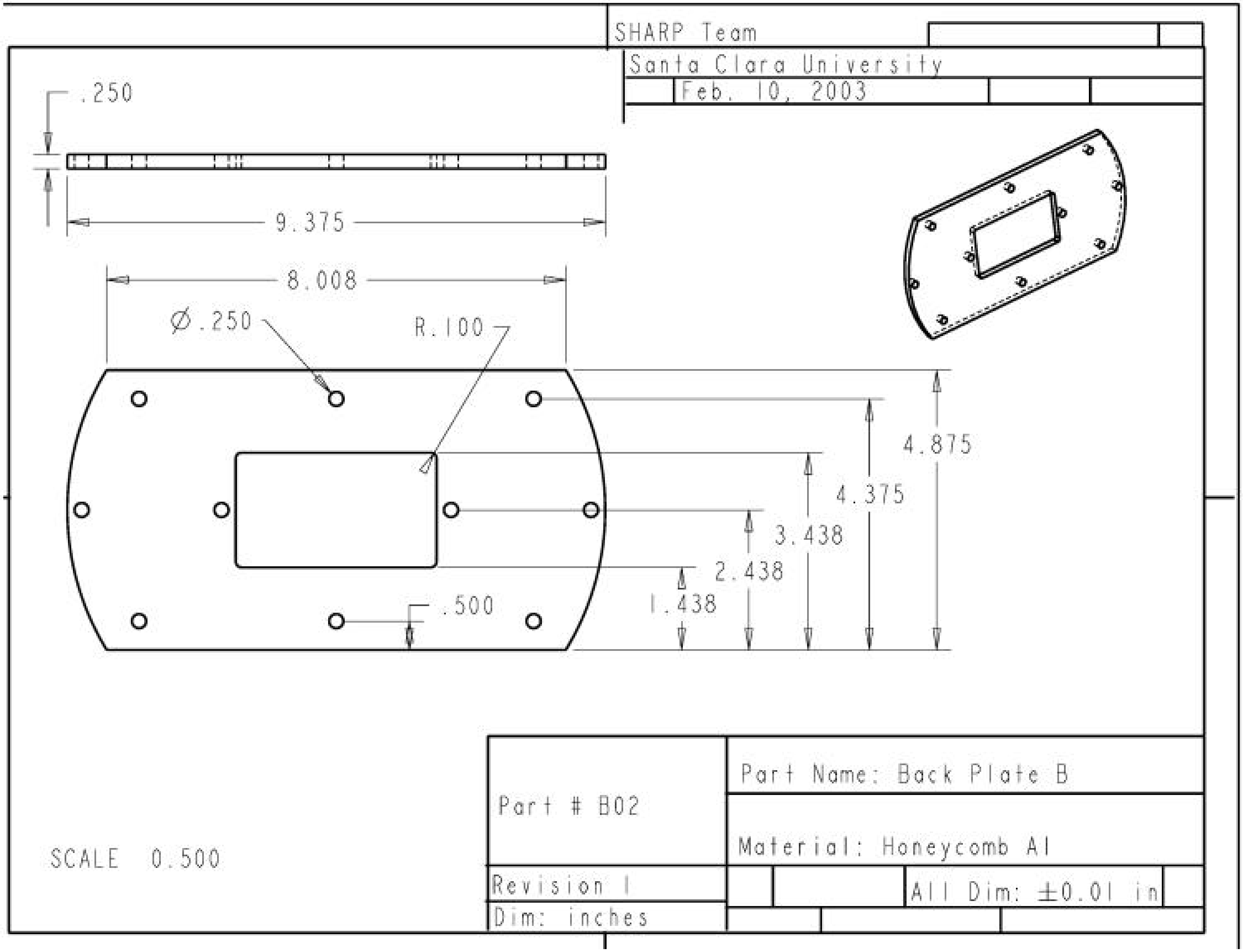
Material: Acrylic

Revision 2

Dim: inches

Qty: 1

All Dim: ±0.01 in



SHARP Team
Santa Clara University
Feb. 10, 2003

Part # B02

Part Name: Back Plate B

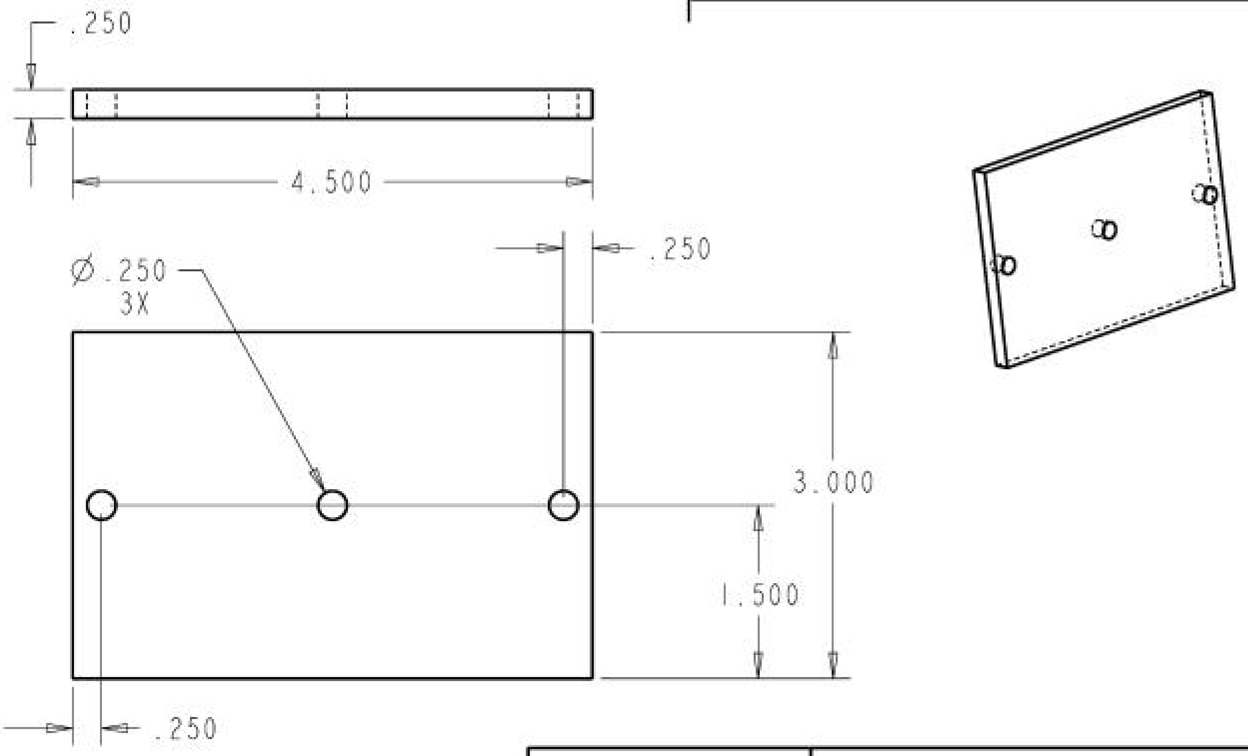
Material: Honeycomb Al

Revision 1

Dim: inches

All Dim: ±0.01 in

SHARP Team
Santa Clara University
March 19, 2003



SCALE 0.850

Part # B03

Part Name: Door

Material: Acrylic

Revision 2

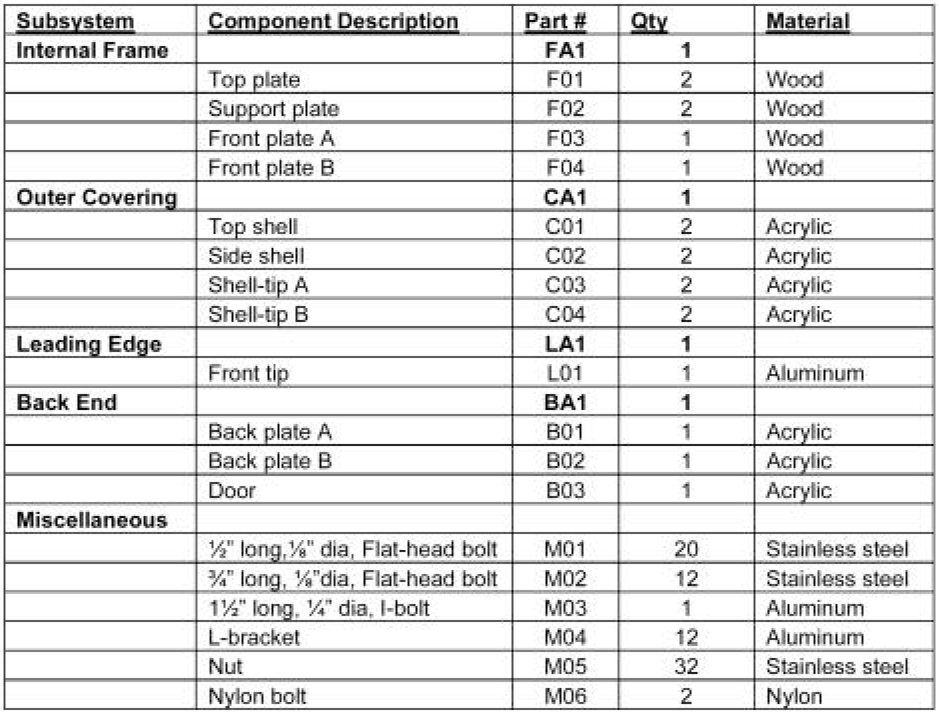
Dim: inches

Qty: 1

All Dim: ±0.01 in

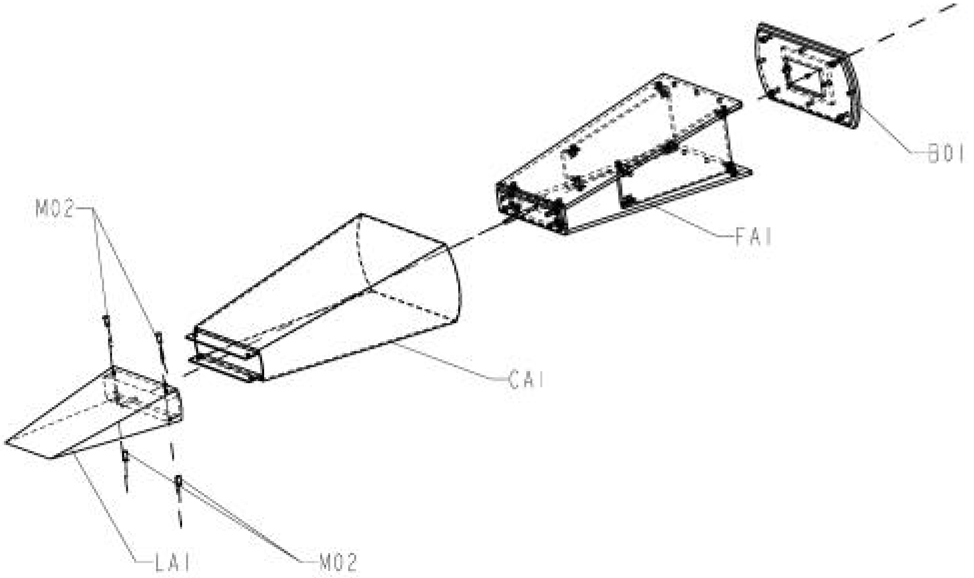
Appendix C: Assembly Drawings

Bill of Materials



Subsystem	Component Description	Part #	Qty	Material
Internal Frame		**FA1**	**1**	
	Top plate	F01	2	Wood
	Support plate	F02	2	Wood
	Front plate A	F03	1	Wood
	Front plate B	F04	1	Wood
Outer Covering		**CA1**	**1**	
