Final Report
Tyndall AFRL: Marsupial Robot Deployment and Recovery

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Abstract

It is the purpose of this report to detail the entire process for the design and manufacture process that is required to create a mounting system that will engage a Bombot to a Yamaha RMAX helicopter for Tyndall Air Force Research Laboratories. The introduction of the project is given including background information of the two specimens. The Project Scope, Specifications, and Constraints are then displayed. A Project Plan follows documenting how the process was organized. The conceptual designs are then explained. A Telescoping Pole Concept and Swinging Platform Concept make up the choices for mounting the camera assembly. For engagement, these designs consist of the Telescoping Rods Concept, Tractive Wheel Concept, Box Concept, and Ball and Socket Concept. The Swinging Platform and Ball and Socket designs are selected using a design matrix. Detailed designs of the ball and socket as well as the swinging platform are then shown. CAD Prototypes are created for the Fabrication and Assembly of the two concepts. For these systems a total of four servo motors were needed. Therefore a control system was installed to operate the added servo motors. Testing of the prototypes occurs and modifications follow so that the team may build the design to operate as smooth as possible. A flight test finishes up the testing with positive results. The goals of the project are successfully completed within the required specifications and constraints.

1.0 Introduction

1.1 Overview

Tyndall Air Force Research Laboratories is the sponsor for the Marsupial Robot Deployment and Recovery project. Tyndall is a government funded company that specializes in research and development for the United States Air Force. The main interest of this project is to combine two items that Tyndall uses on a frequent basis. These items are the Yamaha RMAX and the Bombot. In the following report the Bombot will also be called ‘robot’ or ‘marsupial robot’. The Yamaha RMAX will be referred to as ‘helicopter’ or ‘RMAX’. Our main contact with the sponsor is Lt. Andrew Kopeikin.

1.2 Background

1.2.1 Yamaha RMAX

The Yamaha RMAX is a remote controlled helicopter that is used in many different applications. Its most impressive feature is t that it can be used without a person controlling it. This attribute allows the RMAX to be called a UAV, Unmanned Aerial Vehicle. Although militaries utilize the versatility of the RMAX, its primary purpose is for civilian applications such as farming. Yamaha first designed an unmanned helicopter 1987 called the R-50. The purpose of the helicopter was intended for crop dusting in Japan. The RMAX is based on the R-50 however it is much improved due to the advancement of technology throughout the years. With these changes in technology the RMAX is no longer used simply for agriculture, but the military as well. The Yamaha RMAX is equipped with a GPS navigation system that allows the user to enter a coordinate and the RMAX will fly to that location autonomously. This is very important for military applications because a pilot's life is no longer at risk. There is an area in the belly of the RMAX where a payload can be attached for whatever purpose the RMAX is intended. Some of the functions that Tyndall AFRL uses the Yamaha RMAX for consists of agriculture, surveillance, and tracking. Figure 1 shows an image of a RMAX from Yamaha's website.

Figure 1: Stock Yamaha RMAX

The RMAX will be graphically depicted in the remainder of the report as just the legs and the skids and necessary components that the design will be referenced from. A solid model of the entire RMAX was not created because it was not necessary and would have been a waste of resources. The solid model of the Yamaha RMAX is seen in Figure 2.

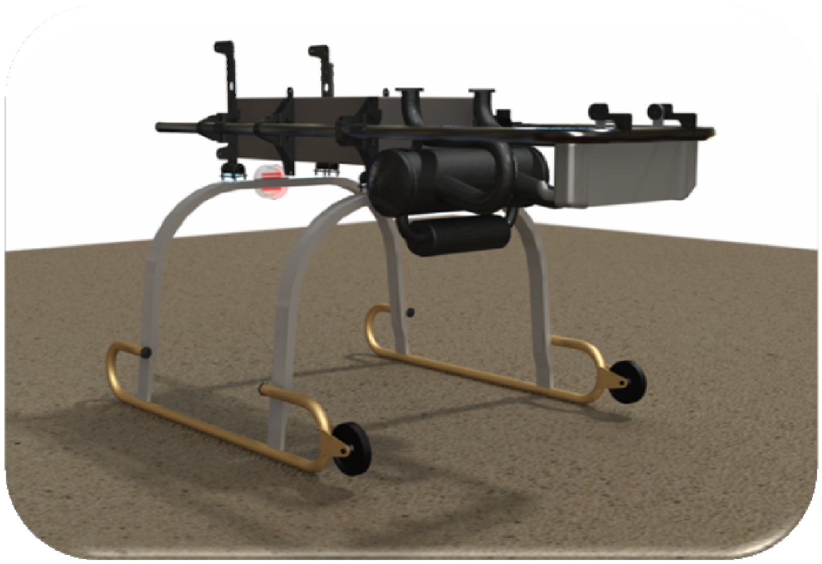


Figure 2: Rendered Solid Model of RMAX Skids representing Yamaha RMAX

1.2.2 Bombot

The Bombot, when delivered to the senior design team, was outfitted with the standard equipment from IRT-robotics. The Bombot is a UGV (Unmanned Ground Vehicle), essentially a modified remote control multi terrain truck. It is controlled in the same fashion as common RC vehicles but had been given modifications that enable it to perform other non commercial tasks. The Bombot chassis is the Traxxas E-maxx, a 1/10 scale 4wd monster truck that is very popular among hobbyists. The E-Maxx is displayed in Figure 3. The truck frame is removed and in its place is an aluminum platform that hosts a payload carriage, a high range antenna, much larger tires, and a video camera for user guidance at distances beyond the human eye. The payload container can hold many different items and deploy these items by means of actuating a servo motor. A major purpose of the payload container is to hold a bomb charge, hence the name 'Bombot'. These features are standard equipment on board the Bombot and can be seen in Figure 4.

Figure 3: Traxxas E-Maxx as seen on Traxxas's website

Figure 4: Bombot with standard equipment from IRT Robotics

2.0 Project Scope

The goal of this project is to design, build, and test a system in which the Yamaha RMAX and Bombot can coexist. The Bombot must be remotely attached and detached from the RMAX in a matter that does not require any physical human interaction. In accomplishing this task, the Bombot can then be deployed in remote locations that the user would not be able to otherwise. The user can then remotely control the Bombot and deploy the payload at the predetermined location. Once the payload has been successfully deployed the Bombot can then return to the RMAX where reengagement will occur. The Yamaha RMAX then has the ability to remove itself along with the Bombot from the engagement zone to a safe drop zone. This entire process is done via remote controls and therefore removes the human element from any dangers that may exist in the engagement area. The accomplishment of this task allows the user to be at a safe location and resultantly will reduce the risk of injury or death of the operator. The sponsor and the team members believe this goal is achievable and a functioning prototype is expected.

3.0 Specifications

All of the transformation and engagement/disengagement processes must happen with no human physical interaction. The reasoning behind this is to take the human out of the danger zone. The assumption of an autonomous artificially intelligent system is not a specification but a possible consideration for this project. Specifications for this project include:

1. The Robot and the additional components can be no more than 66 lbs combined.
2. Robot must be able to transform between active and passive structure.
    a. The transition between active and passive structures will be accomplished by raising and lowering the camera and spotlight unit which will be referred to as the camera assembly.
    b. The active structure will be used for the robot to complete a mission.
    c. The passive structure will be used for transportation purposes via RMAX only.
3. The Robot must be able to fit under the RMAX. Entrance will occur from the front of the RMAX and must clear the underbelly of the RMAX. Entrance from the rear leaves potential for the Bombot to collide with rear stabilizing propeller.
4. Passive structure while engaged to the RMAX must be able to withstand an air velocity of up to 20 knots with a factor of safety of about 2.5.
5. Consider the robot engaged and in flight with the RMAX.
    a. Once the RMAX safely lands and skids are firmly planted on the ground, the robot must be able to disengage and drive out from under the RMAX.
    b. Once the robot is out from underneath the RMAX it must be able to transform into its active structure and complete its mission and return to the RMAX. When

the robot arrives at the RMAX it must transform back into its passive structure and engage to the RMAX.

c. The center of mass of the robot and engagement device must be inline (directly underneath) the center of mass of the RMAX, or negligibly close.

6. The robot must be secured in all six degrees of freedom.
   a. Locking mechanism must be activated before liftoff.
   b. The Bombot cannot have contact with the ground while it is attached to the RMAX.
7. The engagement system must be ¼ inch from the ground when installed to the RMAX.
8. The budget for this project is $1500.

4.0 Constraints

There will be several constraints that the group will encounter throughout the design and manufacture process. Time is one of the most important constraints. Since the group has to submit a finalized design for the fall and a working prototype in the spring, the team must stay on course when certain tasks are due. Each semester will provide 13-15 weeks of working time. During these semesters each student is enrolled in several other classes, further emphasizing the importance in managing time wisely. Another constraint is the most obvious, funding. The budget assigned to the group in the product description is $1500. However, the customer has expressed to the team that they expect the total costs to exceed the given budget. The sponsor explained that money will not be much of a factor if the budget is exceeded as long as it is not spent in a wasteful manner. The customer will also be able to fabricate certain parts for the team therefore saving money that would be spent through a third party. Clearance of the two devices will be a main concern as well. Because the helicopter has limited amount of clearance while grounded, modifications to the robot and/or helicopter will need to occur for the product to be fully functional. The sponsor stated to the group that when choosing electronics for the project that 900 MHz and 72 MHz frequencies must be avoided in order to avoid any interference with the pre-existing controls of the Yamaha RMAX. Availability may also become a factor. The customer and helicopter is located over 100 miles away, which will leave the group with limited time to spend working with and or modifying the helicopter. Time with the sponsor must then be spent wisely. Therefore the group must have record accurate dimensions so that there is not an issue when the group is able to work with the helicopter.

5.0 Project Plan

Possibly the most important constraint of this project as mentioned earlier is time. The project is set for two semesters and each student is also attending several other classes during this time making it more difficult. The plan for this project is divided into two major subsets, design and construction.

The design aspect will take place during the first of the semesters. During this time is when project scope, specifications, concept generation and selection, analysis, final design, and testing are executed. Physical prototyping and testing was not achieved during the first semester due to time constraints. A final design following the constraints that were given at the time was completed by the end of the fall semester.

The construction portion will consist of modifying the design, ordering materials, fabricating parts, assembly, testing, and a final working product. These tasks will be completed during the second semester. Other major events include the Final Report, Final Presentation, and Open House. To begin the spring semester the team was given several new constraints. With these new constraints the team had to modify their design. A drastic delay was avoided despite not having begun fabrication. However the team needed to come up with a new design quickly so that fabrication, assembly, and testing can occur before the given deadlines.

Lt. Kopeikin required that a Technical Review Board and Safety Review Board presentation be performed at least 5 weeks before an actual flight test. The presentations were to be given by Lt. Kopeikin to his fellow employees at Tyndall. Approval from Kopeikin's peers was needed in order for a flight test to occur. This information was vital as it shortened the deadline for a working prototype significantly. With only fourteen weeks in the Senior Design course the team had to meet this deadline within nine weeks. The team restructured the course schedule in order to give the greatest chance to complete the project. The course instructors understood the severity of the situation and approved this restructure. The Course Schedules and Microsoft Project Gantt Charts for each semester are displayed in Appendices E.1 and E.2.

6.0 Concept Generation and Selection

6.1 Initial Concepts

Knowing full well that there were many solutions to solve the problem, the team set aside an afternoon to brainstorm every possible way to engage Bombot with the Helicopter. The team members documented all the ideas that were discussed. No ideas were rejected no matter how simple or complex. The team would use these ideas as a basis to generate concepts.

Each member of the team created a detailed concept based on the ideas from the 'Brainstorming' sessions and presented them to one another. The team presented the designs then collectively decided on which concepts to move forward with for the Concept Generation and Selection. The initial concepts that were developed early on for engagement between the RMAX and the Bombot were the Telescoping Rods Concept, the Tractive Wheels Concept, the Ball & Socket Concept, and the Box Concept. Note: Some designs were based on initial constraints and specifications and may not comply with the final constraints and specifications.

6.1.1 Telescoping Rods Concept

The Telescoping Rods Concept has the Bombot drive underneath the helicopter. Driving underneath the helicopter became essential for all of our concepts because this aligns the Bombot's center of gravity with the RMAX's center of gravity. When the Bombot is underneath the belly of the helicopter, rods will telescope out the side of the robot and engage to the RMAX during takeoff. A CAD image of the Telescoping Rod Concept is below in Figure 5.

Figure 5: Telescoping Rods Concept

Pros

- Minimal modifications to Yamaha RMAX needed
- Potential to optimize through modifications

Cons

- Bombot free to slide
- Wheels will hang free
- Does not safely secure the Bombot in all six degrees of freedom

6.1.2 Tractive Wheel Concept

The Tractive Wheel Concept was loosely based off of an automated carwash where the car is pulled by the front tire through the automated assembly. The benefit to this design over the Telescoping rods is the Bombot is centered with self aligning into a loading zone specifically designed to house and safely carry the Bombot. The Bombot will be guided into this safety zone by tracks that the wheels will follow. Once the Bombot is in the safety zone the metal plates in between the wheels will displace away from each other thus applying force on each wheel and securing the Bombot. Figure 6 gives a visualization of how this system operates.

Figure 6: Tractive Wheel Concept

Pros

- Secures Bombot in all degrees of freedom
- Potential for optimization
- No modification to Bombot needed

Cons

- Attaches to gold skids (Not allowed)
- Clearance issues while entering
- Large materials needed, causes clearance issues with RMAX

- Heavy design

6.1.3 Box Concept

The Box Concept means simply a box, or a bay, that the Bombot will drive into. This bay will mount directly underneath the helicopter and will captivate the Bombot during flight. Although being the least innovative the Box concept would prove to be a benchmark that the team could use to compare designs. The Box was designed with holes to allow airflow and therefore not create lateral air resistance. This design was also used as a failsafe. If sometime late in the final semester the team ran into issues that were beyond repair with a different design, the Box design could be implemented to ensure that a working prototype was produced. The benefits of this box were not completely clear until later in the design process. The box concept can be seen in Figure 7 below.

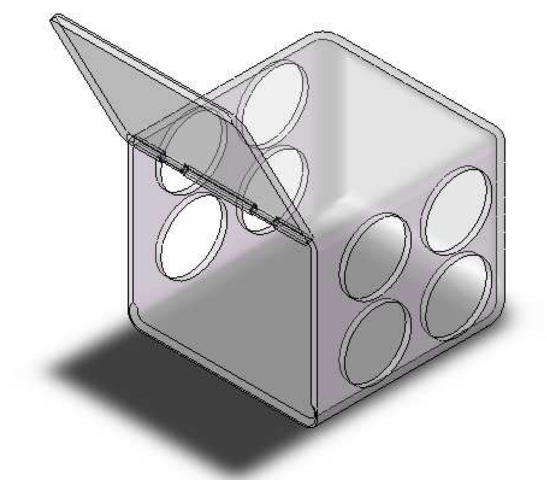


Figure 7: Box Concept

Pros

- Simple design
- Completes the goal

Cons

- Non innovative
- Bombot will not be completely secured, only contained
- Movement while inside Box is expected

6.1.4 Ball and Socket Concept

The Ball and Socket Concept relied on tracks that the Bombot would slide into. This design would require modifications to the Bombot as well as the RMAX. Unlike the Tractive Wheel Concept these tracks did not come in contact with the wheel but arms that extended out from the Bombot. These arms will help align and guide the Bombot safely underneath the helicopter. Alignment happens when the Balls and Ball Flanges come in contact with the Funnel and the Funnel Clips. This system will give the user a larger margin of error when driving on board the RMAX from a distance. Figure 8 explains the Ball and Socket Concept more clearly.

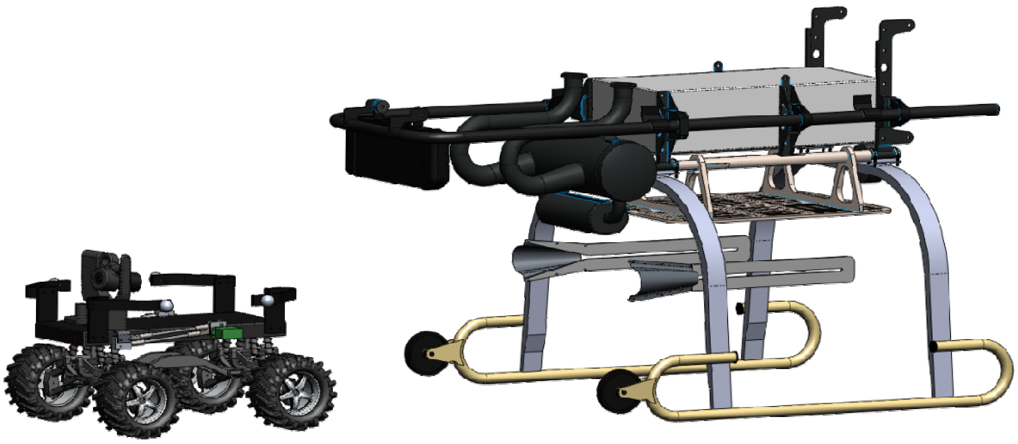


Figure 8: Ball and Socket Concept as first imagined

The name Ball and Socket comes from the ball that funnels its way into the socket which allows the Bombot to align itself through the funnel clip path and into secure valleys. These secure valleys are load bearing surfaces for the Bombot to rest. The benefit to this design is its simplicity of manufacturing and engineering. Many of the initial concepts required electronic hardware mount onto the RMAX itself. AFRL shied away from mounting excess electronics onto the Yamaha RMAX. All of the electronics and moving parts are mounted onto the Bombot. The Bombot platform with the aligning balls can be viewed in Figure 9 Below. The Ball Flange is the piece of hardware that suspends the ball and aids in aligning.

Figure 9:The initial development of the Ball System for the Ball and Socket System

Pros

- Funnels allow margin of error
- Lightweight design
- Prevents lateral movement
- Mounts to mounting bracket of RMAX

Cons

- Wheels will hang free
- Complex design
- Requires advanced machining

6.2 Concept Selection

The team analyzed all aspects of the designs in order to decide which one to move forward with. A design matrix, Table 1, was also created to determine which design best fits the criteria. The telescoping rods concept was the first design that the team decided to not move forward with. The design was simple and may achieve the require goal of attaching the Bombot to the RMAX but it did not do this in a secure fashion. The design would have to be drastically revamped in order for the team to feel comfortable as a final design. The Tractive Wheel Concept was a good design and showed a lot of promise. However due to the clearance constraints it would prove to be very difficult in creating a design that would resolve these constraint issues, especially since the team did not have a RMAX to physically use during the designing. The system would also have to be redesigned in order to mount to the mounting bracket rather than the gold skids. Therefore the team moved on with the Ball and Socket Concept. This design was able to achieve the security that the Tractive Wheel Concept has but without the added weight and clearance issues. From this point on the team would modify and optimize this design unless something occurs where the design cannot be used.

Design Matrix								
	Portability	**Ease of Manufacture**	**Durability**	**Simplicity**	**Solution to Problem**	**Modification ease**	**Cost**	**Weighted Total**
Weight(Scale 10)	**2**	**6**	**8**	**8**	**7**	**5**	**4**	**40**
Weight (Sum 1)	**0.05**	**0.15**	**0.2**	**0.2**	**0.175**	**0.125**	**0.1**	**1**
BomBot Engagement								
Tractive Wheel	3	3	8	6	6	2	3	**5**
	0.15	0.45	1.6	1.2	1.05	0.25	0.3	
Box	8	7	7	10	7	6	7	**7.525**
	0.4	1.05	1.4	2	1.225	0.75	0.7	
Ball & Socket	8	8	8	9	9	9	9	**8.6**
	0.4	1.2	1.6	1.8	1.575	1.125	0.9	
Telescoping Rods	10	2	5	5	1	4	5	**3.975**
	0.5	0.3	1	1	0.175	0.5	0.5	

Table 1: Engagement Design Matrix

7.0 Camera Mount Design

Included in the standard equipment from IRT-Robotics, as mentioned above, is the camera mounted on the fixed mast. The camera is mounted high to see over tall grass as well as giving a better view of the Bombot's surrounding area. This high mounting camera posed a problem when positioning underneath the RMAX because there was not any clearance between the camera and the underbelly of the RMAX.

The payload and the antenna were removed from the Bombot by the team. The payload container caused clearance issues during entrance to the RMAX and was immediately removed. The antenna had been replaced because of new controls that were later installed. Information on these controls can be seen in the Controls portion.

7.1 Camera Mount Concepts and Selection

Several concepts were brainstormed to solve the camera assembly issue. The simplest solution would be to mount the camera and antenna directly to the top cover of the Bombot. However the customer wanted the camera to be higher than the Bombot's body in order to see over tall grass or any other elements that may inhibit the view of the camera. Furthermore the team did not want to go this direction for several reasons. The first was even though the payload container had been removed for this project, the team wanted the container to be able to be applied in the future and placing the camera directly on the Bombot would cause interference. Another solution was to install a remotely controlled telescoping pole that would have a platform on top. The camera and antenna could then be mounted on this platform and could be raised or lowered as needed. However the team was not comfortable with the strength and stability of a telescoping pole. The team felt that it can be easily damaged and did not move forward with this design. Instead a design was chosen that achieved the clearance issues as well as giving the user more control over the camera. The design matrix for the Camera Mount can be viewed in Table 2.

Design Matrix								
	Portability	**Ease of Manufacture**	**Durability**	**Simplicity**	**Solution to Problem**	**Modification ease**	**Cost**	**Weighted Total**
Weight(Scale 10)	**2**	**6**	**8**	**8**	**7**	**5**	**4**	**40**
Weight (Sum 1)	**0.05**	**0.15**	**0.2**	**0.2**	**0.175**	**0.125**	**0.1**	**1**
Camera Mount Design								
Swinging Platform	7	4	6	6	10	7	8	**6.775**
	0.35	0.6	1.2	1.2	1.75	0.875	0.8	
Telescoping Pole	8	2	3	2	10	1	2	**3.775**
	0.4	0.3	0.6	0.4	1.75	0.125	0.2	

Table 2: Camera Mount Design Matrix

7.2 Swinging Platform

The solution to this problem was a four-bar linkage system. This design was named the Swinging Platform and offered the ability to raise and lower the camera. The camera's orientation to the ground will not change from its lowered position to its raised position, which means the camera will not tilt off axis when being raised or lowered. This is because of the parallel four-bar linkage. Figure 10 shows the swinging platform concept.

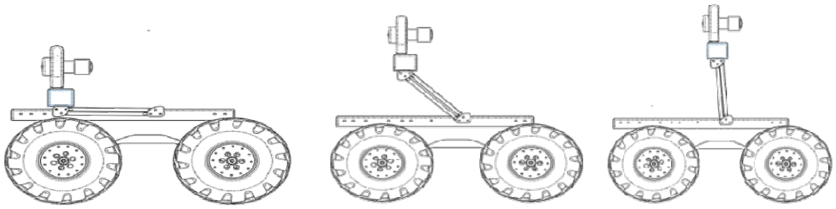


Figure 10: Initial Swinging Platform Concept

8.0 Prototyping

8.1 Ball & Socket

To save money and time digital prototypes were created in place of actual prototypes. The Swinging Platform and the Ball and Socket Concepts were chosen to continue ahead on a full production digital design. The use of a computer was used everywhere potential was seen to help throughout the project, the design program of choice was SolidWorks 2008. The sponsor is familiar with this program thus making it more convenient when ordering parts.

The Ball and Socket Concept was chosen because of the auto aligning features and ability to make use of the mounting rack unlike most of the other initial concepts. The mounting rack was designed by AFRL to mount onto the belly of the RMAX and carry any equipment. The mounting rack is represented in Figure 11.

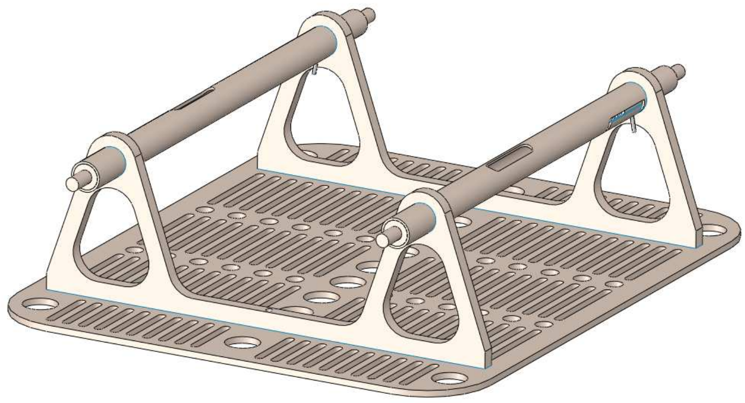


Figure 11: AFRL's Mounting Rack

The Ball and Socket (B&S) System is the term used for the entire design that engages the Bombot to the RMAX. The B&S is broken down into two sub systems: Funnel System and Ball System. The Ball System is the design of the balls and the ball flanges. The Funnel System is the design of the sheet metal funnel and the funnel clip it is attached too.

8.2 Bombot Modifications

The team performed several minor modifications to the actual Bombot. The first of which was the removal of the payload container and corresponding servo motor. The height of the payload caused clearance issues with the RMAX and was removal was approved by the client. The final modification was the installation of smaller wheels. The stock wheels where very large thus raising the overall height of the robot. The smaller wheels also gave the user more precise control during operation. The comparison in wheel height is seen in Figure 12.

Figure 12: Aftermarket Wheel on left, Stock Wheel on right

8.3 Funnel System

In the early stages the Funnel Clip received the most attention. The evolution of the funnel clip is shown below in Figure 13. The first revision of the Funnel Clip did not have any way of securing longitudinal movement of the Bombot. Longitudinal movement will allow the bombot to slide out and can cause sudden failure to the mission.

Figure 13: Evolution of the Funnel Clip. Top Left was the first revision of the Funnel Clip

The second revision of Funnel System allowed a safety zone within the funnel clip profile.   The second revision can be seen below in Figure 14 with the original funnel design. The safety zone is seen in the enclosed area behind the hump. Once the bombot enters into the safety zone it should be considered completely secure. Revision 2 was soon tossed out because a large enough acceleration in the longitudinal direction could cause the bombot to escape the safety zone during flight resulting in sudden failure to the mission. Getting into and out of the safety zone would require excellent traction with the ground throughout suspension travel.

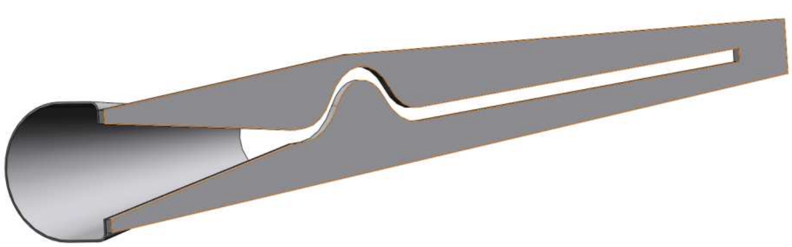


Figure 14: Revision 2 Funnel Clip with the Funnel attachment

The third revision of the Funnel system created two load bearing low valleys in which the ball entered into upon lift of helicopter. Once the RMAX is lifted off the ground during take-off the Bombot will lower into the load bearing surfaces, security is achieved. This is a major improvement over the second revision because the Bombot will stay secure throughout flight. This method solved an issue by merely using gravity to allow the Bombot to lower itself during liftoff this securely itself in one degree of freedom. The third version of the Funnel Clip is depicted in Figure 15.

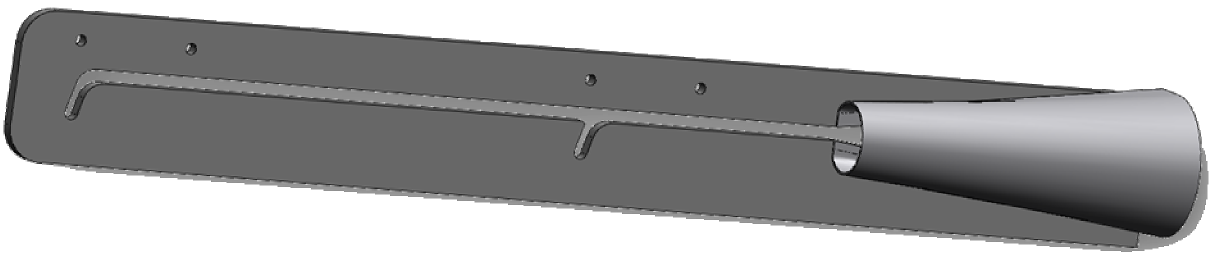


Figure 15: Third Revision with valleys

The fourth revision of the Funnel system was purely for structural integrity, the functionality of the design did not change. Due to high stress concentrations and a large moment created in the connection between the upper and lower halves the funnel clip was made thicker and additional material was added to decrease deflection of the part.

