Marsupial Robot Deployment and Recovery

Sponsored by

Tyndall Air Force Base
&
Air Force Research Lab

Presented to

The Department of Mechanical Engineering

Florida Agricultural and Mechanical University

&

Florida State University

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Abstract

It is the purpose of the following report to detail the conception and design process that was implemented in order to design a mounting system for the engagement of a BomBot to a RMAX helicopter. The project is introduced and background is given, the objective is reviewed, and expected results are laid out. The product specifications and methodology that was used are then laid out. Conceptual designs are then introduced. These include a telescoping rod and swinging platform design to hold the BomBot's antenna and camera. To mount the BomBot several designs are presented these include a tire rack and ball and socket design. The swinging platform as well as the ball and socket designs were selected using a design matrix that is presented. Detailed designs of the ball and socket as well as the swinging platform are then presented. Based upon customer needs, prototyping has already begun and is plainly presented with accompanying figures. It is in the future plans of this project to have the BomBot be autonomously controlled; this is also discussed with possible ideas presented. Overall, the following documents the actions and decisions that have been made over the past semester and outlines some of the future plans for the project.

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I. Introduction

(a) Background

The Yamaha RMAX helicopter is commonly used by Tyndall AFB and AFRL to do surveillance, tracking, and ground imaging missions. The helicopter is designed to carry attachments as its payload which can be interchanged in order to accomplish different missions. The RMAX can be seen below in Figure 1.

Figure 1: RMAX Helicopter in Flight

The BomBot, which is also commonly used by Tyndall AFB, is designed to carry a payload while being remotely controlled by a human who is a safe distance away from the BomBot. The BomBot can be seen below in Figure 2.

Figure 2: BomBot in Standard Configuration

This project will allow a soldier to get the BomBot closer to the event without risk of danger for himself. Currently the BomBot is used for recon, surveillance, and transfer missions. The limitations of the BomBot are distance and terrain. The helicopter can fly the BomBot unseen into many situations and environments that the BomBot could not reach alone.

The specific solution to our problem has not been formerly solved; however similar problems have been solved before. IRobot solved a similar issue of a robot (Roomba) leaving its home where it charges to clean household floors and returning to its home to recharge and empty its contents. We believe the Marsupial project will require a similar solution with a different style of engagement.

Tyndall AFB is sponsoring the Marsupial Deploy and Engage project. Charles Young is the primary contact of the project. Andrew Kopeiken is the contact regarding the Yamaha RMAX Helicopter. Christopher Walsingham is the contact regarding the BomBot made by IRT. Brian Skibba is the project director.

(b) Project Scope

Currently the BomBot is designed to allow for a small container to be placed into the payload bay of the BomBot and then utilizing remote controls the BomBot is driven to the destination site where the payload is ejected from the payload bay. The BomBot is then capable of returning to the origination site, or continuing on to another location depending on the mission objectives defined by the user.

The RMAX helicopter is a small remotely controlled helicopter that allows the user to remotely control the destination of the helicopter.

The current objective is to develop a method and attachment system in which the BomBot can be remotely attached and detached from the RMAX helicopter. In accomplishing this task, the BomBot can then be deployed in remote locations defined by the user. The user can then remotely control the path of the BomBot, and deploy the payload at its predetermined location. Upon mission completion the BomBot can then return to the RMAX where it will be reengaged to the RMAX. The RMAX then has the ability to remove itself and the BomBot from the engagement zone, and relocate to a safe drop zone.

This process will allow for the remote deployment and reattachment of the BomBot therefore removing the human element from engagement zone. The accomplishment of this task will allow for human users to be safely located away from the engagement zone and resultantly will reduce the risk of injury or death to any human user.

(c) Needs Assessment

The current need is for a mounting system for the RMAX Helicopter that will allow the BomBot to be remotely attached and detached. The attachment system plus the weight of the weight of the BomBot must be less than sixty pounds and must allow the user to attach and detach the BomBot without any physical interaction with either the RMAX or the BomBot. Once mounted, the system must be able to withstand a maximum in air velocity of twenty-one knots. The system may make use of modifications to the skid pads of the RMAX as well as modifications to the BomBot. All modifications must allow for full functionality of the RMAX and BomBot as they are currently.

(d) Objective

There has been much work in the field of production control helicopters. Although these helicopters were initially designed for agriculture applications, anticipated new applications have been considered. Recently there has been interest in the helicopters by the air force, in particular for use in reconnaissance and surveillance accompanied by marsupial robots. The objective of our project as described to the team by Tyndall Air force Base is to outfit the Tyndall AFRL's RMAX helicopter with a deployment and recovery device that will be capable of deploying and recovering a marsupial robot while still maintaining full communication with the operator. The team will have to be able to incorporate the application of sensors, actuation devices and necessary controller hardware/software, and an interlock system(s). The Robot will also have to be outfitted with actuation devices for antenna, eye (camera and lights), and bomb carriage extension and contraction. A working prototype(s), must meet design expectations, be accompanied by solid models, and not exceed 60 pounds. The timeframe, in which this project must be completed, also as reported by Tyndall Air Force Base, is not to exceed that of 30 weeks.

(e) Expected Results

A working prototype is expected at the end of this project and is to be presented at the final presentation. Along with the prototype a detailed user manual is to be written. This user manual should include a checklist to complete prior to operation. This checklist is paramount to ensure proper operation to the novice user.

Our built product will be the linkage between the Yamaha RMAX helicopter and the BomBot, but may still require modification of the RMAX and the BomBot to maximize efficiency. As is the BomBot does not fit directly under the helicopter unless it is in its packed position, which means the antenna is lowered, the camera is not installed, and the carriage is locked. When the BomBot is in its action position the antenna is raised, the camera is installed, and the carriage may or may not be secured. It is expected that the BomBot after modification can go from its packed position to its action position autonomously.

It is expected that the BomBot be secured to the helicopter, for the helicopter will be flying at altitudes up to 300 ft and speeds of 21 knots. This engagement device will only be useful if the BomBot is one hundred percent locked into the helicopter while in flight.

Throughout the length of this project our team will not just be presenting to the staff at the college of engineering, but to the employees of AFRL. If the employees of AFRL are not able to make it to the meeting in Tallahassee it will be our responsibility to present to them at Tyndall.

(f) Constraints

There will be several constraints that the group will encounter throughout the design and manufacture process. Time is one of the very important constraints. Since the group has the fall semester to submit a finalized design, the group must stay on task when certain tasks are due. As for manufacturing the design, the spring semester will consist of that element. Each semester will provide about 13-15 weeks of working time. Another constraint is the most obvious, money. The budget given to the group in the product description is $1500. However, the customer has already expressed to the group that they expect the group to exceed the given budget. The customer explained that it will not be much of a factor if the budget is exceeded, as long it is not in a wasteful manner. Clearance for the two devices will be a main concern as well. Because the helicopter has a limited amount of clearance while grounded, modifications to the robot and/or helicopter will need to occur in order for the product to be fully functional. The customer stated to the group that there may be some constraints as to what frequencies we may use for electronics that will be installed. 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; Therefore the group must have accurate dimensions so that there is not an issue when the group is able to work with the helicopter.

II. Concept Specification & Methodology

(a) Product Specification

Robot is synonymous with marsupial robot or BomBot. Helicopter is synonymous with RMAX. 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 60 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 antenna, camera, and spotlight.
    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. To do so the robot must be no taller than 15.75 inches for front entry and xx inches for rear entry in its passive structure.
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 in its passive form 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.