	Top shell	C01	2	Acrylic
	Side shell	C02	2	Acrylic
	Shell-tip A	C03	2	Acrylic
	Shell-tip B	C04	2	Acrylic
Leading Edge		**LA1**	**1**	
	Front tip	L01	1	Aluminum
Back End		**BA1**	**1**	
	Back plate A	B01	1	Acrylic
	Back plate B	B02	1	Acrylic
	Door	B03	1	Acrylic
Miscellaneous				
	½" long,⅛" dia, Flat-head bolt	M01	20	Stainless steel
	¾" long, ⅛"dia, Flat-head bolt	M02	12	Stainless steel
	1½" long, ¼" dia, I-bolt	M03	1	Aluminum
	L-bracket	M04	12	Aluminum
	Nut	M05	32	Stainless steel
	Nylon bolt	M06	2	Nylon

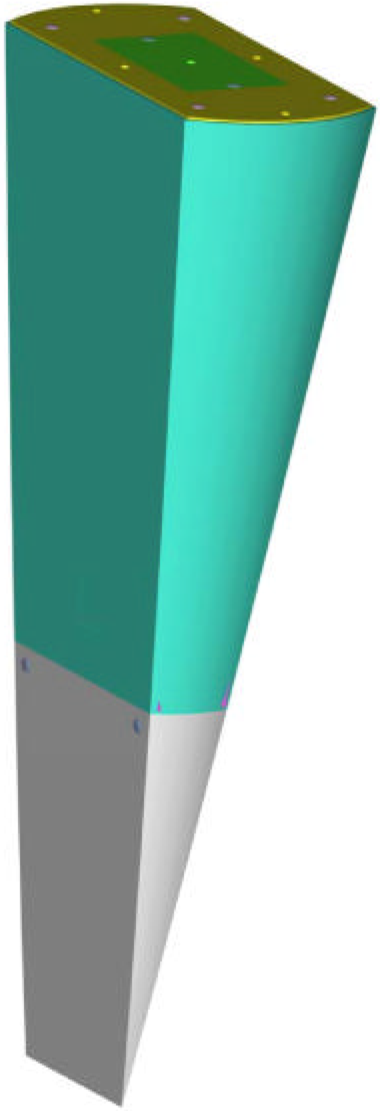
Part No.	Description
LA1	Leading edge
CA1	Outer covering
FA1	Internal frame
BA1	Back end
M02	Flat-head screw (long)
M05	Nut*

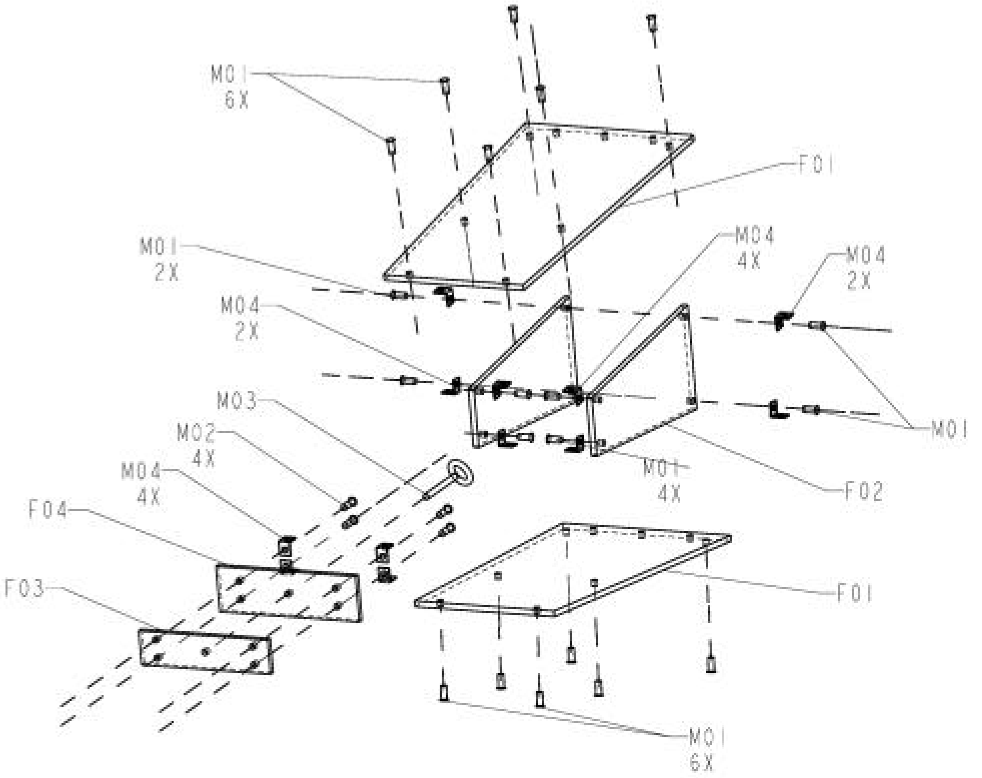


SCALE 0.225

*Note: Nuts are not shown.
They are placed on end of all screws.