8.3.1 Stress Analysis of Funnel System

The excess material added was kept to a minimum. A complete stress analysis was completed in CosmosWorks. The goal of a Finite Element Analysis is to create an accurate simulation to represent the system and in our case isolating the component of interest. The fixed positions of the object were chosen to be the mounting locations. The load was applied to the load bearing surfaces of the low valleys.

The load was chosen to be twice the maximum payload, or 120 lbs. This load is highly unlikely, but if the helicopter was to land suddenly we could expect the system to experience two g's or twice gravity. Each load bearing surface was loaded with 30 lbs. The stress analysis on the Socket System can be seen on revision 4 in Figure 16.

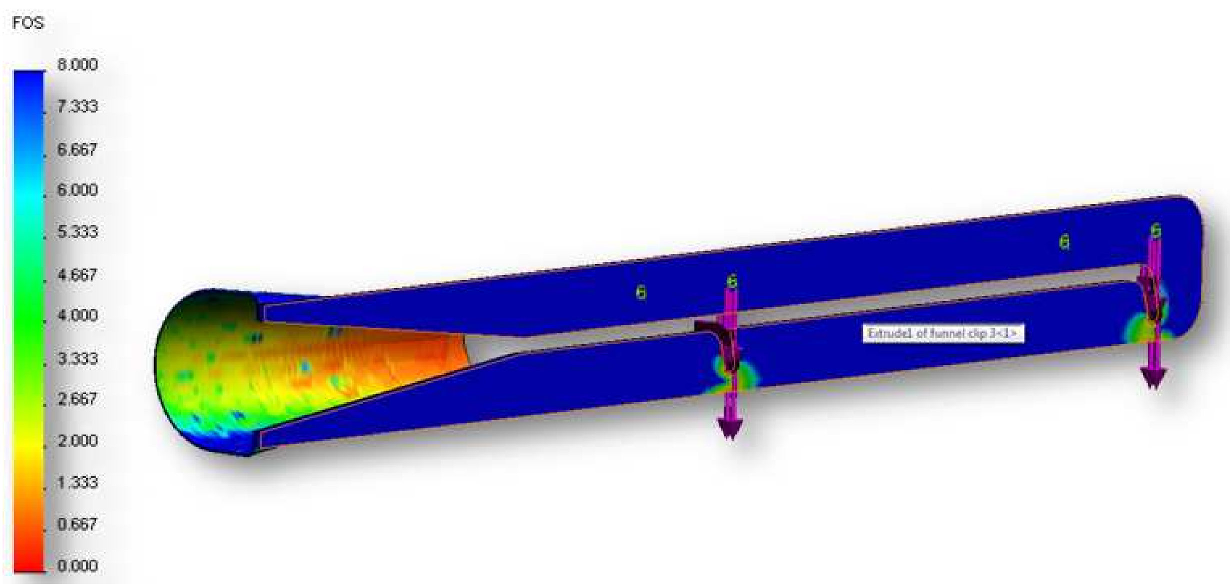


Figure 16: Stress Analysis of Revision 4. Factor of Safety Plot

The goal is to have a factor of safety higher than 2.5. Most aeronautical applications have a factor of safety between 1.3 and 1.7 because of the amount of service and maintenance. The Ball and Socket system is designed for low serviceability. Figure 17 highlights the areas of revision 4 Funnel System where the factor of safety is below 2.5.

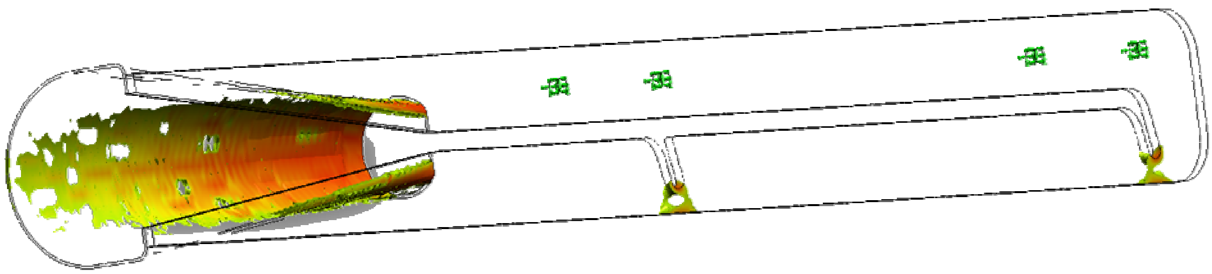


Figure 17 : FOS below 2.5 has been highlighted in revision 4 of the Funnel System

The last revision of the Ball and Socket system was based on design for manufacturing. The Funnel is made out of sheet metal and the flat pattern has been created in the first revision and unchanged until the fifth revision. Achieving the bends necessary for the previous revisions was to prove difficult until the mounting tabs were flexed outwards instead of inwards. The evolution of the funnel clips can be seen in Figure 18 with the new and old funnel design in Figure 19.

8.3.2 Evolution of Funnel Clip

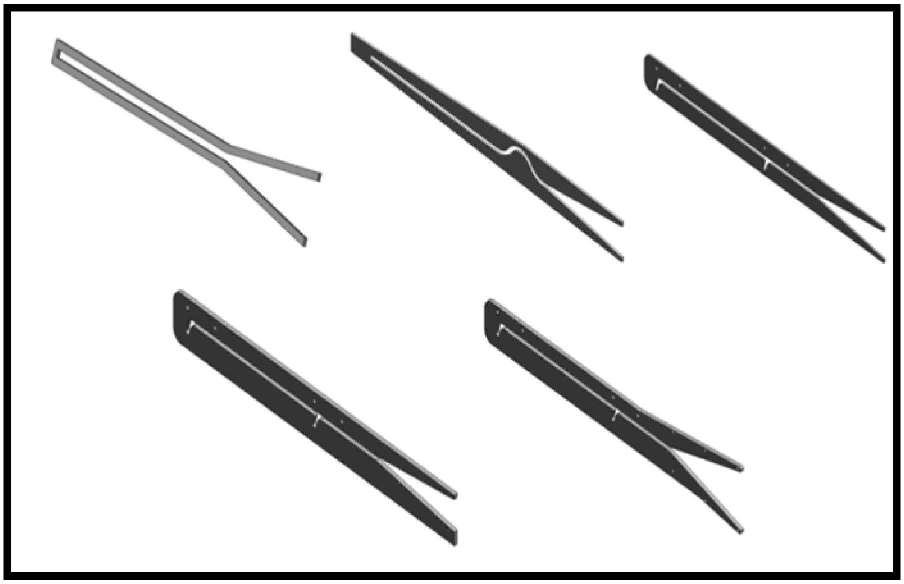


Figure 18: Evolution of Socket

Figure 19: Funnel Design Changed for Manufacturing

8.3.3 Final Funnel Design

The designs of the Sockets seen above were created before the end of the fall semester. During the break between the Spring and Fall Semesters is when the team received several new constraints. One of them would cause the team to have to modify the Ball and Socket design. The constraint was that AFRL now wanted the locking to occur before liftoff. The reasoning behind AFRL's request is the unpredictable behavior of the RMAX during flight. The Bombot is not secure until the RMAX is lifted an inch off the ground or more with a purely vertical take-off. Realistically the RMAX will take off in a slightly chaotic manner. This chaotic manner is not harmful to the RMAX but the tolerances needed for Bombot security in Revision 5 of the Funnel System do not exist. The sponsor also decided they did not want the wheels of the Bombot to hang freely once engaged. This could cause some issues when trying to land the RMAX. If the Bombot made contact with the ground before the skids it may cause some disruption and can risk damages to the RMAX as well as the robot.

9.0 Fabrication and Assembly

9.1 Materials Selection

Although the sponsor did not specify or limit the choices in materials, it was deemed necessary that a mid-grade aluminum be used for the majority of the manufacturing process to stay within the given budget and also weight limitations given by the RMAX. It was also the most readily available due to its abundance located in the FAMU/FSU COE Machine shop’s scrap box. The type of aluminum that was used was T4-6061 aircraft grade aluminum. Aluminum is known for its great strength to weight ratio (ultimate tensile strength of 207 MPa, yield strength of 107 MPa) and also being very machinable, thus being a great choice for the application at hand. For the most part, steel lock-nuts and bolts of varying sizes were chosen to secure the machined parts together.

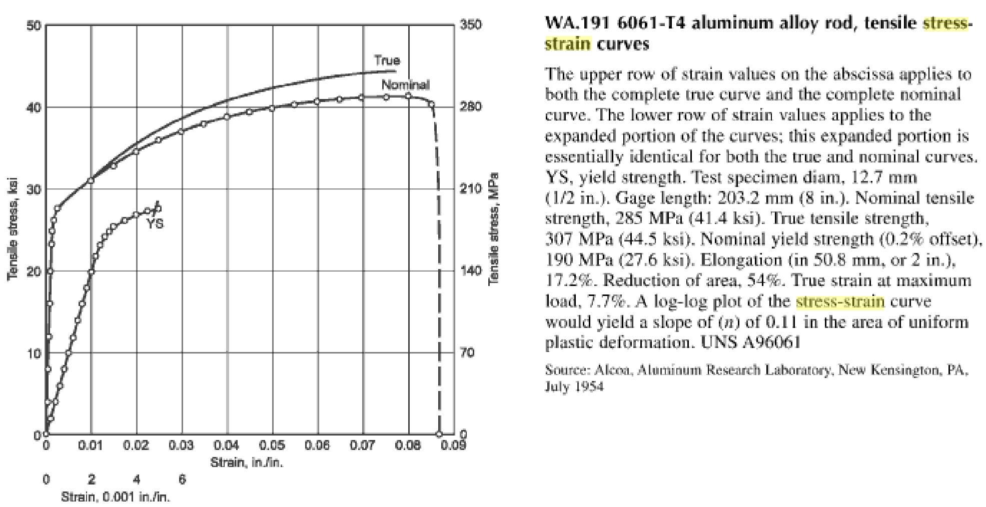


Figure 20: Stress/Strain curve of Aluminum 6061-T4

9.2 Bill of Materials

With the final design created using Solidworks, orders to Tyndall were sent to begin fabrication of the required parts. Turnaround time to receive the parts was about a week. Tyndall created the larger more difficult parts but did not have enough time for the smaller parts. Therefore the team had to find a way to fabricate the remaining parts. The team went to Keith Larson who is in charge of running the FAMU/FSU College of Engineering machine shop and asked if they may use the machines as well as seek some help. Larson agreed and also provided the team with the materials needed from scrap pieces of aluminum. After all the scrap aluminum from the FAMU/FSU College of Engineering machine shop was examined and deciphered through, the specimens that were deemed good and met the required thicknesses were kept while the rest were discarded. Once all the necessary material was gathered, the fabrication process began. The AFRL Team made use of the FAMU/FSU College of Engineering machine shop and Professor Jonathan Clark's Mobile Robotics Lab for most milling. This proved to be a bit of a challenge as well as a learning experience as the students had very limited machine experience. For the next couple weeks the team would spend any free time in the machine shop fabricating the necessary items. Tables 3-5 cover all of the parts in the Bill of Materials.

Part Number	Part Name	Material	Qty.
1	Platform Overhang	AL 6061-T4	1
2	Parallel Linkage #1	AL 6061-T4	2
3	Parallel Linkage #2	AL 6061-T4	2
4	Linkage Rod	Carbon Fiber	4
5	Counter Sink Flat head Screw	Stainless Steel	12
6	Female Tie Rod End	Stainless Steel	8
7	Round Spacer	Nylon	8

Table 3: Bill of Materials. Swinging Platform

Part Number	Part Name	Material	Qty.
1	RMAX Landing Gear	AL 6061-T4	1
2	RMAX Mounting Rack	AL 6061-T4	1
3	Socket System	AL 6061-T4	1
4	Funnel Clip Bracket	AL 6061-T4	4
5	Funnel Clip	AL 6061-T4	2
6	Funnel	AL 6061-T4	2
7	Bombot Container	AL 3003	1

Table 4: Bill of Materials. Swinging Platform

Part Number	Part Name	Material	Qty.
1	Base Platform	AL 6061-T4	1
2	Ball Flange 1	AL 6061-T4	2
3	Ball Flange 2	AL 6061-T4	4
4	Ball Flange 3	AL 6061-T4	2
5	Camera Assembly		1
6	Servo Mount 1	AL 6061-T4	4
7	Servo Mount 2	AL 6061-T4	2
8	Servo Mount 3	AL 6061-T4	2
9	Servo Mount 4	AL 6061-T4	2
10	Pittman Arm		2
11	Aligning Knob	AL 6061-T4	4
12	HS-5645MG Digital Servo		4

13	#8-32x.5625	Stainless Steel	16
14	#10-32x3.00	Stainless Steel	4
15	#10-32	Stainless Steel	2
16	#10-32x.50	Stainless Steel	4
17	#6-40x.5	Stainless Steel	16

Table 5: Bill of Materials. Platform Assembly

9.3 Swinging Platform Fabrication and Assembly

9.3.1 Parallel Linkage Blocks 1 & 2

The parallel linkage blocks 1 and 2 were both made from half inch, thick pieces of 6061-T4 Aluminum. While both sets of blocks are similar in shape, they each are responsible for executing different tasks. While the two sets of blocks look simple in design, they were very difficult to machine due to their extremely small size. Each cut and pass on the mill had to be very precise (much within a ± 0.001 in tolerance). After drilling three #21 bit holes, each hole had to then be tapped. Parallel linkage block 1 is used to fully secure the lower set of female tie rod ends to the Bombot's frame as well as insure alignment among the two sets of carbon fiber rods. There was $\frac{1}{16}$ inch clearance inserted between the inside of the block and the tie rod ends to allow for uninhibited movement among the tie rods and swinging platform as a whole. Parallel linkage block 2 is used to secure the upper set of tie rod ends to the overhang platform. While securing the overhang platform, they also provide a level surface in which the platform rests on and maintains the horizontal in such that the camera system utilizes the plane sight of view.

Figure 21: Scale view of Parallel Linkage Blocks

9.3.2 Female Tie Rod End

Although the female tie rod ends were purchased components, they were however modified. About 0.05 inches were shaved off of either side of each rod end so that it would fit inside the parallel linkage blocks and have enough room to move about freely within the blocks. There was also a #2-56 tapped hole placed about 1.35 inches from the end of the lower tie rods such that the servos that would control the ascension and descension of the overhang platform and camera system, could be attached using a #2-56 screw.

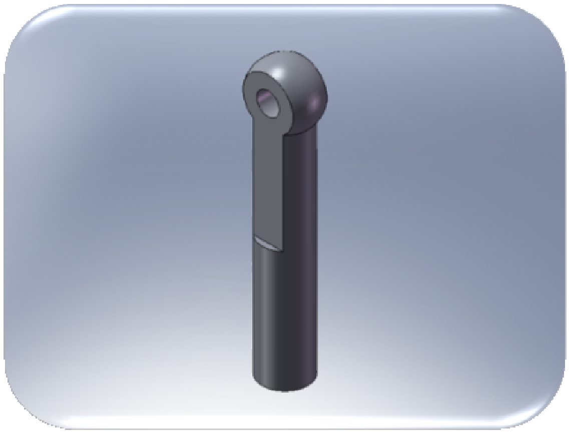


Figure 22: Female Tie Rod End

9.3.3 Overhang Platform

Due to the complex geometry and relatively thinness of the overhang platform, this component could not be milled upon. Therefore a 6-axis HAAS CNC machine was used to pre-drill holes and cut the flat outline of the overhang platform out of 1/8 inch thick 6061-T4 aluminum. The overall design of this component initially had two brackets for the camera system mounting. However after optimizing the system, the two brackets were minimized to one and then centered due to the second bracket being unnecessary since the camera's transmitter and battery packs was going to be attached to the Bombot's frame. Once the CNC machine cut out the overhang platform, 90º bends were inserted on both ends so that the platform could be attached to the upper parallel linkage blocks. The changes to the overhang platform are shown below in Figure 23.

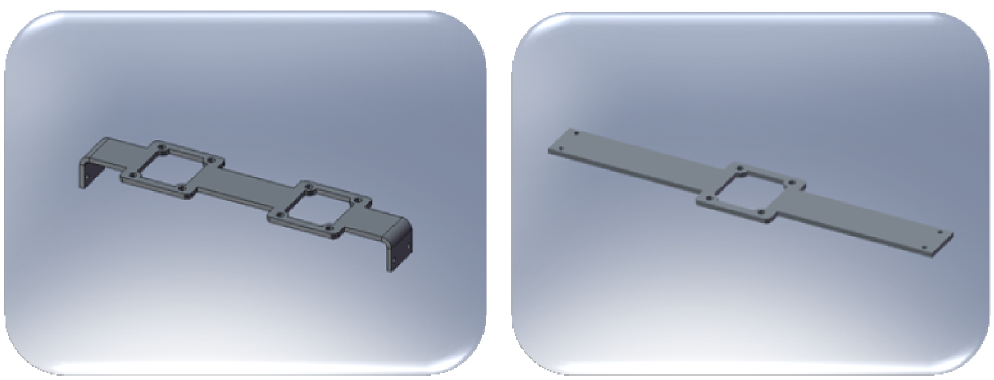


Figure 23: Overhang Platform; Old & New Comparison

9.4 Marsupial Payload

The RMAX's landing gear and mounting rack were both manufactured by an OMAX water jet cutting machine at Tyndall AFRL's fabrication shop. The other components which make up this assembly were also fabricated by AFRL however, finished by the team.

9.5 Funnel & Funnel Clip

As mentioned above, the funnel, which is paramount in the self aligning feature of the Bombot, was cut out of 0.032 inch thick sheets of aluminum. Once the flat shape was cut out, it was then formed with a solid steel cone and rubber mallet. An English wheel was the preferred machine to use for forming, however due to lack of in-town experience and virtually no wheels available, a rubber mallet was used to make the conical form of the funnel. As one could imagine, this was neither a quick nor easy task. Both funnels had to be identical as well as keep a 57º angle gradient which is vital to the lowering of the Bombot upon entering the container and avoiding the exhaust fixture of the RMAX.

The funnel clip was also manufactured by AFRL’s OMAX. Due to its unique profile, a regular mill fitted with a routing bit would be too cumbersome to handle the amount of precision needed to make the necessary cuts in the 0.20 inch thick sheet of aluminum. The OMAX left a clean and finished cut. The funnel systems components are displayed in Figure 24.

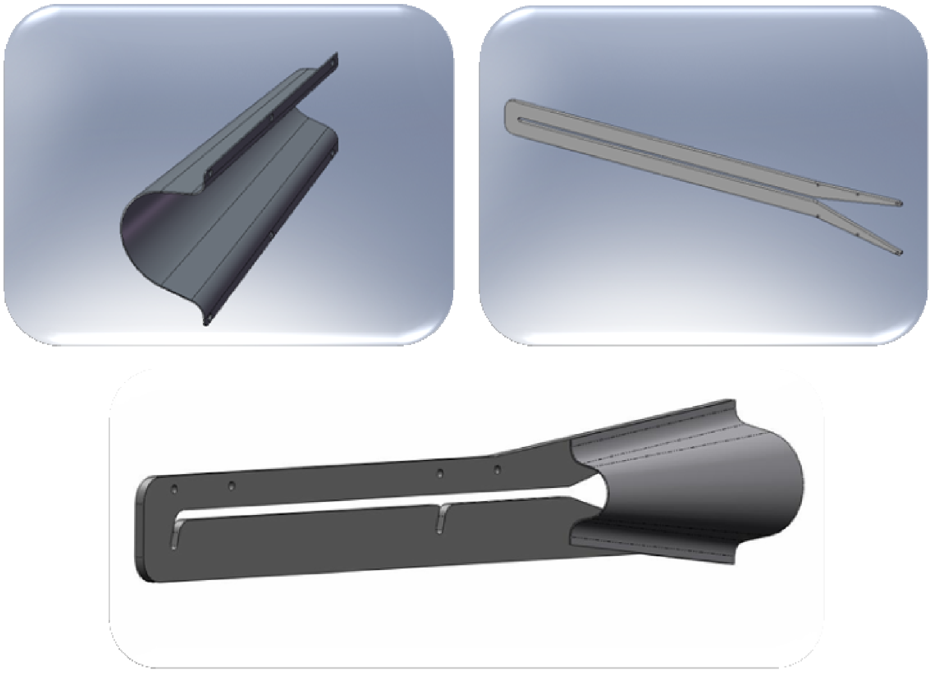


Figure 24: Funnel & Funnel Clip

9.6 Bombot Container

The Bombot container took several different shapes before finally being settled upon. The first among these shapes was a fully encompassing shell which had portholes along the side of the container to counter aerodynamics that the container would add as well as a door which would completely enclose the Bombot once inside as demonstrated in Figure 25.

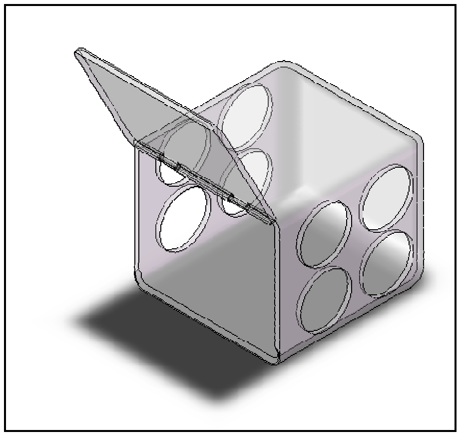


Figure 25: Old Box Design

Due to structural integrity and change of the project scope, it was later decided that the portholes on the side of the container were no longer needed. The lid was also discarded from the design due to the overall complexity of the system. The team wanted the system to be overall simplistic in nature such that manufacturing ease and time would be considerably cut down. After these changes were made to the container, the team had the new challenge of incorporating the self aligning feature of the Bombot. This was accomplished by making an indention profile along the sides of the container in which the funnel and funnel clips would rest; thus solving the challenge of adding the self aligning feature. The team also removed the top of the container due to it being unnecessary and overall weight reduction. The final design of the container was cut out of a 0.06 inch thick sheet of aluminum. The container was then folded to shape and welded together to increase the overall rigidity of the container and system. Figure 26 shows the changes that were done to the Box.

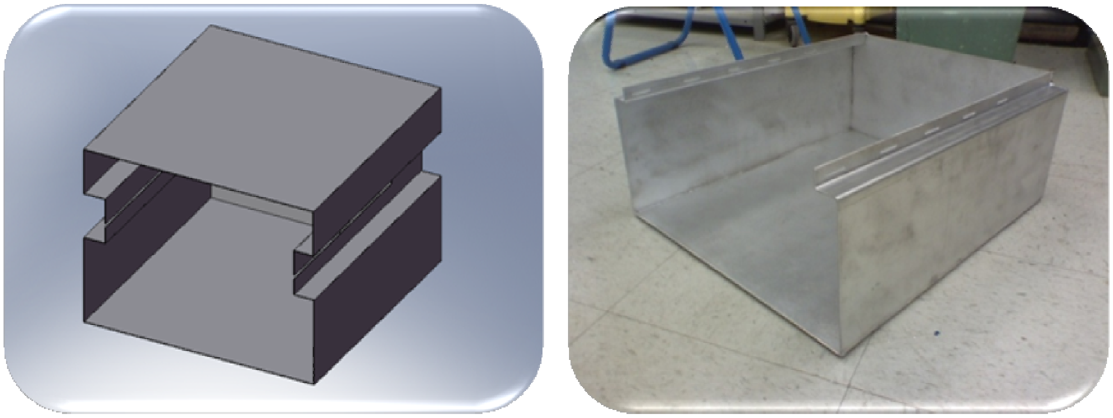


Figure 26: Non-Optimized(Left) & Optimized Container(Right)

9.7 Servo and Ball Mounting

9.7.1 Flanges

The manufacturing of ball flanges 1 and 3 were the simplest out of all the fabricated components. Both flanges were made from 0.25 inch thick pieces of aluminum. The main differences between the two are the heights and the hole placements about each flange. While ball flange 1 is 1.85 inches high, ball flange 2 is 1.9 inches high. There were a total of four through holes, measuring 0.161 inches in diameter placed in each of the two flanges.

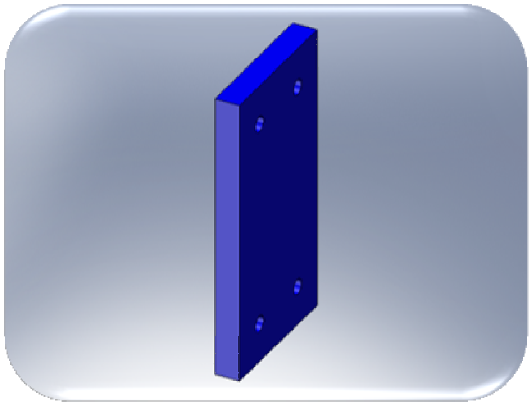


Figure 27: Ball Flange 1 and 3

Because of the abnormal design of ball flange 2, this component had to be fabricated with AFRL's OMAX. They were cut out of 0.25 inch thick blocks of aluminum 6061-T4. Ball flange 2 is paramount in supporting the Bombot's aligning knobs and is shown in Figure 28.

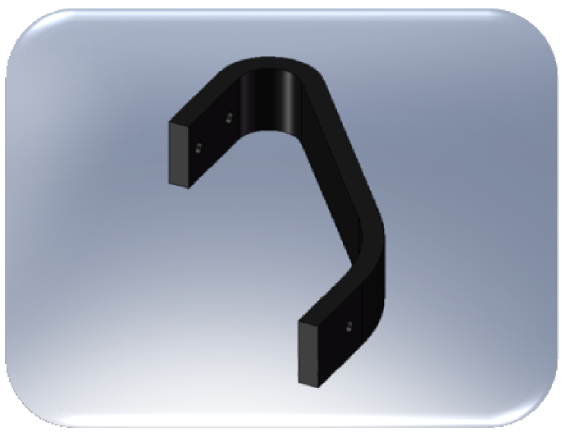


Figure 28: Ball Flange 2

9.7.2 Servo Mounts 1-4

Servo mount 1 was one of the more challenging components to fabricate. Measuring 1.90 x 0.25 x 1.42 inches, several precise passes on the mill had to be made before the four pre-drilled holes on the piece could be tapped. This component is vital in holding the locking servo which secures the Bombot in the container prior to lift off of the RMAX. A CAD image of this servo mount is in Figure 29.

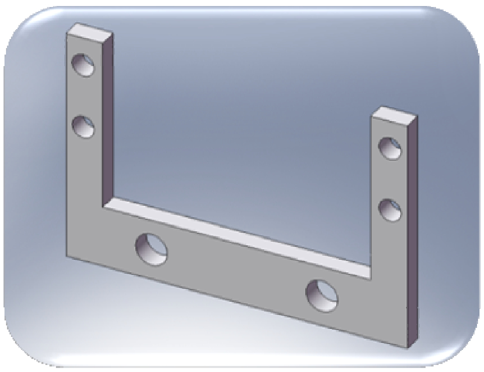


Figure 29: Servo Mount 1

Servo mounts 2 & 3 were also fabricated at the college of engineering's machine shop. Servo mount 2 was the simplest of the four mounts to fabricate due to it being a 0.375 inch thick piece of aluminum in which two through holes were drilled. Servo mount 3 was 0.2 inches thick and was made in the shape of a "T". Again four #30 through-holes were placed in the piece as shown by Figure 30.

