SPLAT

Small robotic Platforms for Limited Access Terrain

Team # 5
Eglin Air Force Base

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Table of Contents

ABSTRACT

The Department of Defense along with Eglin Air Force Base and other government militaries have recently voiced a need for Small robotic Platforms for Limited Access Terrain, or SPLAT. Reliable surveillance is uncompromising in the world of urban warfare, but obtaining that reliable surveillance can often be dangerous to military personnel. For this reason, Eglin AFB has sponsored the SPLAT project. The goal of this project is to design subsystems that would give a small robotic platform the capability to transition from horizontal to vertical surfaces, and then have the ability to maneuver in that vertical plane.

In order to complete this project, the SPLAT team first set rules and guidelines for team dynamics and behavior. Background research was then done on already existing platforms. Next, ideas were generated and evaluated to determine the best overall design concept. The final concept chosen was a cart that utilized a blower/turbine as the means of adhesion to the wall. The thrust generated would have to be large enough to cause sufficient lift and normal forces so the platform can remain on a vertical surface and maneuver on that surface. Once the final concept was chosen, the necessary components for that design were laid out, and the initial components were bought in order to begin testing. These included a ducted fan, a radio and receiver unit, and a speed control to vary the thrust of the fan. While the parts were on order, an initial design of the body was completed and the tests that were to be run were set out in detail. Once the initial components arrive, testing can begin to optimize the design and each of its subsystems.

1.0 INTRODUCTION

1.1 Background and Problem statement

U.S. military efforts around the world have highlighted the need for platforms on “limited –access” terrain. The issue is that conventional weapons can be limited due to inadequate intelligence information. Following the need for more and better intelligence, it can be see that there is a need for small platforms that can maneuver on both horizontal and vertical surfaces to collect information. The Department of Defense (DoD) is interested in a platform to provide capability to navigate, sense, map, and reconnoiter in an urban environment.

The proposed task is to focus on designing subsystems that would give a small robotic platform the capability to transition from horizontal to vertical surfaces, and then have the ability to maneuver in a vertical plane. The capability concepts should incorporate mechanical design, size, weight, and material considerations, and the concepts for vertical motion must not interfere with the platforms ability to translate on horizontal surfaces.

1.2 Design Specifications

As with any design, specifications must be met in order to design the correct product. For this project Eglin Air Force Base, the sponsor of the project, and Mr. Jeffrey Wagener, the main contact for the project, set forth the main design specifications. The team also implemented a few others. All the design specifications are:

- The design should take into account three common interior/exterior wall surfaces.
- The capability concepts should incorporate mechanical design, size, weight, and material considerations.
- Three to four designs should be considered with a design matrix developed to rank the pros and cons of each design and to show which design will be pursued further. A few topics for rating designs are capability, cost, power requirements, etc…

- The platform must be able to remain on a vertical surface for a minimum of 30 minutes.
- Platform must be able to translate vertically a minimum of 5ft.
- Final design should be confined to a box no bigger than 6”x 6”x 6”.
- Platform can be controlled digitally or by radio control.

1.3 Eglin Deliverables

Eglin Air Force base, as our sponsor, also specified that certain aspects of the project would be expected when it was completed. The first deliverable is a report documenting test results, cost analysis, materials, conclusions, and future research. The second deliverable is a working prototype of the design demonstrating the transition from a horizontal plane to a vertical wall ascent.

2.0 SPLAT TEAM

The SPLAT team consists of four members: Jeff Dalisay, Michael Genovese, Ivan Lopez, and Ryan Whitney. The first tasks that were completed when the project was assigned were to lay out the ground rules for team behavior and team dynamics. This was done in order to keep problems from arising, and if they did, to solve them as quickly as possible. This was done so the focus of the team would remain on delivering a successful product to Eglin Air Force Base.

2.1 Code of Conduct

The code of conduct is a document that lays out the rules that the team will abide by throughout the course of the project. This is to assure the team stays on task and that problems within the group are kept to a minimum. It is also to document the rules of behavior that the team has agreed to follow. It contains rules that deal with attendance of team meetings, how meetings will be conducted, and task responsibilities. The entire SPLAT code of conduct can be found in Appendix A.

2.2 Team Procedures and WBS

The team procedure is how the team is going to complete the project. It deals with the means of file sharing and how the tasks are going to be divided and completed. It is similar to the code of conduct in that it lays out the groundwork for team communication, but it deals more with the details of the documentation and design of the project than the behavioral aspects that the code of conduct dealt with. This complete document can be found in Appendix B. Deciding what aspects of the design were necessary to any concept helped to complete this document. This included the means of adhesion, motion initiation, the control of the platform, and other similar characteristics that the design must incorporate. A Work Breakdown Structure (WBS) is a document that lists these same necessary characteristics in a design tree format. It can also be found in Appendix B.

3.0 DESIGN APPROACH

3.1 Background Research

After learning more about the team members and setting the guidelines for how the team was to act and perform, it was time to begin on the actual design process. The first step was to begin gathering information on platforms that already existed to see what concepts work, and if similar ones could be adapted to solve the specific problem. Mr. Jeff Wagener sent a brief PowerPoint presentation with a few design concepts that he had found when he was initially given this assignment. Figures 1 and 2 show two concepts he had found and both were looked at more closely to see the advantages or disadvantages of each.

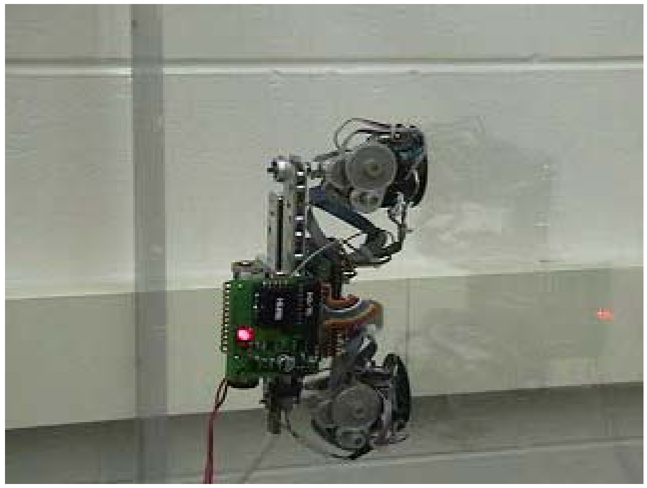


Figure 1- Michigan State “Crawler” Robot

The “Crawler” robot above was designed at Michigan State University and met many of the specifications that were given by Eglin Air Force Base. It is less than 6” in size, it can climb 5’, and it can remain on the wall an extended period of time. Some disadvantages to this robot are the way it climbs the wall and the means of adhesion. It inches its way up the vertical surface by extending or contracting one of the suction cups. This is undesirable because it takes large amounts of time to move not so large distances. The method of adhesion, suction cups, is also a disadvantage because a smooth surface is needed to generate the suction. The “Crawler” would not be able to scale porous materials, some of which are found as common surfaces, i.e. brick. Another major disadvantage to this robot is that it cannot transition from a horizontal surface to a vertical one. It has to be placed on the vertical surface in order to travel vertically.

The second existing platform that was looked at closely is shown in Figure 2. It uses a fan driven concept to attach itself to the vertical surface.

Figure 2- Fan Driven Wall Climbing Cart

An advantage to this platform is that it can be controlled either by radio control or digital control. The radio control means that it can be controlled from a remote location, and it has the ability to change direction at the will of the operator. The digital control means that it can be set to move on a given path. Since this platform does not use suction, it has greater versatility as to what surfaces it can be used on. As can be seen from the picture, it is able to maneuver on a brick wall unlike the "Crawler" in Figure 1. A disadvantage of this design is that it needs a large amount of power if it is to be used for an extended period of time, but since it is driven much like an RC car, it can travel large distances in a short amount of time.