SHARP Team	March 19, 2003
Santa Clara University	Revision 1
Overall Vehicle Assembly	



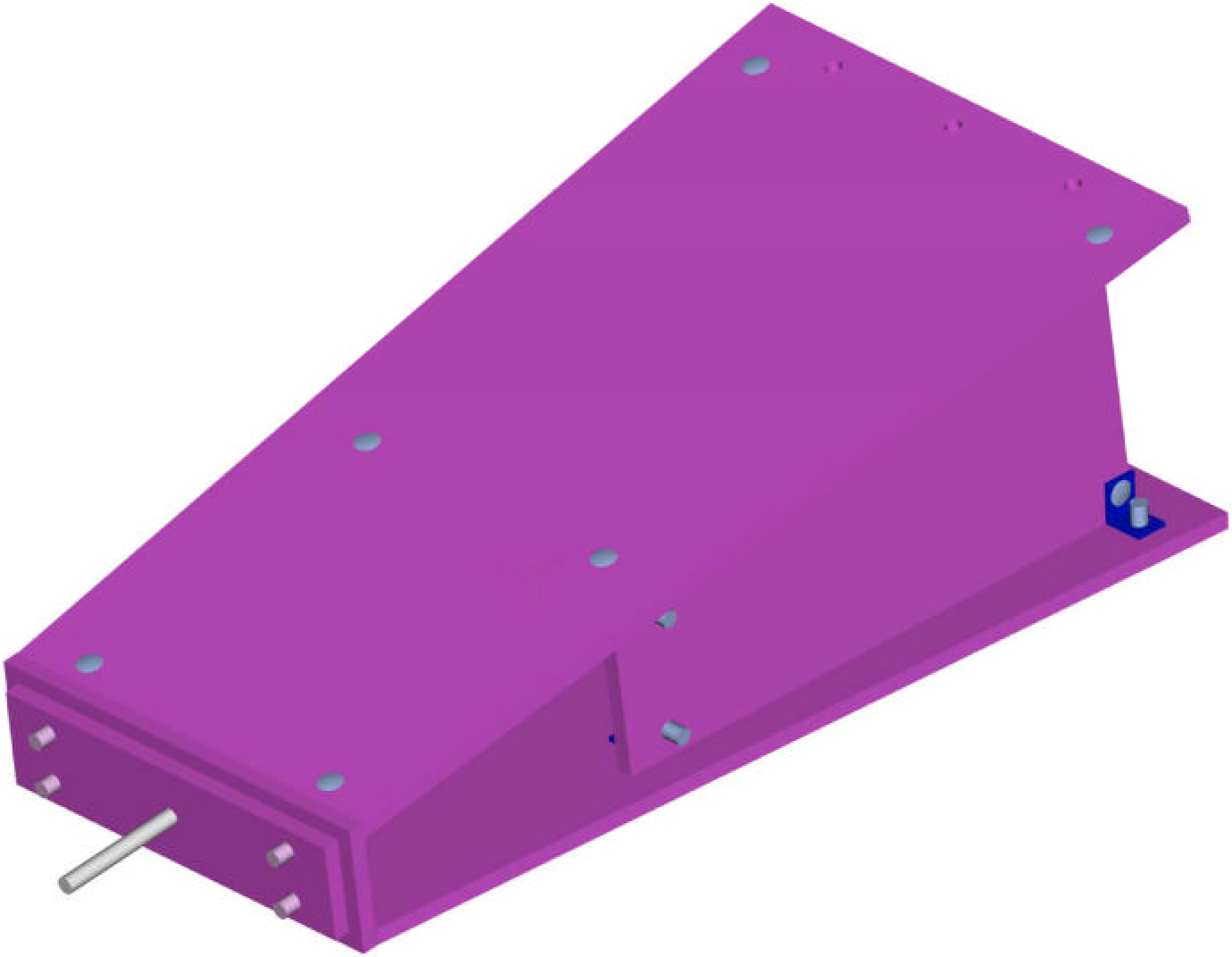


Part No.	Description
F01	Top Plate
F02	Support Plate
F03	Front Plate A
F04	Front Plate B
M01	Flat-head screw (short)
M02	Flat-head screw (long)
M03	I-bolt
M04	L-bracket
M05	Nut*

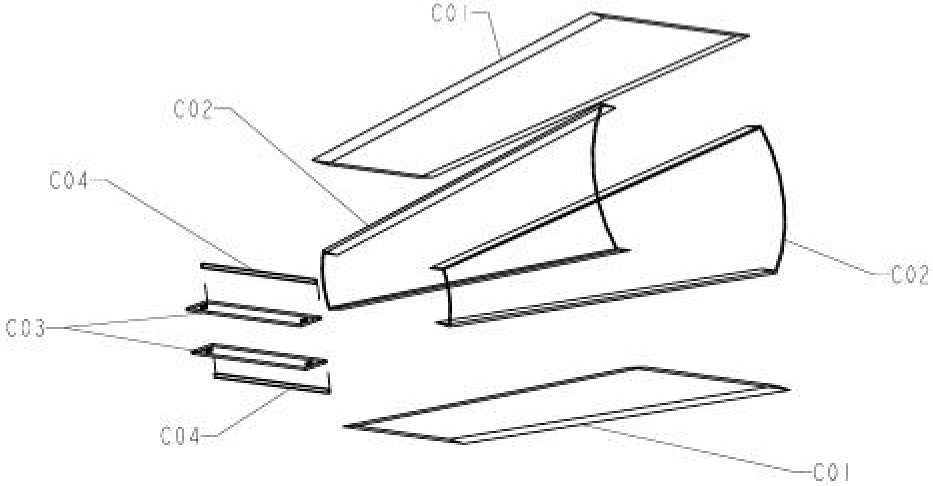
SCALE 0.350

*Note: No nuts are shown.
They are placed on ends of all screws.

SHARP Team	March 19, 2003
Santa Clara University	Revision 1
Subassembly: Internal Frame	



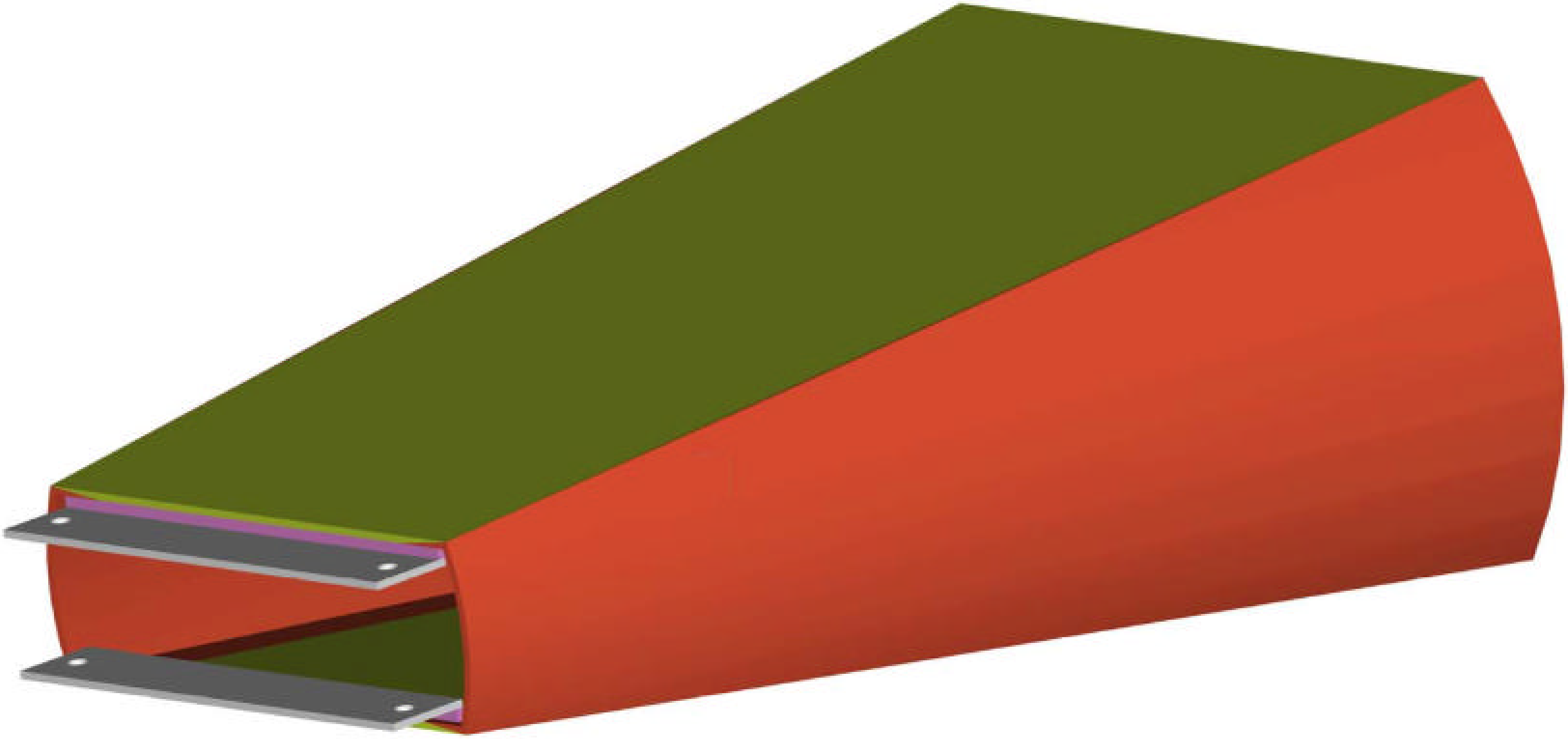
Part No.	Description
C01	Top shell
C02	Side shell
C03	Shell-tip A
C04	Shell-tip B