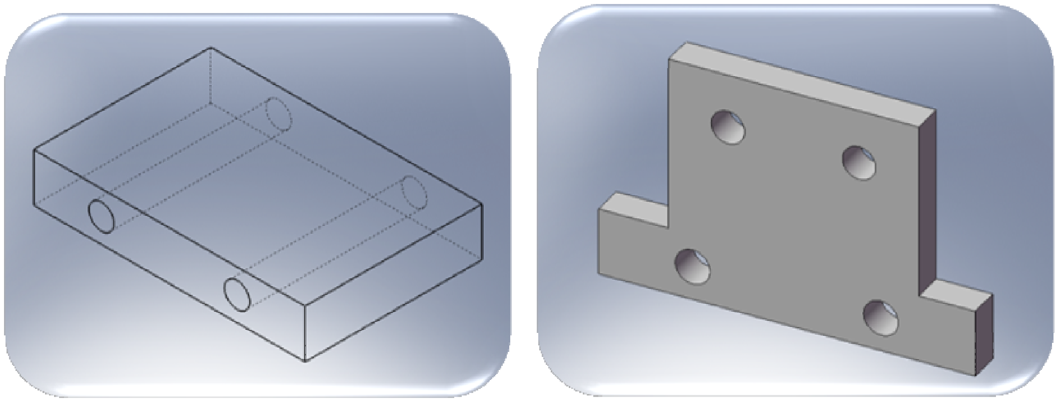


Figure 30: Servo Mount 2 (Left) & 3 (Right)

Servo Mount 4 was another difficult component to manufacture due its complex geometry and curves. The team believed that it would be best to manufacture the component using the HAAS CNC. Once the drawings for the component were transferred from the SolidWorks file format to the AutoDesk format which is more readily accepted by the HAAS, it was a quick process to transform the blocks of aluminum into the finished product located below in Figure 30. The component had a shape defining radius located at the top of the piece which measured 0.25 inches and several smaller splines which had radii measuring 0.12 and 0.15 inches. A built in design feature which was incorporated into the component was the off-centering of two through holes which aid in angling of the locking servos. Another two through holes were drilled into the bottom of the component such that it could be secured to the frame and ball flange 2 component. This mount is shown in Figure 31.

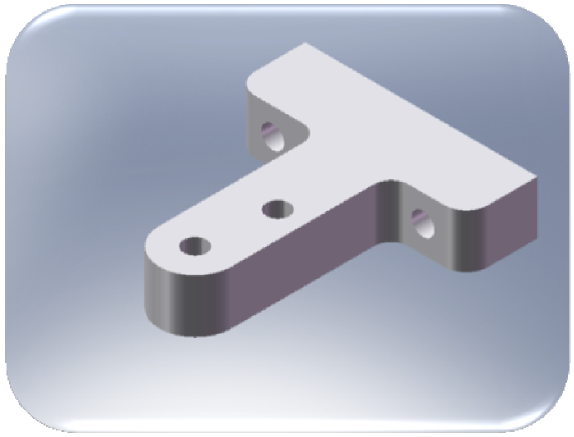


Figure 31: Servo Mount 4

10.0 Exploded View of Assemblies

The following are exploded views of how the systems are assembled. Actual Solidworks drawings are located in Appendix F. Figure 32, and 33 exploded views of the Swinging Platform, and Funnel System with the Payload container.

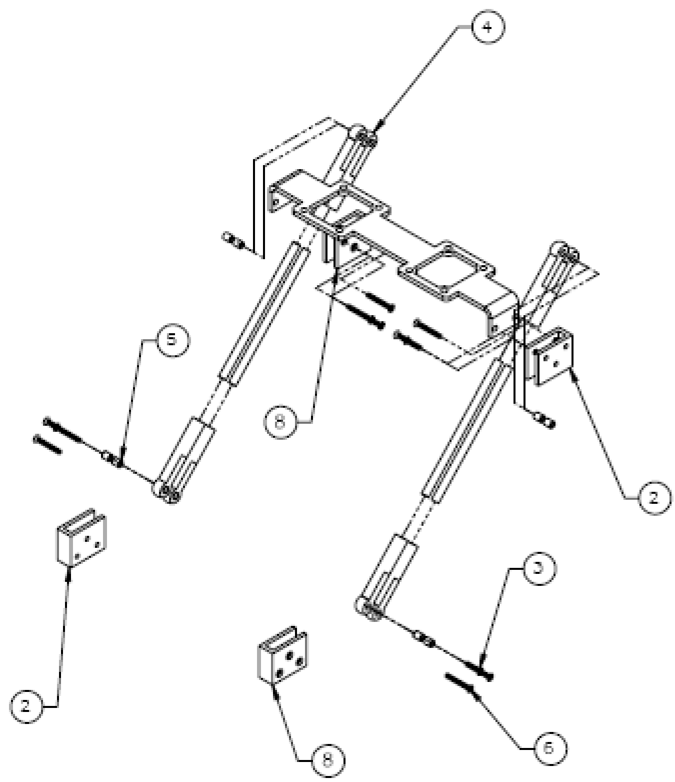


Figure 32: Swinging Platform Exploded View

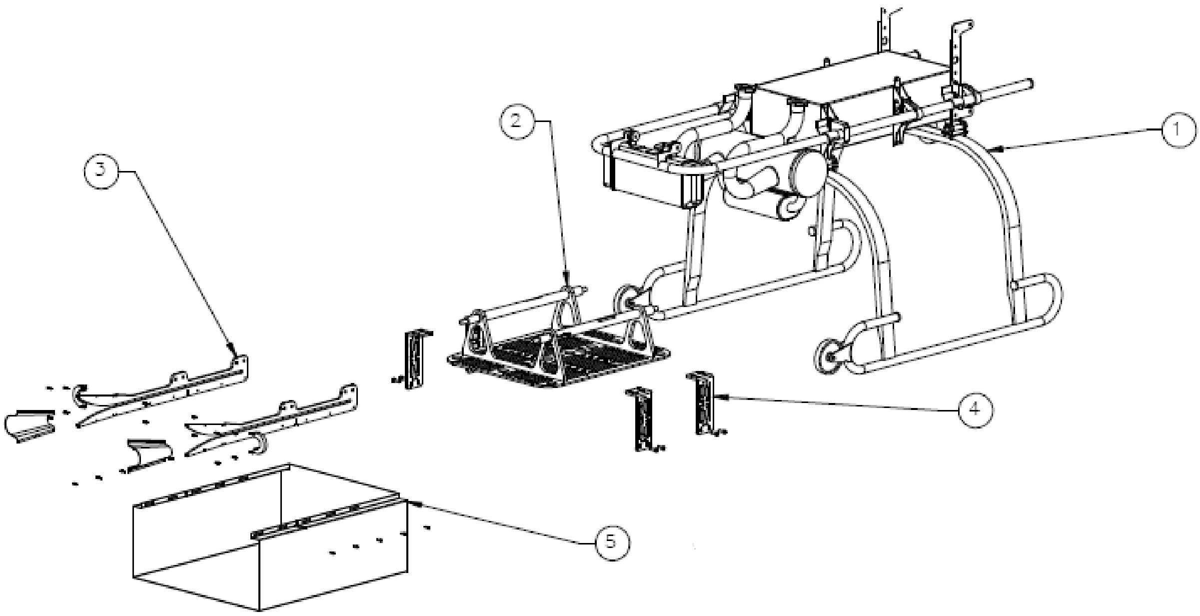


Figure 33: Exploded View of Funnel and Box System

11.0 Controls

Now that the team had a finalized design and ordered the raw materials for fabrication, the next issue to address was system control. Several members of the team took a trip to a local Hobbytown USA store to ask for some advice from the employees. The members spoke with the store manager, Sherman, and told him that they needed controls to activate the four servos. The two servos that would control the swinging platform needed to be activated simultaneously. These servos are depicted below in Figure 34. However the controls for the locking mechanisms can be controlled individually. It was also established that if the payload container was reinstalled to the Bombot the left and right locking servos could be coupled together into one channel in order to have the additional channel available to deploy the payload container. These goals needed to be achieved without creating any interference with the existing controls of the Bombot which operates at 2.4 GHz.

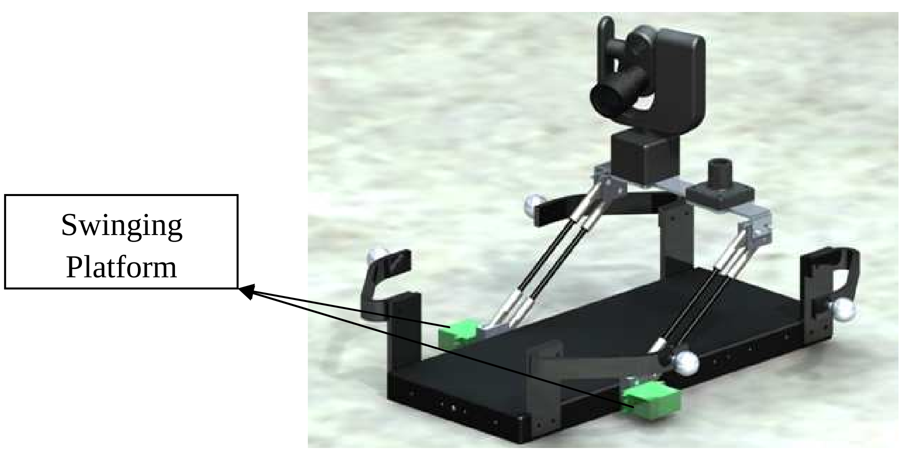


Figure 34: Location of swinging platform servos

Sherman expressed that the easiest and most efficient way to control all of the servos without any interference was to purchase an entirely new controller with seven channels to control all of the team's desires. This controller would take place of the existing controller while being able to control the camera assembly as well as the servos. The team accepted his advice and decided to go this route. An order through Hobbytown USA was placed for the necessary parts. The parts ordered for the controls are listed in Table 6.

Part Description	Quantity	Unit Price	Total Price	Account	Supplier
18" Ext Cord for Servo	2	$4.75	$9.50	FSU	Hobby Town USA
Y Connector	1	$5.99	$5.99	FSU	Hobby Town USA
Spectrum Radio Controller	1	$269.99	$269.99	FSU	Hobby Town USA
Servo Programmer	1	$115.00	$115.00	FSU	Hobby Town USA
Heavy Duty Cut Off Wheels	1	$11.00	$11.00	FSU	Hobby Town USA
Servo	4	$54.99	$219.96	FSU	Hobby Town USA

Table 6: Part List for Controls

The team needed individual channels to control the following: Throttle, Steering, Tilt of the Camera, Pan of the Camera, Height of the swinging platform, Left locking servo, and Right locking servo. Because of these requirements the team needed to purchase a controller with seven channels. Sherman suggested the Spectrum DX-7 to achieve these goals. This decision was based upon multiple reasons. First of all it had the ability to control the range of motion and reversing of each channel. Secondly the receiver that it utilized was very compact and would not interfere with the weight or size requirements that were necessary for the Bombot. Thirdly, it was within the budget set out for the total installation of the controls, and lastly it was already in stock and could be picked up and utilized in a timely manner. As a bonus this new control system eliminated the large antenna used by the stock controls.

For the actual installation of the controls, the first order of business was to change out the speed controller. The speed controller that came installed on the Bombot was prone to flipping the unit if the user made quick throttle changes, and it also did not come with any literature for the use or alteration of it. A new speed controller was installed and it was programmed to allow for only fifty percent of the available braking during forward motion. This alleviated much of the flipping that had been occurring with the Bombot.

After the new speed controller was programmed and installed the additional servos could be installed. Inherent to the DX-7 controller, as aforementioned, was the ability to reverse the servomotor, as well as change the range of motion. Both of these options were utilized. The steering of the Bombot was reversed in order to allow for the user to steer the wheels left and right with a left and right motion of the steering stick respectively. The pan of the camera was also reversed for the same reasons.

The throttle control of the Bombot was set below full throttle to allow for more control of the speed of the robot, as well as the range of motion of the locking servos to allow for the proper positioning of the locking servos when they were activated. An instructional breakdown of the DX-7 controller is shown in Figure 35.

Figure 35: Spektrum DX-7 User Guide

11.1 Autonomous Controls

During the fall semester the team spent time researching ways to make the engaging system autonomous. Beacon sensors became the option for achieving this goal. The team's plan was to implement an autonomous system in the Spring semester if a final product was completed earlier than expected. The team was not required to perform this for the project and simply researched it as a means of optimization. When the beginning of the spring began and the team received news of the mandatory five week testing deadline the team decided to not continue with the controls needed for autonomy. Given the amount of programming and components needed the funds needed to purchase the required parts would not be possible under the $1500 budget.

12.0 Final Prototype Design

With the new information received during the middle of the December the team needed to create a new project scope. The new scope covered all the new constraints that the team was to follow. A new design was created also created following these new constraints. The new and improved Ball and Socket System became a convolution of all the previous designs. The new design exposes all the previous designs benefits while deleting their flaws. The new design can be seen in Figure 36. This design is near identical to the previous, except for the updated container that the Bombot can drive into, the addition of a preload bracket added to the funnel clip for near zero deflection under load, and slots for a latching mechanism to completely secure the Bombot prior to take-off. The profile of the Funnel Clip was also changed as there was no longer a need for the lowered valleys. The latching mechanism and the preload bracket is shown in Figures 37 and 38 respectively.

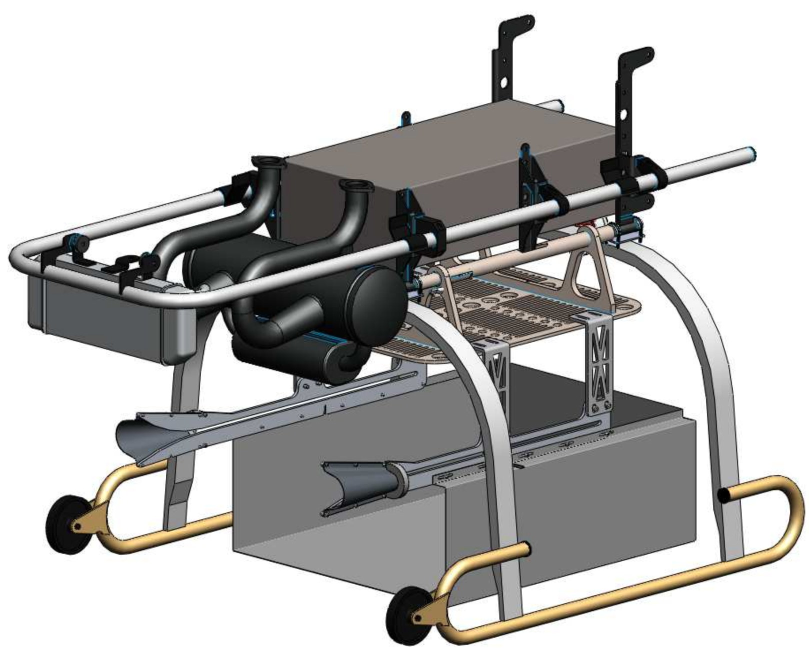


Figure 36 : Ball and Socket Prototype Design

The container was added to raise the Bombot off the ground. The bottom of the container is held ¼ in off the ground. The only contact the RMAX will have with the ground is the skids. This will minimize any unwanted forces onto the Bombot from its tires making contact with the ground.

The latching mechanism will keep the Bombot locked in place. If power is lost the servos will remain locked and the Bombot will remain secure. If signal is lost the servos will remain in their locked positions. Thus, the only way the Bombot will be rendered insecure is at the users will. Images of the locking notch and the preload bracket are seen in Figures 37 and 38.

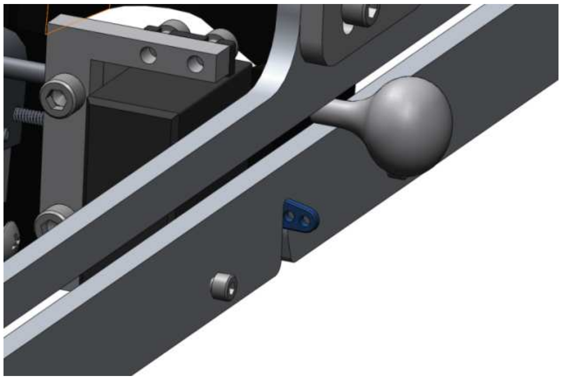


Figure 37: Bombot Locking in Funnel

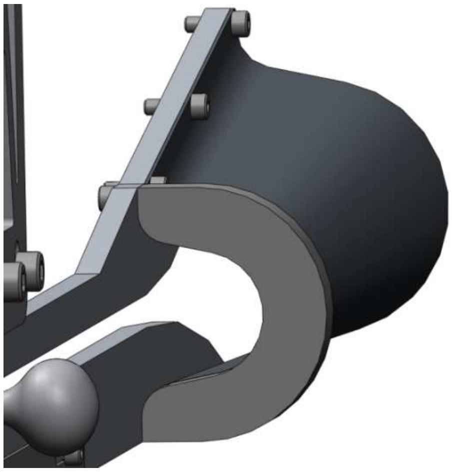


Figure 38: Preload Bracket

The Bombot's equipment had to be updated with the necessary hardware. Servos needed to be added to raise and lower the swinging platform carrying the camera as well as servos for locking the Bombot into the Funnel System. Once the servos were positioned a system of brackets needed to be designed as well. Designing the brackets that would mount the servos proved difficult because of all the different considerations such as different configurations, designing for manufacturing, and designing for assembly. The updated platform assembly is shown in Figure 39.

Figure 39: Bombot with updated Hardware

13.0 Testing

13.1 Testing Stage I: AFRL Static Tests

On the morning of February 26th 2009 the team met at the College of Engineering to get ready to embark on another visit to Tyndall Air Force Base. This visit was intended to perform testing of the prototype while attached to the RMAX. It was at this time that some final assembling and modifications took place. During some previous tests the team experienced some issues as engagement was attempted. The balls were a bit too large for the end of the funnel and the Bombot would get stuck occasionally. The team ground the surface of the Balls in order to create a temporary fix for the static tests that would take place later in the day. The next modification performed was the removal of the front bumper of the Bombot. This was done to avoid any part of the Bombot hanging out of the ball of the Box. This issue would be resolved later by ordering a new box with the corrected dimensions.

The Yamaha RMAX was taken outside to the testing grounds and the prototype was attached via the mounting bracket. Immediately the team noticed an issue. The bottom of the box made contact with the ground while attached to the RMAX instead of the expected ¼ inch. This would not alter the results of the testing but will have to be solved in the future. Lt. Kopeikin instructed the team to perform test runs by having the user operate the Bombot fifty feet away from the RMAX. The goal was to complete 10 flawless runs in a row before Lt. Kopeikin would approve the design for a test flight. A flawless run consisted of entering the RMAX, locking securely, and exiting the RMAX all without issues. The team recorded over fifty trials and came very close to achieving ten perfect runs in a row. The Bombot had a problem when reversing away from the RMAX and got stuck in the process. This issue mainly occurred due to the Bombot's steering system. While going in reverse the Bombot turns the wheels slightly to the left thus creating a chance that the Bombot may get stuck. Some other problems with the design were that the notches that were cut for the locking mechanism were not in the correct location. The locking servos were still strong enough to hold itself securely in the Box but they were not aligned properly. The operator of the Bombot would accelerate in the reverse direction to test security while engaged. Even with the notches slightly cut in the wrong location the Bombot would still be secure due to the strength of the locking servos. The team will address this issue when a new Box is ordered to fix the clearance issue as well. The mounts that held the locking servos in place had been missing a screw causing the servo to rotate slightly. The team planned to strengthen the stability of this mount once they returned back to Tallahassee. Overall the testing had gone successful. The tests that took place were the first actual tests that the team had done so they were pleasantly surprised with the results. The team felt that had they been able to perform full tests prior to the trip to Tyndall that these issues would be nonexistent. The proof of concept had clearly been shown and the team felt that the issues that arose were very simple to solve with some minor modifications. Lt. Koepeikin approved the design for a flight test if the team modified the Bombot to prevent the issues from occurring again. Note: The camera system had not been installed during these tests as the team was in the process of completing it. Images during the testing are displayed in Figures 40 and 41.

Figure 40: Bombot aligning with Engagement System

Figure 41: Inspecting the Locking Servos

13.1.1 Modifications from Testing Stage I

The team ordered a new box from AFRL with corrected dimensions as soon as they returned home from Tyndall. Extra screws were added to the servo mounting brackets in order to improve rigidity, movement was no longer an issue. With the installation of the new controls the steering issue was solved and the pervious mentioned problem did not repeat. A new profile and material for the Balls of the system were ordered. The previous balls had too great of a diameter and was a cause for some of the issues during testing. Relocation of the notches for the locking servos was performed at this time as well.

13.2 Testing Stage II: Team Static Tests

Shortly after the aforementioned modifications had been completed the team performed some more trial runs. The goal was twenty perfect runs in a row. These tests were done at the College of Engineering using the replica skids with the Engagement system attached via the mounting bracket. The system was placed about ¼ inch off the ground to simulate what it will be when attached to the RMAX. The first twenty trial runs were completed flawlessly with the locking servos engaging perfectly in the newly cut slots, see Figure 42. Following this, another twenty runs were performed again with similar results. After these tests the team received the completed camera system and began installation. The team installed the system to near completion however there was an issue with the wires of the camera. These wires were not very long and therefore the movement of the swinging platform was limited. Despite this the swinging platform was able to be lowered to its lowest point which is what was needed for the tests. The team performed more trial runs in order to be sure that there were no clearance issues with the camera. Figure 43 shows the amount of clearance available while engaged to the system. The outcome was twenty more perfect runs. Overall there were several runs that ran into issues but each time the Bombot was safely removed without the use of human interaction. Most of the issues that occur can be attributed to human error. It is very difficult to maneuver the Bombot and a large portion of success is due to the experience of the user.

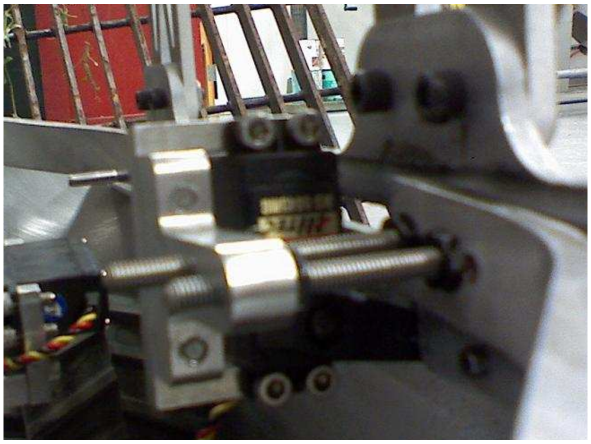


Figure 42: Locking servo engages successfully

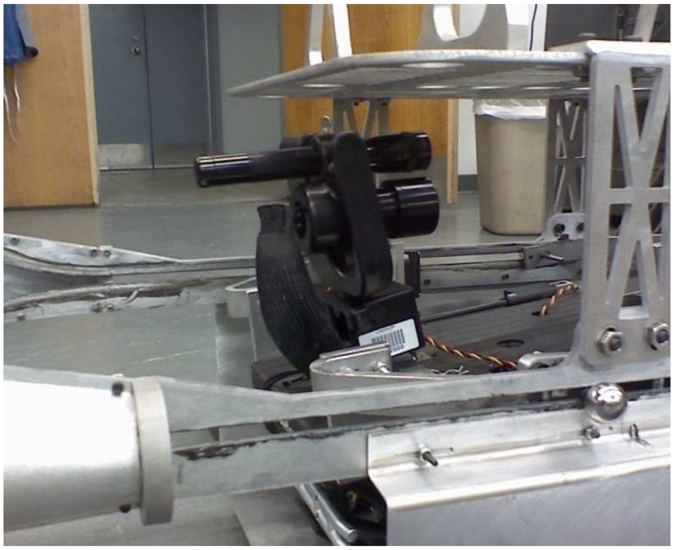


Figure 43: Camera clearance

13.2.2 Modifications from Testing II

The next modifications performed were mainly focused on optimization. The team felt comfortable with how successful the system had been and just wanted to strengthen several parts of the prototype that may fail due to fatigue. The swinging platform and locking servos were two parts of the system that were optimized. With the added weight of the camera system to the swinging platform the team did not want any flex to occur and therefore replaced the carbon fiber arms with aluminum. Longer wires for the camera system were also installed allowing the swinging platform to move freely in the total range of motion. Several tests were performed after these modifications with the results being just as successful as prior tests. An image of the aluminum arms for the swinging platform is seen in Figure 44.

Figure 44: Aluminum arms for swinging platform

13.3 Testing Stage III: AFRL Flight Tests

The team traveled to Tyndall on April 7th, 2009 for the scheduled flight test. The scheduled flight window was between 3:30pm and 5:30pm ET. Upon arrival the team received news that a flight test may not be possible due to the wind conditions. The winds were gusting between 15-22 mph throughout the day. These conditions are dangerous for operating the RMAX which as a wind limit of 13 mph. The pre-operation checklist was performed and the system was ready for testing. The checklist located in Appendix D. The team performed static tests before any flight testing occurred. Lt. Kopeikin instructed the team to perform ten flawless runs of engaging and disengaging to the RMAX. The first ten runs resulted perfectly and the team was cleared to fly. However due to the velocity of the wind the flight testing was placed on standby as the team waited for the wind to decrease. During this time the team took photographs of the system for the Final Report and Presentation. At 4:17pm ET the wind had died down enough for Phase I of the flight tests. The wind was still gusting so the RMAX was only to be flown about 5-10 ft above the ground. Phase I consisted of takeoff and landing of the RMAX with just the engagement container installed, the Bombot would not be engaged. While attempting to liftoff the payload container experienced heavy vibrations and the RMAX was shutdown. The RMAX briefly experienced a section of oscillations while accelerating. These oscillations are completely normal during liftoff. Unfortunately due to the lightness of the container these oscillations traveled directly to the system. The team and the sponsor believed that these vibrations can be prevented by adding more weight to the system, as the RMAX usually has counterweights installed when other applications are attached. At 4:24pm ET the next part of the testing was Phase II. This phase consisted of liftoff with the Bombot attached to the RMAX. The flight was a clear success as the vibrations that occurred before were nearly non-existent. The RMAX hovered between 5 and 10 ft from the ground for over a minute. Finally at 4:34pm ET Phase III of the testing was executed. Phase III was to have the Bombot attached to the RMAX while it was idling, deploy itself, return back to the RMAX and then experience liftoff. This phase of the testing was also a success as the team achieved similar results to Phase II, hovering for nearly two minutes. The team congratulated one another as well as Lt. Kopeikin. Lt. Kopeikin declared the project to be a complete success. Despite Phase I experiencing vibration issues, Phase II and III proved that adding counterweights to the system will eliminate the aforementioned problem. This is something that the team recommends for future work. Videos and photographs were recorded throughout all of the tests. Two of the images from the flight tests are shown in Figures 45 and 46.

Figure 45: Flight Test Image I

Figure 46: Flight Test Image 2

14.0 Final Project Design

This portion of the report will showcase some images of the completed design. The only changes that occurred were the ones that were mentioned in the Modifications from Testing section. Figures 47 – 50 are images of the system in its final state.