(b) Methodology

The first step in the design process is to understand the goal of the customer. For the task at hand, the customer wants to combine and utilize two devices together to perform a task that neither device could do alone. The two devices consist of a Yamaha RMAX remote control helicopter and marsupial robot designed to carry and deploy a specific payload. The helicopter must be modified in a way to efficiently carry the marsupial robot, deploy it at a specified location, and then retrieve the robot once the payload is deployed.

The next step is to define the problem to be solved that the customer is in need of. The goal of the project is to present a final product that can flawlessly carry, deploy, and retrieve the robot. Our objective is to design and manufacture the necessary modifications so that no human interaction is needed other than using the remote controls of the helicopter and the robot. Another objective is that once the robot is within a specified distance to the helicopter, an autopilot mode is engaged which will automatically transport the robot into the payload of the helicopter. With the objectives stated above, there are some clear constraints to achieving these. The first issue is a clearance issue. Both of the devices used are not common everyday items. Dimensions are not known for either device, and we are not sure exactly what either device looks like. As far as constraints on the materials, the customer will be able to supply many sources for supply materials. The customer has access to many machines that can fabricate custom parts. Resources as of now consist of a budget of $1500.

The most important part of planning a project is to have equal effort by each group members. For this we have several guidelines in order. The most basic is to meet at least bi-weekly with one another and discuss progress and ideas. In addition, deadlines will be assigned according to each specific task to be completed. If a member does not meet the deadline, then it is the remaining group members' responsibility to assist that member to complete the necessary assignment.

As for gathering information of the assignment, the most obvious is to ask the customer themselves. The group has met with the customer and received information that we did not know based on the project description. An overview of what tasks are to be completed and what the restrictions are were presented to the team. The group was able to see the two devices that are to be modified in order to reach the goal. In fact the group was allowed to temporarily possess two robots so that we can design the necessary modifications. Dimensions of the helicopter have been made available to the team. Some background information for the helicopter is available on several websites, whereas the background information for the robot has been given to us in a brief oral review.

Many approaches to the design have and will be discussed during our gatherings that will take place. Every idea is considered no matter how abstract. These meetings are designed so that the members can express their creativity towards the desired goals. These ideas are to be recorded. Although ideas will be accepted throughout the project, there will be a deadline given to determine the route for which we will base our design from. This is so that the group can designate enough time to ensure that a finished product can be completed. The ideas are then evaluated on several different factors. The first and most important factor is performance. We must determine based on the research and knowledge whether or not the each approach can perform the necessary goal. The next factors are all crucial and are listed in random order. Cost, Safety, Reliability, Appearance, and Specifications are just a few. We will take each of the factors into consideration for each design idea, and rank them essentially creating a decision matrix. We will determine which idea will be the most compatible given all of the objectives and constraints as well as referencing to the decision matrix.

Communication of the design will take place from day one of the project. All information, ideas, research, problems, breakthroughs, etc. will be documented. We must then create an efficient presentation so that others may be able to understand the design without having to read all the documents that are produced.

The final design will come from every step described previously. Once the final design is chosen a system diagram will be created. This diagram will be a configuration of the systems, subsystems, and components needed for completion of the design. Once this layout is completed, the detail design begins. This will consist of the final specifications of the system. Detailed drawings with full dimensions and list of materials will be included. From then the process on how to manufacture the design will be documented. Instruction booklet on how to use the device will be included as well. Once these details have been finalized a prototype will follow. This prototype will go through many tests and reviews to determine if modifications need to be made.

Finally a production ramp-up and delivery will take place. The team will present means to produce and market the product to the customer using all the aforementioned details from the design process.

III. Conceptual Designs, Selection, & Analysis

(a) Telescoping Arms Design

This Design incorporating four (4) telescoping arms with hooks on each end that also folded. It would be utilized by having the arms stay folded up it the vertical position while the Bot was being used. Upon completion of the mission the Bot would drive under the RMAX, lower the telescoping arms, and then extend the arms. The RMAX would then take off, and hover, while the arms slightly retracted, engaging the hooks on each end, and therefore securing the Bot to the RMAX.

In order for this design to mechanically work it would be necessary for the BOT to be modified it four motors that allowed for the independent rotation of each of the telescoping arms, as well as the four telescoping actuators.

It was decided that this was not a feasible idea for a plethora of reasons. First of all, the cost of all of the actuators necessary for the completion of the movements would be very high, therefore limiting the budget in other areas of the project. Also, this deign would require an extensive controlling method that would be inherently complex. This complexity issue would lead to more problems later in the design.

Also, during prototyping it was discovered that the vertical position of the telescoping arms would interfere with the underbody of the RMAX, therefore requiring a suspension modification of the Bot.

Therefore due to the sheer complexity of the design, as well as the large budget required to complete, it was decided that this design would not be utilized.

(b) Tire Rack Design

After several brainstorming and individual research sessions, one of the ideas the team agreed as a possible design was a tire rack device. This idea originated from the way that car wash machines operate. Some of the car washes have a tire rack component on the ground of the car wash. The tire will move into a certain position, a clamping device will lock the tire into place, and the device will move the car forward using a conveyor belt type action.

Using this knowledge, a three dimensional model of the tire rack idea was created to achieve the goal of the project (Figures 3 and 4 below). In our application the conveyor system is not needed. We used the car wash design to help implement a design to lock the BomBot into a secure position. The way the design functions, if that the BomBot will be aligned with the rack using remote controls. The racks are designed so that they are wider than the tires, (approximately 6 inches compared to the tires 4.8 inches) so that the BomBot would not be required to be perfectly aligned. The rack is composed of two ramps, one located on each end. In the middle of the rack are 2 plates that will displace from each other and act as a clamping device. In between the ramp and the clamping components are cavities that are 5 inches deep and 6 inches wide. The BomBot will be driven forward and go over the first ramp. It will then be driven over the clamping device so that each tire is positioned in a cavity. Once the BomBot has reached this destination, the clamping devices will displace from each other and place pressure onto each tire. The clamping plate will place enough force onto each tire so that it locks the tire in a stationary position with the flat side of each ramp. To allow the BomBot to be released from the device, the clamping components will release their pressure, and the BomBot will be allowed to drive out of the racks.

Pros:

-Achieves the required goal of securing the BomBot to the Helicopter and allows for deployment and recovery.

-Secures the BomBot sufficiently.

-Achievable design

-Relatively inexpensive

-Requires no modification to BomBot

-Requires no modification to Helicopter (other than skids)

Cons:

-Does not secure top of BomBot

-There may be clearance issues do to due large size of the BomBot wheels and the small dimensions of the helicopter skids.

-Needing relatively flat landing surface for most convenient operation.