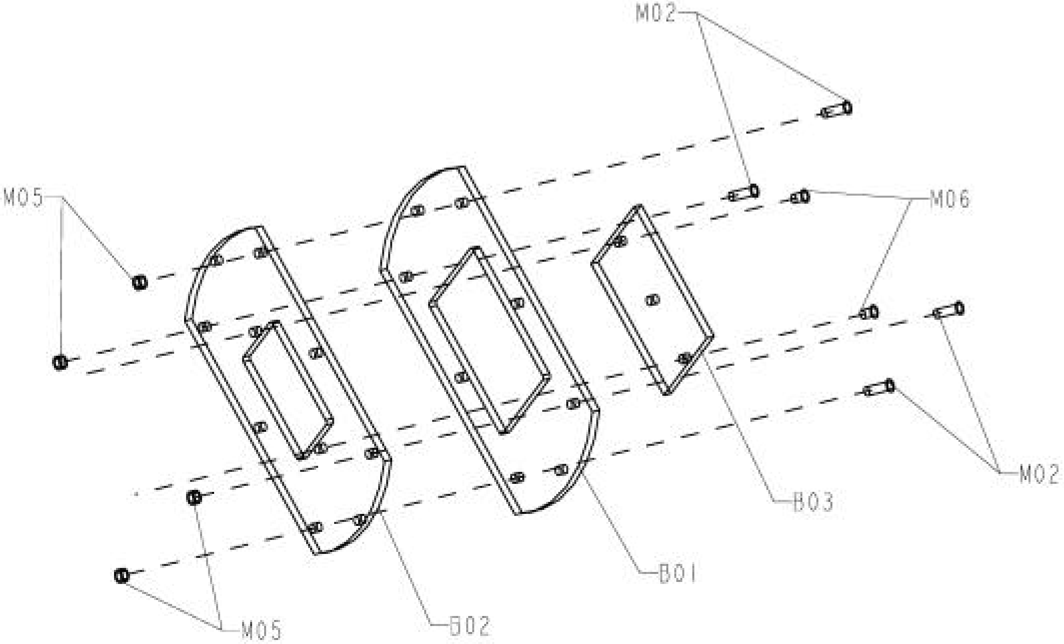


SCALE 0.400

Note: All pieces are joined by:
IPS Weld-On #16 Cement for Acrylic Sheet

SHARP Team	March 19, 2003
Santa Clara University	Revision 1
Subassembly: Outer Covering	

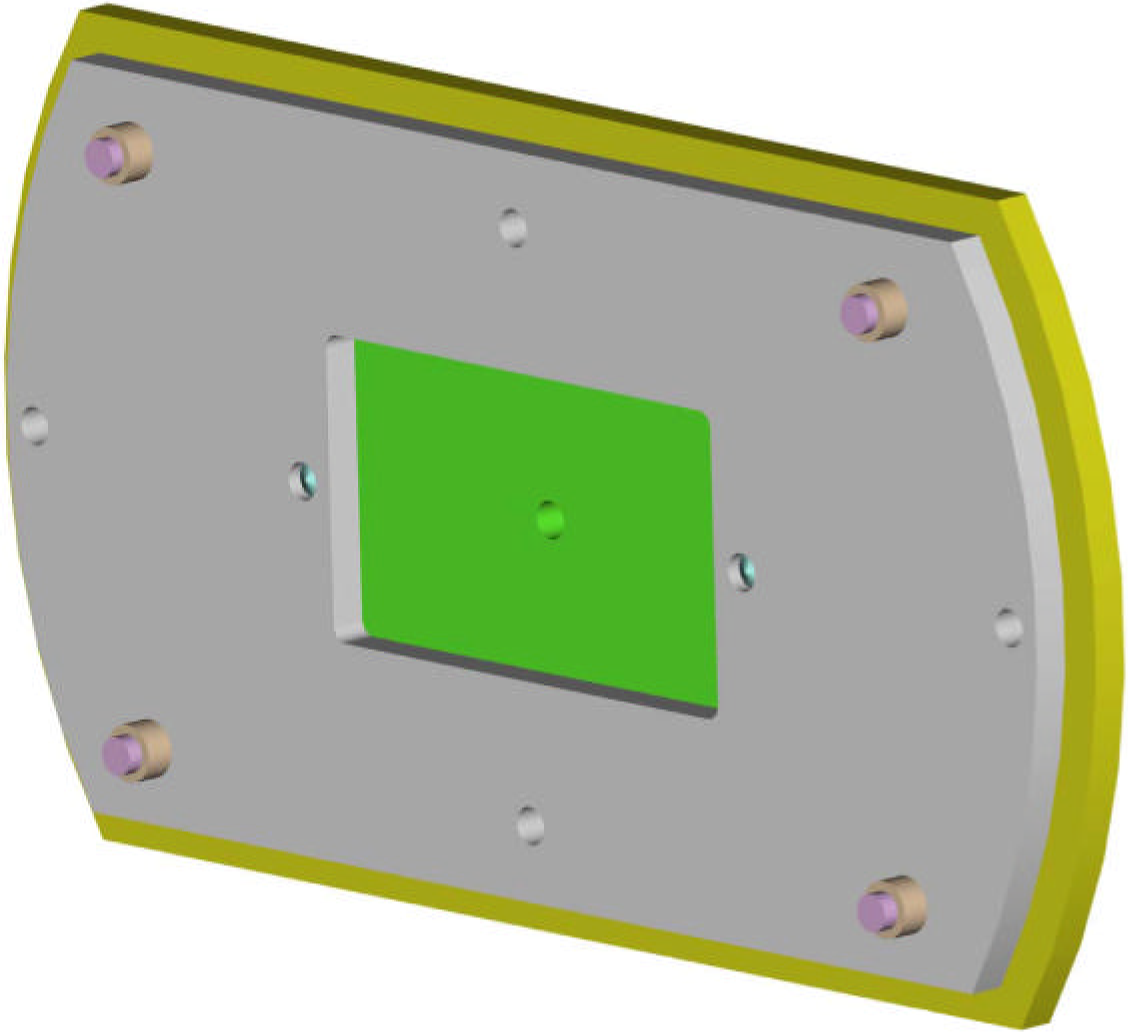




Part No.	Description
B01	Back Plate A
B02	Back Plate B
B03	Door
M02	Flat-head screw (long)
M05	Nut
M06	Nylon bolt

SCALE 0.500

SHARP Team	March 19, 2003
Santa Clara Univesity	Revision 1
Subassembly: Back End	



Appendix D: Project Design Specification

Design Project: SHARP Reentry Vehicle

Team: SHARP Date: May 24, 2003 Revision: 4

Datum Description: NONE—SHARP is a pioneering project

ELEMENTS/REQUIREMENTS	UNITS	PARAMETERS		
		DATUM*	INCREMENTAL	BEST
Communication Link				
# of data channels	#of pins		8	12
Data sampling rate	Hz		2	5
On-board data storage	KB		30	50
Transmit data rate	bit/sec		1200	2500
Data sample resolution	bit		8	16
Duration of data gathering	Sec		95	120
Transmission range	Mi		30mi	50mi
Physical Properties				
Center of mass	%length from tip		35	15
Center of pressure	%length from tip		70	85
Target drag coefficient			0.45	0.3
Mass	Kg		6.67	2.75
Angle of tip	degree	11.3*	12	9.5
Volume	m3		0.03	0.025
Usable volume	m3		0.015	0.02
Length	M	1.00*	0.67	0.75
Width	M	0.425*	0.33	0.4
Thickness	M	0.165*	0.11	0.2
Environmental Factors				
Max winds	km/hr		100	150
Drifting distance	M		2000	500
Max lateral acceleration	m/s2		10	15
Altitude achieved	M		24,000	30,000
Max temperature of air	deg. C		20	35
Min temperature of air	deg. C		-60	-80
Max temperature of surface	deg. C		50	70
Max atmospheric pressure	Pa		101,325	110,000
Min atmospheric pressure	Pa		2800	1100