Figure 47: Bombot next to RMAX

Figure 48: Bombot Engaged to RMAX

Figure 49: Rodney, AFRL RMAX Operator, performing a successful flight test

Figure 50: Side view of flight test

15.0 Budget

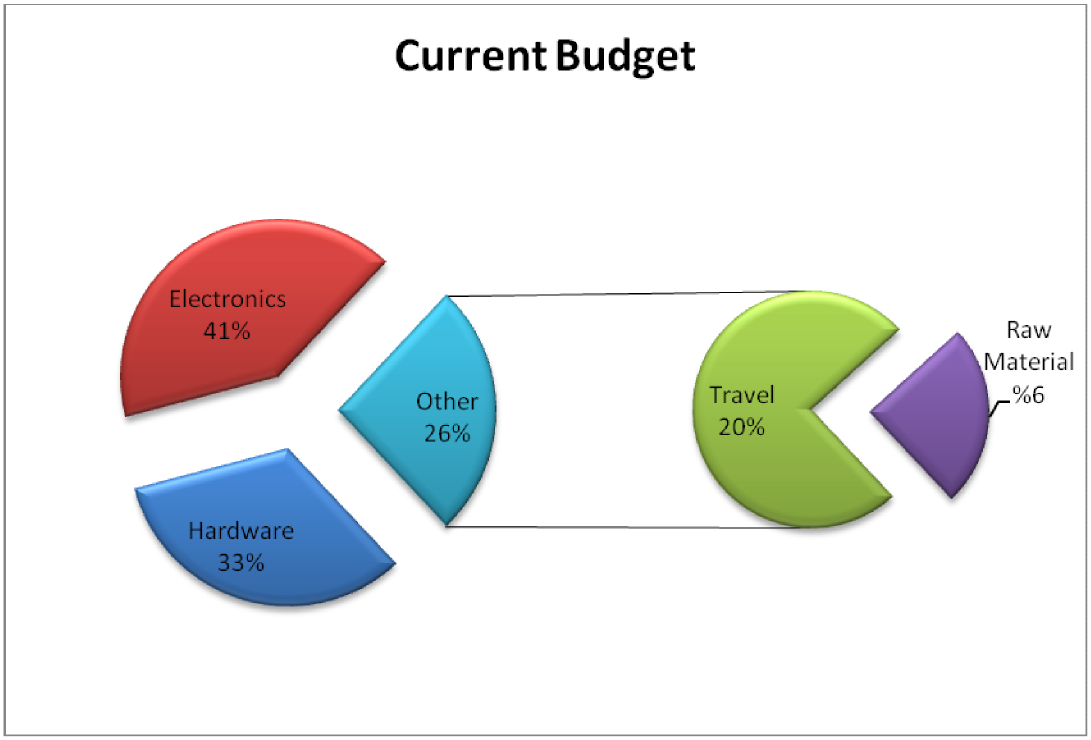


Figure 51: Pie Chart Breakdown of the Budget

The team was given a budget of $1500.00 to complete this project. Figure 51 shows a brief breakdown of how the budget was spent. The majority of the budget was allocated towards the electronic components for the build for a total of 41%. 33% of the budget was then allocated to hardware needed to complete the build. Items such as nuts and bolts, screws, batteries, and hook & loop are just a few that make up the hardware section. The other 26% of the budget went to travel and raw material. Since the team made use of the College of Engineering's machine shop, the cost of raw material was essentially very small; a mere 6% of the total budget. The team managed to stay within the budget only spending $1192.97 of the given $1500.00. Although the team did not fully utilize the $1500.00, the left over $325.68 could have been put towards higher quality servos or controls. A fully detailed version of the budget is located in Appendix A.

16.0 Conclusion

Throughout the year the team has worked diligently to design a Marsupial Deployment and Recovery system for Tyndall Air Force Laboratories. Based on the constraints and project goals given by the sponsor, the team identified the specifications and generated a project scope to guide them during the entire process. Initial concepts were developed and analyzed to determine which design would give the team the greatest chance of reaching the project objective. The team moved forward with the Ball and Socket design and spent several months modifying it so that it satisfied all of the constraints. Next the team gathered all the parts necessary to create a prototype that would be optimized as needed. Many tests were performed and notes were recorded on issues that had occurred. The team used these tests to modify the system so that the issues no longer occurred. A flight test was performed near the end of semester at AFRL with successful results. Overall the team achieved all of the required goals and the sponsor deemed the project, “Mission Accomplished”. The team is very satisfied with the outcome of the design and believes that given the time and budget constraints, there was not much that could have been improved.

16.1 Reccomendations

Regarding any further research for this project, the team has several recommendations that they wish to pass along. With the final prototype built the team experienced only one issue. As mentioned earlier the issue occurred during the first phase of the flight test with the Engagement system installed without the Bombot connected. The system experienced heavy vibrations while the Yamaha RMAX accelerated to prepare for liftoff. After performing additional tests the team determined that adding counterweights to the carriage will eliminate this issue. The vibrations did not occur while the Bombot was attached to the RMAX which is how the team determined the cause of this issue.

The battery system for the camera is also a portion of the system that can be improved. Currently it requires eight AA batteries to operate the functions of the camera. The batteries lose their life very quickly. Lithium-Ion or some other type of quality rechargeable batteries is highly recommended.

During the fall semester the team researched means of making the entire system autonomous. Due to lack of time and funds the team was not able to implement this into their project. The AFRL team believes that adding autonomous controls to the existing engagement system would be a create Senior Design project for the future.

17.0 References

Technical References

Tyndall Air Force Base Website:

< http://www.tyndall.af.mil/>

FAMU-FSU College of Engineering Website:

<http://www.eng.fsu.edu>

Mechanical Engineering Senior Design Website

<http://www.eng.fsu.edu/ME_senior_design>

Product References

Yamaha RMAX:

< http://www.yamaha-motor.co.jp/global/news/2002/02/06/sky.html>

Bombot:

< http://www.irt-robotics.com>

<http:// www.traxxas.com>

Materials and Parts

Controls:

< http://www.hobbytown.com/fltal/>

Miscellaneous Parts:

<http://www.mcmaster.com>

Box System, Funnel System:

<http://www.tyndall.af.mil/>

CAD Software:

<http://www.solidworks.com>

FEA Software:

<http://www.cosmosm.com>

18.0 Acknowledgements

The team would like to thank the following people for their outstanding support, without these people the project would not be what it is today.

First and foremost the team would like to thank Tyndall Air Force Research Laboratories for sponsoring this project as it has been a great learning experience for each of the team members. We thank our Liaison Engineer Lt. Andrew Kopeikin for the guidance and supervision throughout the entire project. Also we would like to thank Charles Young who was the team's Liaison Engineer for the fall semester. Charles provided the team with helpful information and tips in regards to completing a successful project.

Next we would like to thank our faculty advisor Dr. Clark who answered many questions regarding the controls portion of the project as well as the design aspect.

The team gives thanks to Daryl Stepp the AFRL machinist who fabricated very difficult parts needed for the project. Also from AFRL we thank Rodney who operated the Yamaha RMAX during Flight Tests.

The Store Manager of the Tallahassee Hobbytown USA – Sherman – provided the team with valuable information on what components were needed to have a successful controls system. Thank you for your politeness and expertise.

Thank you Keith Larson and Cody Epperson, Head of FAMU/FSU College of Engineering Machine shop and shop supervisor respectively, for your supervision and expertise in supplying the team with materials as well as helping the team to fabricate the necessary parts.

Lastly, the group would like to thank Dr. Waryoba and Dr. Shih for their efforts in providing information that helped the team throughout the entire project. Also thank you sincerely for allowing the team to restructure their spring course schedule, a finished product would be hard to believe had you two not cooperated so well with the teams needs.

Appendix A – Budget / List of Materials

Part	Part No.	Description	Quantity	Unit Price	Total Price	Account	Supplier
Paint Brush	FOAM-30	Foam paint Brushes	5	$0.70	$3.50	AFRL	US Composites
Chopped Strand Mat	FG-10538	Fiberglass chopped mat	6	$2.75	$16.50	AFRL	US Composites
404 Tooling Polyester	SM-404100	Fiberglass Resin	1	$36.50	$36.50	AFRL	US Composites
MEKP Hardner	SM-MEKP320	Fiberglass hardner	1	$12.95	$12.95	AFRL	US Composites
Fiberglass Roller	FR-1315A	Roller	1	$5.80	$5.80	AFRL	US Composites
Mix & Measure Buckets	CON-MM160	Measuring & Mixing cups	5	$1.65	$8.25	AFRL	US Composites
Stir Sticks	GLV-PS050	Stir sticks	1	$3.95	$3.95	AFRL	US Composites
Dust Respirator	3M-8210	Respirators	4	$1.50	$6.00	AFRL	US Composites
Latex Exam Gloves	GLV-LL100	Gloves	1	$10.00	$10.00	AFRL	US Composites
Plastic Squeegy	SQ-04	Squeegy	5	$0.50	$2.50	AFRL	US Composites
Mold Release	MEG-108	Fiberglass Release	2	$9.95	$19.90	AFRL	US Composites
Electric Conduit	-	Tubing_Skids First Mock up	1	$10.00	$10.00	FSU	Home Depot
Aluminum	9536K41	Color-Coded Aluminum Shim Stock .030" Thick, 12" X 24", Coral	2	$14.70	$29.40	AFRL	McMaster-Carr
Low Carbon Steel	9517K159	Low-Carbon Steel Tight-Tolerance Flat Stock 1/8" Thick, 3-1/2"	2	$32.81	$65.62	AFRL	McMaster-Carr

		Width, 2' Length					
Screws	90471A163	100 Degree Flat Head Phillips Machine Screw Zinc-Plated Steel, 4-40 Thread, 1/2" Length, Packs of 100	1	$9.81	$9.81	AFRL	McMaster -Carr
Screws	90273A114	Zinc-Plated Stl Flat Head Phil Machine Screw 4-40 Thread, 7/8" Length, Packs of 100	1	$4.16	$4.16	AFRL	McMaster -Carr
Spacers	94639A714	Nylon Unthreaded Round Spacer 3/16" OD, 1/2" Length, #4 Screw Size, Packs of 100	1	$8.12	$8.12	AFRL	McMaster -Carr
Rods	1581K11	Female Threaded Rod End 1/4"-20 Thread Sz, 3/4" L Thread, 1/2" Head Dia, 2" L	8	$10.34	$82.72	AFRL	McMaster -Carr
Steel Balls	9528K39	E52100 Alloy Steel Ball 15/16" Diameter, Grade 25, Packs of 15	1	$14.99	$14.99	FSU	McMaster -Carr
Alluminum	7830K121	Multipurpose Aluminum (Alloy 6061) Chrome-Coated, 3/16" Diameter, 1' Length (Same as 7830K21)	1	$5.66	$5.66	FSU	McMaster -Carr
Threaded Round Standoff	96110A035	Nylon Female Threaded Round Standoff 1/4" OD, 3/16" Length, 10-32 Screw Size (Same as 96110A530)	8	$0.94	$7.52	FSU	McMaster -Carr
Steel Rod	93250A056	Type 316 Stainless Steel Threaded Rod 10-32 Thread, 1' Length	2	$3.14	$6.28	FSU	McMaster -Carr

Cap Screw	92200A345	Military Specification Socket Head Cap Screw 300 Series SS, 10-32 Thrd, 3/4" Length, MS 16996-12, Packs of 10	1	$4.33	$4.33	FSU	McMaster-Carr
Cap Screw	92196A281	18-8 Stainless Steel Socket Head Cap Screw 10-32 Thread, 2-1/2" Length, Packs of 25	1	$9.75	$9.75	FSU	McMaster-Carr
Cap Screw	92200A194	Military Specification Socket Head Cap Screw 300 Series SS, 8-32 Thrd, 1/2" Length, MS 16995-26, Packs of 10	2	$3.95	$7.90	FSU	McMaster-Carr
Cap Screw	92196A082	18-8 Stainless Steel Socket Head Cap Screw 2-56 Thread, 7/16" Length, Packs of 100	1	$6.62	$6.62	FSU	McMaster-Carr
Machine Screw	96877A216	82 Deg Flat Head Phillips Machine Screw 300 Series SS, 4-40 Thrd, 1/2" L, MS51959-17, Packs of 50	1	$7.51	$7.51	FSU	McMaster-Carr
Machine Screw	91771A114	18-8 SS Flat Head Phillips Machine Screw 4-40 Thread, 7/8" Length, Packs of 100	1	$4.95	$4.95	FSU	McMaster-Carr
Machine Screw	91771A124	18-8 SS Flat Head Phillips Machine Screw 5-40 Thread, 1/4" Length, Packs of 100	1	$5.28	$5.28	FSU	McMaster-Carr
B.O. Cap Screw	91251A459	Black-Oxide Alloy Steel Socket Head Cap Screw 12-24 Thread, 5/8"	1	$11.19	$11.19	FSU	McMaster-Carr

		Length, Packs of 25					
I. Locknut	90715A115	Type 316 SS Nylon-Insert Hex Locknut 10-32 Thread Size, 3/8" Width, 15/64" Height, Packs of 50	1	$8.51	$8.51	FSU	McMaster -Carr
Thin Locknut	90101A004	18-8 SS Nylon-Insert Thin Hex Locknut 4-40 Thread Size, 1/4" Width, 7/64" Height, Packs of 50	1	$7.25	$7.25	FSU	McMaster -Carr
Thin Locknut	90633A006	Grade 2 Steel Nylon-Insert Thin Hex Locknut Zinc-Plated, 5-40 Thread Size, 1/4" W, 7/64" H, Zinc-Plated, Packs of 100	1	$4.38	$4.38	FSU	McMaster -Carr
AL. Plug	27175A115	Vanadium Steel Hand Tap for Aluminum Plug, 8-32, H3 Pitch Dia, 3 Flute	1	$8.43	$8.43	FSU	McMaster -Carr
Machine Screw	96537A160	Black-Oxide 18-8 SS Machine Screw Hex Nut 10-32 Thread Size, 3/8" Width, 1/8" Height, Packs of 100	1	$8.52	$8.52	FSU	McMaster -Carr
S.S. Cap Screw	92196A751	18-8 Stainless Steel Socket Head Cap Screw 5-40 Thread, 5/16" Length, Packs of 50	1	$6.81	$6.81	FSU	McMaster -Carr
S.S. Cap Screw	92196A126	18-8 Stainless Steel Socket Head Screw 5-40 Thread, 3/8" Length, Packs of 50	1	$7.05	$7.05	FSU	McMaster -Carr

Hex Nut	90257A038	Type 316 SS Machine Screw Hex Nut 12-24 Thread Size, 7/16" Width, 5/32" Height, Packs of 50	1	$11.65	$11.65	FSU	McMaster -Carr
Ball Bearings	9613K37	Nylon 6/6 Ball 1" Diameter, Packs of 10	1	$9.28	$9.28	FSU	McMaster -Carr
Vel. Tape	94985K812	Super Adhesive All- Purpose Nylon Hook & Loop 1" W X 10' L, Black, Packs of 10 Ft.	1	$17.67	$17.67	FSU	McMaster -Carr
Extension Cord	Vp2104	18" Ext Cord for Servo	2	$4.75	$9.50	FSU	Hobby Town
Connector	Vp2110	Y Connector	1	$5.99	$5.99	FSU	Hobby Town
Controller	Spm2712	Spectrum Radio Controller	1	$269.99	$269.99	FSU	Hobby Town
Servo Programmer		Servo Programmer	1	$115.00	$115.00	FSU	Hobby Town
Cut Off Disks		Heavy Duty Cut Off Wheels	1	$11.00	$11.00	FSU	Hobby Town
Servo	hrc35645s	Servo	4	$54.99	$219.96	FSU	Hobby Town
Trip #	**Travel Date**	**Destination**	**# In Atten.**	**# of Miles**	**$/Mile**	**Account**	**Total**
1	9/12/2008	Tyndall AFB	3	200	0.38	FSU	$76.00
2	9/26/2008	Tyndall AFB	2	200	0.38	FSU	$76.00
3	10/17/2008	Tyndall AFB	4	200	0.38	FSU	$76.00
4	2/26/2009	Tyndall AFB	4	200	0.38	FSU	$76.00
5	4/7/2009	Tyndall AFB	4	200	0.38	FSU	$76.00
Total Funds	**$1,500.00**						
Total Spent through FSU	**$1,192.97**						
Total Spent through AFRL	**$325.68**						
Amount Left	**$307.03**						

Appendix B – Addition Information of Design

B.1 Aerial Marsupial for UGV TP V2

B.1.1 UGV Marsupial Payload

The UGV marsupial payload is designed specifically to contain and secure the bombot in all six degrees of freedom. The payload is attached to the RMAX mounting rack. The RMAX mounting rack is commonly used to attach external systems to the RMAX and is therefore considered a secure attachment point.

The bombot will be stored in a partial container with an open top and front to allow access and camera clearance. This container will keep the bombot suspended above ground during pre take-off and post landing. Ideally the only forces acting on the UAV are the normal forces of the ground acting on the skids and the thrust due to the blades. Although other loads will inherently be present on the UAV throughout the flight procedure, they are considered minimal and have been designed for. The partial container prevents the tires of the bombot from contacting the ground and non-ideal forces due to the contact. The partial container is shown in Figure 52.

Mechanical slots will guide the bombot into a secure position. The overall shape and geometry of the slots will correct misalignments and human error of the steering of the bombot relative to the RMAX. When the bombot reaches its furthest position into the partial container two servos will activate and engage a failsafe locking system. This locking mechanism combined with the entire UGV marsupial payload will secure the bombot in six degrees of freedom relative to the RMAX. The locking mechanism is programmed to default to the locked position, so when communication is lost the bombot will remain secured. The locking mechanism uses an interlocking method keeping the bombot fully engaged to the RMAX with no motor torque necessary. The force keeping the bombot secure is distributed through the pin of the servo, and not the servo itself. This concept is similar to the deadbolt on a door, whereas on a door little force is necessary to lock and a lot of force is needed to open the door once the lock is engaged. These mechanical slots can be seen in Figure 52.

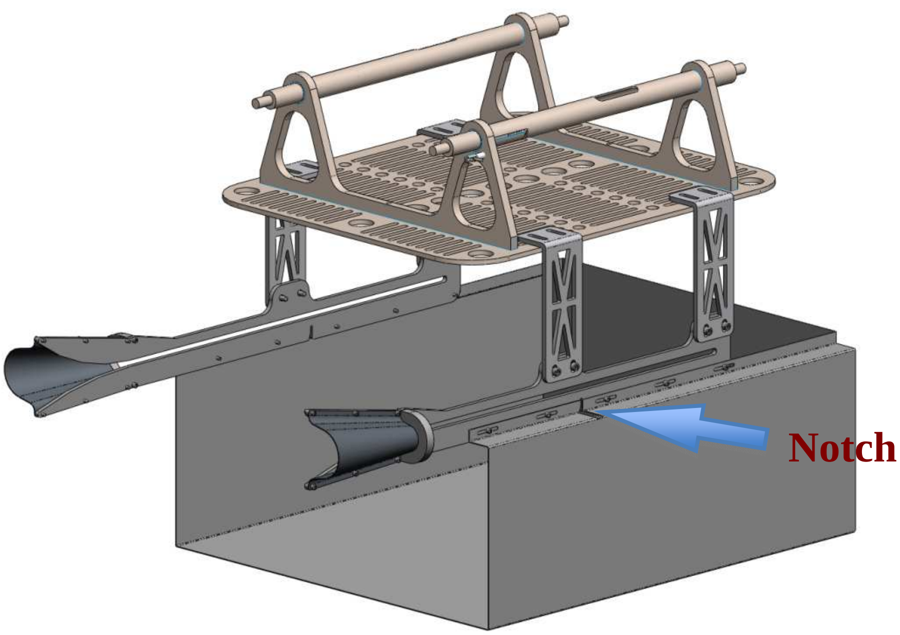


Figure 52: UGV Marsupial Payload for Bombot

B.1.2 Bombot UGV

The bombot UGV is a four wheel drive all terrain vehicle. The bombot has been equipped with the necessary hardware to engage the RMAX UAV. The system is designed for the bombot to gain entrance from the front of the UAV. The necessary hardware consists of multiple brackets, the swinging platform system, and alignment balls.

The swinging platform allows the bombot's video camera clearance to fit underneath of the belly of the RMAX as well as provide appropriate height of the camera to view the surroundings. Hence, the swinging platform will raise and lower the video camera assembly to the desired height. The height of the Bombot is controlled by two servos working in sync to raise and lower the camera assembly's platform. The platform also redistributes weight to the center of the platform creating better performance for the Bombot. The swinging platform can be seen in Figure 53 in its upright position.

Four steel balls are used to correct the Bombot's heading angle, constrain in the partial container, and compress the rear suspension to give the camera extra clearance from the UAV's exhaust system. The UAV's exhaust system jets hot exhaust onto the Bombot so sensitive materials such as the camera and electronics are going to be shielded with heat wrap.

Figure 53: Bombot UGV

B.2 Power Supply System

The RMAX UAV uses a 12V 7A lead acid battery for boot-up sequence and starting from a pinion-plunge type electric starter. Power is supplied to the aircraft avionics and components from a 12V 140W on-board generator.

B.3 Airborne Equipment Weight and Balance and Configuration Control Management

The weight and balance of this configuration will be verified upon installation of all utilized components. The manufacturer has identified the correct weight and balance requirements for the RMAX. Below is a list of known airborne test equipment and respective weights. Configuration 1 lists the weight of the RMAX with the UGV Marsupial Payload, but without a mounted Bombot. Configuration 2 lists the same weights and includes a latched robot.

Configuration 1 – RMAX with Marsupial payload (without Bombot):

Baseline weight	
RMAX Aircraft:	136.0 lbs
WePilot Autopilot:	0.5 lbs
Full tank of Fuel	11.1 lbs
UGV Marsupial Payload\(without Bombot)	6.8 lbs
Total Anticipated Weight:	**154.4 lbs**

Configuration 2 – RMAX with Marsupial payload (with Bombot):

Baseline weight	
RMAX Aircraft:	136.0 lbs
WePilot Autopilot:	0.5 lbs
Full tank of Fuel	11.1 lbs
UGV Marsupial Payload\(without Bombot)	6.8 lbs
Bombot	19.5 lbs
Total Anticipated Weight:	**173.9 lbs**

A systematic approach is followed for configuration control management. Any desired configuration change is compared to the original RMAX configuration to ensure the desired change will meet the space, weight, and balance limitations of the aircraft. A surrogate payload is then mounted on the aircraft for the evaluation steps and suspended from the center of gravity to determine initial moment changes. The aircraft is then hovered and flown manually with the surrogate payload by the chief UAV operator to determine acceptable flight characteristics in the lateral and longitudinal planes (not to exceed full trim scale deflection to remain level). A pre-established series of maneuvers are performed to ensure the aircraft performs as expected. Autonomous flight is then activated and the aircraft follows a similar series of procedures. Upon success, the flight configuration is stored on the local Ground Control Station computer (via the operator interface) and backed up on an external drive. Any unacceptable deviations are noted and discussed to determine the best method for improvement. Flights with the surrogate payload are repeated until the aircraft control is acceptable. All physical configuration changes to the aircraft are documented in detail in the daily aircraft log.

B.4 AFRL's Machining of Container's Issues:

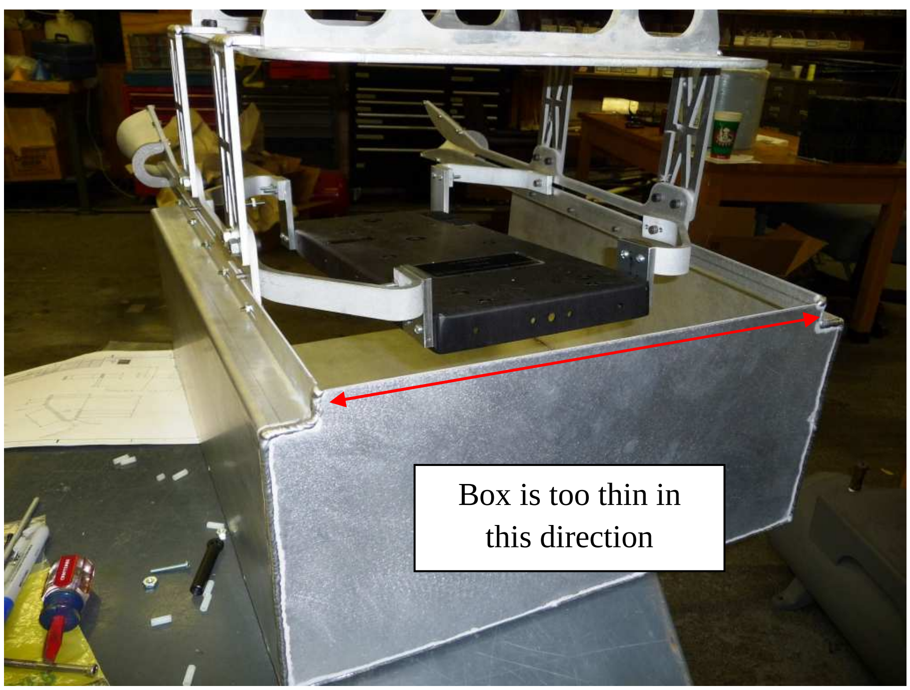


Figure 54: Box Container Issue 1

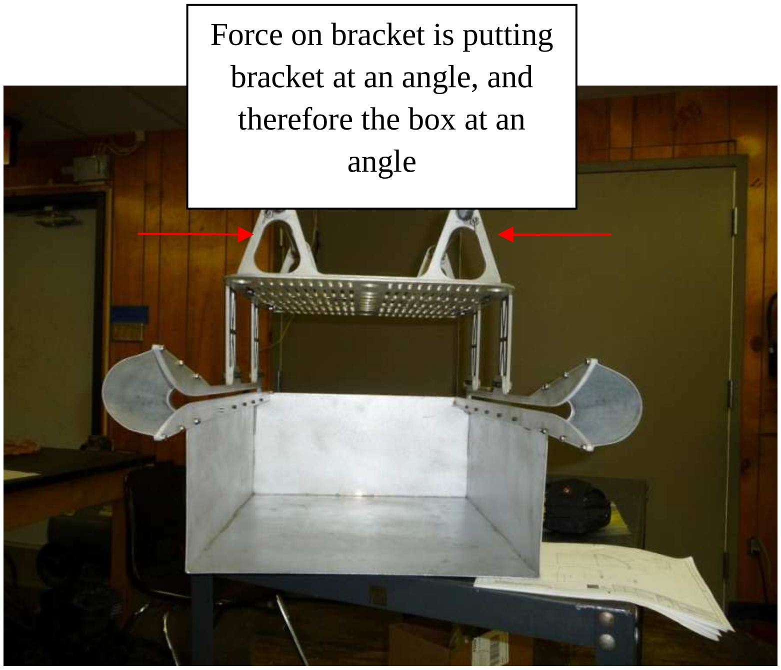


Figure 55: Box Container Issue 2

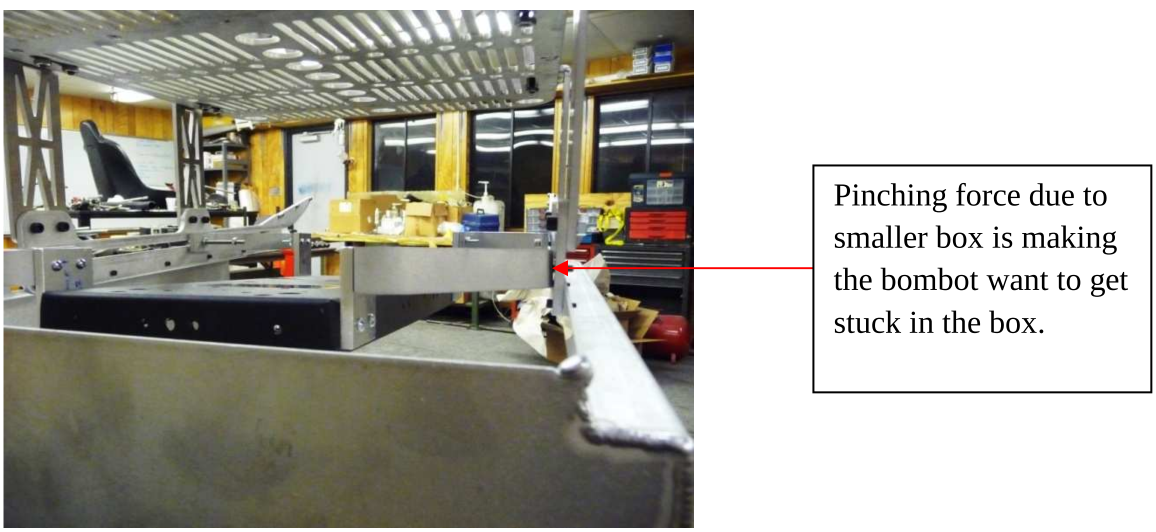


Figure 56: Box container issue 3

Appendix C – Stress Analysis

Stress analysis of Marsupial Payload Analysis

Author: Robert Skapof

Company: AFRL

Note:

Optimization decisions will not be based solely on the analysis report. This information used in conjunction with experimental data and practical experience is necessary for optimization. Field testing is mandatory to validate final design.

C.1 Description

The entire payload is to be supported by the four Funnel Clip Brackets. The Funnel Clip Brackets connects the funnel system to the mounting rack. The funnel system fixes the Bombot container to the RMAX. Due to characteristics of the payload it was only necessary to test the funnel system and the four Funnel Clip Brackets.