-May have issue with getting wheel over clamping device

-Possible alignment issue

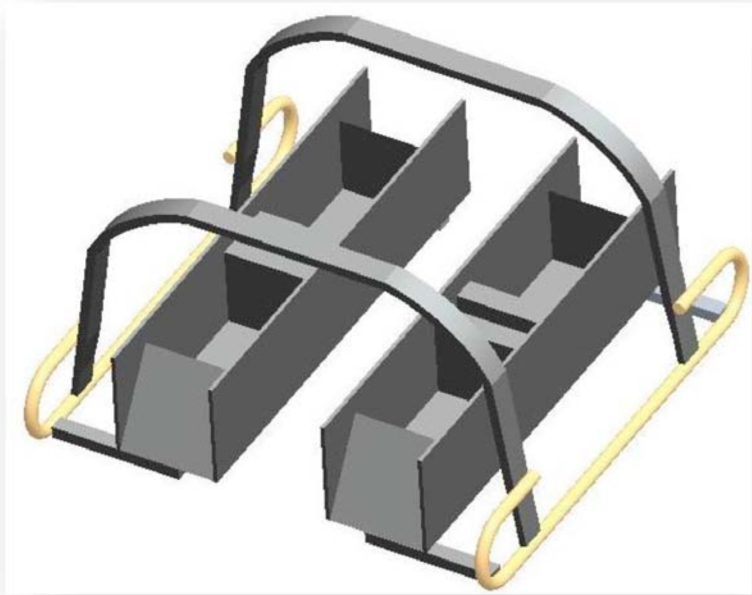


Figure 3**:** Tire Racks Mounted to the Helicopter Skids

Figure 4**:** BomBot Secured in the Tire Rack Assembly

After creating a three dimensional model with the correct dimensions of the helicopter skids and BomBot, a problem clearly arose. Because the team possesses only a BomBot and not the helicopter, the true size of the helicopter skids relative to the BomBot was not always known initially. Therefore, when drawing hand sketches of the idea, there was no indication of any clearance issues. Once the true dimensions of the helicopter skids were obtained, this idea became very difficult to achieve. Because the tires of the BomBot are so large, the cavity had to be a significant size. Because of the large size of the cavity, the angle of the ramp had to be increased in order to shorten the overall length of the ramps so that it was not longer than the skids. This provides difficulty for the tires to get over the ramp. Also with the high angle of the ramp, the BomBot will change heights rather significantly, resulting in a clearance issue with the bottom of the bottom of the helicopter. Although there are some serious issues with this design, other designs may still be created based on this idea. An idea that had arisen while writing this report follows the idea of an animal trap. Keeping the two track design, removing the clamping components, and making the ramps so that they are collapsible, one can create a design that can be successful. Once the BomBot reaches the end of the track, the ramp from the front that collapsed due to the weight of the BomBot can be triggered upwards to create a locking point for the BomBot.

(c) Swinging Platform

The parallel four-bar was very useful in raising and lowering the camera; Depicted in Figure 5.

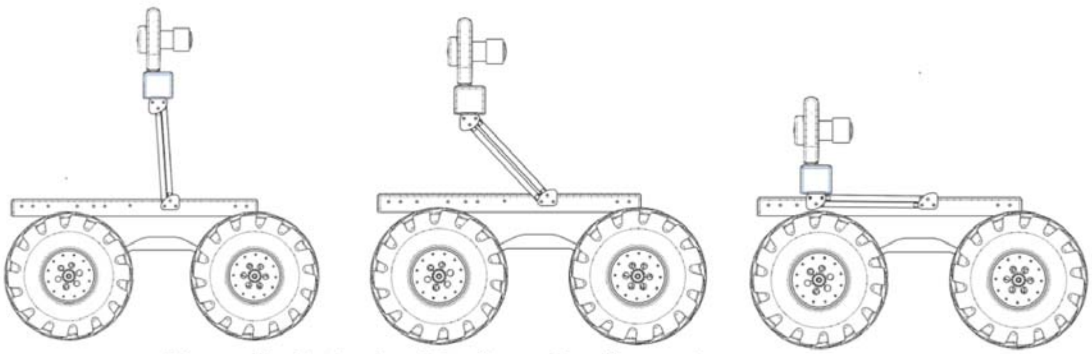


Figure 5: Swinging Platform Configurations

A stiff member, as used in the original design, was used to keep the camera and the antenna mounted in a permanently raised position. This can be seen in Figure 6.

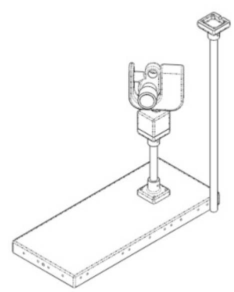


Figure 6: Current BomBot Platform

The original design of the robot's platform seen in Figure 6 is a robust design that met all of the design criteria of the past but has created many problems with the RMAX interaction. The use of the four-bar seen in figure 5 was designed specifically for BomBot and RMAX interaction.

The problem with the original design is it will not allow the BomBot to fit underneath the helicopter because the masts holding the camera and antenna are too tall and rigidly fixed. The problem faced as an engineer is how the camera and antenna should be high enough to maintain visuals and connection during a mission, yet still fit underneath the helicopter. This can be accomplished with telescoping masts, although such a design proves costly and complicated.

Given that this is an open ended design, it is easily clear that many paths are available and there are even more variations of each path. The challenge is to keep the design as simple and robust as possible. If failure should occur a simple fix should be a temporary option while out in the field. If asked where the mechanical arm with 8 degrees of freedom that can autonomously capture the robot with extreme precision, a response based of simplicity will be the answer.

Not only does the design in Figure 5 lower the camera to a point of clearance, but because it utilizes a parallel four bar the camera base remains on a horizontal plain at all times. If the camera was to fold straight down visuals would be lost while engaging with the helicopter. Visuals are essential for the first phase of RMAX engagement.

Another simplification taken is combining the antenna and the camera into one unit. Two motors are not better than one. Two motors to raise and lower the camera and antenna would overly complicate the design. A complicated design can be attractive to buyers who want their bells and whistles or be disastrous to others who demand there practicality and ease of use.

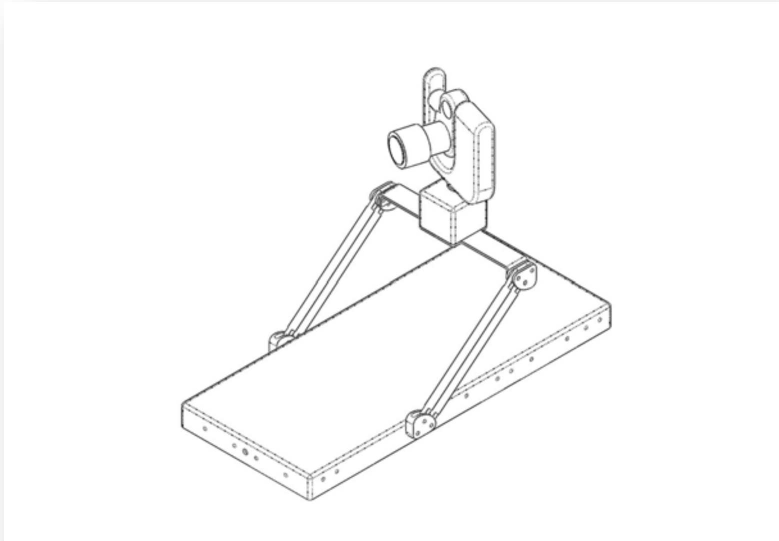


Figure 7: Swinging Platform with Camera Mounted

The original design that held up the camera was completely robust and was designed to support the camera at an elevated height to give the user a visibility all around. The design (pictured below) did just that. By using ABS plastic bases and a pvc plastic mast the robust design was easily achieved.

The swinging platform is designed to meet much more specifications:

- Variable Elevation
  - The height of the camera is not important during engaging procedures. The camera can be at its lowest possible elevation during engagement. Our device must change the elevation from a completely visibility to lowest elevation achievable for clearance underneath RMAX helicopter.
  - By coupling the antenna with the camera we can minimize moving parts on the machine.

- Support
  - The design must support the camera and antenna completely at all sorts of acceleration and vibrations which will happen during travel of BomBot.
- Parallel Four Bar
  - The use of a parallel four bar allows the camera to mount on to a plane that is constantly parallel to its mounting platform (under expected travel conditions the camera will then be parallel to the ground).

