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The riveting helper

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THE RIVETING HELPER

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Technical Design Report

The Riveting Helper

Project #W02/S02

Final Report

Design Advisor: Prof. Blucher

Design Team

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May 29, 2002

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RIVETING HELPER

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Abstract

The project purpose is to design a device that allows one person to rivet large pieces of sheet metal. When riveting, the operator must hold both the riveting gun and the bucking bar at the correct distance from the work piece, with the forces in the axis of the rivet. Two people are needed if the work piece is too large for the operator to hold both the riveting gun and the bucking bar simultaneously. The Riveting Helper device will allow one person to rivet large pieces. This will be accomplished by having the Rivet Helper hold a bucking bar assembly in place while the riveter operates the riveting gun on the other side of the pieces being riveted. This device will be of practical size and accommodate rivet sizes between 1/16 in. and 5/32 in. The device will also notify the operator when to stop riveting based on the diameter of the rivet being used at a specific time. A prototype will be manufactured for a cost no greater than \$750 (see Appendix B). The Riveting Helper can be broken down into three major design components; the bucking bar holder, the frame or positioning system, and the base. Current design paths will be discussed, followed by a description of future considerations and experiments, which will lead us toward a design that satisfies the specified criteria.

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Acknowledgments

The rivet helper group would like to acknowledge Prof. Blucher for sharing his experience and wisdom of riveting.

Copyright

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“We the team members,

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CHAPTER 1 INTRODUCTION AND BACKGROUND

1.1 Introduction

The WWII image of Rosie the Riveter became a famous icon symbolizing the resilience, strength, and determination of women. However, few are familiar with Rosie's occupation, riveting. A rivet is a connecting part similar to a screw of a bolt. However, it has no threads. Riveting is a process in which a rivet shaft is passed through a hole in two or more pieces of metal, plastic, wood, or other material in order to join the pieces by deforming the shaft end of the rivet into a second head. Rivets are made out of plastics and many different metals including steel, aluminum, and copper. The riveting process has been applied to many industries such as, clothing, construction, and aerospace. Amazingly, riveting was observed in Inca Indian engineering designs as early as the 13th century, and the process is still widely used and appears to be far from becoming obsolete. The Rivet Helper project deals specifically with riveting using a pneumatic hammer and bucking bar for sheet metal applications, such as airplane fuselages.

1.2 Background Information

Understanding exactly how the riveting process works is crucial to understanding The Rivet Helper design. Although riveting is a fairly simple process, there are important factors that have a major impact on the final design. During riveting, there are two forces that act on the rivet to compress it to hold the two sheets of aluminum (or other metal) together. Ideally, the end of the rivet will compress on the backside of the sheet until the rivet thickness from the end of the rivet to the surface of the sheet metal is one half the diameter of the rivet. (See Figure 1) This is a F.A.A. specification calculated to give the rivet optimal strength; and is thoroughly checked by qualified inspectors. Strong and consistent rivets are very important because of the high stress they might endure from holding the fuselage or wing of an airplane together. Shown below is a diagram illustrating the two forces acting on the rivet. Also shown is a profile of a rivet before and after the proper riveting process.