C.2 Assumptions

The assumptions are used to define normal operating conditions. Abnormal operating conditions are unpredictable and are dependent on the environment, the RMAX pilot, and the Bombot pilot. The air born RMAX carrying the engaged Bombot is declared normal operating conditions.

C.3 Model Information

DOCUMENT NAME	**DATE MODIFIED**
Marsupial Payload Analysis	Sun Feb 22 17:03:06 2009
Funnel Clip Bracket-1	Sun Feb 22 17:02:57 2009
Funnel Clip Bracket-2	Sun Feb 22 17:02:57 2009
Funnel Clip Bracket-3	Sun Feb 22 17:02:57 2009
Funnel Clip Bracket-4	Sun Feb 22 17:02:57 2009
Funnel System 2-1/Funnel Preload Bracket-1	Sun Feb 22 17:02:59 2009
Funnel System 2-1/Funnel Preload Bracket-2	Sun Feb 22 17:02:59 2009
Funnel System 2-1/funnel 3-3	Sun Feb 22 17:03:01 2009
Funnel System 2-1/funnel 3.1-1	Sun Feb 22 17:03:03 2009
Funnel System 2-1/funnel clip 5-1	Sun Feb 22 17:03:02 2009
Funnel System 2-1/funnel clip 5-2	Sun Feb 22 17:03:02 2009

C.4 Study Properties

Study name	Study 1
Analysis type	Static
Mesh Type:	Mixed Mesh
Solver type	Direct sparse solver
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Thermal Effect:	Input Temperature
Zero strain temperature	298.000000
Units	Kelvin
Include fluid pressure effects from COSMOSFloWorks	Off
Friction:	Off
Ignore clearance for surface contact	Off
Use Adaptive Method:	Off

C.5 Units

Unit system:	English (IPS)
Length/Displacement	in
Temperature	Fahrenheit
Angular velocity	Hz
Stress/Pressure	psi

C.6 Material Properties

C.6.1 Solid Bodies

NO.	BODY NAME	MATERIAL	MASS	VOLUME
1	**Funnel Clip Bracket**-1	[SW]6061 Alloy	0.0857622 kg	3.17638e-005 m^3
2	**Funnel Clip Bracket**-2	[SW]6061 Alloy	0.0857622 kg	3.17638e-005 m^3
3	**Funnel Clip Bracket**-3	[SW]6061 Alloy	0.0857622 kg	3.17638e-005 m^3
4	**Funnel Clip Bracket**-4	[SW]6061 Alloy	0.0857622 kg	3.17638e-005 m^3
5	Funnel System 2-1/**Funnel Preload Bracket**-1	[SW]Plain Carbon Steel	0.0756157 kg	9.69432e-006 m^3
6	Funnel System 2-1/**Funnel Preload Bracket**-2	[SW]Plain Carbon Steel	0.0756157 kg	9.69432e-006 m^3
7	Funnel System 2-1/**funnel 3**-3	[SW]3003 Alloy	0.0270619 kg	1.00229e-005 m^3
8	Funnel System 2-1/**funnel 3.1**-1	[SW]3003 Alloy	0.0270635 kg	1.00235e-005 m^3
9	Funnel System 2-1/**funnel clip 5**-1	[SW]6061 Alloy	0.285369 kg	0.000105692 m^3
10	Funnel System 2-1/**funnel clip 5**-2	[SW]6061 Alloy	0.285369 kg	0.000105692 m^3

MATERIAL NAME:	[SW]6061 ALLOY
Description:	Aluminum cut by water jet and machined on mill.
Material Source:	Used SolidWorks material
Material Library Name:	SolidWorks Materials

Material Model Type:	Linear Elastic Isotropic

PROPERTY NAME	VALUE	UNITS	VALUE TYPE
Elastic modulus	6.9e+010	N/m^2	Constant
Poisson's ratio	0.33	NA	Constant
Shear modulus	2.6e+010	N/m^2	Constant
Mass density	2700	kg/m^3	Constant
Tensile strength	1.2408e+008	N/m^2	Constant
Yield strength	5.5149e+007	N/m^2	Constant
Thermal expansion coefficient	2.4e-005	/Kelvin	Constant
Thermal conductivity	170	W/(m.K)	Constant
Specific heat	1300	J/(kg.K)	Constant

MATERIAL NAME:	[SW]PLAIN CARBON STEEL
Description:	Steel cut on water jet and machined on mill.
Material Source:	Used SolidWorks material
Material Library Name:	solidworks materials
Material Model Type:	Linear Elastic Isotropic

PROPERTY NAME	VALUE	UNITS	VALUE TYPE
Elastic modulus	2.1e+011	N/m^2	Constant
Poisson's ratio	0.28	NA	Constant
Shear modulus	7.9e+010	N/m^2	Constant
Mass density	7800	kg/m^3	Constant

Tensile strength	3.9983e+008	N/m^2	Constant
Yield strength	2.2059e+008	N/m^2	Constant
Thermal expansion coefficient	1.3e-005	/Kelvin	Constant
Thermal conductivity	43	W/(m.K)	Constant
Specific heat	440	J/(kg.K)	Constant

MATERIAL NAME:	[SW]3003 ALLOY
Description:	Sheet metal 3003 Alloy.
Material Source:	Used SolidWorks material
Material Library Name:	SolidWorks materials
Material Model Type:	Linear Elastic Isotropic

PROPERTY NAME	VALUE	UNITS	VALUE TYPE
Elastic modulus	6.9e+010	N/m^2	Constant
Poisson's ratio	0.33	NA	Constant
Shear modulus	2.7e+010	N/m^2	Constant
Mass density	2700	kg/m^3	Constant
Tensile strength	1.103e+008	N/m^2	Constant
Yield strength	4.1361e+007	N/m^2	Constant
Thermal expansion coefficient	2.3e-005	/Kelvin	Constant
Thermal conductivity	170	W/(m.K)	Constant
Specific heat	1000	J/(kg.K)	Constant

C.7 Loads and Restraints

C.7.1 Restraint

RESTRAINT NAME	SELECTION SET	DESCRIPTION
Mounting Rack Top Surface	on 4 Faces **Roller/Sliding**	The roller restraint constrains the lips of the Funnel Clip Brackets to the top surface of the mounting rack.
Mounting Rack Machine Screws	on 16 Faces **Fixed**.	The machine screws clearance holes for mounting the Funnel Clip Brackets to the mounting rack are fixed to simulate the mounting rack constraining the Funnel Clip Brackets.

C.7.2 Load

LOAD NAME	SELECTION SET	LOADING TYPE	DESCRIPTION
Bombot Mass	on 2 Faces apply normal force 12 lb using uniform distribution	Sequential Loading	The bombot weighs 19 pounds and the container with accessories weighs 5 pounds. This force is distributed across the tracks of the Funnel Clip.

C.8 Mesh Information

Mesh Type:	Mixed Mesh
Mesher Used:	Standard
Automatic Transition:	Off
Smooth Surface:	On
Jacobian Check:	4 Points

Element Size:	0.16015 in
Tolerance:	0.0080073 in
Quality:	Draft
Number of elements:	248130
Number of nodes:	61701
Time to complete mesh(hh;mm;ss):	00:00:42
Computer name:	ROB-PC

C.8.1 Mesh Control Information:

Mesh Refinement of the funnel clip 5-1 and funnel clip 5-2	Mesh control on Funnel Clips with seed 0.08 in, 4 layers and ration 1.2.

C.9 Study Results

NAME	TYPE	MIN	MAX
Stress Plot	VON: von Mises Stress	0.0121159 psi Node: 3207	3445 psi Node: 28315
Displacement Plot	URES: Resultant Displacement	0 in Node: 326	0.0274173 in Node: 44539

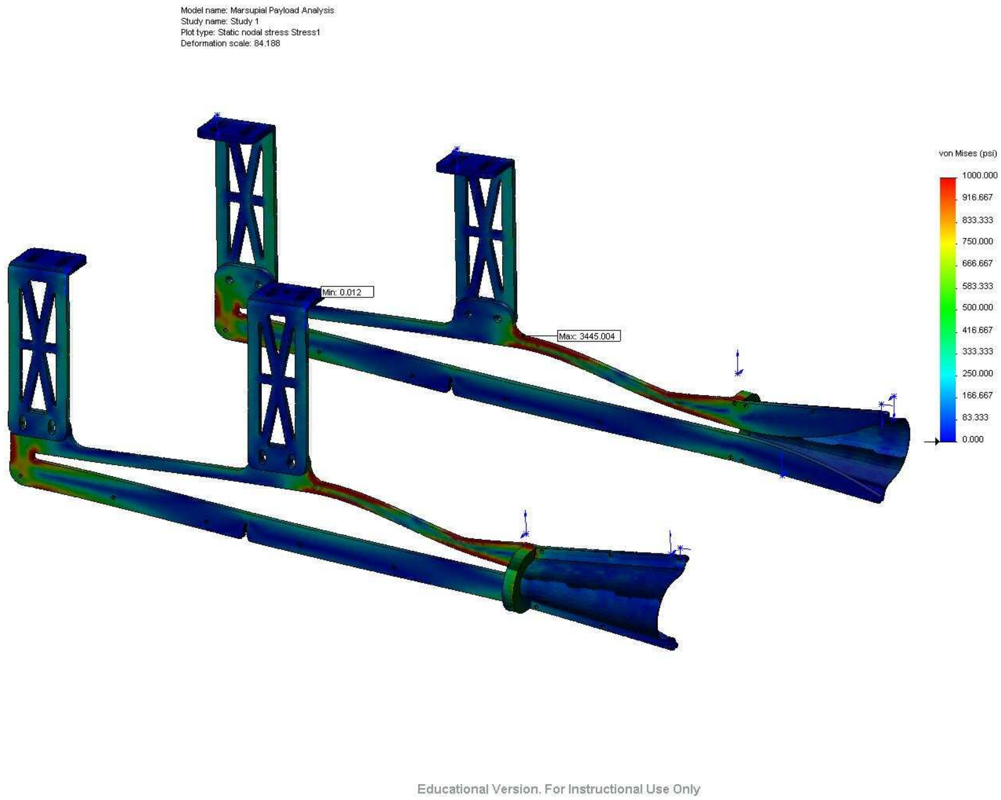


Figure 57: Marsupial Payload Analysis - Stress Distribution (psi)

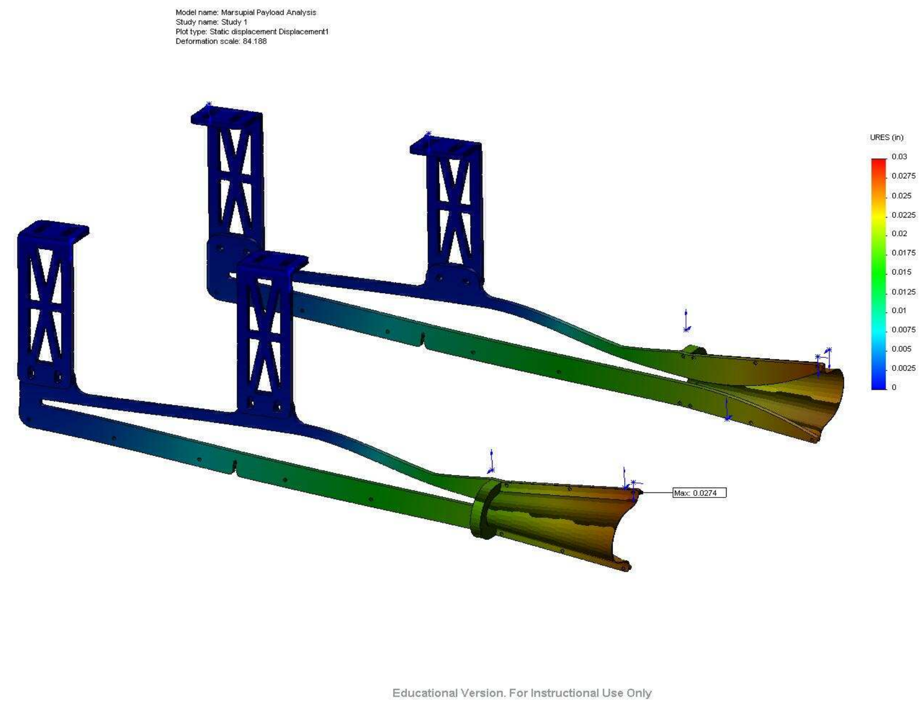


Figure 58:Marsupial Payload Analysis – Displacement Distribution (in)

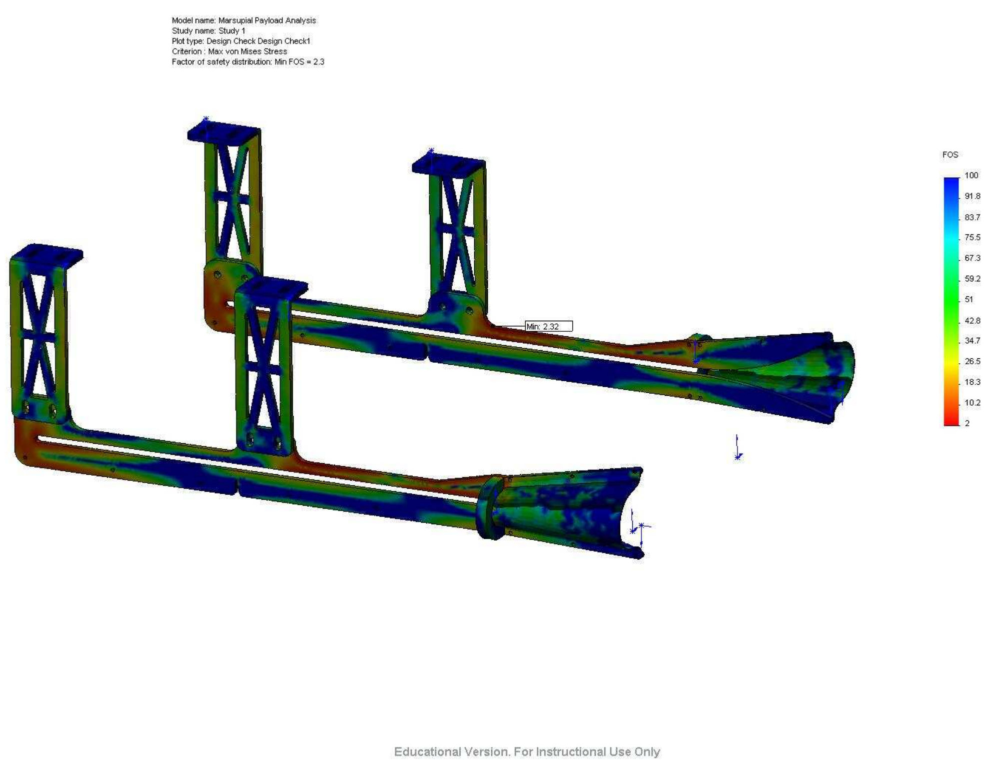


Figure 59:Marsupial Payload Analysis – Design Check and Factor of Safety Distribution

C.10 Conclusion

The lowest factor of safety achieved is 2.32. The funnel system can support twice the weight of the payload before plastic deformation is achieved. This factor of safety holds under the assumption of zero lateral force due to external forces.

Appendix D – Bombot and Marsupial Payload Checklist

- ☐ **Pretest 1. Bombot control verification.**
  - Verify no interference from bombot controller due to RMAX control.
  - Check bombot servo actuation and fail safe. Operate servos.
  - Verify manual control, both magnitude and direction, for all surfaces.
  - Verify reported controls match the actual control positions.
  - Verify all bombot flanges, mounts, and brackets are secure. Tighten all fasteners.
  - Verify proper operation of swinging platform. Lower and raise platform several times.
- ☐ **Pretest 2. Marsupial Payload verification.**
  - Verify all brackets, flanges, and mounts are secure. Tighten all fasteners.
  - Check slotted tracks for debris.
- ☐ **Engagement Test.**

  Pre-Engagement.
  - Locate UAV relative to Bombot to gain visual.
  - Raise swinging platform if not already raised.
  - Locate UAV on video screen from Bombot feed.
  - Align heading direction of Bombot with the grounded heading direction of UAV.
  - Minimize distance between Bombot and UAV to approximately 5 feet.

  Engagement
  - Lower swinging platform. Verify on video screen from Bombot feed that camera has been lowered. Operator will see support legs parallel to Bombot top surface.

- Drive forward at a slow steady pace penetrating the tracks of the marsupial payload and the partial container itself until the furthest position possible has been reached.
- Verify the furthest position possible has been reached by observing on the video screen the Bombot's front alignment balls have reached the end of track.

Activate failsafe locking mechanism. Observe on video screen servo in slot engagement.

Appendix E – Course Schedules

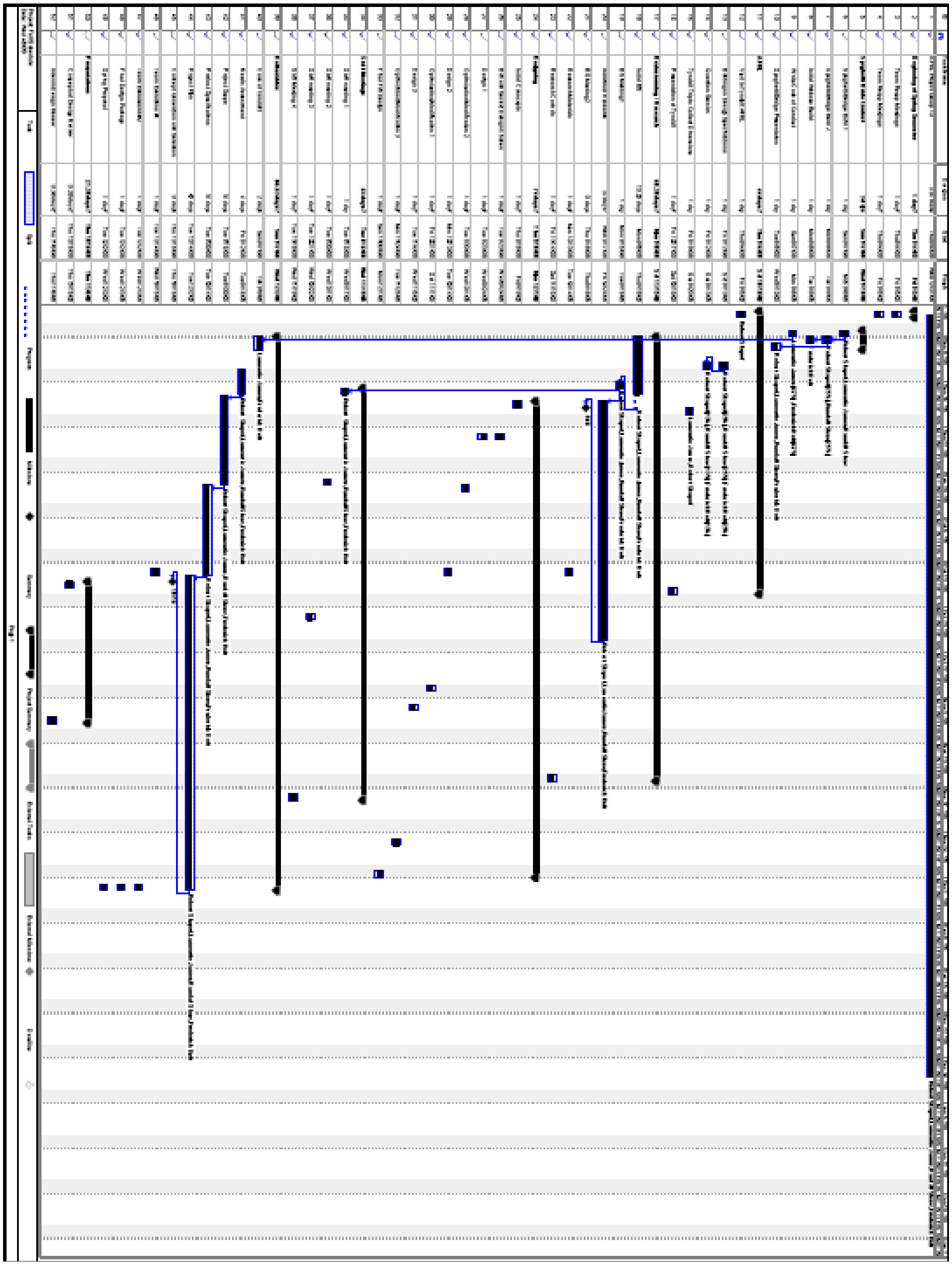
E.1 Fall Course Schedule

Semester 1	**Tue**	**Thu**
Week 01	08/26 Introduction/Roll Call	08/28 Roll Call/ Team Assignments.
Week 02	09/02 Project Assignments Lecture: The design Process	09/04 Introduction to Senior Design Lecture: Team building
Week 03	09/09 Project kickoff/Planning meeting **Due: Team building Activity (N-B), Report, and Code of Conduct**	**NO CLASS*** (Teams meet with clients to establish Needs Assessment/Project scope)
Week 04	09/16 Staff Meetings **Due: Needs assessment report/Project scope**	09/18 Staff Meetings **Due: Needs assessment report/Project scope**
Week 05	09/23 Tutorial on Scheduling software **Guest Lecture – CAT?**	09/25 **EGLIN Visit (Dr. House)?** **Guest Lecture – CAT?**
Week 06	09/30 Staff Meetings **Due: Product Specification** **Due: Project Procedures/Project Plan (schedule)**	10/02 Staff Meetings **Due: Product Specification** **Due: Project Procedures/Project Plan (schedule)**
Week 07	10/07 No class	10/09 No class
Week 08	10/14 **Presentation: Conceptual Design Review**	10/16 **Presentation: Conceptual Design Review**

	Due: Concept Generation and Selection **Due: Team evals. #1**	**Due: Concept Generation and Selection** **Due: Team evals. #1**
Week 09	10/21 Staff meetings (team eval.)	10/23 Staff meetings (team eval.)
Week 10	10/28 No class	10/30 No class
Week 11	11/04 **Presentation: Interim Design Review**	11/06 **Presentation: Interim Design Review**
Week 12	11/11 **Veterans Day**	11/13 **Staff Meeting (team eval.)**
Week 13	11/18 Staff Meetings (team eval.)	11/20 MEAC Presentation
Week 14	11/25 No class	11/27 No class (Thanksgiving)
Week 15	12/02 **Presentation: Final Design Review** **Due: Final Design Package** **Due: Spring Proposals** **Due: Team evals. # 2**	12/04 **Presentation: Final Design Review** **Due: Final Design Package** **Due: Spring Proposals** **Due: Team evals. # 2**
Week 16	12/09 No class/No exams	12/11 No class/No exam

* No class – may be substituted for Guest speaker, Travel/Industrial visit, or Lecture if deemed necessary

E.1.1 Fall 2008 Gantt Chart



E.2 Original Spring Course Schedule

Semester 2	Tue	Thu
Week 01	01/06 Lecture: Introduction to 2nd Semester	01/8 Lecture: Technical Communications
Week 02	01/13 Staff meetings **Due: Restated Project Scope & Project Plan**	01/15 Staff meetings **Due: Restated Project Scope & Project Plan**
Week 03	01/20 No class *	01/22 No class *
Week 04	01/27 Presentations: Progress report **Due: Team evals. #3**	01/29 Presentations: Progress report **Due: Team evals. #3**
Week 05	02/03 No class	02/05 Guest Lecture: Technical Writing (Dr. Moulton)
Week 06	02/10 Staff meetings	02/12 Staff meetings
Week 07	02/17 No class	02/19 No class
Week 08	02/24 Presentations: Mid-point review	02/26 Presentations: Mid-point review
Week 09	03/03 No class	03/04 No class
Week 10	03/10 Spring Break	03/12 Spring Break
Week 11	03/17 Staff meetings	03/19 Staff meetings
Week 12	03/24 No class	03/26 No class
Week 13	03/31 No class	**04/02 Picture Day and Exit interviews ?**
Week 14	04/07 Presentation: Final project review (walkthrough for Open House) **Due: Operations Manuals** **Due: Web pages** **Due: Final Reports** **Due: Team evals. #4 (final)**	04/9 Presentation: Final project review (walkthrough for Open House) **Due: Operations Manuals** **Due: Web pages** **Due: Final Reports** **Due: Team evals. #4 (final)**
Week 15	04/14 No class	04/16 OPEN HOUSE (all day)
Week 16	04/21 No class/No exams	**04/23 Awards Ceremony**

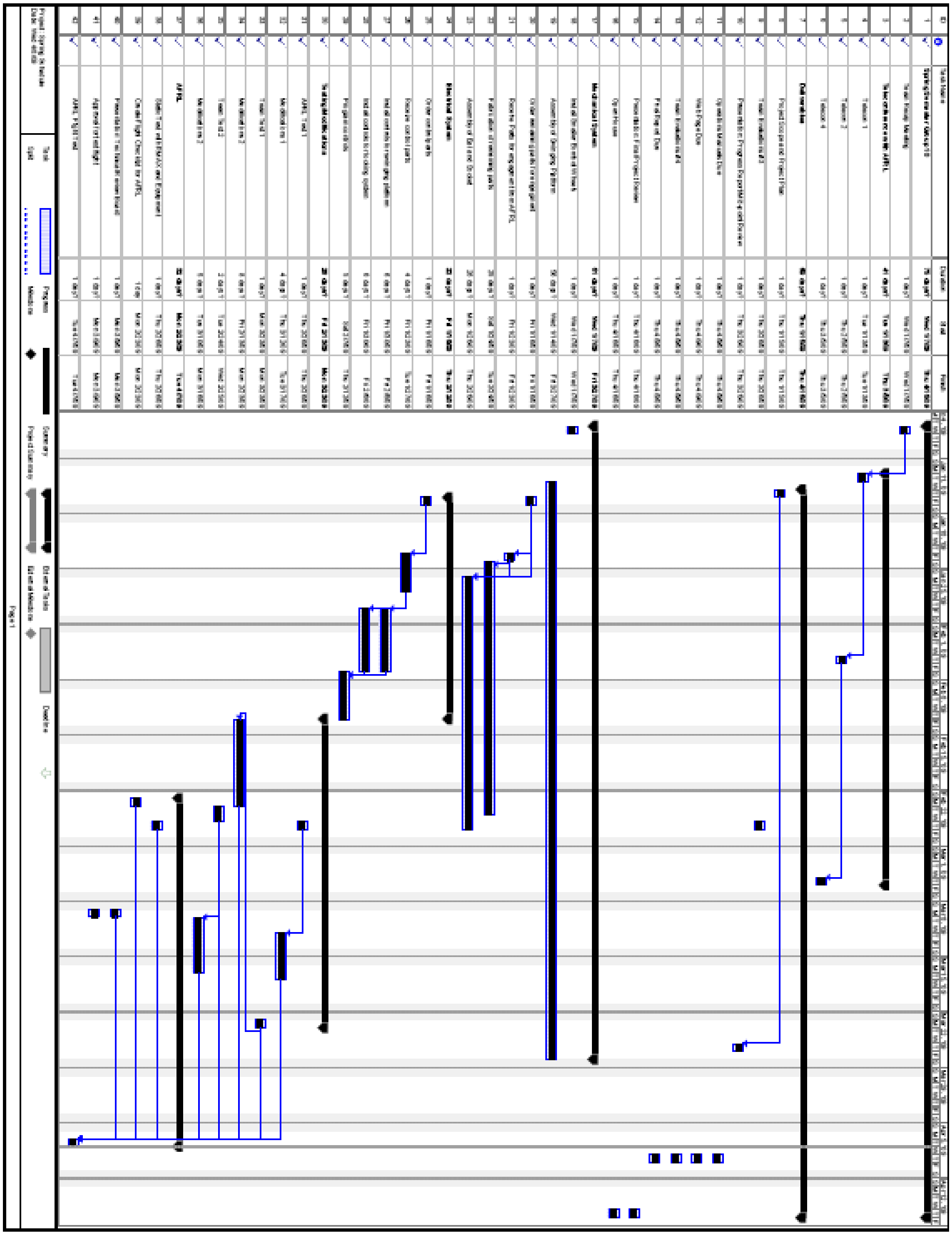
* No class – may be substituted for Guest speaker, Travel/Industrial visit, or Lecture if deemed necessary