By the use of computer aided design a simulated prototype was created. This prototype was used to construe ideas to sponsors and directors. This CAD prototype can only be so useful because it is built out of conveniently created solid parts that are intangible. Designing for manufacturing proved to be challenging because the swinging platform had to have relatively tight tolerances while maintaining ease of movement/rotation. Throughout the design process of the swinging platform one could see the evolution of design. The evolution of design was based on improvements or fixes to make the design more compact, cheap, and flexible while also allowing mounting of an antenna to reduce weight by another costly design of elevating antenna. The final revision can be seen below in Figure 8.

Figure 8: Final Revision of Swinging Platform

The pin joints do not need bearings because maintaining efficient movement is not necessary and some energy lost in movement will be negligible. Instead of bearings nylon cylindrical spacers are being used around a #4-40 flat head screw to create the pin. The lateral load of the rotating rods/arms will be supported by the parallel linkage bracket. High lateral loads are not expected and can be assumed negligible. The purpose of the parallel bracket is to provide a fixed base for the rod ends and necessary hardware.

Optimization of this parallel bracket will be filleted ends which will reduce mass and increase space and ease of movement. Filleted ends will not be necessary for the first prototype and can be expected to be seen in Spring.

The second revision of the Swinging platform had design for manufacturing in mind. All of the parts used in the first revision of the Swinging Platform could be manufactured given the proper molding processes and machining but doing so would be prove to be costly and labor intensive. The second revision used shoulder screws for pins. The rods became carbon fiber with a female threaded tie rod on each end to create a pin joint around the shoulder screws. The overhang platform tabs ran into the platform making it impossible to bring itself flush with the base platform. The second revision is an improvement over the first revision though it still falls short of the sponsor's expectations.

The third revision was a vast improvement over the second. The shoulder screws were eliminated to the current screws and nylon cylindrical spacers. This was a huge improvement because the shoulder screws were rather expensive and the nylon will provide a lower frictional coefficient on the inside of the tie rod ends. The design was made more compact by countersinking flat head screws and threading them into the parallel linkage base. The overhang platform was widened and attached to the outside of the parallel linkage bracket creating clearance for the platform. By countersinking flat head screws the overhanging platform was finally able to become flush with the base platform, thus allowing the lowest possible elevation of the camera without changing the weight distribution or making dramatic changes to the panning and tilting features.

Overall the price was greatly reduced by the third revision utilizing cheaper yet effective components such as the nylon spacers. Below in Figure 9 you can see that the Swinging Platform can continue all the way to the surface of the base platform.

Figure 9: Final Revision of Swinging Platform

(d) Ball & Socket

The BomBot needs a way to easily be transported by the BomBot helicopter. The BomBot needs to attach to the helicopter without any ergonomic human interaction. Ergonomic human interaction would be if the human needed to fasten the BomBot to the helicopter and potentially put himself in harm's way. The human is expected to attach to the BomBot remotely instead to ensure safety of himself. The attachment device must secure the BomBot completely while the helicopter is preparing to be or is currently in flight.

The name Ball & 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 which allows load bearing surfaces for the BomBot to rest. The benefit to this design is its simplicity of manufacturing and engineering. Many of the other designs could only work due electronic controllers.

The first revision of the Ball & Socket system did not have any way of securing longitudinal movement of the BomBot. Longitudinal movement will allow the BomBot to slid out and can cause sudden failure to the mission.

The second revision of the Ball & Socket system allowed a safety zone within the funnel clip profile. Once the BomBot enters into the safety zone it should be considered completely secure. Although the safety zone worked under theoretical conditions, a large enough acceleration could cause the BomBot to escape the safety zone and cause sudden failure to the mission. Getting into and out of the safety zone would require excellent traction with the ground throughout suspension travel and ideal ground conditions. The second revision can be seen below in Figure 10.

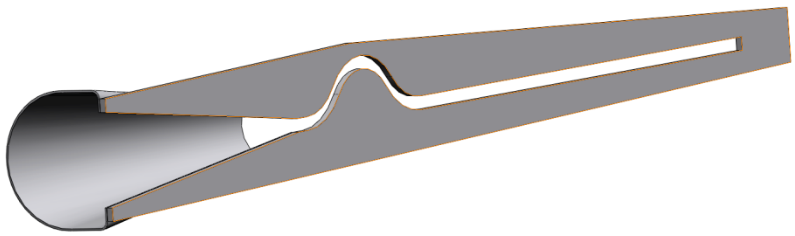


Figure 10: Revision 2 of Ball & Socket

The third revision of the Ball & Socket system created two load bearing low valleys in which the ball entered into upon lift of helicopter. Once the BomBot is lowered and the four balls fall upon the load bearing surfaces security is achieved. This is a major improvement from the second revision because of constant traction between the tires and the ground until liftoff of the helicopter.

The fourth revision of the Ball & Socket system was purely for structural integrity. Due to high stress concentrations and large moment created in the connection between the upper and lower halves of the funnel clip thickening and addition of material was added to decrease flexing of the part. The addition of the material is backed by FEM provided by CosmosWorks.

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 11 and the Final Revision can be seen in Figure 12.

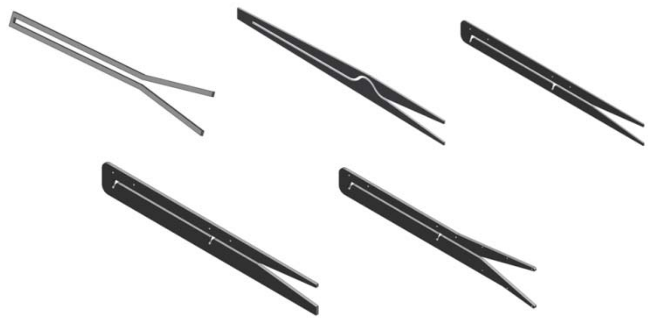


Figure 11: Evolution of Funnel Clip

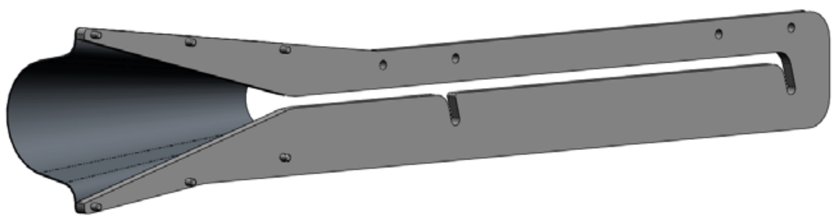


Figure 12: Final Revision of Ball & Socket

Future optimizations of the Ball & Socket system include a spring loaded latch that will increase security of the BomBot.

(e) Design Matrix

Shown below in Figure 13 is the design matrix that was utilized in order to decide which designs should be utilized for the project

Design Matrix								
	Portability	Ease of Manufacture	Durability	Simplicity	Solution to Problem	Modification ease	Cost	Total
Camera & antenna Clearance								
Swinging Platform	+	0	+	0	+	+	0	4
Telescoping Rod	+	-	0	-	0	0	-	-2
BomBot Engagement								
Tire Rack	-	-	+	0	-	0	-	-3
Ball & Socket	+	+	-	+	+	0	+	4
Cylinders/Telescoping	-	-	-	0	0	-	-	-5

Legend: + Good 0 Neutral - Bad

Figure 13: Design Matrix

IV. Detailed Design

(a)Entire Assembly

After many virtual prototypes, brainstorming, and conferences both within the group and with others a final prototype was decided upon. This can be seen below in Figure 14.

Figure 14: Entire Assembly

(b) Swinging Platform

This prototype uses the swinging platform described above, but a detailed design is shown below in Figure 15.