Operational Factors				
# of accelerometers			3	5
# of pressure sensors			7	20
GPS accuracy range	M		5	0.002
Time to deploy parachute	Sec		5	3
Ascension time	Min		90	60
Total system power	watts		50	40
Operational lifetime	#of drops		2	10
Shock from parachute deployment	G		8	4
Shock from ground impact	G		2	1.5

*angle value from Montana SU SHARP vehicle—this is the only datum taken from this project

Appendix E: Decision Matrices

Mechanical System Design Decision Matrix

CRITERIA		1	2	3	4	5	6	7	8	TOTAL	FACTOR
1	Cost		1	0.5	1	1	0.5	0	1	5.0	5.5
2	Weight	0		0	1	0.5	0.5	0	1	3.0	3.5
3	Vehicle Safety	0.5	1		1	1	0.5	0.5	0.5	5.0	5.5
4	Aesthetics	0	0	0		0	0	0	0	0.0	0.5
5	Stability	0	0.5	0	1		0	0	0.5	2.0	2.5
6	Accessibility	0.5	0.5	0.5	1	1		0	0.5	4.0	4.5
7	Data Gathering	1	1	0.5	1	1	1		0	5.5	6.0
8	Reliability	0	0	0.5	1	0.5	0.5	1		3.5	4.0

Design Ideas

		Parachute recovery systems						Balloon drop systems						Basic geometry							
CRITERIA	**FACTOR**	Multi-stage parachute		Pre-deployment streamers		Single parachute		Hot wires		Carriage/ trap door		Minor explosion		Slender		Fat		Flat		Rounded	
Cost	5.5	3	17	4	22	4	22	3	17	2	11	2	11	3	16.5	3	16.5	3	17	2	11
Weight	3.5	3	11	4	14	4	14	3	11	1	3.5	3	11	3	10.5	2	7	3	11	3	11
Vehicle Safety	5.5	3	17	1	5.5	1	5.5	3	17	3	17	1	5.5	3	16.5	3	16.5	3	17	3	17
Aesthetics	0.5	3	1.5	3	1.5	3	1.5	3	1.5	2	1	3	1.5	3	1.5	2	1	3	1.5	4	2
Stability	2.5	3	7.5	2	5	2	5	3	7.5	3	7.5	3	7.5	3	7.5	2	5	3	7.5	4	10
Accessibility	4.5	3	14	3	14	3	14	3	14	2	9	2	9	3	13.5	4	18	3	14	3	14
Data Gathering	6.0	3	18	3	18	3	18	3	18	3	18	3	18	3	18	3	18	3	18	3	18
Reliability	4.0	3	12	1	4	2	8	3	12	3	12	2	8	3	12	3	12	3	12	3	12
	TOTAL		96		84		88		96		79		71		96		94		96		94
	RANKING		1		3		2		1		2		3		1		2		1		3

		Internal frame					
CRITERIA	**FACTOR**	I-beam		Hollow interior		Simple supports	
Cost	5.5	3	17	3	17	3	17
Weight	3.5	3	11	2	7	4	14
Vehicle Safety	5.5	3	17	2	11	2	11
Aesthetics	0.5	3	1.5	3	1.5	3	1.5
Stability	2.5	3	7.5	2	5	2	5
Accessibility	4.5	3	14	2	9	2	9
Data Gathering	6.0	3	18	3	18	3	18
Reliability	4.0	3	12	3	12	2	8
	TOTAL		96		80		83
	RANKING		1		3		2

Software System Design Decision Matrix

CRITERIA		**1**	**2**	**3**	**4**	**5**	**TOTAL**	**FACTOR**
1	Performance		1	.5	1	1	3.5	4.0
2	Maintainability	0		0	1	.5	1.5	2.0
3	Test Ease	.5	1		1	1	3.5	4.0
4	Development Ease	0	0	0		0	0.0	0.5
5	Scalability	0	.5	0	1		1.5	2.0

Design Ideas

		Development Architectures						Development Model					
CRITERIA	**FACTOR**	Object Oriented		Multi-threaded		Sequential		Chaotic		eXtreme Pgrmg.		Itterative Dev.	
Performance	4.0	1	4	3	12	5	20	3	12	3	12	3	12
Maintainability	2.0	5	10	2	4	3	6	1	2	4	8	3	6
Test Ease	4.0	4	16	1	4	4	16	1	4	5	20	4	16
Development Ease	0.5	4	2	2	1	3	1.5	5	2.5	2	1	4	2
Scalability	2.0	4	8	3	16	2	4	1	2	4	8	3	6
	TOTAL		40		37		47.5		22.5		49		42
	RANKING		2		3		1		3		1		2

Appendix F: Timelines

Mechanical Engineering Timeline

Fall Quarter:

Week of:

9/23

-Entire project team meets

9/30

-Develop a thesis statement
-Rough block diagram of our system

10/7

-Begin designing more detailed block diagram of system and listing parts and materials

10/14

-Begin designing layout within SHARP vehicle and brainstorming timeline
-Determine a loose weight approximation for vehicle

10/21

-Brainstorm subsystem tests with respect to communication link and data acquisition
-Create detailed functional block diagram of entire system and all subsystems
-Contact sponsor and relay project layout and refine customer needs of project
-Tradeoff analysis of borderline design parameters

10/28

-Research for needed and necessary parts in system that aren't available in RSL
-Debug detailed functional block diagram after meeting with advisor
-Begin discussion of outer fuselage material for vehicle
-Project planning, rapid prototyping
-Print copy of customer needs and turn in report

11/4

-Functional analysis of block diagram/system layout and review
-Initial analysis of prototype, product architecture and planning
-Determine component communication and functionality
-Selection matrices for design, QFD

11/11

-Finite element analysis of vehicle and research FEA with past vehicles
-More development of mock up and initial drawings
-Determine in more detail cost and budgeting
-Continue analysis of prototype

11/18

-Begin conceptual design of vehicle

-More FEA
-Continue development of mock, drawings, and analysis

11/25
-Thanksgiving Holiday Week

12/02
-Continue mock up and initial drawings of vehicle
-Conceptual design report and analysis report
-Finalize cost estimating
-Clean up design notebook

12/11
-Turn in design drawings
-Turn in mock up

Winter Quarter:

1/12
-Purchase Al for front tip
-Meet with machine shop managers about tip machining procedure
-Contact fiberglass manufacturers for outer shell
-Weigh and measure purchased control/communication components
-Obtain necessary honeycomb

1/19
-Begin machining front tip
-Begin drawings
-Discuss outer shell material and manufacturing

1/26
-Continue machining front tip
-Continue drawings
-Review budget and make report
-Revise product design specification
-Plan a the independent conceptual design review for sponsor

2/2
-Continue drawings
-Continue machining front tip
-Begin machining some honeycomb
-Decide on shell manufacturing
-If necessary, continue FEA of more parts

2/9
-Finish drawings

-Decide on details of outer shell manufacturing
-Continue tip machining

2/16

-Continue tip machining
-Begin outer shell purchasing of components
-Meet with parachute and high altitude balloon expert

2/23

-Continue tip machining
-Begin outer shell manufacturing
-Begin parachute design and placement

3/2

-Begin design of placing internal components inside vehicle
-Decide on wood for internal frame material
-Continue assembly drawings
-Continue tip machining
-Write Progress Report and plan a presentation
-Purchase parachute

3/9

-Finish front tip
-Begin assembly of internal frame
-Complete any overlooked details and fine-tune vehicle
-Finish assembly drawings
-Refine budget

3/16

-Turn in assembly drawings
-Finish assembly of internal frame
-Purchase a high altitude balloon

Spring Quarter:

3/30

-Write table of contents and introduction to Thesis

4/6

-Interview with Alumni Association for funding
-Begin manufacturing of back end system

4/13

-Continue fastening internal components
-Update PDS and do an experimental protocol
-Continue manufacturing backend system
-Parachute purchasing

4/20

- Turn in updated PDS and experimental protocol
- Finish back end plate
- Parachute arrives

4/27

- Begin preparation for Senior Design Conference
- Finish back end door for parachute

5/4

- Senior Design Conference presentation

5/11

- Business Plan
- Begin writing Thesis
- Take digital pictures
- Parachute experiments

5/18

- Turn in Business Plan
- Continue working on Thesis

5/25

- Finish up a draft of the Thesis and turn in
- More parachute, CG and weight testing

6/1

- Continue working on Thesis for improvements
- Open House for hardware

6/8

- Finish final draft of Thesis and turn in

Electrical Engineering Timeline

Fall Quarter:

Week of:

9/23
- Entire project team meets

9/30
- Develop a thesis statement
- Rough block diagram of our system

10/7
- Begin designing more detailed block diagram of system and listing parts and materials

10/14
- Begin designing layout within SHARP vehicle and brainstorming timeline

10/21
- Brainstorm subsystem tests with respect to communication link and data acquisition
- Create detailed functional block diagram of entire system and all subsystems
- Tradeoff analysis of borderline design parameters

10/28
- Research electrical components necessary for prototype
- Debug detailed functional block diagram after meeting with advisor
- Project planning, rapid prototyping

11/4
- Functional analysis of block diagram/system layout and review
- Determine component communication and functionality

11/11
- More development of mock up
- Determine in more detail cost and budgeting
- Continue analysis of prototype

11/18
- Begin conceptual design of vehicle
- Continue development of mock, drawings, and analysis

11/25
- Thanksgiving Holiday Week

12/02
- Continue mock up and initial internal electrical drawings of vehicle
- Conceptual design report and analysis report
- Finalize cost estimating

12/11
- Search for sensor components
- Pick up components available at RSL lab.