E.2.1 Revised Schedule for Team 10

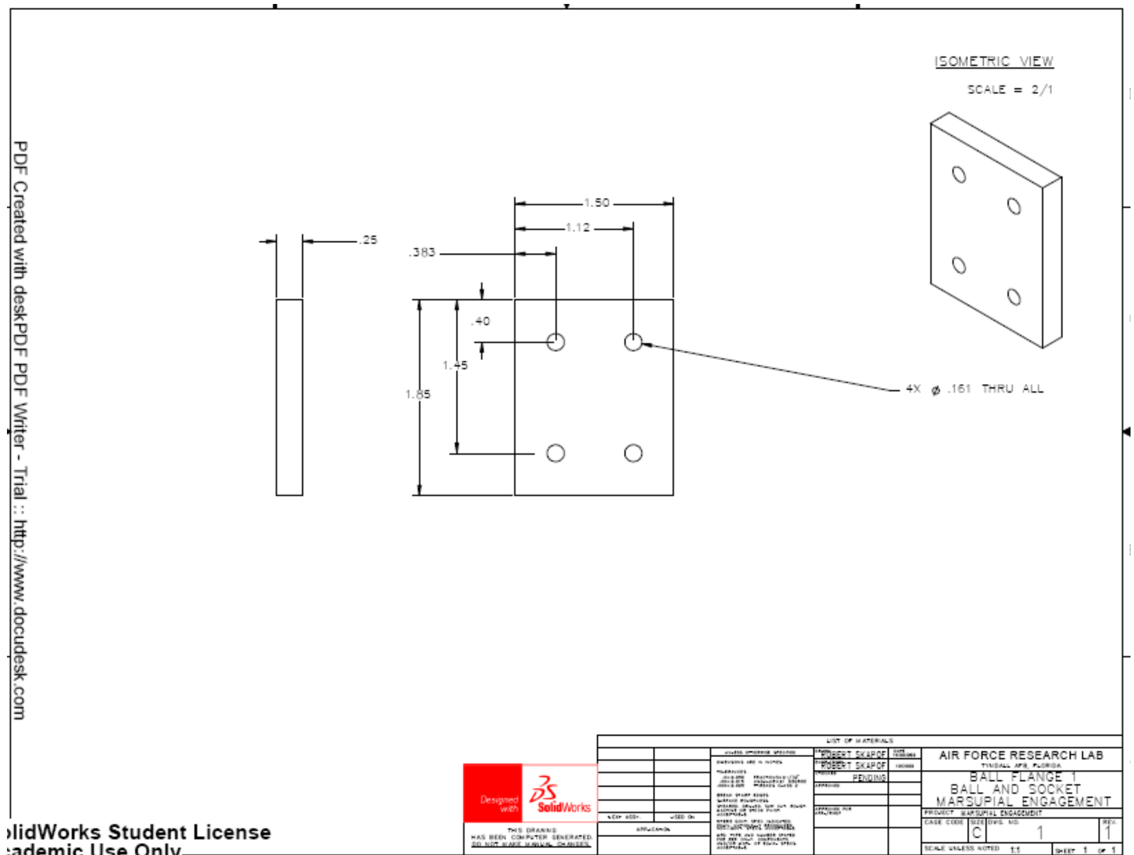
Semester 2	Tue	Thu
Week 01	01/06 **Lecture: Introduction to 2nd Semester**	01/8 **Lecture: Technical Communications**
Week 02	01/13 Staff meetings **Due: Restated Project Scope & Project Plan**	01/15 Staff meetings **Due: Restated Project Scope & Project Plan**
Week 03	01/20 **No class ***	01/22 **No class ***
Week 04	01/27 **No Class**	01/29 **No Class**
Week 05	02/03 **No class**	02/05 **Guest Lecture: Technical Writing (Dr. Moulton)**
Week 06	02/10 **No Class**	2/12 **No Class**
Week 07	02/17 **No class**	02/19 **No class**
Week 08	2/24 **Presentations: Progress report** **Due: Team evals. #3**	2/26 **Presentations: Progress report** **Due: Team evals. #3**
Week 09	**03/03 No class**	**03/04 No class**
Week 10	03/10 **Spring Break**	03/12 **Spring Break**
Week 11	3/17 No Class	3/19 No Class
Week 12	2/24 **Presentations: Mid-point review**	3/26 **Presentations: Mid-point review**
Week 13	03/31 **No class**	04/02 **No class**

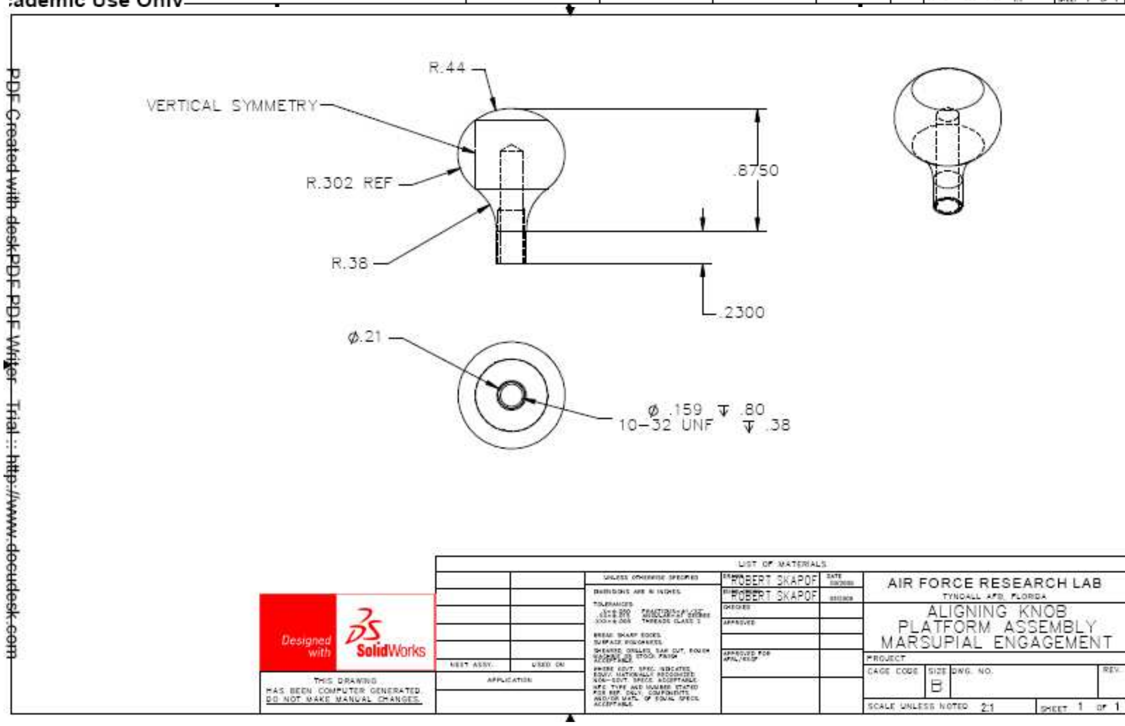
Week 14	04/07 Presentation: Final project review (walkthrough for Open House) - Not graded **Due: Team evals. #4 (final)**	04/09 Presentation: Final project review (walkthrough for Open House) – Not graded **Due: Team evals. #4 (final)**
Week 15	04/14 Picture Day? **Due: Operations Manuals** **Due: Web pages** **Due: Final Reports**	04/16 **OPEN HOUSE (all day)**
Week 16	04/21 Exit interviews Picture Day?	04/23 Exit interviews Awards Ceremony

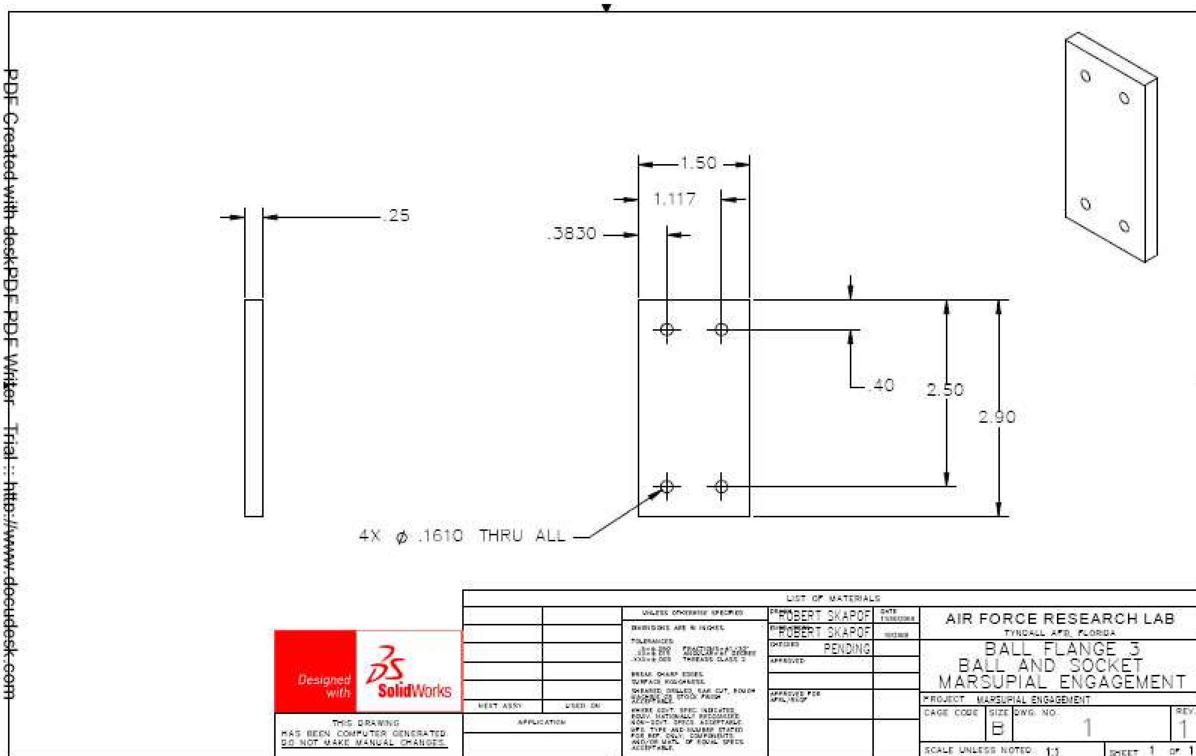
E.2.2 Spring 2009 Gantt Chart



Appendix F – Solidworks Drawings







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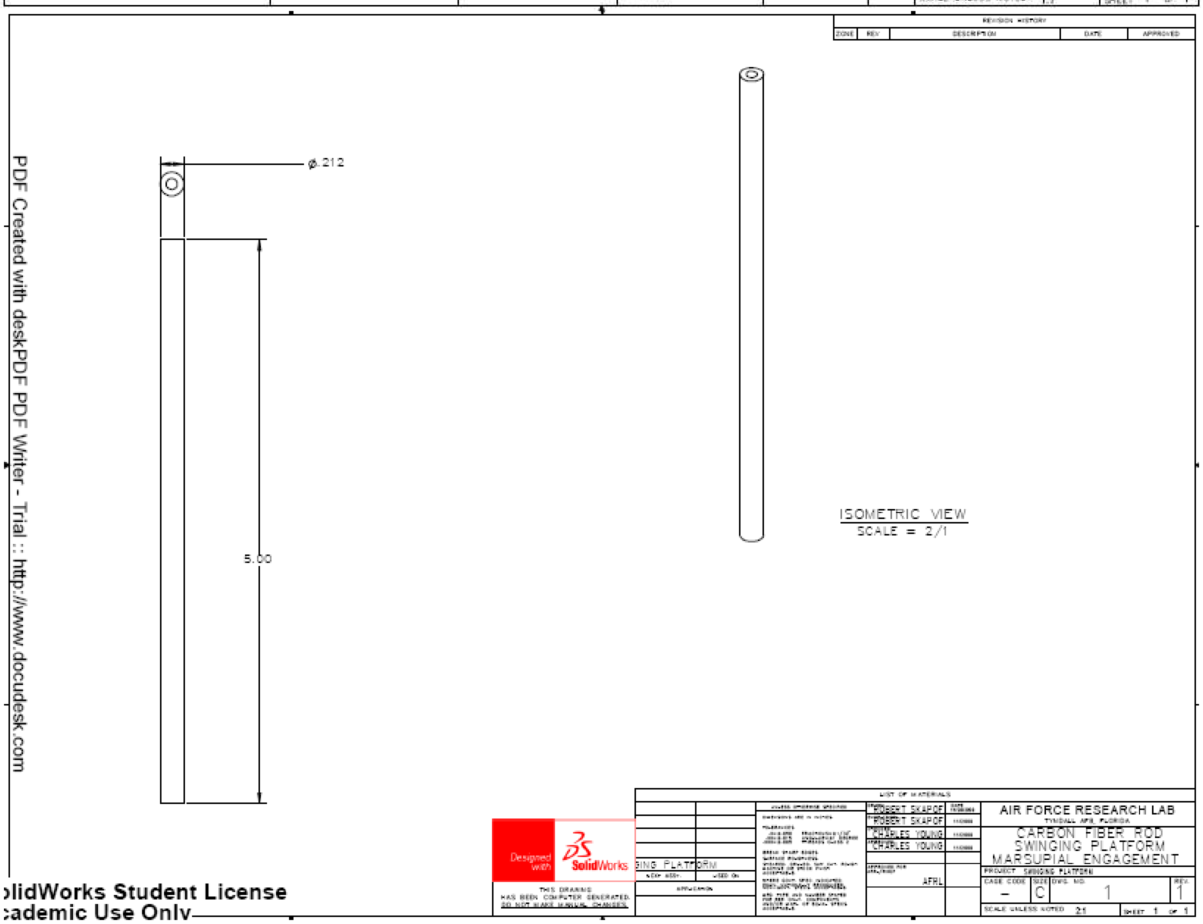

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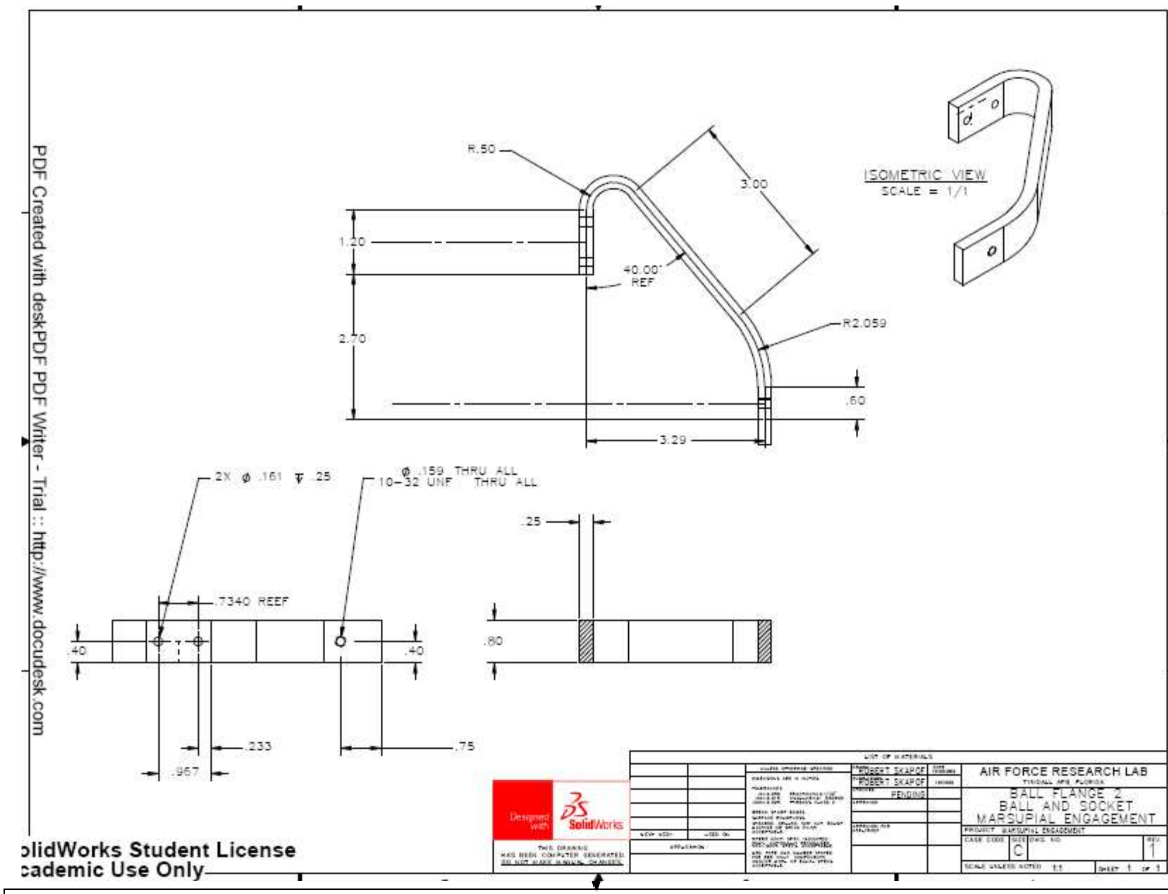
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Academic Use Only
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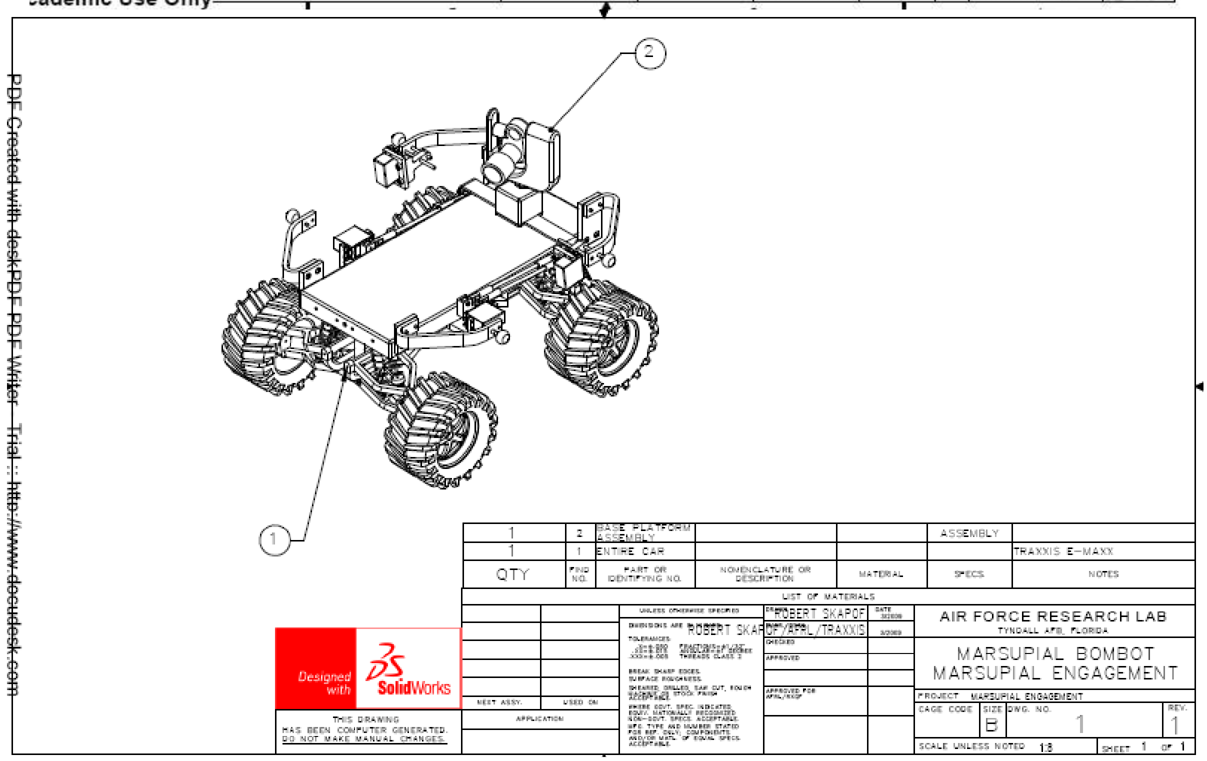
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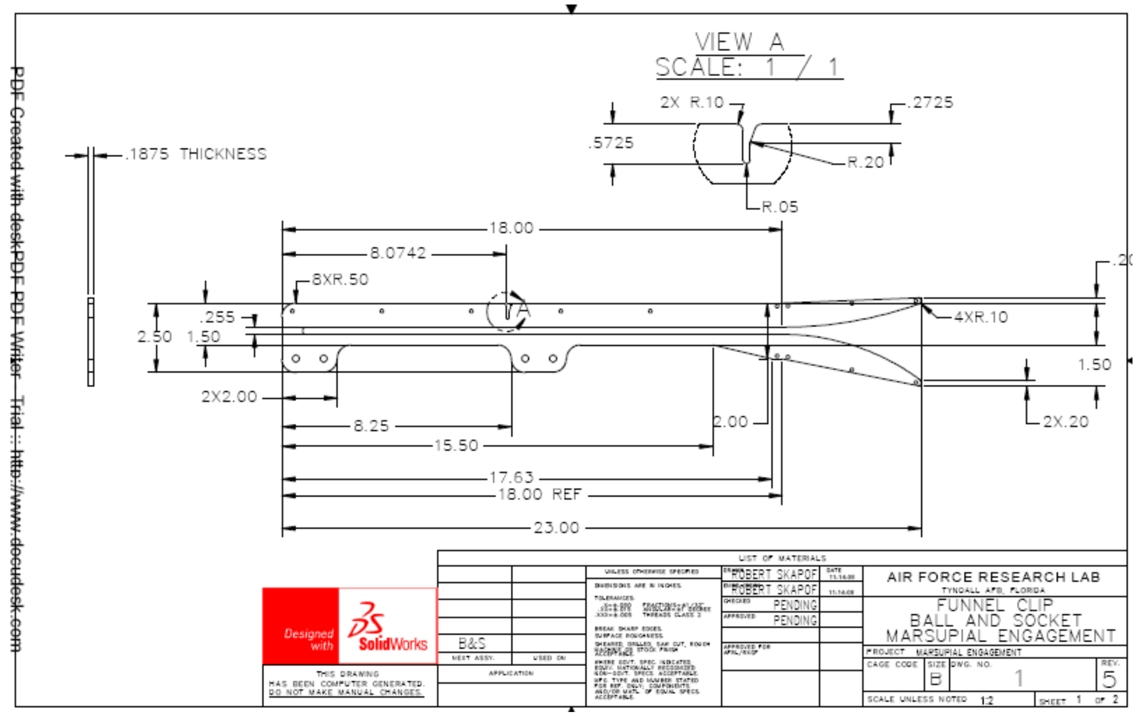
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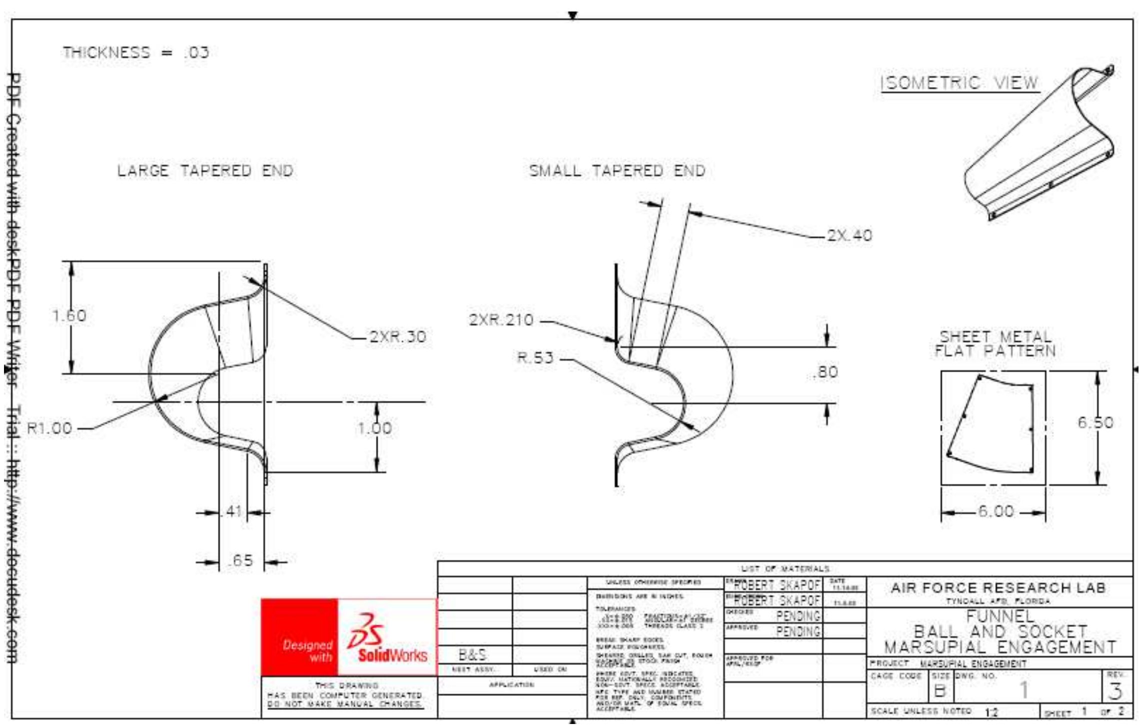
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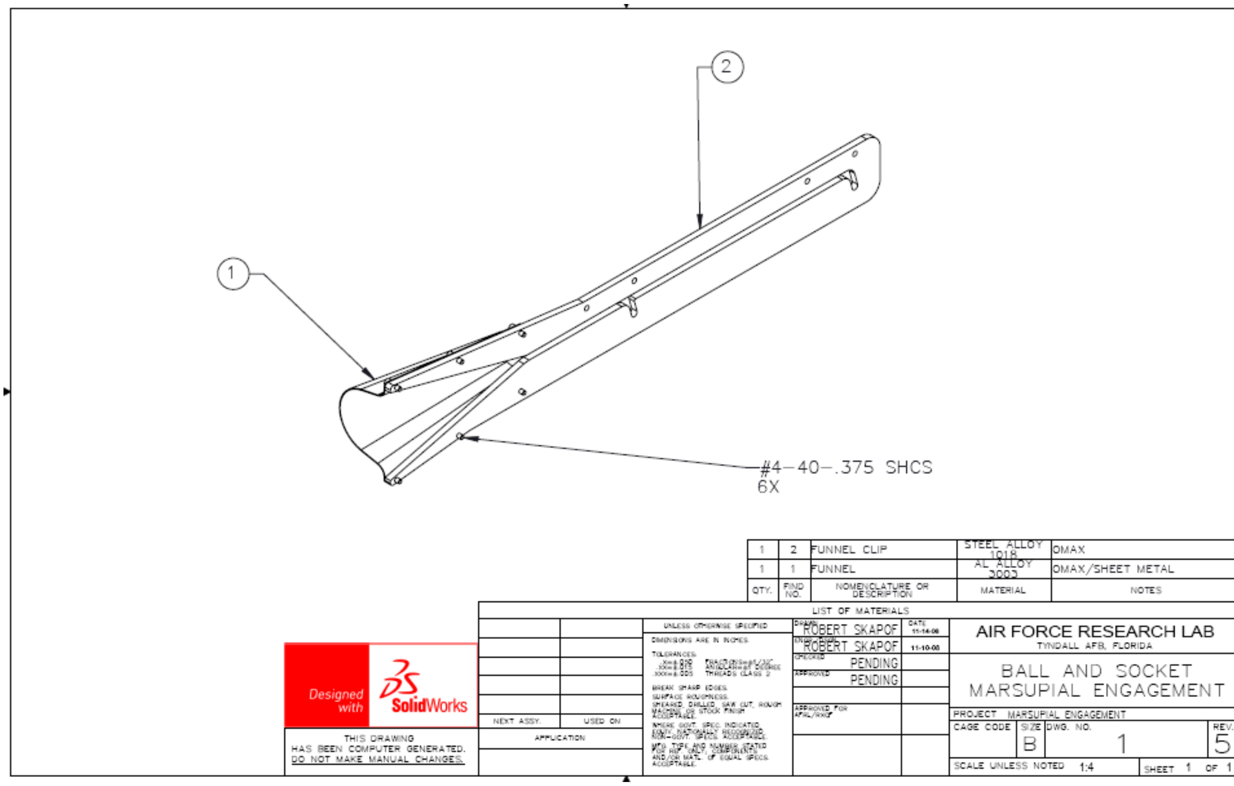
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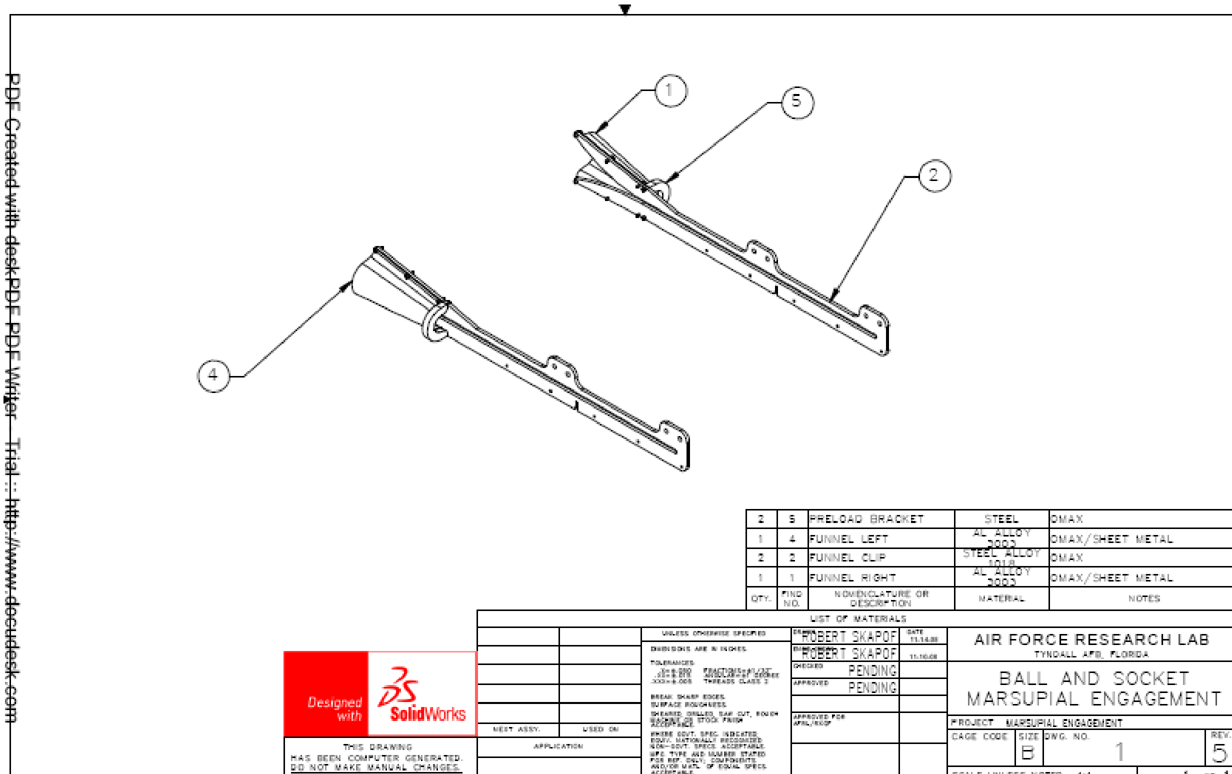
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REV. 5
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SHEET 1 OF 1
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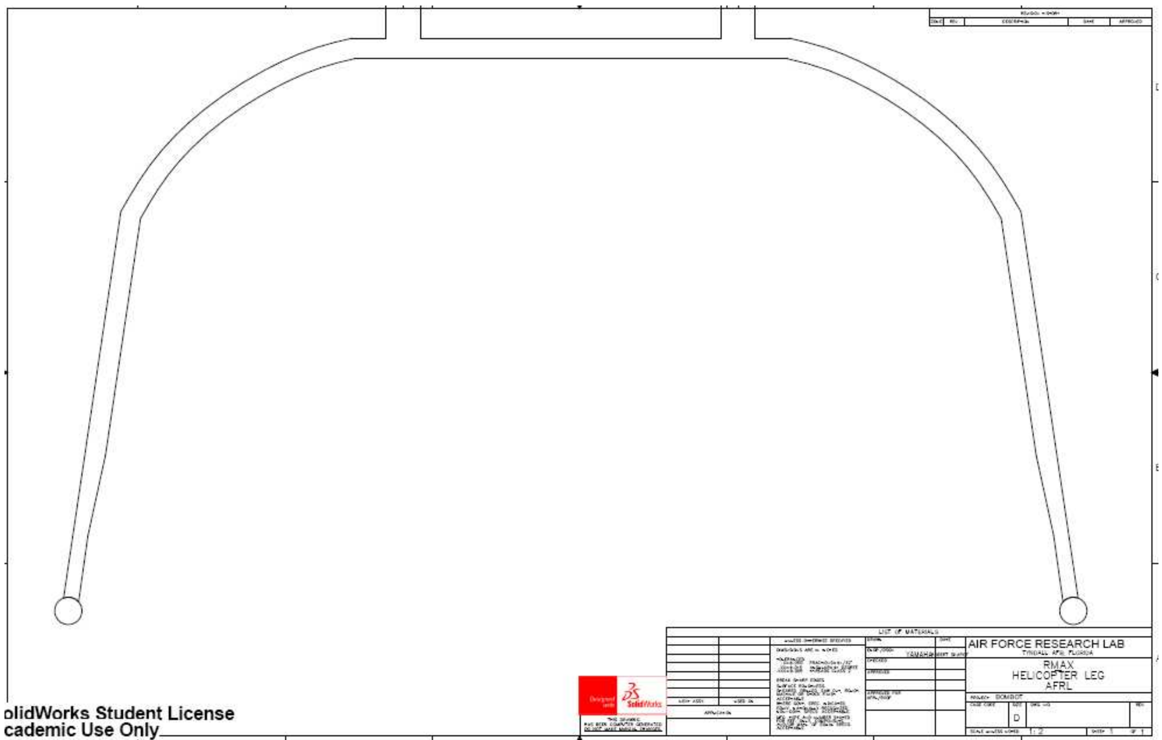
USED ON
APPLICATION


AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
RMAX
HELICOPTER LEG
AFRL
D
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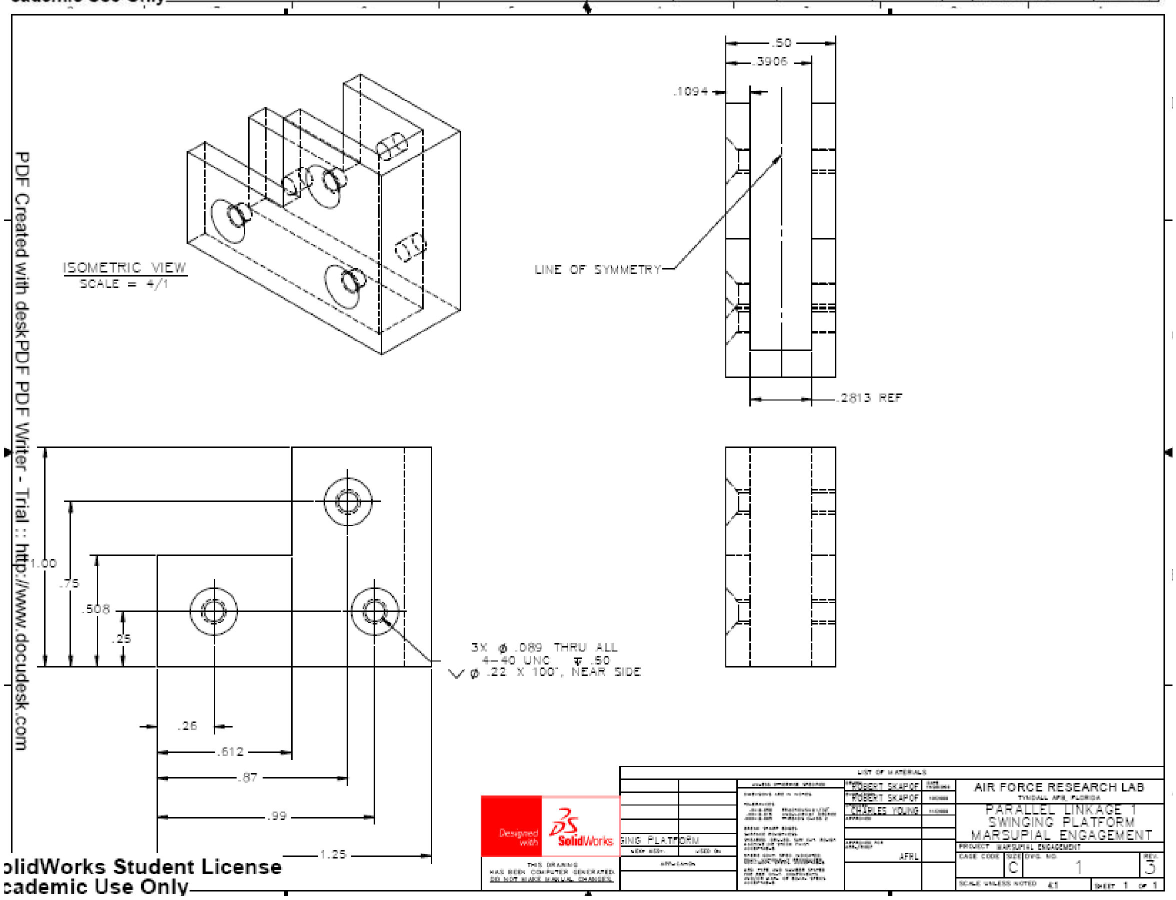
ISOMETRIC VIEW
SCALE = 4/1
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.3906
.1094
LINE OF SYMMETRY
.2813 REF
1.00
.75
.508
.25
.26
.612
.87
.99
1.25
3X ø .089 THRU ALL
4-40 UNC ⊽ .50
⌵ ø .22 X 100°, NEAR SIDE
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
PARALLEL LINKAGE 1
SWINGING PLATFORM
MARSUPIAL ENGAGEMENT
ROBERT SKAPOF
CHARLES YOUNG
AFRL
C
1
3
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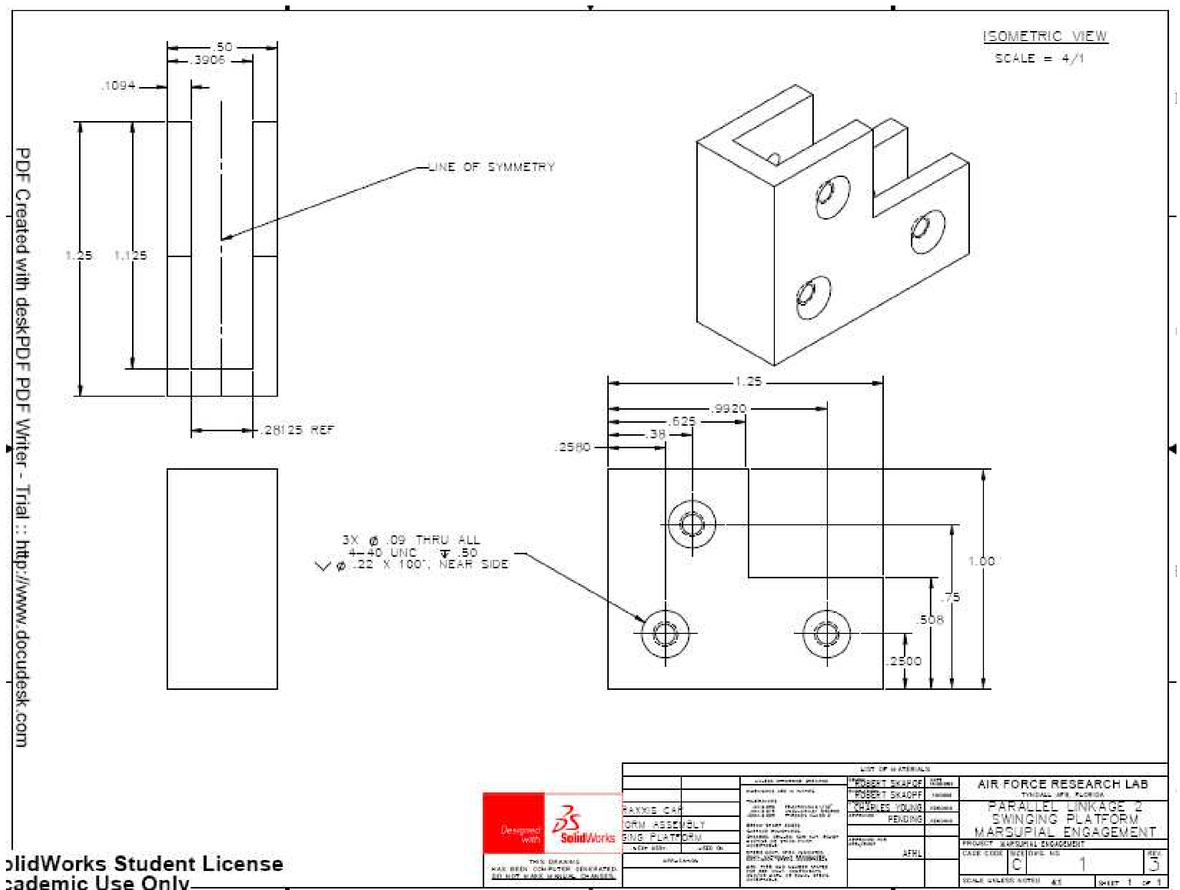
ISOMETRIC VIEW
SCALE = 4/1
.50
.3906
.1094
LINE OF SYMMETRY
1.25
1.125
.28125 REF
1.25
.9920
.625
.38
.2580
3X ⌀ .09 THRU ALL
4-40 UNC ⏷ .50
⌵ ⌀ .22 X 100°, NEAR SIDE
1.00
.75
.508
.2500
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
PARALLEL LINKAGE 2
SWINGING PLATFORM
MARSUPIAL ENGAGEMENT
ROBERT SKAPOF
CHARLES YOUNG
PENDING
AFRL
C
1
3
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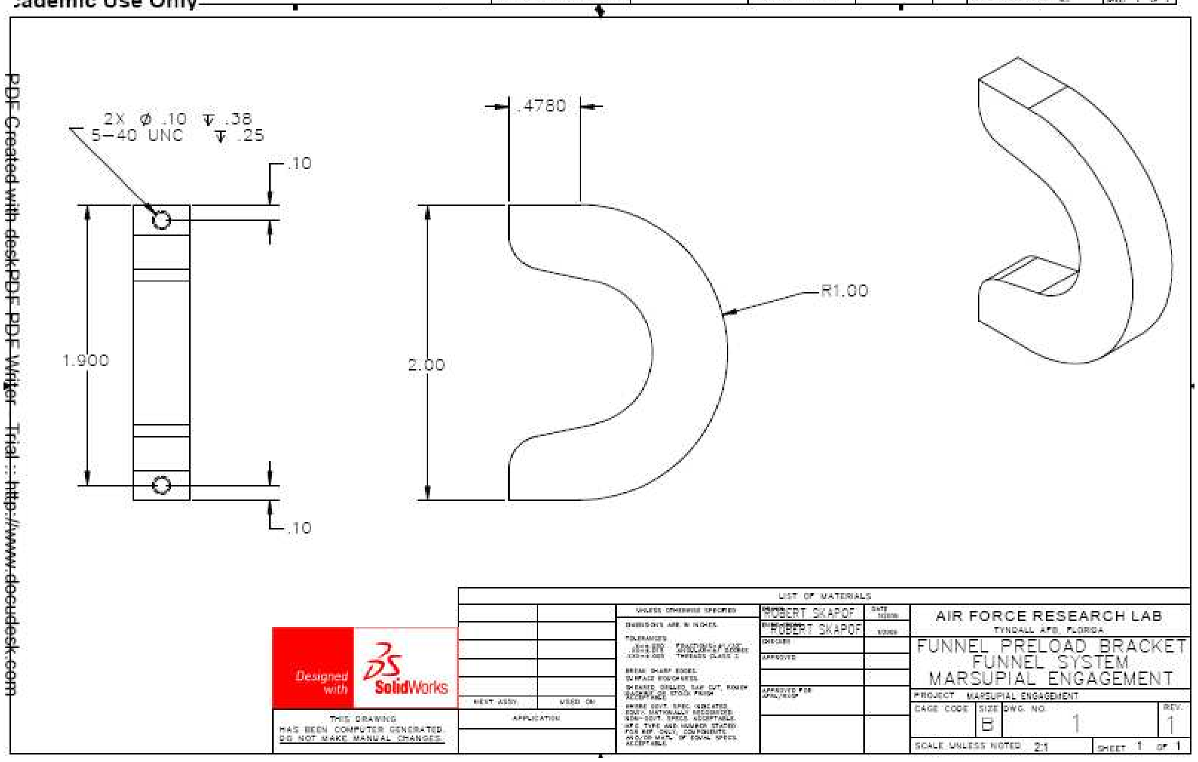
2X ⌀ .10 ⏷ .38
5-40 UNC ⏷ .25
.10
1.900
.4780
2.00
R1.00
.10
LIST OF MATERIALS
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
FUNNEL PRELOAD BRACKET
FUNNEL SYSTEM
MARSUPIAL ENGAGEMENT
ROBERT SKAPOF
B
1
SCALE UNLESS NOTED 2:1
SHEET 1 OF 1
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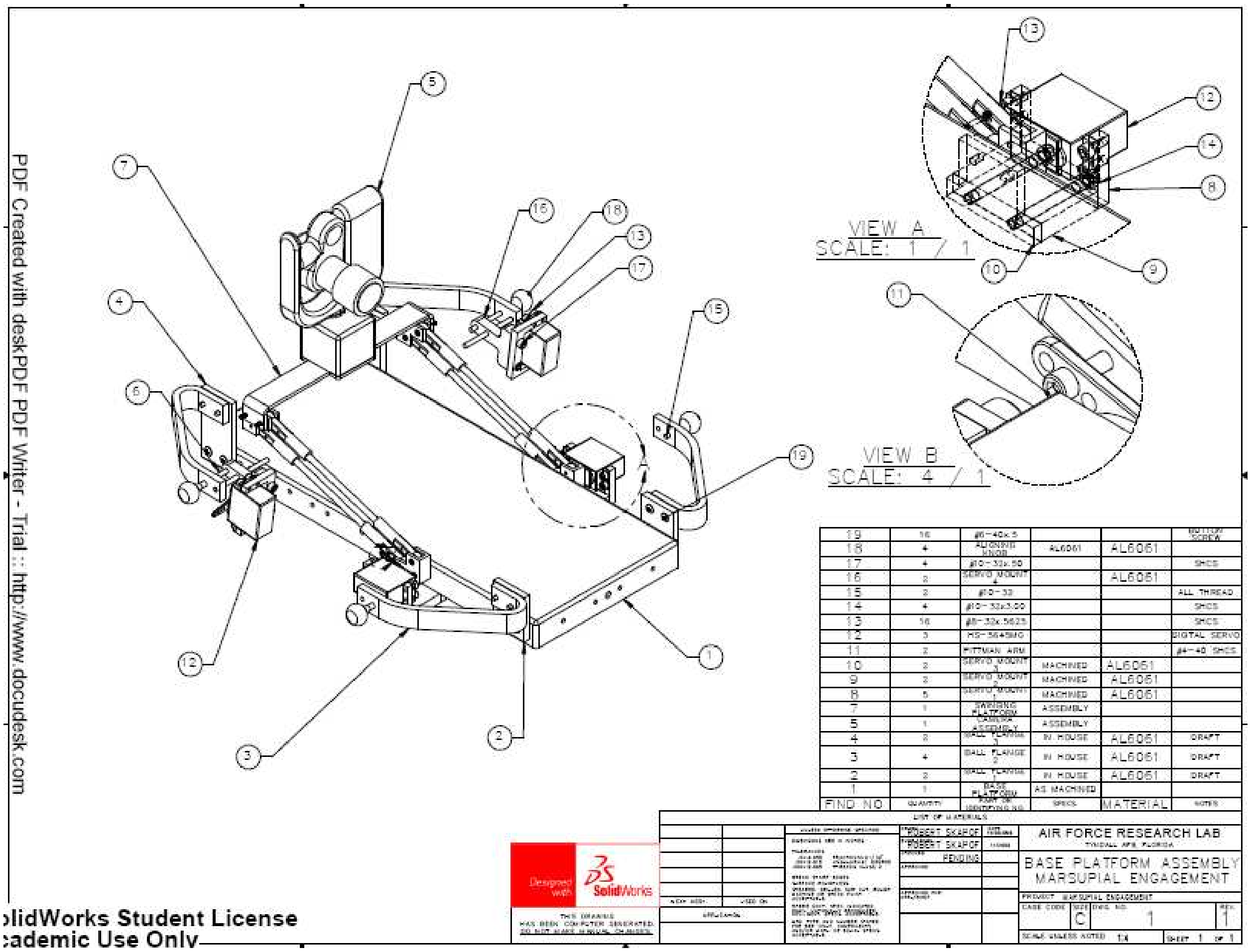
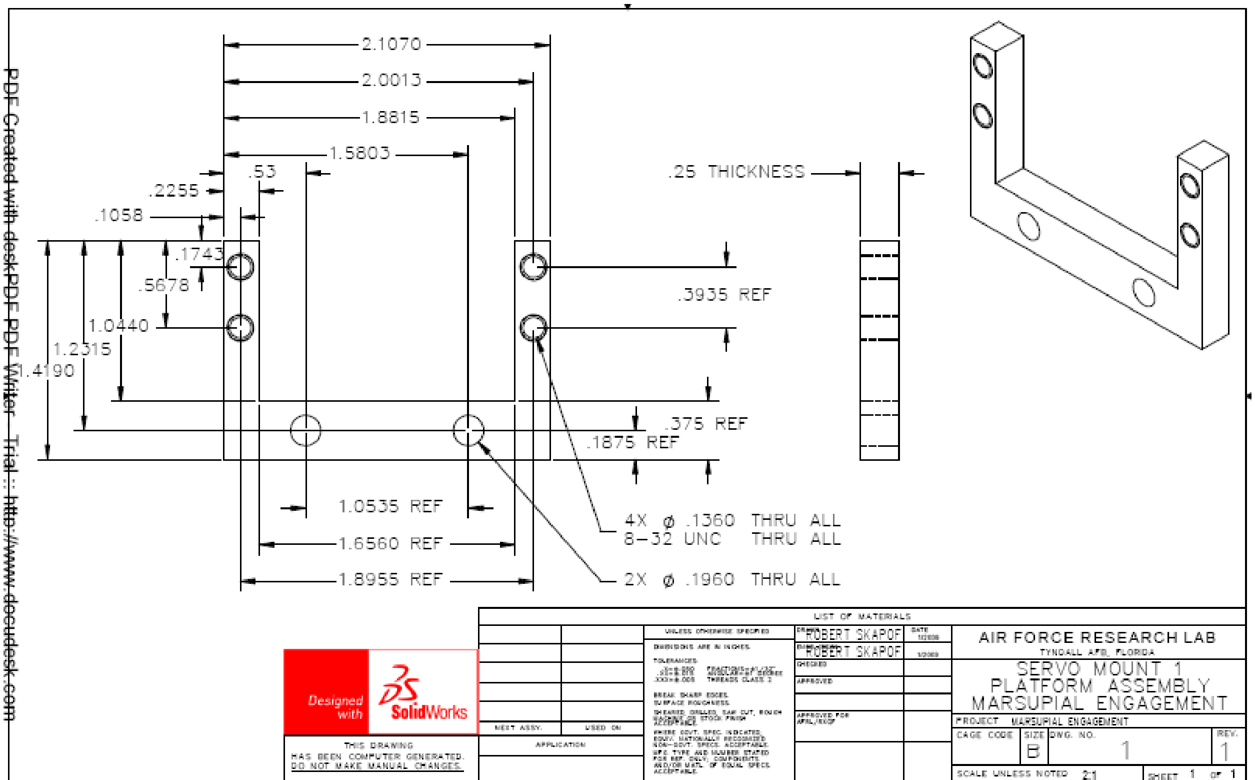