3.2 Design Idea Generation

After initial research was done on existing platforms, two of which are described above, the team set a meeting to generate ideas on a platform that would meet all the requirements set forth by Eglin Air Force Base. Initially, no concepts were thrown out, and any concept voiced was taken into consideration. Some ideas that came up were: an electromagnetic robot that would climb the wall through the use of electricity and magnets, a driller robot that drilled into the surface of the wall, a suction car that had suction cups around the tires, a fan driven cart, a robot that used an adhesive substance to adhere to the wall, a robot that secreted an adhesive substance out of a tank as it was needed, and a suction robot that swiveled around the suction cups.

3.2.1 Necessary Components

The team realized that certain aspects of the project were universal to all the design concepts generated. Mainly, they were that the platform had to be able to move, that it had to have some form of adhesion, and that it had to have some means by which it could be controlled. From these three main features of any design, a first screening of all the ideas was done. The aspects of the power needed and the body of the robot were not as important because an off-board power supply could be used and a body could be built and adapted to whichever design was agreed upon.

3.2.1.1 Motion

The first major characteristic of any design would be that it had to be able to maneuver both on horizontal and vertical surfaces. It could have wheels, tracks, robotic legs, or pivot points that the body would pivot about in order to move. By looking at all the designs, the team felt that every concept could be adapted rather easily to one of these means of mobility. The next step would then be to how to initiate the motion, i.e. how to make the wheels spin, or the legs to walk. From the size constraints, an engine would not be feasible, so electric motors were deemed the most suitable. With the vast range of sizes and outputs available, the motors could be easily adapted to any of the concepts.

3.2.1.2 Adhesion

The second major and most crucial characteristic of any of the designs is the means of adhesion to the vertical surface. Without a means of staying attached to the vertical surface, success in the project was not possible. From the range of ideas, the means of adhesion ranged from magnetic, destructive, an adhesive substance, and suction, to airflow. The problem with using magnets is that not all common surfaces are made of magnetic materials. If the platform used magnets, it would only be useful on a limited range of surfaces. A destructive method could destroy the surface completely. For example, if a glass wall was used, the glass may form spider-web cracks and shatter with the next step. An adhesive substance could be used on a wide range of surfaces, but the problem with this is that if a layer was put over a track/tread, the adhesive substance could get dirty and would lose its adhesiveness. This limits the platforms use to clean surfaces. If the adhesive substance was continually secreted, the problem of losing the adhesiveness would be resolved, but the problems of storing the substance and running out of the substance arise. For these reasons the electromagnetic concept, the driller robot, and the adhesive substance concepts fell behind the suction and airflow concepts. This does not mean the suction and airflow concepts are without fault, but overall they would be the most versatile. The suction would need a rather smooth surface, but many common wall surfaces are smooth, and the fan driven concept could work on a vast range of surfaces.

3.2.1.3 Control

The control of the platform was the third major characteristic that needed to be considered because without a way to control it, it would be useless. Three means of control were considered: remote, radio, and digital. Remote was the least favored because it needs to have a tether from the operator to the platform. This limits the use and the range of the platform. Radio was favored because it is simple to implement and can be used over a large distance. Digital control could also be used over a large distance, but it requires the technical knowledge of programming so the operation of the platform would be more difficult to learn. Operators would have to be trained if it was digital control whereas a wide range of people could pick up radio control rather easily. For these reasons, and the fact that it could be implemented on any design concept, radio control was the final choice of the team.

3.2.2 Three Preferred Design Concepts

Looking at the three major characteristics of any concept and doing an initial screening limited the choice of concepts to three possible candidates for a final design. They were the fan driven cart, the suction robot that swiveled, and the suction car. These concepts were evaluated more closely to see which design would be the best. Each concept was taken, in turn, and an explanation was written to provide information on how each one would work, and the advantages and disadvantages of each were recorded.

3.2.2.1 Concept 1: Fan Driven Cart

The main idea of this design was to utilize a type of fan, or impeller, to pull air from the underside of the cart, and blow it out the top of the cart. The thrust generated would be the main force acting to keep the cart on the wall. The thrust would be large enough to create a frictional force between the tires and the vertical surfaces in order to not only keep the cart on the wall, but to maneuver on the wall as well.   The fan would have to be placed close enough to the wall to use as much pulling force as possible as the air is sucked in but far enough from the wall to maintain sufficient airflow. A skirt could be used to direct air into the fan optimizing the airflow if needed. Figure 3 is the initial sketches of the design.

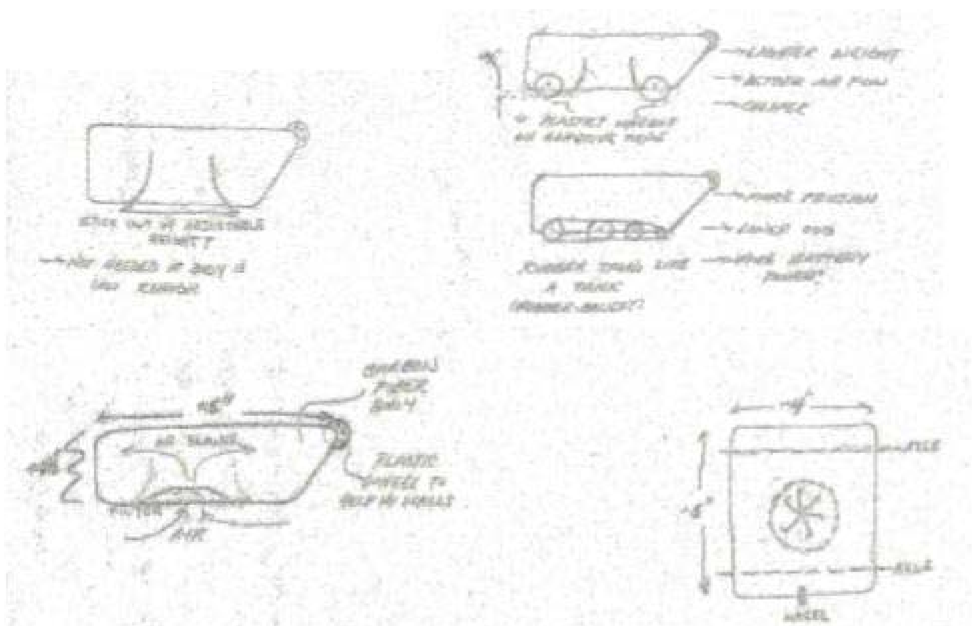


Figure 3- Initial Design Sketches for Fan Driven Concept

This design could be adapted to meet all the necessary specifications. It could be kept with a 6" cube, it could transition from a horizontal surface to a vertical one, it could climb 5', and it could remain on the wall for 30 minutes.

The design would need a strong enough fan and motor combination, plus other motors to drive the cart. The entire cart could be operated via remote control, and a track could be put around the tires to provide the cart with a large contact area for friction.

The advantages of this design concept are:

- Similar designs have already been proven to work
- It will operate similar to an RC car, thus, it will be mobile and fast
- The small scale will not be an issue
- RC components mean no computer programming
- All the necessary components can be fit inside the housing
- Turning the fan in the opposite direction can create hover-like properties

The disadvantages of this design concept are:

- The fan must be operating at all times in order for the cart to remain on the wall. This leads to large amounts of power consumption.
- A filtration system might have to be used to keep dust and debris out of the housing
- The body and housing will have to be a lightweight material

3.2.2.2 Concept 2: Suction Robot

The suction robot is based on the concept of suction cups as the means of adhering to the vertical surface. Figure 4 is the initial sketches of this concept.