Figure 15: Detailed Design of Swinging Platform

(c) Ball and Socket

It was also decided upon that the Ball and Socket design should be utilized. A detailed design of this is shown below in Figure 16.

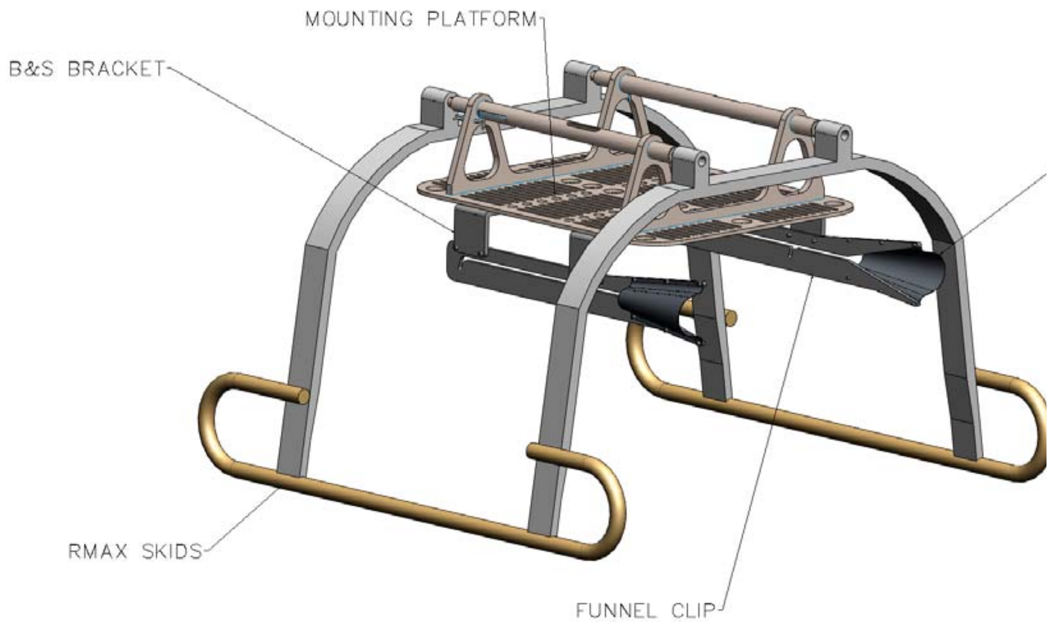


Figure 16: Detailed Design of Socket Mounted onto RMAX

Dimensionalized drawings of all of the parts have been completed but have been left out to avoid overkill.

V. **Prototyping**

(a) Currently Accomplished

At this point, as requested by the customer, prototyping has begun. A test bench that will serve as a visual representation of the skids currently on the RMAX is almost completed. The following is a discussion of the materials, and processes used in order to accomplish these tasks.

(b) Materials

Below is a list of the materials used to prototype the RMAX skids.

1. Resin
2. Fiberglass chopped mat
3. Fiberglass woven cloth
4. Liquid Hardener
5. Paint Brush
6. Drop Cloth
7. 3/8 & 1/4" thick Balsa Wood Sticks
8. Several Mixing buckets
9. Several Mixing Sticks
10. Wood Glue (If necessary)
11. Gloves
12. 80-120 grit sandpaper
13. Rotary Tool
14. 50/50 water-De-Natured alcohol solution
15. Protective Eye-Wear
16. Protective Mask
17. Jig

(c) Process

Certain processes were used in order to fabricate the skids, what follows is a discussion of these processes.

Construct a jig such that it will give you the wanted bends. This can be made from a .25" thick piece of MDF board and nails that follow the form of the wanted bends. Be aware however that you will want to construct the jig such that there is slight over bend to accommodate flexing (Elasticity of the wood) when the wood dries.

Once you have purchased the balsa wood sticks, you will want to start soaking the .25" thick pieces in a 50/50 water-De-Natured alcohol solution for about a couple of hours to ensure that the wood is totally saturated as shown in figure (1). This solution will start to soften the fibers in the wood such that they become flexible enough for you to bend the balsa wood without breaking it. Although some may tend to want to use a 50/50 water-ammonia solution this solution however often acts as a catalyst in mold growth as the balsa wood dries in the bent shape.

Figure 17: Mixing the Bending Catalysts

Pre-cut 3/8" thick pieces of wood to appropriate length. This will expedite the forming process. Approximately 1-2 pieces per skid will be needed.

You will want to have all your materials laid out due to the limited work time of the resin and fiberglass.

Tear small pieces of fiberglass mat for it will be easier to work with.

Cut long strips of fiberglass cloth about 2 ½ inches in width.

Pre-determine the amount of resin/liquid hardener ratio. This will need to be known in order to complete the fiberglassing process. Here's a chart for reference.

Amount Of Resin	**Hardener Required**
1 Ounce	10 Drops
1 Pint (16oz)	1/8 Ounce (7cc)
1 Quart (32oz)	¼ Ounce
½ Gallon (64oz)	½ Ounce
1 Gallon	1 Ounce

Figure 18: Materials for Bonding Resin

Forming:

Step 1: Carefully place pre-soaked balsa wood sticks into jig making sure that the bends are located in the appropriate areas. Note that you can only bend two sticks at a time or construct a jig that would allow for more sticks. You wouldn't want to place more than two sticks in jig at the same time due to the fact that the more sticks would not allow for proper drying. Once the sticks are in the jig with all the precautions taken that are listed earlier, they will have to remain in the jig for a suggested drying time of 3 hours. A handheld dryer may be used to expedite this process.

Step 2: Once all sticks of balsa wood has been successfully formed into shape, approximately 4 per skid, you will want to grab the .25" thick pieces of balsa that you pre-cut to length earlier, and start forming the straight sections of the skid figure(2). Using wood glue is advised. Most brands are easy to clean up and the glue won't affect the fiberglassing phase later. A picture of the finished formed product is shown in Figure 19 below.

Figure 19: Formed RMAX Skid

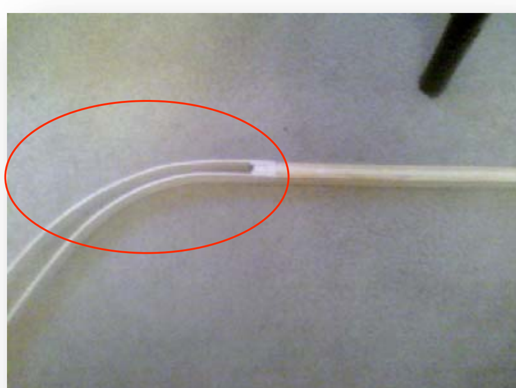


Figure 20: RMAX Skid Bend Closeup

Fiberglassing:

Step 1: With all your materials laid out and ready for fiberglassing, proper care should be taken to wear protective eye, breathing, and hand wear. All fiberglassing should be done in a well-ventilated area. Lay down drop cloth to protect any surface that fiberglass will not be applied to.

Step 2: Mix the resin and liquid hardener as shown in Figure 21. The resin and hardener will need to be mixed very well to ensure full reaction.

Figure 21: Mixing the Resin

Step 3: Apply a layer of resin to formed skid. Then quickly apply torn pieces of fiberglass mat followed by another layer of resin completely saturating the fiberglass. Repeat this process until the entire side of skid is fiberglassed. You may want to apply more than one layer of mat to ensure rigidity. By this time the remaining resin should start to form into a jelly-like texture. Once this happens the resin is no longer useable. Discard remaining hardened resin. Let skid dry for about 1 ½ hours. The resultant skid thus far should look something like that in Figure 22.