Winter Quarter:

1/12
- Purchase Accelerometer, Pressure Sensor
- Familiarize with communication system

1/19
- Begin work on power budget
- Research possible power sources

1/26
- Communication System equations developed
- Review budget and make report
- Revise product design specification
- Plan an independent conceptual design review for sponsor

2/2
- Purchase communication components: antennas and connectors.
- Prepare for communication test

2/9
- Finalize power budget
- Select and purchase batteries

2/16
- Create a wiring diagram
- Conduct communications test on Mt. Hamilton

2/23
- Research voltage regulation system and purchase components
- Purchase temperature sensor

3/2
- Begin implementation of sensors
- Write Progress Report and plan a presentation

3/9
- Implement power and voltage regulation system
- Research possible test bed for pressure sensors
- Continue calibration for internal sensors

3/16
- Begin System level testing of all components
- Implement GPS and HAM radio system

Spring Quarter:

3/30
- Write table of contents and introduction to Thesis

4/6
- Finalize electrical system including fabrication of all circuits
- Test the finalized system with computer architecture

4/13
- Continue fastening internal components
- Continue testing components

4/20

- Begin work on presentation for Senior Design Conference
- Continue testing and calibration

4/27

- Continue preparation for Senior Design Conference
- Finish presentation level prototype for demonstration

5/4

- Senior Design Conference presentation

5/11

- Begin writing Thesis
- Take digital pictures

5/18

- Continue working on Thesis

5/25

- Finish up a draft of the Thesis and turn in

6/1

- Continue working on Thesis for improvements

6/8

- Finish final draft of Thesis and turn in

Computer Engineering Timeline

Fall Quarter:

Week of:

9/23
- Entire project team meets

10/14
- Software Analysis Begins

10/21
- Create detailed functional block diagram of entire system and all subsystems

10/28
- System Story Defined

11/11
- Flight Plan Defined

11/18
- AVR Family Chosen

11/25
- Thanksgiving Holiday Week

12/02
- AVR training session
- Atmega128 Microprocessor and AVRMini 3.1 Proto-board Chosen

12/11
- Software Architecture Chosen
- Atmega 128 Microprocessor Acquired
- eXtreme Programming Chosen as Software Development Model
- Fall Design Report Due

Winter Quarter:

1/12
- Initial Software Requirements Defined
- AVRmini 3.1 Proto-board acquired

1/19
- Software Development Schedule Defined

1/26
- Computer Engineering Design Review

2/2
- AVR Microcontroller and AVRMini 3.1 Proto-board Integrated

3/9
- Base Station Implementation Completed

Spring Quarter:

4/6
- AVRMini Fully Functional

-AVR Coding Begins
-Interview with Alumni Association for funding

4/13

-A/D Converter Analyzed and Calibrated
-Initial integration with Electrical System

4/20

-GPS and HAM Integration Begin

4/27

-First round of Integration Testing with Electrical System

5/4

-Senior Design Conference presentation
-Sr Design Conference

5/11

-Begin writing Thesis

5/18

-Continue working on Thesis

5/25

-Finish up a draft of the Thesis and turn in

6/1

-Continue working on Thesis for improvements

6/8

-Finish final draft of Thesis and turn in

Appendix G: Budget

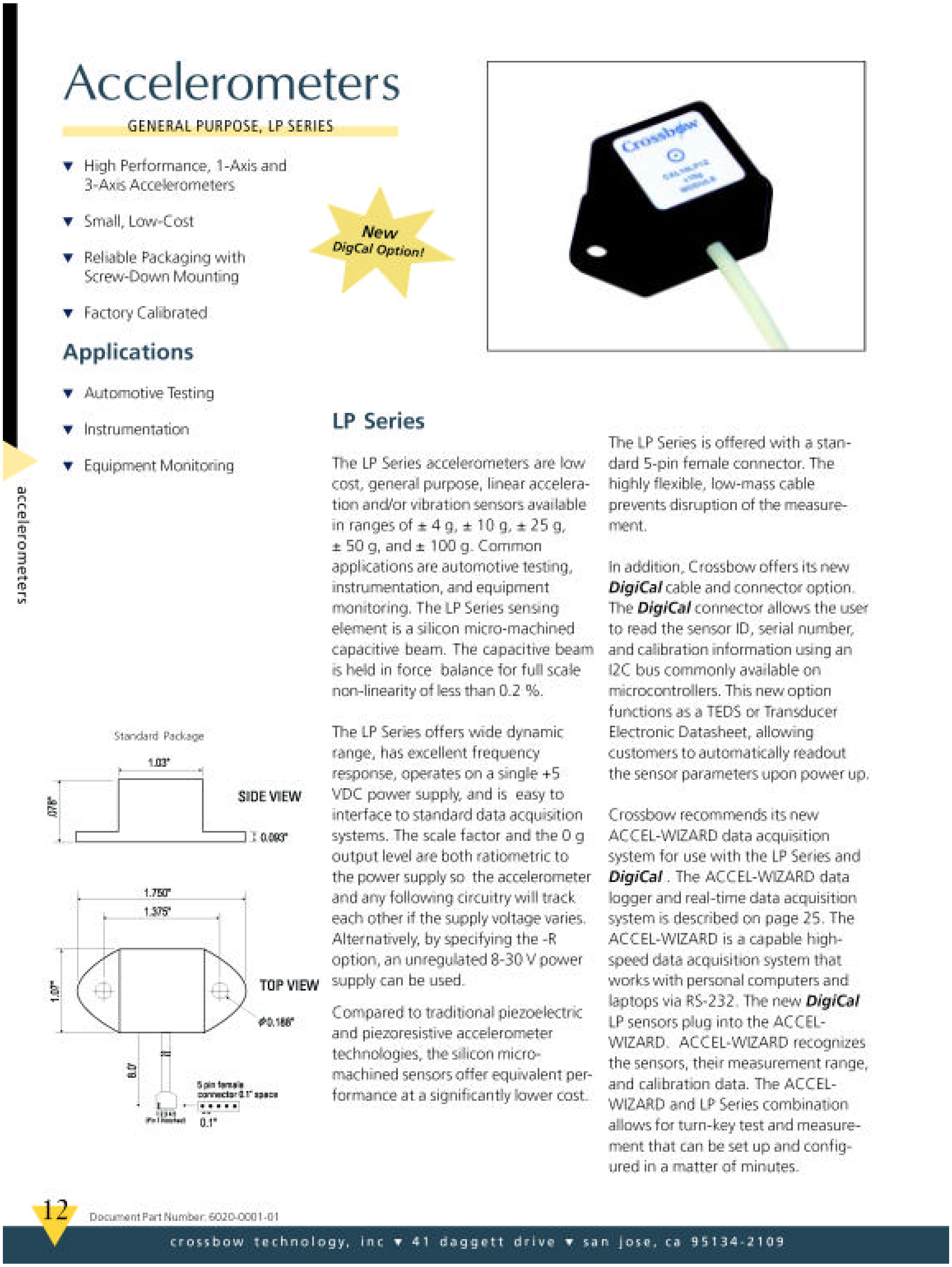
Parts in Possession and provided by RSL:
GPS
HAM radio
ATMEL Microcontroller

Parts Purchased:

Aluminum slab (for front tip)	$100
Internal Frame Wood	$15
Crossbow Accel. Sensor	$377
Digikey Pressure Sensor x 5	$108
ATMEL memory chips x 3	$33
SHARP shell	$20
Comm./Electrical modifiers and connectors	$50
Parachute	$75
Internal fasteners	$20
Total Expenditures	**$798**

All funding for the SHARP project is provided by Dr. Kitts and the Robotic Systems Laboratory. Other funding may be provided by NASA at a later point.