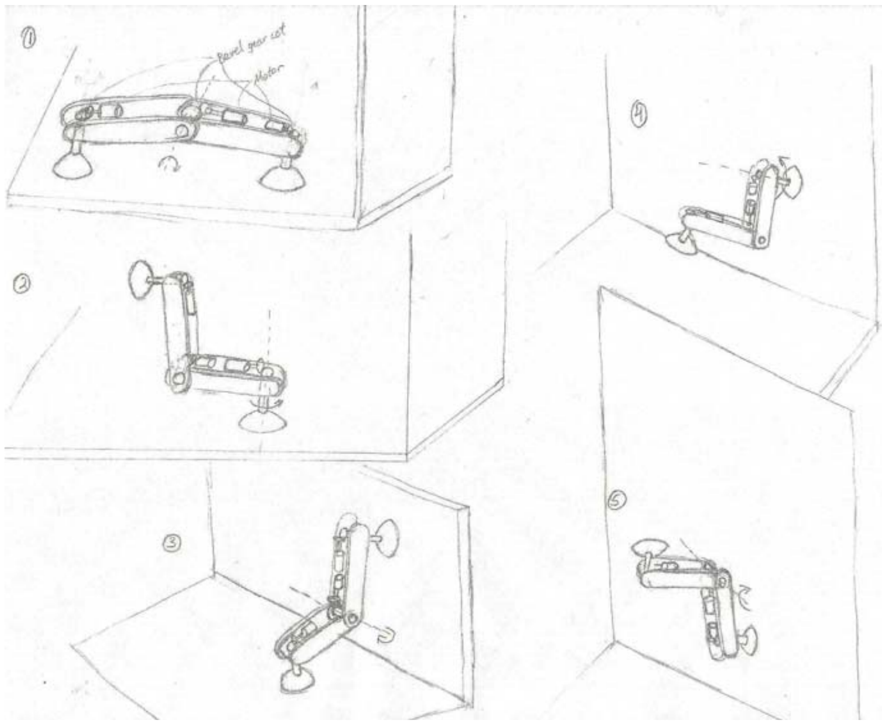


Figure 4- Initial Design Sketches for Suction Robot Concept

The two suction cups would generate the force necessary for the robot to remain on the wall. To travel to the wall on the horizontal surface, the robot would walk by alternately rotating about the two suction cups. One suction cup would be activated to give the necessary stability, and the rest of the robot would pivot about this suction cup driven by an electric motor. The second suction cup would then be activated and the first released, and the body would again pivot around the activated suction cup. This would continue until the robot reached the wall. The transition would be made by pivoting around a third axis that is situated through the center of the body. This axis would allow one suction cup to raise 90^o and become perpendicular to the wall. This suction cup would be activated and the body would again pivot around the activated suction cup to begin its ascent of the wall. This transition process is depicted in the sketches of Figure 4. Once the robot is on the wall, it scales the wall in the same manner as it moves on the horizontal surface.

The advantages to this design concept are:

- Versatile: the nature of the robot will allow for more than just the transition from floor to wall. It will be able to transition around corners and from wall to roof if necessary.
- Suction will allow the robot to remain on the wall for extended periods of time without consuming large amounts of power
- Mobility in the horizontal and vertical planes will be identical

The disadvantages of this design concept are:

- Due to size, the time to move large distances will be large
- The moments generated by rotations about suction cup axes may cause leaks in the suction seal and cause loss of suction.
- Smooth surfaces are necessary for suction
- Operation may be tedious
- May not have enough surface area on the body to place all necessary components

3.2.2.3 Concept 3: Suction Car

The suction car, as the name implies, is also based on suction. In this design small suction cups are placed on the surface of the car's tires. The suction cups operate one row at a time when they come into proper alignment. Alignment occurs by channeling the suction from the vacuum, through a tube, into the hollow wheel axles, up through the hollow chambers in the wheel, and out the suction cups. The openings in the axles will always be oriented towards the wall by putting bearings on the axle to keep it free from the wheels and the frame. The axle would be weighted on the bottom to assure that the opening for the vacuum is always facing the wall; therefore, always having the suction activated for the row of suction cups facing the wall. The vacuum pump would constantly be running and vacuuming the air from between the cups and the wall. Figure 5 is the initial sketch for this concept.

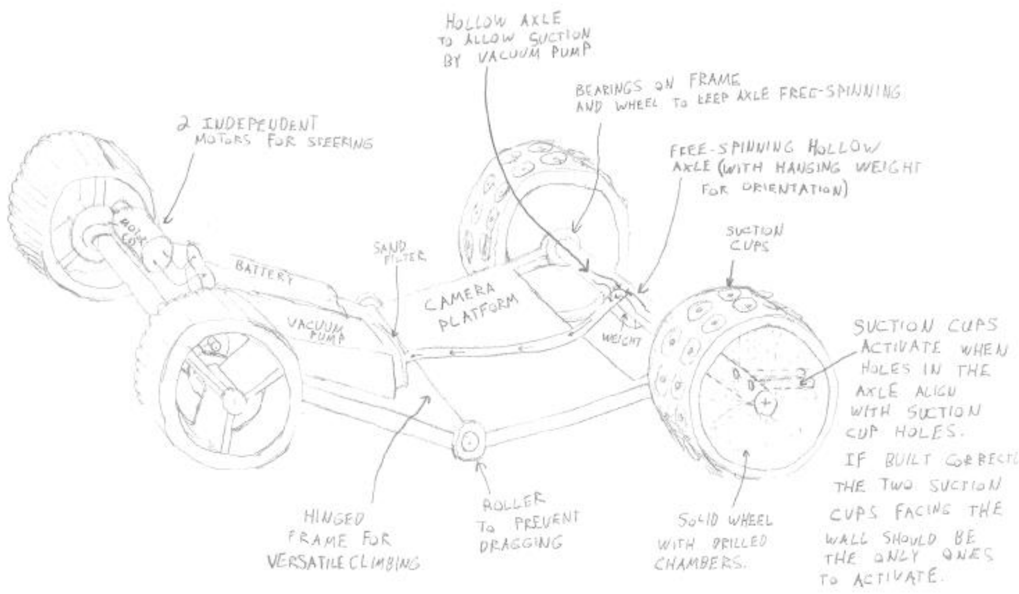


Figure 5- Initial Design Sketch for Suction Car Concept

The car also has a hinge in the center, as can be seen from Figure 5. This is to allow for the transition from the horizontal to vertical surface. Also seen in Figure 5 is that the front tires have suction cups, but if needed, the rear tires could be equipped with them as well. The car is then driven by electric motors and all the components are placed on the frame of the small vehicle.

The advantages of this design concept are:

- Operation will be quick
- Maneuverable; can transition quickly
- Simple to control once everything is working
- Suction timing is mechanized to alleviate the need for complicated valve timing programming

The disadvantages of this design concept are:

- On a small scale, the suction cups may be too small to operate efficiently
- Power consumption will be large if needed to stay stationary because vacuum pump is constantly working
- Many components, would be difficult to fabricate and could be heavy

- Smooth surfaces are necessary for suction

3.3 Design Selection

Once the three main design concepts were each, in turn, looked over and analyzed, a decision on which concept would become the final design concept had to be made. In order to do this, a decision matrix was used to aide in the decision making process, alleviating some of the subjectivity that may arise. The design matrix consisted of six different factors that were felt necessary to consider in the design: cost, size, ease of assembly, ease of operation, power consumption/speed, and mobility. Each category was then assigned a numerical weighting factor, which measured its relative importance. The sum of the weighting factors was made to equal a value of one. Table 1 shows the numerical weighting factors along with the entire decision matrix.

Table 1- Decision Matrix

Concept	**Cost**	**Size**	**Ease of Assembly**	**Ease of Operation**	**Power Consumption/Speed**	**Mobility**	**Total**	
	0.175	0.225	0.125	0.1	0.15	0.225		Weighting Factor
Fan Driven cart	7	8	6	7	4	7	**6.65**	
	1.225	1.8	0.75	0.7	0.6	1.575		
Suction Robot	5	7	5	5	6	8	**6.275**	
	0.875	1.575	0.625	0.5	0.9	1.8		
Suction Car	3	5	4	7	4	7	**5.025**	
	0.525	1.125	0.5	0.7	0.6	1.575		

From the specifications given by the sponsor, size and mobility were at the top of the list in order of relative importance. Both categories carry a weighting factor of 0.225. Cost is the next category, and has been given a weighting factor of 0.175. Cost includes the materials, manufacturing, and testing. The higher the rank is, the more cost efficient the design is. It is not as important as size and mobility because in order to meet the size requirements the cost could become rather large. However, it was felt that the importance of maintaining low costs was still critical in the design process. Power consumption and speed was assigned a weighting factor of 0.15. The specifications for the design call for a platform being able to translate on a vertical surface a minimum distance of 5’ and hold that position for 30 minutes. If the design requires constant power to remain attached to the wall, it is important to consider. By the same token, the slower a platform moves the more power it will consume. Ease of assembly has a weighting factor of 0.125. This category is a measurement of how easy the design will hold all the necessary components. Also, a design that will be difficult and time consuming to assemble was not wanted because of the tight work schedule. The category of least importance among the six is ease of operation, which was assigned a weighting factor of 0.1. Will this design be “user friendly”? Will it take a long time to learn how to use it properly? These are some questions that were asked when ranking in this category.