Figure 22: Skid with wet Fiberglass

Step 4: Using a rotary tool, cut away any excess fiberglass from skid.

Step 5: Repeat the above process until entire skid is covered in fiberglass mat.

Step 6: Once the above process is complete you should have a pretty rough surfaced skid. Use an 80 grit sandpaper to smooth any rough edges working your way up to an 120 grit sandpaper.

Step 7: Ounce skid is smooth, you will need to grab the pre-cut strips of fiberglass cloth and wrap the skid in the strips ensuring that the entire surface of the skid is covered once done. Small staples may be used to secure strips as they later will not affect the finished product.

Step 8: Mix more resin and hardener.

Step 9: Apply resin to skid ensuring to again completely saturate fiberglass cloth.

Step 10: Allow to skid to dry again for about 2 ½ hours. Be sure to discard remaining resin again.

Step 11: Repeat sanding process until skid is smooth. Skid should be very rigid.

Step 12 (optional): If your skid has a lot of uneven and holey spots, body filler may be applied and sanding process will have to be done again except using finer grit sandpaper.

VI. Autonomous Control Plans

(a) Robot Control

Now that the physical attaching element of the project has been finalized, the team now looks to improve the design using robotic modifications. Some of these modifications consist of maneuvering the swinging platform and creating an autopilot mode. For each of these aspects a robot control needs to be purchased. A very nice small dimensioned controller was selected. It is the Baby Orangutan B-168 Robot Controller. Using this controller in conjunction the Orangutan USB programmer the team can write programs that perform the necessary tasks below. Each of these components were found on www.Pololu.com.

Figure 23:
Baby Orangutan B-168
Robot Controller

Figure 24:
Orangutan USB
Programmer

Specifications for Baby Orangutan B-168:
• Overall unit dimensions: 1.2" x 0.7"
• I nput voltage: 5-13.5 V (15 V absolute maximum)
• Two bidirectional motor ports (3 A peak per channel; ~1 A continuous per channel)
• Programmable 20 MHz Atmel ATmega48 AVR microcontroller (4 kB flash, 512 bytes
SRAM, 256 bytes EEPROM) or Atmel ATmega168 AVR microcontroller (16 kB flash,

1 KB RAM, 512 bytes EEPROM)
• 18 user I/O lines, 16 of which can be used for digital I/O and 8 of which can be used as • Analog input channels
• 1 user LED
• User potentiometer tied to ADC7
• 20 MHz external resonator

(b) Swinging Platform Motor

As shown during the swinging platform section of the report, the physical design has been accounted for. We then needed to select the method to control the swinging platform. There were several options that can be chosen for this task including linear actuators, gear motors, and servo motors. The first choice analyzed was the linear actuator. This method would work appropriately but there were some drawbacks. The cost of the linear actuators examined were very expensive, exceeding $100. As well as the high cost, the actuators also were long therefore taking space on the BomBot and possibly causing interference with other components. The next choice was the geared motor. In contrast to the linear actuators the geared motors were much lower in cost, ranging in the mid $20's. However for use with the swinging platform it seemed to be overkill. Most of these geared motors are designed to move wheels of robots therefore being very powerful. For the swinging platform speed is not much of a factor, torque and control are the main factors. So the team then examined the use of servo motors. Servo motors can generate a good amount of torque while being very small in size. These servo motors are also much easier to control as far as determining what angle we need the platform to achieve. Therefore the servo motor is the method the team has chosen to move forward with. The motor chosen is the Hitec HS-125MG Servo Motor from www.Robotshop.ca. We will be able to attach the arm of the servo motor to the base of the swinging platform and control the rotation of the platform to manipulate the position of the camera that will be mounted on the platform. In the case that we are not permitted by our sponsors to utilize the servo controller already used on the BomBot then the servo controller to be used is the Pololu Serial 8-Servo Controller from the same website. Some of the specifications for the servo motor is listed below.

Figure 25:
Hitec HS-125MG Servo Motor

- Speed (sec/60°): 0.13
- Torque (Kg-cm/Oz-in): 3.5/49
- Size (mm): 30 x 10 x 34
- Weight (g/oz): 24/0.84.
- Price: USD $36.04

Figure 26:
Pololu Serial 8-Servo Controller

- Controls up to 8 servos
- Serial interface (TTL or RS-232)
- Price: USD $26.95

(c) Autonomous Driving Controls

This is where the controls aspect starts to get a bit more difficult. Ideally we are planning to be finished with the attachment part of the BomBot to the Yamaha RMAX relatively early into the Spring semester. So this section will cover optimization of our design to have the BomBot and RMAX enter an “autopilot” mode to direct the BomBot into the perfect location so that attachment will be achieved without the use of human interaction. After researching many sources the team focused on several methods of completing the task. These methods are the use of GPS Navigation, Compass Sensors, or Proximity Sensors. The GPS Navigation is the most ideal method to perform our goal. The idea is to have a Navigation Localization System located on both the Yamaha RMAX and the BomBot. This would enable the team to know the exact locations of the BomBot and RMAX. The team when then be able to create a program that would control the BomBot to drive it under the RMAX and be in the perfect location for engagement to occur. Ultimately because this is such an efficient method, the cost for this application exceeds $1000. So then the team began to analyze alternate methods. The compass sensor is a great tool used to navigate robots. It uses the magnetic field of the earth to determine the direction the robot is traveling. However for our goal it does not seem as if this path would be the best. This will not determine how far in either direction the BomBot is relative to the helicopter, and thus we will not know in what direction to adjust the BomBot in order for it to be properly aligned. Also because it senses magnetic fields, there may be some interference due to the motor of the BomBot or other surrounding elements. That left the team with the Proximity (Distance) Sensors. The sensors examined can sense if there are any obstacles in the path of the BomBot using reflection. A certain part on the RMAX can be coated with the necessary reflective surface and the team can then determine what range the BomBot needs to be in order for proper alignment to be attained. Using this range the team can then create a program that will guide the BomBot within this specified range. The Proximity sensor chosen is the Sharp GP2Y0A21YK0F Distance Sensor found at www.Pololu.com. Below are some of the specifications.

Figure 27:
Sharp GP2Y0A21YK0F Distance Sensor

- Operating voltage: 4.5 V to 5.5 V
- Average current consumption: 30 mA (typical)
- Distance measuring range: 10 cm to 80 cm (4" to 32")
- Output type: analog voltage
- Output voltage differential over distance range: 1.9 V (typical)
- Response time: 38 +/- 10 ms
- Package size: 29.5×13.0×13.5 mm (1.16×0.5×0.53")
- Weight: 3.5 g (0.12 oz)
- Price: USD $9.95

VII. Conclusion

What has been presented above is a representation of the decisions and actions that have been taken throughout the past semester. It was shown through the analysis of the ideas that were developed and the use of a design matrix that the swinging platform and ball and socket designs would be implemented. It should also be known that both of these ideas are soon to be prototyped so that failure methods of these designs can be found early. Resultantly the designs will then be optimized.

Overall our team, with the guidance of our sponsors and faculty, has developed ideas, which should more than accomplish the needs assessment presented. Future analysis, both virtual and real, is still to take place such that the team can fully develop a product that meets and exceeds all expectations from the university as well as Tyndall Air Force Base.

The team understands that this is a work in progress, and although these designs have been chosen, the team is by no means stuck on these ideas only. Future development will shape the direction of the project and allow for an optimized design.

The team would like to thank the staff at Tyndall Air Force Base, as well as the Faculty of FAMU-FSU College of Engineering.