Appendix H: Data Sheets



Accelerometers

GENERAL PURPOSE, LP SERIES

- High Performance, 1-Axis and 3-Axis Accelerometers
- Small, Low-Cost
- Reliable Packaging with Screw-Down Mounting
- Factory Calibrated

New
DigCal Option!

Applications

- Automotive Testing
- Instrumentation
- Equipment Monitoring

accelerometers

LP Series

The LP Series accelerometers are low cost, general purpose, linear acceleration and/or vibration sensors available in ranges of ± 4 g, ± 10 g, ± 25 g, ± 50 g, and ± 100 g. Common applications are automotive testing, instrumentation, and equipment monitoring. The LP Series sensing element is a silicon micro-machined capacitive beam. The capacitive beam is held in force balance for full scale non-linearity of less than 0.2 %.

The LP Series offers wide dynamic range, has excellent frequency response, operates on a single +5 VDC power supply, and is easy to interface to standard data acquisition systems. The scale factor and the 0 g output level are both ratiometric to the power supply so the accelerometer and any following circuitry will track each other if the supply voltage varies. Alternatively, by specifying the -R option, an unregulated 8-30 V power supply can be used.

Compared to traditional piezoelectric and piezoresistive accelerometer technologies, the silicon micro-machined sensors offer equivalent performance at a significantly lower cost.

The LP Series is offered with a standard 5-pin female connector. The highly flexible, low-mass cable prevents disruption of the measurement.

In addition, Crossbow offers its new ***DigiCal*** cable and connector option. The ***DigiCal*** connector allows the user to read the sensor ID, serial number, and calibration information using an I2C bus commonly available on microcontrollers. This new option functions as a TEDS or Transducer Electronic Datasheet, allowing customers to automatically readout the sensor parameters upon power up.

Crossbow recommends its new ACCEL-WIZARD data acquisition system for use with the LP Series and ***DigiCal*** . The ACCEL-WIZARD data logger and real-time data acquisition system is described on page 25. The ACCEL-WIZARD is a capable high-speed data acquisition system that works with personal computers and laptops via RS-232. The new ***DigiCal*** LP sensors plug into the ACCEL-WIZARD. ACCEL-WIZARD recognizes the sensors, their measurement range, and calibration data. The ACCEL-WIZARD and LP Series combination allows for turn-key test and measurement that can be set up and configured in a matter of minutes.

12 Document Part Number: 6020-0001-01

crossbow technology, inc ▼ 41 daggett drive ▼ san jose, ca 95134-2109

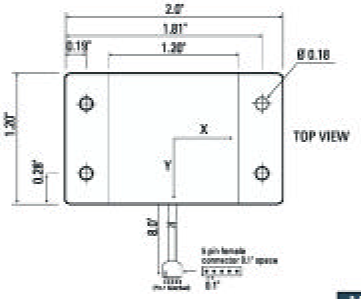
Specifications	CXL04LP1 CXL04LP1Z CXL04LP3	CXL10LP1 CXL10LP1Z CXL10LP3	CXL25LP1 CXL25LP1Z CXL25LP3	CXL50LP1 CXL50LP1Z CXL50LP3	CXL100LP1Z	Remarks
Performance						
Input Range (g)	± 4	± 10	± 25	± 50	± 100	± 5%
Zero g Drift (g)	± 0.2	± 0.2	± 0.2	± 0.2	± 0.2	0°C to 70°C
Sensitivity (mV/g)	500 ± 25	200 ± 10	80 ± 4	40 ± 2	20 ± 4	
Transverse Sensitivity (% Span)	± 5	± 5	± 5	± 5	± 5	
Non-Linearity (% FS)	± 0.2	± 0.2	± 0.2	± 0.2	± 0.2	typical
Alignment Error (deg)	± 2	± 2	± 2	± 2	± 2	typical
Noise (mg rms)	10	10	10	50	80	typical
Bandwidth (Hz)	DC -100	DC -100	DC -100	DC -100	DC -100	
Environment						
Operating Temp. Range (°C)	-40 to +85	-40 to +85	-40 to +85	-40 to +85	-40 to +85	
Shock (g)	2000	2000	2000	2000	2000	
Electrical						
Supply Voltage (Volts)	+ 5.0	+ 5.0	+ 5.0	+ 5.0	+ 5.0	
Supply Voltage -R option (VDC)	+ 8.0 to 30	+ 8.0 to 30	+ 8.0 to 30	+ 8.0 to 30	+ 8.0 to 30	
Supply Current (mA)	5/axis	5/axis	5/axis	5/axis	5/axis	typical
Zero g Output (Volts)	+ 2.5 ± 0.1	+ 2.5 ± 0.1	+ 2.5 ± 0.1	+ 2.5 ± 0.1	+ 2.5 ± 0.1	@25°C
Span Output (Volts)	± 2.0 ± 0.1	± 2.0 ± 0.1	± 2.0 ± 0.1	± 2.0 ± 0.1	± 2.0 ± 0.2	
Output Loading	> 10 kΩ, < 1 nF	> 10 kΩ, < 1 nF	> 10 kΩ, < 1 nF	> 10 kΩ, < 1 nF	> 10 kΩ, < 1 nF	
Physical						
Size	Standard package		0.75" x 1.875" x 1.00 (1.90 cm x 4.76 cm x 2.54 cm)			
	Aluminum package		0.95" x 2.00" x 1.20" (2.41 cm x 5.08 cm x 3.05 cm)			
Weight	Standard package		1.62 oz (46 gm)			
	Aluminum package		2.40 oz (68 gm)			

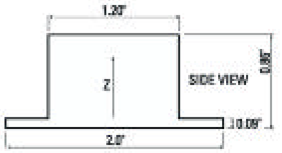
Notes

Sensitivity is ratiometric to supply: Vout = [Vs/2 + (sensitivity x Vs/5 x accel)]. Zero g Output is ratiometric to supply, proportional to Vs/2. Non-linearity is the deviation from a best fit straight line at full scale. Transverse sensitivity is error measured in the primary axis output created by forces induced in the orthogonal axis. Transverse sensitivity error is primarily due to the effects of misalignment (i.e., much of it can be tuned out by adjusting the package orientation or mathematical compensation). Zero g drift is specified as the typical change in 0 g level from its initial value at +25°C to its worst case value at Tmin or Tmax. Specifications subject to change without notice.

Pin	Color	Function
1	Red	Power In
2	Black	Ground
3	White	X-axis Out
4	Yellow	Y-axis Out
5	Green	Z-axis Out

Pin Diagram (w/o DigiCal)





DigCal Connector
(Right Hand British-Telcom)

High Temperature Package

Ordering Information

Model	Axes	Span (g)	Sensitivity (mV/g)	Noise (mg rms)	Bandwidth (Hz)
CXL04LP1	X	±4	500	10	DC-100
CXL04LP1Z	Z	±4	500	10	DC-100
CXL04LP3	TRI	±4	500	10	DC-100
CXL10LP1	X	± 10	200	10	DC-100
CXL10LP1Z	Z	± 10	200	10	DC-100
CXL10LP3	TRI	± 10	200	10	DC-100
CXL25LP1	X	± 25	80	10	DC-100
CXL25LP1Z	Z	± 25	80	10	DC-100
CXL25LP3	TRI	± 25	80	10	DC-100
CXL50LP1	X	± 50	40	50	DC-100
CXL50LP1Z	Z	± 50	40	50	DC-100
CXL50LP3	TRI	± 50	40	50	DC-100
CXL100LP1Z	Z	± 100	20	80	DC-100
OPTIONS					
-R	Voltage Regulator, 8 – 30 VDC input (not available with DigiCal)				
-AL	High Temperature Package (see package drawing above)				
-D	Digital Calibration EEPROM (DigiCal)				

Appendix I: Mass Budget

SHARP Mass Budget **8/5/2003**

Part	Weight (lb.)	Dimensions (in.)	Accuracy
Front Tip	5.69	10.5 x 6.25x 2.25	measured
Shell	2.02	16.75 x 8.42 x 5.63	measured
Frame (totals)	1.53	460.7 cubed	measured
I-bolt	0.18	6 length	measured
Batteries	0.5	.75 x .75 x 1.25	measured
Ham radio	0.8375	5.5 x 2.25 x 2	measured
Antenna	0.275	cord	measured
GPS	0.05	3.7 x 1.8 x .54	measured
Accelerometer	0.1	1.75 x 1.07 x .78	measured
Temp Sensor	0.007	.125 x .125	measured
Pressure Sensors (7)	0.04	.5 x .5 x .5	measured
Microcontroller	0.333	4.25 x 3.0625 x .5625	measured
Parachute	0.441	60" diameter	measured
Range for unknowns	**12 to 13**		
Average Total	**12.0035**		
Max Total	**13**		