Each design occupies a row in the matrix. The body of the matrix was then filled with numbers that rank each aspect of the design on a scale from 1 to 10, with 10 being the best. This ranking was then multiplied by the designated weighting factor. The sum of the resulting values for each design was taken and the design with the highest score was, in theory, the “best” design.

The fan driven design was the first one examined. It was given a 7 for cost because it is a rather simple design compared to the other two and won’t need as many special components. Size was given a high ranking of 8 because it would not be an issue to scale this design down to specifications. Ease of assembly was ranked at 6. This design should be able to hold all necessary components within the housing. Ease of operation would be fairly easy and was ranked at 7. It would have the operation similar to that of a RC car. Power consumption was low for the blower ranked at 4. For the 30-minute time period when it is to remain stationary on the wall, the fan will have to run at full speed the entire time. Finally, mobility was given a 7 because it would move similar to an RC car: quick and simple to control. It is not given a very high ranking in this category because it will not be able to go around corners, or onto a rooftop. The final score for the blower is 6.65.

The next design evaluated was the suction robot. A 5 was given in the cost category because the design is not as simple as the fan design and will call for special components. Size will not be much of a problem here and was given a rank of 7. Ease of assembly and operation was given a 5 because the design may not have enough surface area to hold all the necessary components, and may be a bit tedious to fabricate. Power consumption will be the best out of the three designs mainly because it will not require constant power to remain stationary on the wall for 30 minutes, yet the time to move large distances will be large due to size. It was given a rank of 6 in this category. Mobility is this design's strong point because of the ability to transition from floor to wall, wall to roof, and around corners; thus, an 8 was assigned for the category of mobility. The final score for the suction robot was 6.275.

The last design to look at is the suction car. Cost was scored a 3 mainly because all of the special components and special machining required in meeting the tight tolerances. Size was scored a 5 because it would be rather difficult to scale this design to the specified size. It would be a favorable design if the size requirement were not so restricting. Ease of assembly was rather low also with a rank of 4 simply because of the many components required and because each suction cup must be "perfectly" placed to get good suction. Ease of operation would be rather good with a rank of 7 because it would also work similar to that of an RC car. Power consumption was assigned a rank of 4 because of the constant power needed in order for it to remain on the wall for 30 minutes. This design is rather mobile because it would be able to negotiate corners and translate from floor to wall easily, and therefore was given a rank of 7. The final score for the suction car was 5.025.

According to the above criteria, and the manner in which each design was scored the fan driven cart concept was the best design out of the three. After the final selection was made the time and energy of the group focused on improving all aspects of this design in order to produce a working prototype.

4.0 DESIGN SUBSYSTEMS

After the final decision was made for which concept would be pursued, the team set the necessary components that would be needed in order to complete the design. For the primary function of the platform, a ducted fan or other type of impeller will needed. Wheels and motors would be necessary parts for the movement. The control would consist of a multi-channel radio transmitter and receiver. Fiberglass or carbon fiber would be ideal materials to use for the body. Parts such as axles, wires, fasteners, tread, adhesives, and gearing are some miscellaneous components that may or may not be essential for the design

4.1 Parts for Primary Function: Ducted Fan

A ducted fan includes a motor, propeller, and duct for channeling air. It is ideal for testing. If successful thrust is achieved, it will be used in the final design as well. The Wattage Powerfan 400/6 EDF Unit was bought. The cost of the fan was $43.74, and a picture of the fan is in Figure 6.

Figure 6- Wattage Powerfan 400/6 EDF Unit with 400f motor

The Wattage Powerfan 400/6 EDF unit includes:

Propeller: Although several sizes and shapes are being tested, the propeller used in both the testing and design comes with the ducted fan. It is 3 inches in diameter.

Air Duct: Dimensions are 3.1 inches in diameter and 1 inch tall. This air duct should help channel the air, increasing efficiency of thrust.

400f Motor: When operating at 10 Volt and 9 amps, the motor can provide the fan with 9.5 ounces of thrust at 20,700 RPM.

4.2 Movement

Two motors, each fixed to a rear wheel will initiate the movement. Independently driven motors will allow for steering. Motors will be directly coupled to axles, unless speed and/or power deem it necessary to add gearboxes to increase torque or reduce speed. Figure 7 shows an initial body design showing possible placement for the motors.

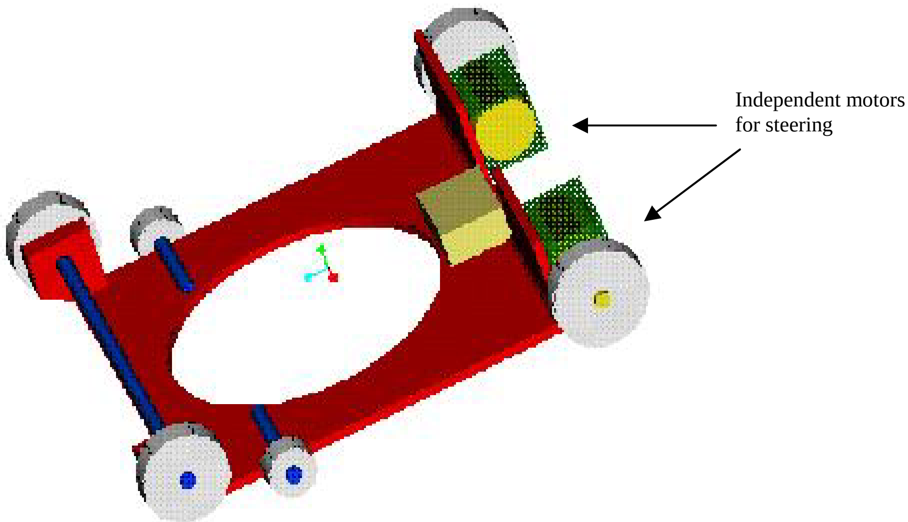


Figure 7- Initial Body Design for testing

Wheels: Made of an extremely lightweight foam material. Six will be used. The wheels can be seen in Figure 8 along with an electric motor that may be used.

Motors: Relatively low-powered compared to the blower motor. Must produce enough torque however to drive the machine up the wall. Testing will help determine the weight of the device, which will aid in selecting exact motors needed to produce the desired output.

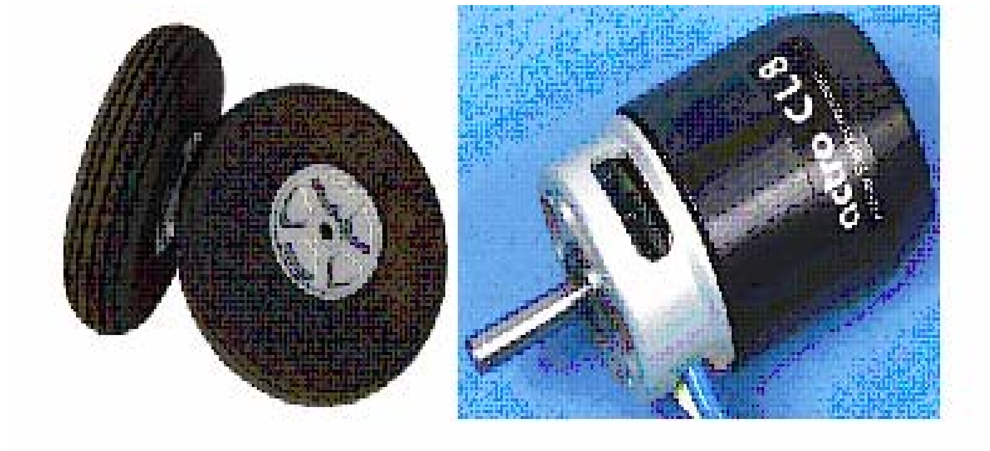


Figure 8- Foam wheels (left) and brushless DC motor (right)

4.3 Control

There are 3 known parts on the fan driven cart that need to be controlled: the fan and each driving motor. More parts may be added, however, in case a steering system, brake system, or adhesion device is necessary. The HiTec Laser 6 was bought for the project. It was purchased for $134.99, and comes with 4 servos, an 8-channel receiver, and a NiCad battery power supply with charger.