VIII. Appendices

(a) Ball & Socket FEA

Stress analysis of Ball and Socket 2 FEA

Table of Contents

List of Figures

Description

The original design of the Ball and Socket seemed to have weak spots below the load bearing surfaces. By adding more material to decrease stress concentrations we increased the factor of safety all around.

Assumptions

The assumptions used in this study were the same assumptions used in the previous study. The clip is rigidly fixed at the 4 rigid mounting locations on the left half of the Ball and Socket system. Only the left half is being tested because of the symmetry of the design. Testing both sides would require longer computer calculation times and would be unnecessary.

A load of 30 lbs is assigned to each of the load bearing surfaces. There are four total load bearing surfaces. The 30 lb load will simulate a 120 lb payload. Though the helicopter cannot pick up 120 lbs and the bombot will never weight 120 lbs an overdesign of the system will prove more reliable.

The funnel is made out of aluminum 6061 and the funnel clip is made out of 4130 annealed steal with poissons ratio .33.

Model Information

Document Name	**Configuration**	**Document Path**	**Date Modified**
Ball and Socket FEA	Default	C:\Rob\AFRL\Ball and Socket FEA.SLDASM	Sat Nov 01 17:03:41 2008
funnel clip 4-1	Default	C:\Rob\AFRL\funnel clip 4.SLDPRT	Sat Nov 01 21:13:09 2008
funnel-1	Default	C:\Rob\AFRL\funnel.SLDPRT	Thu Oct 16 20:54:35 2008
funnel clip 3-1	Default	C:\Rob\AFRL\funnel clip 3.SLDPRT	Sat Nov 01 19:28:36 2008

Study Properties

Study name	Study 2
Analysis type	Static
Mesh Type:	Solid Mesh
Solver type	FFEPlus
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

Units

Unit system:	SI
Length/Displacement	m
Temperature	Kelvin
Angular velocity	rad/s
Stress/Pressure	N/m^2

Material Properties

No.	Body Name	Material	Mass	Volume
1	funnel clip 4-1	AISI 4130 Steel, annealed at 865C	0.421639 kg	5.37119e-005 m^3
2	funnel-1	[SW]6061 Alloy	0.0253507 kg	9.38915e-006 m^3

Material name:	**AISI 4130 Steel, annealed at 865C**
Description:	
Material Source:	Library files
Material Library Name:	4130 steel .33
Material Model Type:	Linear Elastic Isotropic

Property Name	Value	Units	Value Type
Elastic modulus	2.05e+011	N/m^2	Constant
Poisson's ratio	0.33	NA	Constant
Shear modulus	8e+010	N/m^2	Constant
Mass density	7850	kg/m^3	Constant
Tensile strength	5.6e+008	N/m^2	Constant
Yield strength	4.6e+008	N/m^2	Constant
Thermal conductivity	42.7	W/(m.K)	Constant
Specific heat	477	J/(kg.K)	Constant

Material name:	**[SW]6061 Alloy**
Description:	
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

Loads and Restraints

Restraint

Restraint name	**Selection set**	**Description**
Rigid Mounting	On 4 faces fixed.	The rigid mounting is due to the mounting holes designed for the RMAX mounting brackets.

Load

Load name	**Selection set**	**Loading type**	**Description**
30 lb per load bearing surface	30 lb per load bearing surface.	Sequential Loading	The load bearing surface is where the rod extending from the robot will rest.

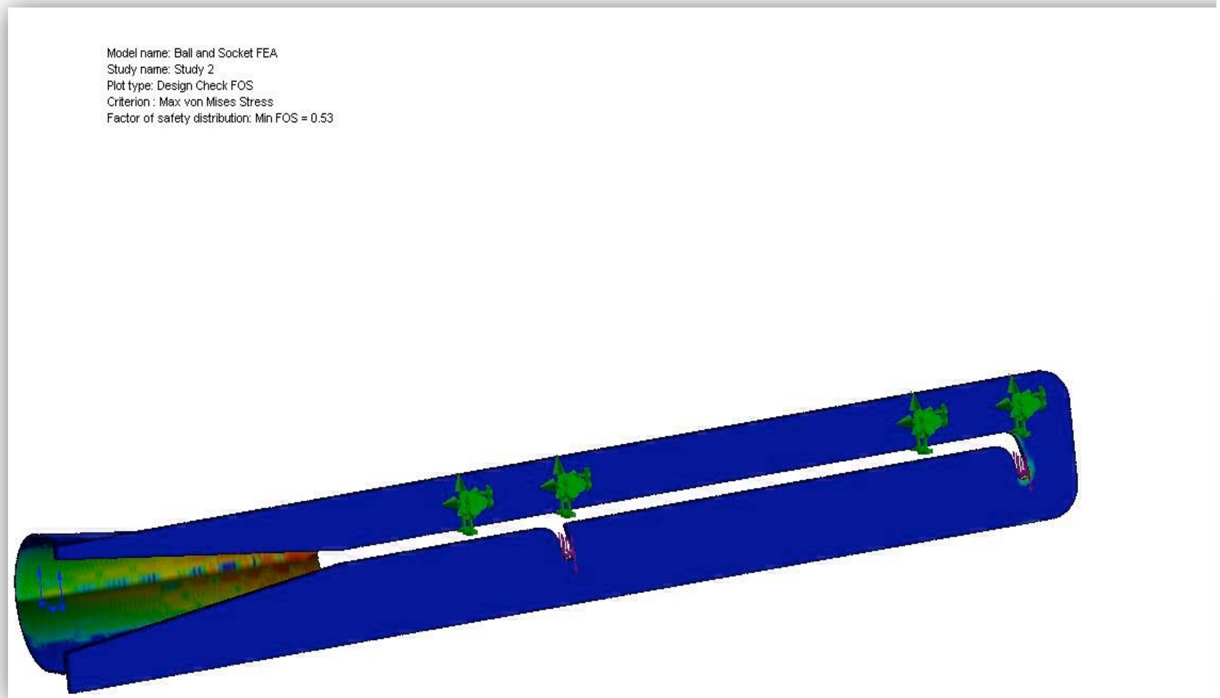
Mesh Information

Mesh Type:	Solid Mesh
Mesher Used:	Standard
Automatic Transition:	On
Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	0.084275 in
Tolerance:	0.0042137 in
Quality:	High
Number of elements:	75376
Number of nodes:	134670
Time to complete mesh(hh;mm;ss):	00:00:19
Computer name:	ROB-PC