FIND NO	QUANTITY	PART OR IDENTIFYING NO.	SPECS.	MATERIAL	NOTES
19	16	#6-40x.5			BUTTON SCREW
18	4	ALIGNING KNOB	AL6061	AL6061	
17	4	#10-32x.50			SHCS
16	2	SERVO MOUNT 4		AL6061	
15	2	#10-32			ALL THREAD
14	4	#10-32x3.00			SHCS
13	16	#8-32x.5625			SHCS
12	3	HS-5645MG			DIGITAL SERVO
11	2	PITTMAN ARM			#4-40 SHCS
10	2	SERVO MOUNT 3	MACHINED	AL6061	
9	2	SERVO MOUNT 2	MACHINED	AL6061	
8	5	SERVO MOUNT 1	MACHINED	AL6061	
7	1	SWINGING PLATFORM	ASSEMBLY		
5	1	CAMERA ASSEMBLY	ASSEMBLY		
4	2	BALL FLANGE 3	IN HOUSE	AL6061	DRAFT
3	4	BALL FLANGE 2	IN HOUSE	AL6061	DRAFT
2	2	BALL FLANGE 1	IN HOUSE	AL6061	DRAFT
1	1	BASE PLATFORM	AS MACHINED		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2.0013
1.8815
1.5803
.53
.2255
.1058
.1743
.5678
1.0440
1.2315
1.4190
.25 THICKNESS
.3935 REF
.375 REF
.1875 REF
1.0535 REF
1.6560 REF
1.8955 REF
4X ⌀ .1360 THRU ALL
8-32 UNC THRU ALL
2X ⌀ .1960 THRU ALL
LIST OF MATERIALS
ROBERT SKAPOF
ROBERT SKAPOF
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
SERVO MOUNT 1
PLATFORM ASSEMBLY
MARSUPIAL ENGAGEMENT
PROJECT MARSUPIAL ENGAGEMENT
SIZE B
DWG. NO. 1
REV. 1
SCALE UNLESS NOTED 2:1
SHEET 1 OF 1
Designed with SolidWorks
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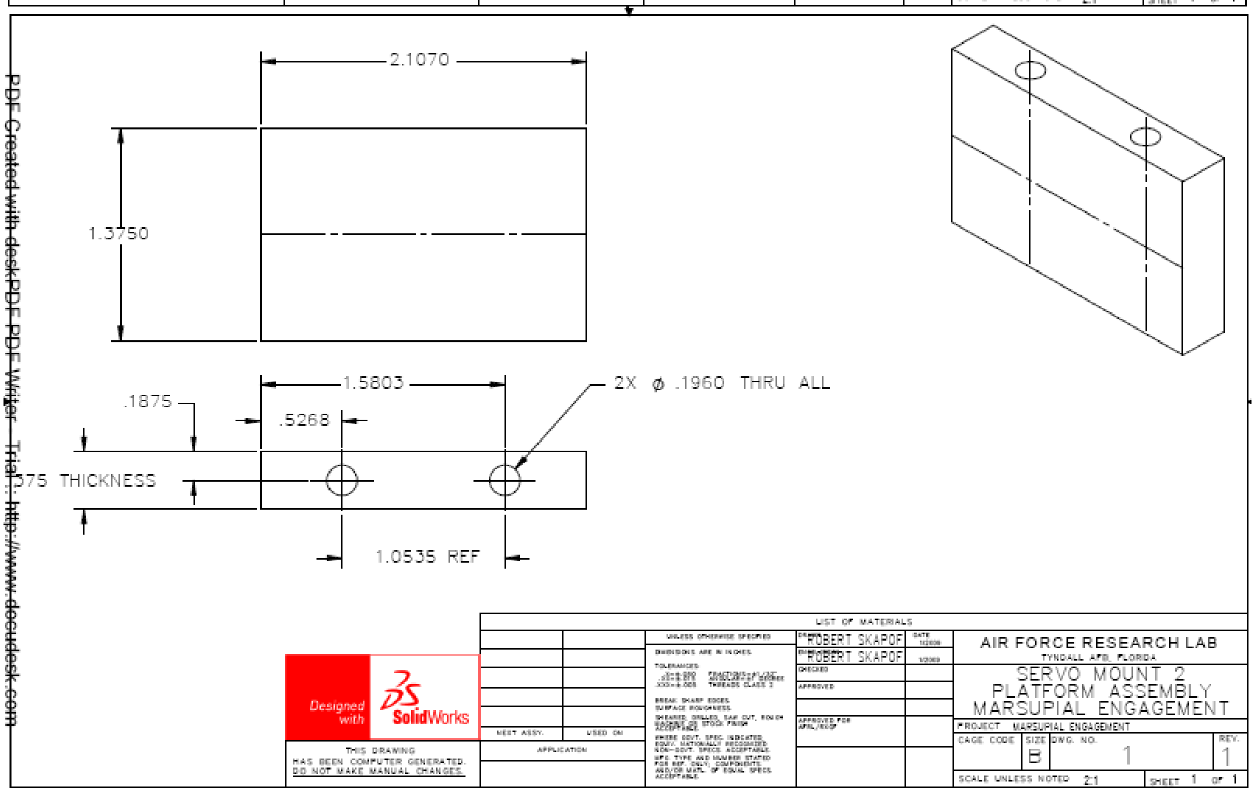
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1.3750
1.5803
.1875
.5268
.375 THICKNESS
2X ⌀ .1960 THRU ALL
1.0535 REF
LIST OF MATERIALS
ROBERT SKAPOF
ROBERT SKAPOF
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
SERVO MOUNT 2
PLATFORM ASSEMBLY
MARSUPIAL ENGAGEMENT
PROJECT MARSUPIAL ENGAGEMENT
SIZE B
DWG. NO. 1
REV. 1
SCALE UNLESS NOTED 2:1
SHEET 1 OF 1
Designed with SolidWorks
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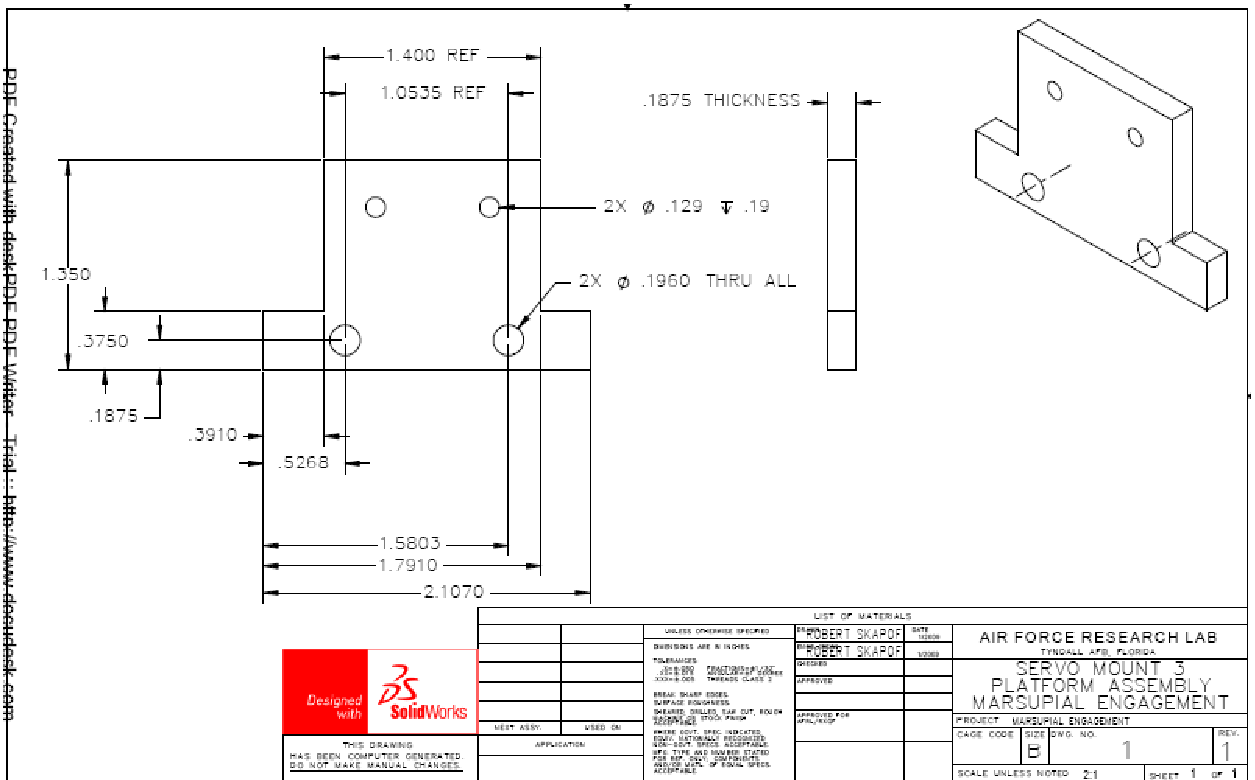
1.400 REF
1.0535 REF
.1875 THICKNESS
2X ⌀ .129 ↧ .19
2X ⌀ .1960 THRU ALL
1.350
.3750
.1875
.3910
.5268
1.5803
1.7910
2.1070
LIST OF MATERIALS
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
SERVO MOUNT 3
PLATFORM ASSEMBLY
MARSUPIAL ENGAGEMENT
ROBERT SKAPOF
PROJECT MARSUPIAL ENGAGEMENT
SIZE B
DWG. NO. 1
REV. 1
SCALE UNLESS NOTED 2:1
SHEET 1 OF 1
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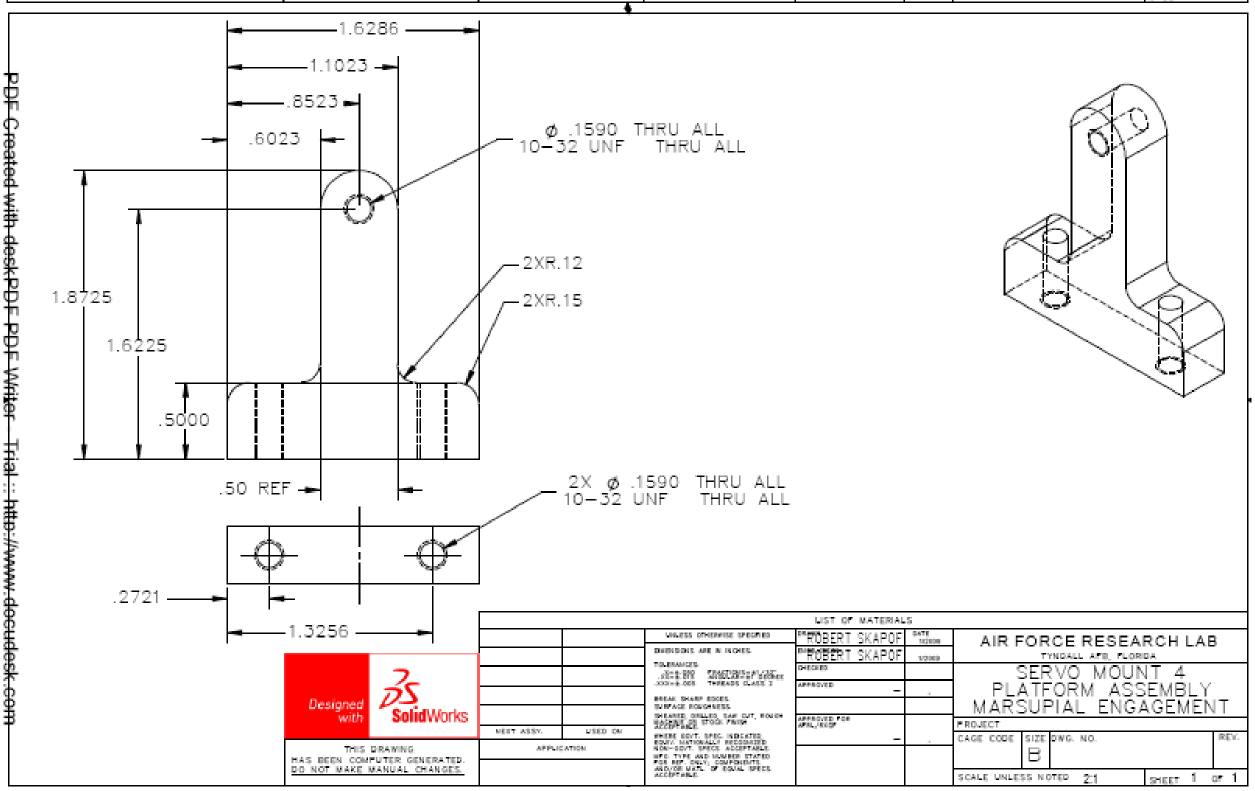
1.6286
1.1023
.8523
.6023
⌀ .1590 THRU ALL
10–32 UNF THRU ALL
1.8725
1.6225
2XR.12
2XR.15
.5000
.50 REF
2X ⌀ .1590 THRU ALL
10–32 UNF THRU ALL
.2721
1.3256
LIST OF MATERIALS
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
SERVO MOUNT 4
PLATFORM ASSEMBLY
MARSUPIAL ENGAGEMENT
ROBERT SKAPOF
SIZE B
SCALE UNLESS NOTED 2:1
SHEET 1 OF 1
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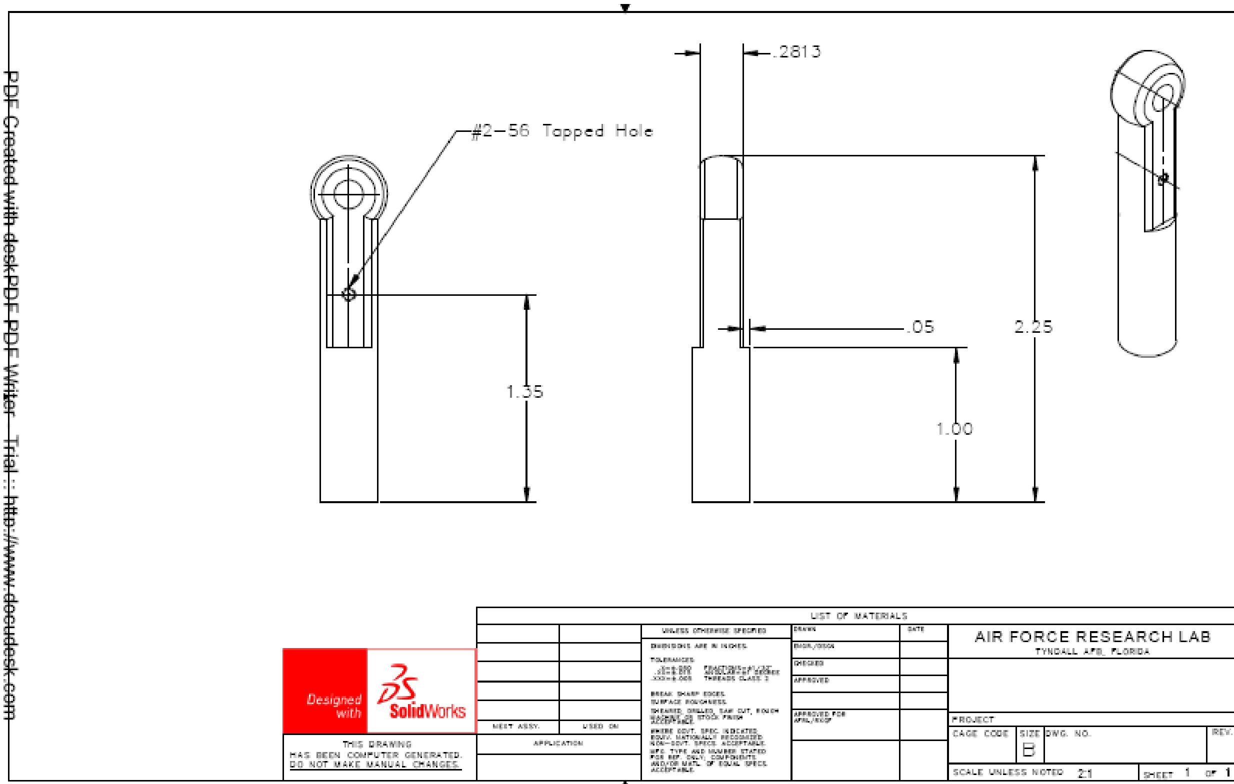

.2813
#2-56 Tapped Hole
.05
2.25
1.35
1.00
LIST OF MATERIALS
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
PROJECT
CAGE CODE
SIZE
B
DWG. NO.
REV.
SCALE UNLESS NOTED 2:1
SHEET 1 OF 1
Designed with SolidWorks
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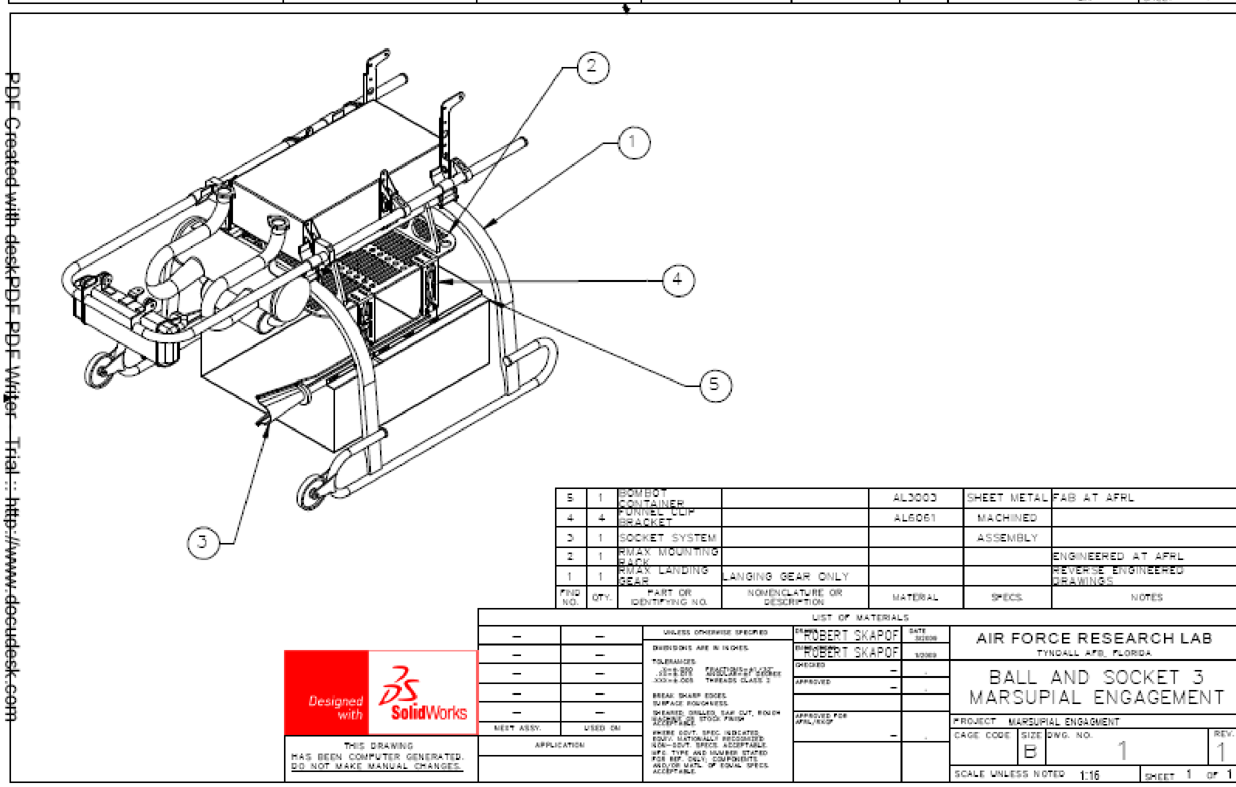
NEXT ASSY.
USED ON
APPLICATION



1
2
3
4
5
5 | 1 | BOMBOT CONTAINER | AL3003 | SHEET METAL FAB AT AFRL
4 | 4 | FUNNEL CLIP BRACKET | AL6061 | MACHINED
3 | 1 | SOCKET SYSTEM | ASSEMBLY
2 | 1 | RMAX MOUNTING RACK | ENGINEERED AT AFRL
1 | 1 | RMAX LANDING GEAR | LANDING GEAR ONLY | REVERSE ENGINEERED DRAWINGS
FIND NO. | QTY. | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECS. | NOTES
LIST OF MATERIALS
ROBERT SKAPOF
ROBERT SKAPOF
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
BALL AND SOCKET 3
MARSUPIAL ENGAGEMENT
PROJECT MARSUPIAL ENGAGMENT
CAGE CODE
SIZE
B
DWG. NO.
1
REV.
1
SCALE UNLESS NOTED 1:16
SHEET 1 OF 1
Designed with SolidWorks
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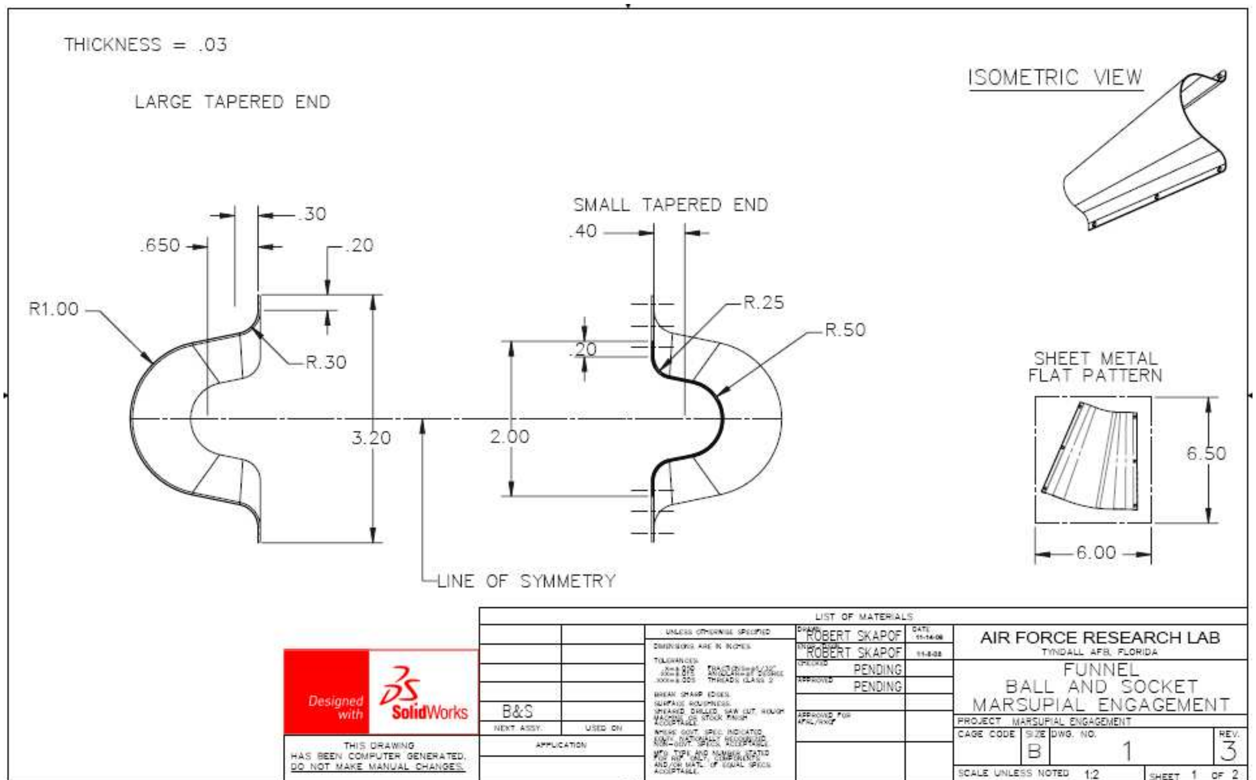
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LARGE TAPERED END
ISOMETRIC VIEW
SMALL TAPERED END
.30
.650
.20
.40
R1.00
R.25
R.50
R.30
.20
SHEET METAL
FLAT PATTERN
3.20
2.00
6.50
6.00
LINE OF SYMMETRY
LIST OF MATERIALS
ROBERT SKAPOF
ROBERT SKAPOF
PENDING
PENDING
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
FUNNEL
BALL AND SOCKET
MARSUPIAL ENGAGEMENT
PROJECT MARSUPIAL ENGAGEMENT
B&S
NEXT ASSY
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CAGE CODE
SIZE
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REV.
B
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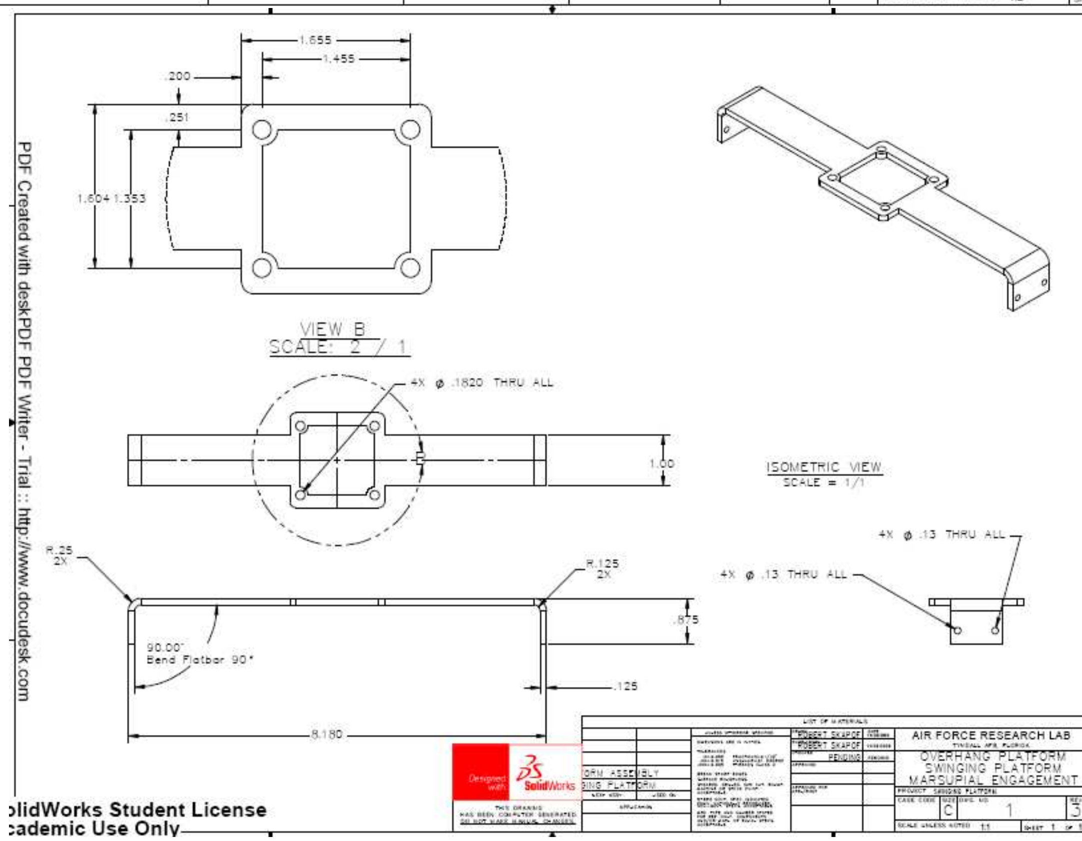
3
SCALE UNLESS NOTED 1:2
SHEET 1 OF 2


1.655
1.455
.200
.251
1.604 1.353
VIEW B
SCALE: 2 / 1
4X ⌀ .1820 THRU ALL
1.00
ISOMETRIC VIEW
SCALE = 1/1
4X ⌀ .13 THRU ALL
4X ⌀ .13 THRU ALL
R.25
2X
R.125
2X
.875
90.00°
Bend Flatbar 90°
.125
8.180
AIR FORCE RESEARCH LAB
OVERHANG PLATFORM
SWINGING PLATFORM
MARSUPIAL ENGAGEMENT
ROBERT SKAPOF
ROBERT SKAPOF
PENDING
C
1
3
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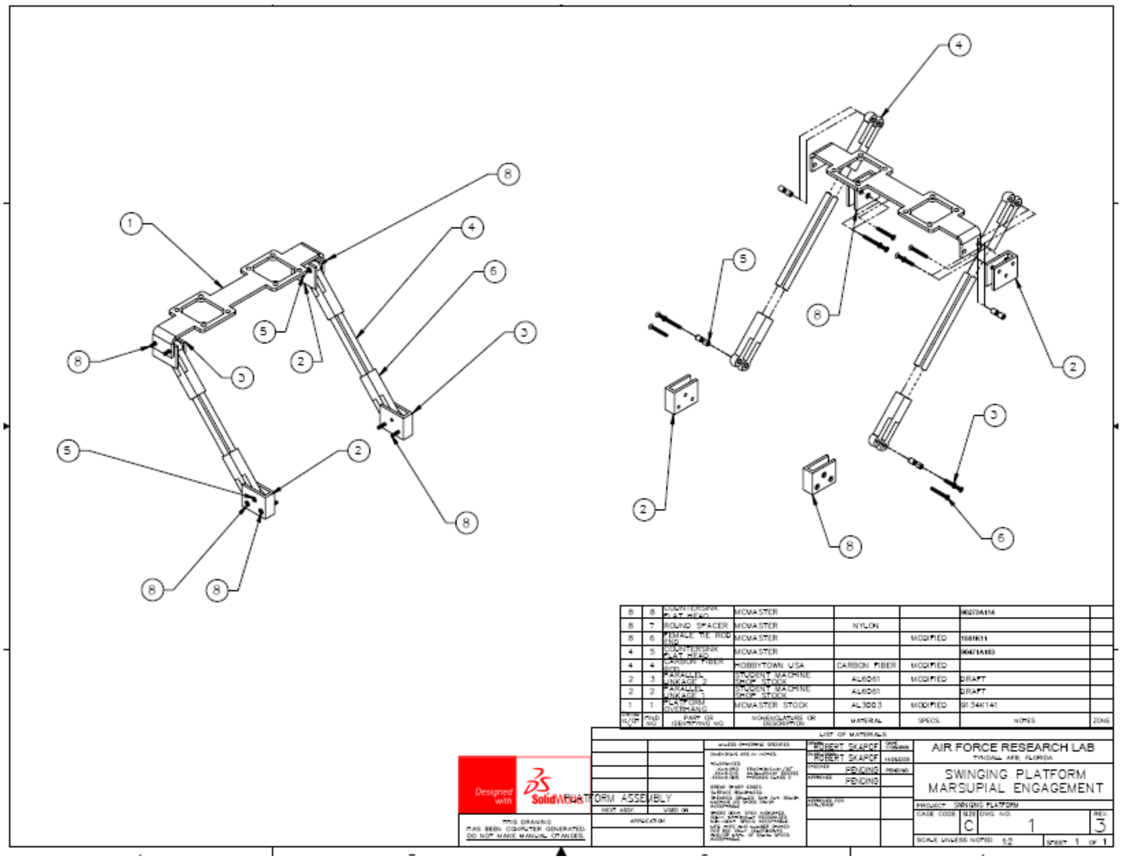
COUNTERSINK FLAT HEAD
MCMASTER
ROUND SPACER
NYLON
FEMALE TIE ROD END
MODIFIED
CARBON FIBER ROD
HOBBYTOWN USA
CARBON FIBER
PARALLEL LINKAGE 2
STUDENT MACHINE SHOP STOCK
AL6061
DRAFT
PARALLEL LINKAGE 1
PLATFORM OVERHANG
MCMASTER STOCK
AL3003
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
MATERIAL
SPECS
NOTES
ZONE
LIST OF MATERIALS
ROBERT SKAPOF
PENDING
AIR FORCE RESEARCH LAB
TYNDALL AFB, FLORIDA
SWINGING PLATFORM
MARSUPIAL ENGAGEMENT
PROJECT SWINGING PLATFORM
CAGE CODE
SIZE C
DWG. NO. 1
REV. 3
SCALE UNLESS NOTED 1:2
SHEET 1 OF 1
PLATFORM ASSEMBLY
NEXT ASSY.
USED ON
APPLICATION
Designed with SolidWorks
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