Figure 9- The HiTec Laser 6 remote control, 6 channel, 4-422 FM / 72MHz transmitter

Transmitter: HiTec Laser 6 contains 6 channels, and is a 4-422 FM / 72 MHz transmitter. It is capable of Elevon and V-tail mixing, which allow for more freedom when assigning controls. The mixing allows for two motors to be run from one joystick.

Receiver: Supreme 8-channel receiver; included with the transmitter.

Servos: (4) HS-325 servos, may be used on braking, adhesion, or other possible subsystems. It is also included with transmitter.

Speed Controller: Adjusts current based on transmitted input from the RC transmitter. Three will be used for the motors, each capable of carrying 30A. The cost is $39.99 each and the following is a photograph of the speed control:

Figure 10- 30 Amp Speed Control

4.4 Body

The necessary materials for the body will be foam and fiberglass initially. A mold of the body will be made with the foam, and the body formed using the fiberglass. Fiberglass was chosen because it is lightweight and durable. The final product may be made of carbon fiber if it is obtainable.

4.5 Miscellaneous

These parts are not necessary or cannot be determined at this stage of the project. Several components' designs are based on testing results, and the rest are not significant until a later date. These include the following:

Axles: The important decision is the material selection. This will be done based on the weight of the car and the forces generated by the motors. All other dimensions will be dependant on those of the car.

Wires: Will be needed to connect the power supply to the speed control, and from the speed control to the motors. Also, they will be needed to connect the power supply to the servos.

Fasteners: May be used to mount and stabilize the driving motors. Other parts will be either screwed into the body, or glued.

Figure 11- Clamps for mounting and fastening motors'

Tread: In case friction between the wheels and the vertical surface is not sufficient, treads similar to a tank's (Figure 14) may be added to increase surface area, thereby increasing friction and preventing sliding. This will only be added if necessary; otherwise it will be left out to minimize weight.

Figure 12- Example of tank treads

Adhesive: To reduce or eliminate the need to use fan power when stationary on the vertical surface, a servo with an adhesive may be used to attach an arm semi-permanently to the wall. An adhesive may also be used on the wheels to increase friction between the car and the wall to prevent sliding.

Gearing system: If the driving motors run too fast or do not have enough power to drive the car up the wall, gearboxes will be added to gear down the motors. This may also help reduce the car's tendency to free roll.

5.0 PROPOSED TESTING

5.1 Preliminary Components

The most important component of this design is that of the air turbine, and thus must also be the most thoroughly tested. However, the turbine cannot run by itself. For the initial testing stages an electric motor will also be needed to spin the turbine, as well as a power source to supply electricity to the entire system. With these basic components, data can be collected that will show what will be necessary for the design to work, as well as any modifications or adjustments that may be necessary.

Although the general principle of an air turbine is the same for all designs, many variations can be chosen for this concept. For this reason different styles for the air turbine will be tested to determine which one will provide the most thrust/suction to keep the cart from coming off the wall. A closed impeller obtained from a broken vacuum cleaner, at no cost, is shown in Figure 13.

Figure 13- Impeller from handheld vacuum cleaner

A closed impeller operates on the principle of a pressure differential and might prove to be a more efficient design. The only drawback for this turbine is that the outer diameter is only 2". This will most likely not provide enough thrust to be the actual impeller used for the cart, but it will show a good comparison between the performances of the closed vs. the open impeller design. A coupling to the motor shaft will need to be fabricated or purchased in order to start testing this impeller.

A ducted fan was purchased from Hobbytown USA after finding a design that seemed to be the best fit for the size and weight constraints placed on the project. The fan chosen was a 3.1" outer diameter ducted fan at a price of $43.74. This fan is shown above in Figure 6. A ducted fan was chosen over other propellers because a channel for the air flow will be needed in either case. For this reason a ducted fan could be used, or a similar shape could be formed through the body with the turbine in the middle. However the tolerances are already set for the ducted fan, and thus do not needed to be taken into account; misalignment will not be a problem between the blade tips and housing. A DC motor (frame size 400) was also included to turn the air turbine. However, only testing will show the true performance for the motor and turbine drive.

To allow for full control of the motor RPM's and polarity a controller must also be used. This was also purchased from Hobbytown USA based on the voltage and current specifications on the motor. The DC motor that was bought with the air turbine uses 12 Amps at peak RPM. For this reason a speed control (basically a PID or Lead-Lag controller) that could handle this current output was needed to assure that the controller does not burn up and short from overload. For this reason a 30 amp speed control was bought. It is shown in Figure 10.

Due to the high price of efficient batteries it was decided that an external power source would be used in order to complete the initial testing. This will be composed of a function generator, DC Power source, and all of the necessary attachments. These can be provided from the school at no cost. This will greatly improve the efficiency and amount of data that is collected. Not only can the output voltage be adjusted and monitored in order to find an RPM vs. Voltage curve, but also no recharging time will be necessary for the setup as would come with a battery pack. Once a better idea of the amount of power needed is obtained, a suitable battery source (Lithium Polymer to reduce weight is one option) may be purchased to use for the final design.

Once the preliminary tests for the air turbine drive alone have been completed, it will then be tested in a mock body to find the payload capabilities. A fiberglass platform will be made using a patterned cloth and epoxy resin formed over a mold. A few different shapes and sizes for the body will be made to find out which design works the best, and any changes that are needed for the final product.

5.2 Testing and Analysis

The first aspect that must be found is the thrust characteristics of each impeller. For a general comparison between the two designs a test to show which one works the best will be done. This will be found using a basic setup with weights first (Figure 14), then a spring if necessary. The electric motor and turbine will be attached to a rolling platform. This will most likely be a rectangular piece of plastic that the impellers will be bolted onto to hold the drive in place. A string will then be attached to the platform, and hung over the side of a table on a small pulley with a hanging mass setup at the end. Once each motor is turned on, masses will be added to the end of the string to find how much thrust/horizontal force the turbine is providing. This data will be found on a range from 3 to 12 volts for each blower design.

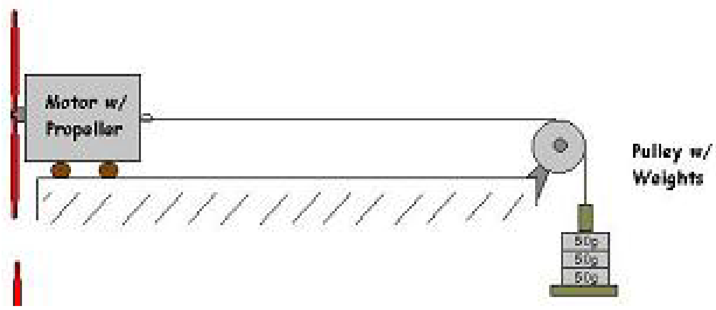


Figure 14- Testing rig for thrust using a pulley and weights

In order to verify the results, another test using the same platform setup could be attached to a fixed spring. In this case the power source will be used in the same fashion and range, and the turbine that stretches the spring the farthest is providing the most thrust. If a spring constant can be obtained, the force could also be found using the spring's elongation (F=kx).

If it is found that the closed impeller design seems to work better, another will be purchased with a larger radius to give more thrust. If necessary a plastic drive shaft could also be made to minimize the overall weight as much as possible.