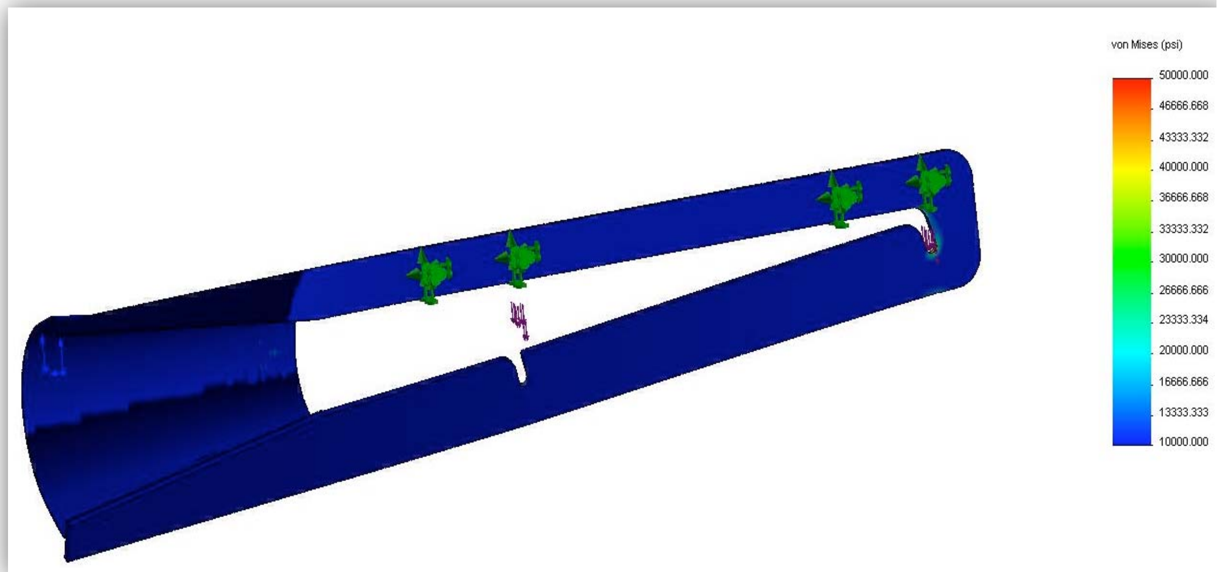
Study Results

The material that is plastically deforming is the sheet metal. The sheet metal was designed as a alignment guide to the robot and to help support the clip.

Name	Type	Min	Location	Max	Location
Stress1	VON: von Mises Stress	0.257874 psi Node: 89849	(-11.1897 in, 0.9 in, 0.05 in)	43098.1 psi Node: 56615	(-17.1164 in, -0.63889 in, 0.0125 in)
Displacement1	URES: Resultant Displacement	0 in Node: 1	(-17.1511 in, 0.5 in, 0.1 in)	0.0645994 in Node: 5953	(0 in, -1.3 in, 0 in)

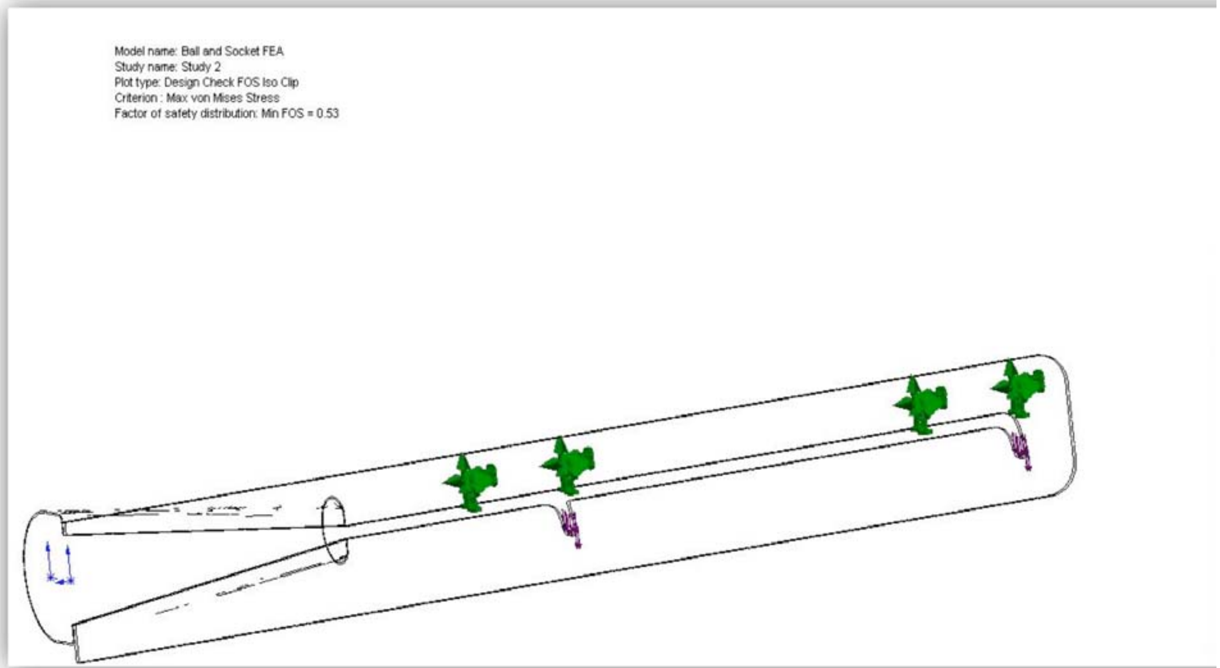


Ball and Socket FEA-Study 2-Factor of Safety distribution throughout the Ball and Socket system.

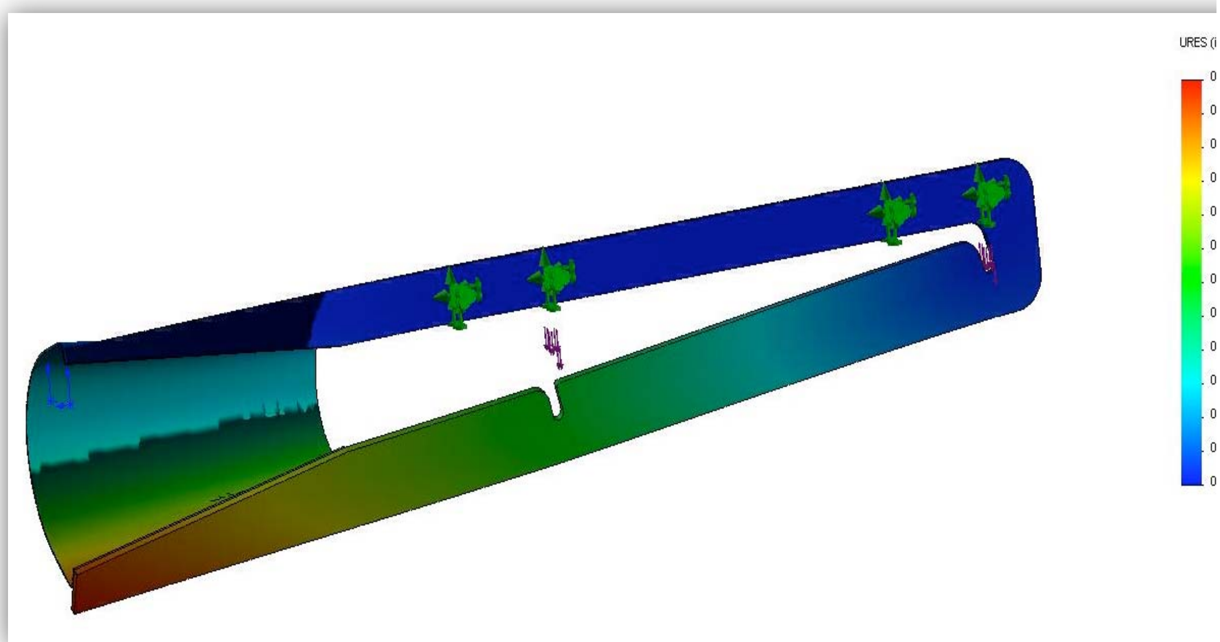


Ball and Socket FEA-Study 2-Stress Distribution throughout the Ball and Socket system

Comment: The entire model is blue except for a few spots directly near the load bearing surfaces and on the sheet metal funnel. Any areas of interest would not show up blue.



Ball and Socket FEA-Study 2 - FOS ISO Clip. This graph displays everything to be transparent unless the factor of safety is below 2. This model is transparent except for a few small areas that are invisible to see in this snapshot.



Ball and Socket FEA-Study 2-Displacement

Conclusion

By adding extra material below the load bearing surfaces we were able to decrease the stress and increase the factor of safety all around.