Appendix J: Power Budgetx

*all values represent a max power needed					Stages and Power Required					
				1	2	3	4	5	6	Comments
Components	V(v)	I(ma)	P(w)	Ascent	Balloon Drop	Free Fall	Parachute Dep.	Par. Flight	Recovery	
Ham Radio(transmit)	6	1100	6.600	6.600	6.600	6.600	6.600	6.600	6.600	
GPS	5	100	0.500	0.500	0.500	0.500	0.500	0.500	0.500	
Accelerometer 1	5	1.66	0.0083			0.0083		0.0083		
Pressure Sensor	5	10	0.050			0.350		0.350		7 sensors
Parachute deployment	6	3000	18.000				18.000			
Balloon Drop Mechanism	6	3000	18.000		18.000					Estimate
AtmelAVR mini board	5	8	0.040	0.040	0.040	0.040	0.040	0.040	0.040	
Temp Sensor	5	0.158	0.00079	0.00079	0.00079	0.00079	0.00079	0.00079		
Miscellaneous	5	0.001	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	
Totals			**43.199**	**7.141**	**25.141**	**7.499**	**25.141**	**7.499**	**7.140**	
Time Per Stage(h)				**1.5**	**0.0014**	**0.25**	**0.0014**	**0.25**	**0.25**	
Energy Required(wh)				**10.7111925**	**0.035197113**	**1.87477375**	**0.035197113**	**1.87477375**	**1.78500125**	
	Power Required(mwh)									
Battery Supply:	**16316.13548**									

Appendix K: Moments of Inertia

Center of Gravity / Moments of Inertia **6/1/2003**

Part	Weight (lbs.)	X (in.)	Y (in.)	Z (in.)
Front tip	5.69	21	0	0
Shell	2.02	7.75	0	0
top plate	0.247	8	0	-1.785
bottom plate	0.247	8	0	1.785
right side plate	0.062	5.24	3.735	0
left side plate	0.062	5.24	-3.735	0
back plate A	0.12	1.125	0	0
front plate A	0.17	15.325	0	0
back door A	0.2	1	0	0
parachute	0.441	3.5	0	0
Press. Snrs. (7)	0.04	2	0	0
HAM radio	0.8375	12	1.5	0.5
MCPU	0.333	5.5	-3.9	0
GPS	0.05	7	3.9	0
Accel.	0.1	12	-1	0.5
I-bolt	0.18	15	0	0
Batteries	0.5	16.5	0	0
CG	11.2995	14.425	0.016	0.013
Actual CG		**15.425**	**0.016**	**0.013**
Distances from CG		6.575	-0.016	-0.013
		-6.675	-0.016	-0.013
		-6.425	-0.016	-1.798
		-6.425	-0.016	1.772
		-9.185	3.719	-0.013
		-9.185	-3.751	-0.013
		-13.3	-0.016	-0.013
		0.9	-0.016	-0.013
		-13.425	-0.016	-0.013
		-10.925	-0.016	-0.013
		-12.425	-0.016	-0.013
		-2.425	1.484	0.487
		-8.925	-3.916	-0.013
		-7.425	3.884	-0.013
		-2.425	-1.016	0.487
		0.575	-0.016	-0.013
		2.075	-0.016	-0.013

	Mass (slugs)	**X^2**	**Y^2**	**Z^2**
CG distances squared	0.17670807	43.23063	0.000256	0.000169
	0.06273292	44.55563	0.000256	0.000169
	0.00767081	41.28063	0.000256	3.232804
	0.00767081	41.28063	0.000256	3.139984
	0.00192547	84.36423	13.83096	0.000169
	0.00192547	84.36423	14.07	0.000169
	0.00372671	176.89	0.000256	0.000169
	0.0052795	0.81	0.000256	0.000169
	0.00621118	180.2306	0.000256	0.000169
	0.01369565	119.3556	0.000256	0.000169
	0.00124224	154.3806	0.000256	0.000169
	0.02600932	5.880625	2.202256	0.237169
	0.01034161	79.65563	15.33506	0.000169
	0.0015528	55.13063	15.08546	0.000169
	0.00310559	5.880625	1.032256	0.237169
	0.00559006	0.330625	0.000256	0.000169
	0.01552795	4.305625	0.000256	0.000169
Individual parts Moments of Inertia		7.51E-05	7.63923	7.639246
		2.67E-05	2.795115	2.79512
		0.0248	0.341454	0.316658
		0.024088	0.340742	0.316658
		0.026631	0.162441	0.189071
		0.027092	0.162441	0.189532
		1.58E-06	0.659218	0.659218
		2.24E-06	0.004277	0.004278
		2.64E-06	1.119446	1.119446
		5.82E-06	1.634655	1.634657
		5.28E-07	0.191777	0.191777
		0.063448	0.15912	0.21023
		0.158591	0.82377	0.982357
		0.023425	0.085607	0.109031
		0.003942	0.018999	0.021469
		2.38E-06	0.001849	0.00185

	about axis	**X axis**	**Y axis**	**Z axis**
Moments of Inertia		**0.352134**	**16.14014**	**16.3806**
		measured in (lbs mass * inches squared)		

Appendix L: Software System Stories

Primary System Story:

The craft will be turned on and loaded into the gondola of a balloon as the balloon is filled with helium. The vehicle will complete a self test upon power up to ensure that all the sensors and communications systems operate correctly. This tests consists of the sensors powering up, recording data at the ground level, recording that data, and transmitting a copy of that data to the base station. Upon completion of this test, the computer system onboard will go into standby mode, except for the GPS system and the accelerometer which will detect when ascent has begun. Once the craft is released, the change in GPS readings and initial acceleration will tell the onboard computer that the ascent has begun and a timer will begin to count to 90 min. The only systems on during ascent are GPS and the onboard timer.

When the vehicle reaches 80,000ft, or the timer goes off, the computer will enter release mode. In this mode all of the sensors are powering up again and the release mechanism is activated beginning the active descent phase. During this critical time, the HAM radio will begin transmitting select data from the sensors, as well as the craft's location as well as recording data to onboard flash memory at a much higher frequency. This phase will continue until the craft reaches 20,000ft, or the timer goes off. This will cause the sensors to power down and the chute to be deployed. GPS location data will still be transmitted. This phase will end when the craft is recovered.

Secondary System Story: (GPS failure at takeoff)

System powered up and runs through power on self test. System transmits sensor data and GPS data to base station and recorded onto local storage. Video camera is turned on and video stream transmitted to base station. System passes test and is prepared for launch. System lifts off and GPS fails to collect new data. System timer passes 5 min and system shifts into begin ascent phase. Sensors are powered down to standby mode.

System begins ascent and turns on camera for a takeoff shot of the ground crew. GPS fails to record location data, but false GPS data is transmitted to base station and recorded to local storage anyway. Video is recorded and transmitted to base station. Timer expires (5 min) and system shifts into ascent mode.

GPS still fails to record new altitude data, but false GPS data is sent down and recorded anyway. Sensors and video are in standby to reduce power consumption. GPS never reaches 80ft, but the timer expires in 90 min so the vehicle deployment phase begins.

During the vehicle deployment phase the sensors are started up and begin to record at full speed. This data, along with the still false GPS data, is recorded on local storage. Samples of this data are transmitted down as fast as the connection allows. The video hardware is also turned on and powered up now. The vehicle is then dropped from the parachute via the self-destructing tether attached. The vehicle deployment phase ends due to timeout since the GPS cannot tell if it has begun falling yet.

The active descent begins and the sensors and GPS are still running at full speed. This will continue until the timer times out after about 5 min of fall time. The sensors will then power down, but GPS is still recorded and transmitted back to the base station. The video hardware is now turned off. The active descent is over and the recovery phase begins.

In this recovery phase the system will attempt to deploy the parachute. It will repeat this procedure until it can tell that the system has decelerated. Since the GPS is not functioning, it will continue to attempt to deploy until the timer expires 5 min later. False GPS data is still being transmitted back to the base station.

During the slow descent and recovery phase, the system will continue to transmit a bad location; however we will be able to use multiple ham radios to triangulate its location based on signal strength.