Once the best turbine design is chosen from initial testing the actual thrust will be determined. Eglin Air Force Base has the available equipment, and has already given their permission for testing to be done there. The setup for a power supply is similar to the spring and hanging mass previously discussed. The motor and turbine are mounted with a thin wire attached to a dynamometer, which is hooked into a computer. When the motor is started, the turbine pulls on the wire and that force is then recorded and shown on the computer monitor. Although this data will be useful for calculations that may be necessary, testing the actual body to make sure it works will be much more useful, and more emphasis will be put in this direction.

The next step in testing will be to put the body and turbine drive system together with the speed control and test the entire setup. The same power source will still be used for this phase of testing until a maximum weight available for the batteries is found. The cart will be placed on a variety of surfaces to find out which one will be the easiest to use. If the cart cannot hold up its own weight while in the vertical position, a maximum angle will be found instead. A sheet of plywood or other available materials will be used to do this. The motor will be turned on, and then one side of the sheet will be lifted until the cart begins to slide down. An idea of how close the design is can be taken from this experiment, and any changes that must be made (i.e. the turbine will not provide the thrust needed) to any of the components used will also become evident. Both air blowers will also be used for this test to verify all results from the previous testing. This procedure will be repeated until a design is found that works.

Once the cart can stay stationary on a vertical surface other calculations will be needed. A minimum voltage and current necessary can be recorded, to get the power needed from the batteries to be used for the final design. This information will also help with calculations to estimate, if batteries are used, how long the cart can be used before recharging is necessary. A maximum payload is needed as well. A string with the hanging mass setup will be attached to the cart, and weights will be added until it can no longer hold itself on a vertical wall. Payloads on a range of voltages (from the minimum necessary to 12V) will be recorded and used for calculations. This maximum payload shows how much weight can be used for the rest of the necessary components such as the other motors, wheels, battery pack, etc.

After the tests have been completed, it will be known which characteristics of the design work or need improving. New material will be purchased and tested if necessary, and the building of the final prototype will begin. Once the prototype is complete, a demonstration for Eglin Air Force Base will be performed.

6.0 Conclusion

The first steps taken to complete the task of designing a platform that can maneuver both on horizontal and vertical surfaces did not deal with any design at all. They were to determine the team dynamics and behavior. This was done to save time during the design process. The two documents that dealt with these two subjects were the Code of Conduct (Appendix A) and the Team Procedures (Appendix B). If problems or questions arose between team members throughout the design process, these documents could be referenced quickly to clear up any misunderstandings.

To start the actual design on the SPLAT, background research was done to gain insight from existing products and robots that performed similar functions. The research included different methods of adhesion, different sizes, and different body types that could be used for a new platform. Ideas were then generated as to how the design would work and perform its function. The ideas ranged from magnets and drilling, to suction, adhesive substances, and impeller thrust. To narrow the number of concepts down, the necessary components for any design were laid out and each concept was evaluated on how easily and effectively these components could be integrated into the overall design. There were three necessary components that were looked at: motion, adhesion, and control. Motion deals with how the platform will maneuver on both horizontal and vertical surfaces and how the platform will transition between the two. Adhesion deals with how the platform will attach to the wall and how effective that means would be. Control is how the platform will be setup to do what the operator wants it to do.

After looking at the three necessary components and evaluating each design, three concepts remained. They were a fan driven cart, a suction robot, and a suction car. These three concepts were analyzed further to determine which design would be the one that would be pursued further. A design matrix was utilized and the best design was the fan driven cart. When the decision was made to focus on this concept, the components that were necessary for this design were laid out. A purchase order was then submitted to obtain the initial components so testing could begin. The initial components were a ducted fan, a radio control transmitter and receiver package, and a speed control to control the fan.

While waiting for the initial parts to come in, the actual tests that would be run were designed. The first test is to determine the amount of thrust the fan can deliver at different power settings. This is to determine if the fan can provide sufficient thrust and also to test the power consumption when the fan is running at that thrust. The next test is to determine the maximum amount of payload that the cart can hold while in a vertical position at the different power settings. This is to determine how much all the components on the cart can weigh. When these tests are completed, it will be known if a larger fan will be needed and how much the final design will have to weigh. From this point the final packaging of the design will be done and a final prototype built.

Appendix A: Code of Conduct

The SPLAT Code of Conduct is the document that set the rules and guidelines for team behavior. It is to minimize or alleviate problems within the group so all time and energy can be focused on designing a successful product. The Code of Conduct is as follows:

- Attendance: If a meeting is called, every one is there unless a valid excuse is given beforehand. Call in advance if meeting cannot be attended.
- Punctuality: Meetings times should be kept, unless valid excuse is given. Call in advance if one will be late.
- Decision Making: If conflict arises, each will have his side heard. The group will then decide. Each side will have his chance to voice opinion, research done on topic, and pros and cons. If decision can't be made, group will ask for outside advice.
- If task is assigned, it will be completed by time agreed, unless complications arise and group is notified.
- Task responsibility will be assigned when tasks arise. i.e. Maybe one or two members will work on a task, and the others will check.
- If problems arise within the group, they will be voiced as soon as possible in a constructive manner. They will then be dealt with quickly and efficiently.
- If a member is feeling too overwhelmed, they can ask others for help. Others will try to be as accommodating as possible.
- Problems will not sit and grow. Not with the group and not with a task.
- Contact with Jeff Wagener will be frequent and constant. Email updates, conference calls as necessary.
- Everyone will have copy of work, and have general understanding of work done by other group members.
- Contact outside of meetings will be dealt with efficiently. Responses to emails and phone calls should be dealt with as soon as possible.
- When meetings are called, all members will be prepared to inform the others about work done.

- If a member is being a delinquent, other group members will try to resolve the problems with that member first before other actions are taken.

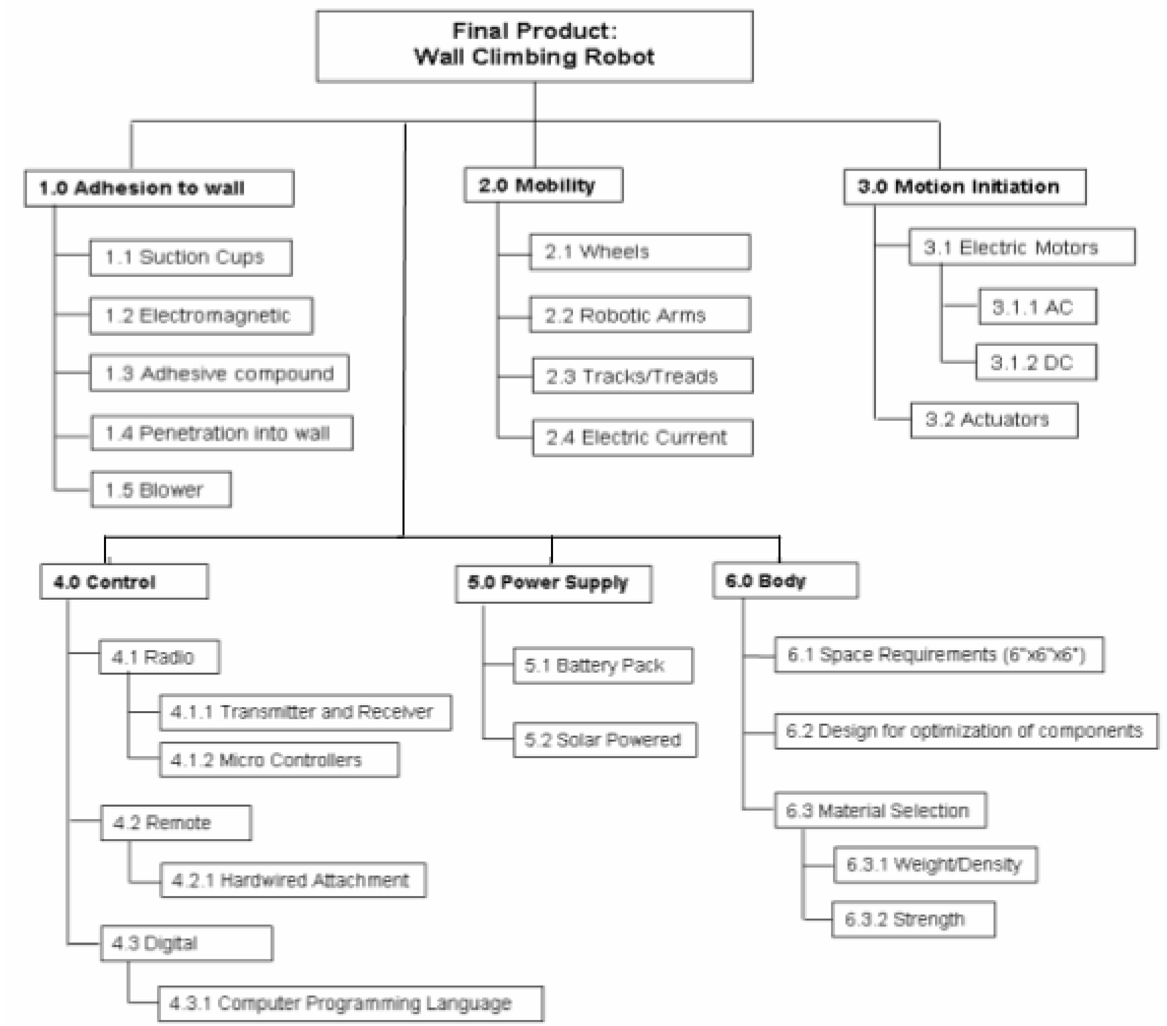
Appendix B: Team Procedures and WBS

The SPLAT Team Procedure is a document that briefly explains how the project is to be completed. It is similar to the Code of Conduct, but the Team Procedure deals more with the issues of task assignment and completion. To help in writing this document, a Work Breakdown Structure (WBS) was created. This is a tree diagram that lays out the necessary subsystems for the design and components that may be utilized. This was done to assign team members different tasks. The Team Procedure is as follows:

> Each main heading in the WBS will be assigned to a certain group member or members to be completed. The person(s) will be responsible for researching background information and designing the subsystem that deals with that particular subject. Each assignment will have to be designed to fit with all other subsystems, so constant meetings and communication will be vital to the success of the project.
>
> The tools needed to accomplish the design will be a mathematics software package such as Mathcad, a 3-D modeling package, ProEngineer, and a machine shop in order to manufacture the components that cannot be bought. An FEM package such as ALGOR may also be utilized if a thorough stress analysis is needed.   If a component is to be made, a full analysis of that part must be completed before it is machined. Mathcad can be used to perform all calculations and then ProEngineer can be used to model the component. If the component is to be bought, research must be done on different types of components that will accomplish the task, and the decision to buy which one will take into account but is not limited to: cost, size, weight, etc. The decision must also take into account the fitting of the purchased component into the overall design. The option of making the component may be possible if it can be done cheaply and effectively.
>
> Whichever member is assigned a certain task, that member will become the team "expert" on that aspect of the design. This does not mean that he cannot ask for help. If he runs into a problem, it is necessary for him to seek help quickly. He cannot spend a significant amount of time on a particular problem

because of the time constraints in place. He can seek help from the team, the sponsor, or any person that he feels will offer valuable advice. When a task is completed, the calculations and design will be checked by other team members and then each member will be given a copy of the necessary documents. This is assure that they do not get lost and for quick reference if any of the team needs them. It is also important for the team members to be in constant contact with each other even when there are not pressing problems with the design. This is to ensure that all aspects of the design will come together and produce one final working prototype. From this prototype, the sponsor will then decide if more time and effort will be placed in this type of design for later use.

The WBS is as follows:



Appendix C: Project Schedule

A project schedule was laid out to stay on task and meet all necessary deadlines. The project included in this appendix is general because the entire project would consist of many pages. The main tasks are listed, and the dates that they were to begin and end are also listed. It is to show how the project was laid out in terms of tasks and deliverables.

Table A. 1- Project Schedule

Task Name	Duration	Start Date	End Date
Group and Project Assignment	1 day	8/31/2004	8/31/2004
Research Exisiting Work	31 days	8/31/2004	10/1/2004
Weekly Team Meeting 1	1 day	9/3/2004	9/3/2004
Team Building Activity/Code of Conduct Due	1 day	9/9/2004	9/9/2004
Weekly Team Meeting 2	1 day	9/10/2004	9/10/2004
Project Scope Due	1 day	9/16/2004	9/16/2004
Weekly Team Meeting 3	1 day	9/17/2004	9/17/2004
1st Presentation	1 day	9/23/2004	9/23/2004
Concept Generation Due	21 days	9/23/2004	9/23/2004
Weekly Team Meeting 4	1 day	9/24/2004	9/24/2004
Needs Assessment/ Product Specification Due	1 day	9/30/2004	9/30/2004
Weekly Team Meeting 5	1 day	10/1/2004	10/1/2004
Product Procedures/Schedule Due	1 day	10/7/2004	10/7/2004
Weekly Team Meeting 6	1 day	10/8/2004	10/8/2004
Staff Meeting 1	1 day	10/12/2004	10/12/2004
Research Task	21 days	10/14/2004	11/4/2004
Concept Selection Due	1 day	10/14/2004	10/14/2004
Individual Task Assignment	1 day	10/14/2004	10/15/2004
Weekly Team Meeting 7	1 day	10/15/2004	10/15/2004
Meeting with Sponsor in Tallahassee	1 day	10/15/2004	10/15/2004
Progress Report Presentation 1	1 day	10/21/2004	10/21/2004
Weekly Team Meeting 8	1 day	10/22/2004	10/22/2004
Staff Meeting 2	1 day	10/26/2004	10/26/2004
Design/Analysis of Necessary Components	21 days	10/28/2004	11/18/2004
Weekly Team Meeting 9	1 day	10/29/2004	10/29/2004
Eglin Visit	1 day	10/31/2004	11/1/2004
Progress Report Presentation 2	1 day	11/4/2004	11/4/2004
Weekly Team Meeting 10	1 day	11/5/2004	11/5/2004
Staff Meeting 3	1 day	11/9/2004	11/9/2004
Weekly Team Meeting 11	1 day	11/12/2004	11/12/2004
Progress Report Presentation 3	1 day	11/18/2004	11/18/2004
Weekly Team Meeting 12	1 day	11/19/2004	11/19/2004
Work on Final Semester Presentation	8 days	11/21/2004	11/29/2004

Work on Final Design/Spring Proposal	10 days	11/22/2004	12/1/2004
Purchase Orders Submitted by this Date	1 day	11/24/2004	11/24/2004
Thanksgiving Break	4 days	11/25/2004	11/29/2004
Final Semester Presentation Due	1 day	11/30/2004	11/30/2004
Final Design Package/Spring Proposal Due	1 day	12/2/2004	12/2/2004
Weekly Team Meeting 14	1 day	12/3/2004	12/3/2004

Appendix D: Feasibility Calculations

After the fan driven cart concept was chosen, some feasibility calculations were done to determine if this design could actually be possible. They consisted of calculating the necessary thrust needed to keep the cart attached to the wall. Figure D.1 shows the free body diagram used for the calculations.

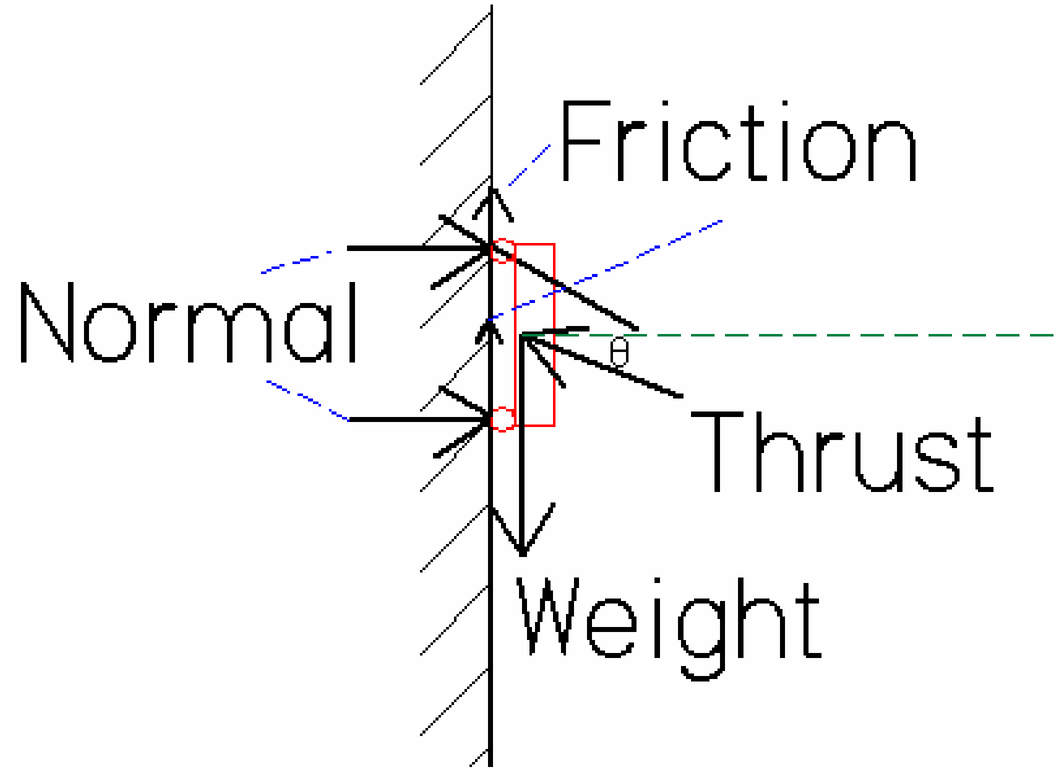


Figure D. 1- Free Body Diagram of the cart on the wall

First the thrust was calculated for the sum of the forces in both the horizontal and vertical directions. The weight of the cart was assumed to be 1 lbf, and the coefficient of friction was assumed to be 0.6. The angle θ was varied from 0^o to 90^o to determine the angle where the minimum thrust force occurred. It was found that the minimum thrust occurred at 59^o from the horizontal. This angle may or may not be optimum because it may not allow for enough normal force to maneuver on the wall. The optimum angle will be determined through testing.

Preliminary Assumption for Design:

$W_{car} := 1lbf$ $\mu := 0.6$ $m_{car} := \frac{W_{car}}{g}$ $m_{car} = 1\,lb$

$F_F = total\_frictional\_force$ $F_N = total\_normal\_force$

$F_F + F_{thrust} \cdot \sin(\theta) = W_{car}$ $F_N = F_{thrust} \cdot \cos(\theta)$ $F_F = \mu \cdot F_N$

$\mu \cdot F_N + F_{thrust} \cdot \sin(\theta) = W_{car}$

$\mu \cdot F_{thrust} \cdot \cos(\theta) + F_{thrust} \cdot \sin(\theta) = W_{car}$

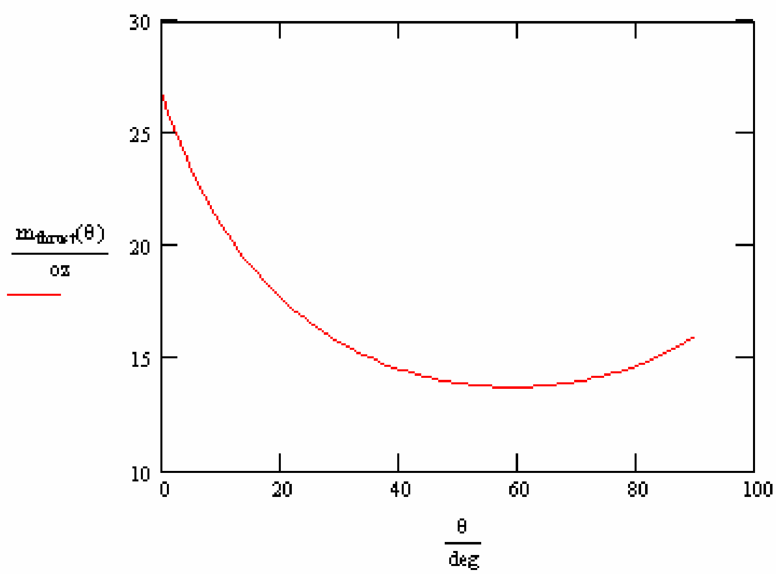
$$F_{thrust}(\theta) := \frac{W_{car}}{\mu \cdot \cos(\theta) + \sin(\theta)}$$

$\theta := 0deg, 1deg .. 90deg$

$$m_{thrust}(\theta) := \frac{F_{thrust}(\theta)}{g}$$

Minimum thrust occurs at 59deg from horizontal

$m_{thrust}(59deg) = 13.72\,oz$



The next calculations were for the moment the center of gravity (CG) created about the rear tires. If the thrust could not counteract this moment, the cart would tip about the rear tires and fall. The same assumptions were used for these calculations.

To counterbalance the moment from the offset CG

F_n = normal_force_on_upper_wheels

d_1 = distance_to_CG d_2 = distance_to_where_thrust_acts

$$F_n \cdot Wheelbase + W_{car} \cdot d_1 = F_{thrust} \cdot \cos(\theta) \cdot \frac{Wheelbase}{2} + F_{thrust} \cdot \sin(\theta) \cdot d_2$$

$$F_n = \frac{1}{2} \cdot F_{thrust} \cdot \cos(\theta)$$

$$F_{thrust} \cdot \cos(\theta) \cdot \frac{Wheelbase}{2} + W_{car} \cdot d_1 = F_{thrust} \cdot \cos(\theta) \cdot \frac{Wheelbase}{2} + F_{thrust} \cdot \sin(\theta) \cdot d_2$$

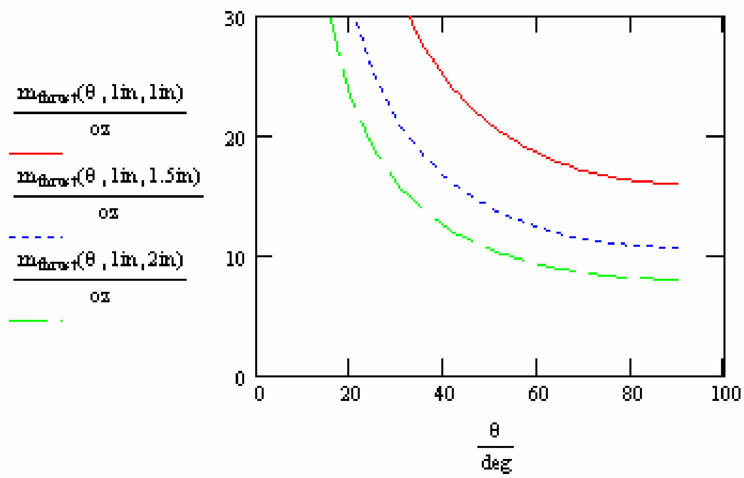
$$F_{thrust}(\theta, d_1, d_2) := \frac{W_{car} \cdot d_1}{\sin(\theta) \cdot d_2} \qquad m_{thrust}(\theta, d_1, d_2) := \frac{F_{thrust}(\theta, d_1, d_2)}{g}$$

$$m_{thrust}(60deg, 1in, 2in) = 9.238\ oz$$

$$\frac{9.238oz}{\sin(60deg)} = 10.667\ oz$$

$$13.72oz \cdot \sin(60deg) = 11.882\ oz$$

$$11.882oz > 10.771oz$$



From the graph above, it can be seen that as long as the thrust force acts at a distance that is twice the distance that the CG is from the wall, the thrust (acting at 60^o from the horizontal) will counteract the moment if it is strong enough to keep the cart from sliding. In other words, under these conditions, if the thrust is large enough to keep the cart from sliding, it will also be large enough to keep if from tipping. If the thrust is directed at less of an angle from the horizontal, more thrust will be needed to counteract the weight. Also, by looking at the values that resulted and researching fans and other impellers, it is possible to generate this thrust making the design feasible.

References

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The Robot Store, www.therobotstore.com

Wattage, http://watt-age.globalhobby.com/

Hitec, http://www.hitecrcd.com/