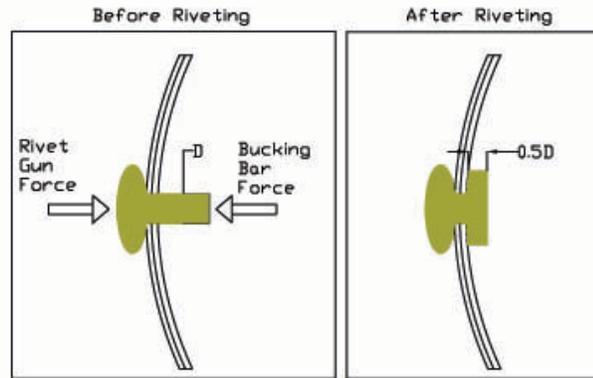


Figure 1: Forces acting on rivet

When riveting by hand, two tools are used. The first is a pneumatically driven rivet gun, which usually has a variable power of 20-50psi that the operator can adjust. An experienced and attentive riveter will push the head of the rivet flush against the surface of the aluminum sheet before and during the riveting process, otherwise the rivet will compress on the wrong side of the sheet and weaken the rivet. The second tool is the one our project will be centered on, a bucking bar. This tool is essentially is a 1-4 lb piece of hand held steel or other dense metal which is held consistently (without skipping off the rivet) and perpendicularly against the end of the rivet, on the opposite side of the head, during the riveting action. The bucking bar supplies the second force that acts to compress the end of the rivet. The following figures show the hand held riveting tools; the bucking bar is shown with a tape measure for scale. The weight of the bucking bar is chosen according to the size of the rivet used. The thicker the rivet, the larger the mass of the bucking bar has to be. Holding the bucking bar perpendicular to the surface of the aluminum sheet metal is a critical part of the riveting process and obviously will have to be a key part of our design. If the bucking bar is angled from the axis of the rivet, the force will not be acting in the same line of the rivet gun, thus causing the rivet to compress improperly and not have the correct thickness on the backside of the sheet metal. It may also cause the rivet to compress on the wrong side of the sheet because the head of the rivet will not sit flush on the surface of the sheet metal with an angled force acting on it.



Figure 2: Rivet Gun



Figure 3: Hand Held Bucking Bar

The weight of the bucking bar is chosen according to the size of the rivet used. The thicker the rivet, the larger the mass of the bucking bar has to be. Holding the bucking bar perpendicular to the surface of the aluminum sheet metal is a critical part of the riveting process and obviously will have to be a key part of our design. If the bucking bar is angled from the axis of the rivet, the force will not be acting in the same line of the rivet gun, thus causing the rivet to compress improperly and not have the correct thickness on the backside of the sheet metal. It may also cause the rivet to compress on the wrong side of the sheet because the head of the rivet will not sit flush on the surface of the sheet metal with an angled force acting on it.

The majority of riveting is done on very large pieces of sheet metal such as airplane fuselages and wings. An example of this is shown in Figure 4, with the riveting gun in position to rivet.



Figure 4: Airplane Fuselage Section

As seen from Figure 4, the sheet is far too large for the riveter to hold both the rivet gun and the bucking bar. The solution to this is either a second person must hold the bucking bar, or a device that can hold the bar for the riveter must be used. Because of the cramped confines of an airplane fuselage, as well as the critical repetitiveness of the riveting process and its needs, a second person cannot always hold it properly.

A well-designed device should be easily repeatable and able to reach everywhere without getting tired, something a second person could not do. Since needing only one person to rivet is also much more convenient for this type of application, a device is required to hold the bucking bar. Since the riveter cannot see the back end of the rivet when working on very large sheets, he or she cannot gauge when the rivet is fully compressed. Thus, a notification method is needed to alert the riveter when to stop riveting. The alerting setup makes it necessary for The Rivet Helper design to incorporate an alarm system that will detect when the rivet end has reached its ideal compression state (thickness equal to one half the diameter). The user's manual will explain to the riveter to stop riveting at the time of alarm.

There are four different sizes of rivets commonly used in aircraft maintenance ($1/16$, $3/32$, $1/8$, and $5/32$ in). Therefore, it is necessary for the design to be able to adapt to four different compression thicknesses on the backside of the sheet. This is incorporated in the sensor/alarm system design. A quick

study of the current riveting process presents a need for a device that will allow one person to rivet alone, taking the place of the bucking bar on the backside of the riveted sheet metal.

1.3 Literature Search

A literature search was conducted on the U.S. Patent & Trademark Office website (<http://www.uspto.gov/patft/>). The results included many patents that may be of interest when designing the Rivet Helper, however none seemed to address the problem statement completely. Patents of particular interest, those that include information that may assist in development of possible designs, are organized in the table below.

Table 1: Patents of interest

Patent No.	Title
6,298,543	Riveting tool and method to reduce marring of work piece
6,279,371	Hand-held riveting tool
6,172,374	Dual laser homing sensor
6,158,666	Vacuum fastened guide and method for supporting tooling on a component
6,134,940	Angular bucking bar
6,073,326	Lap splice mini-riveter system
5,829,151	Multi-axis part positioning system
5,774,968	Electromagnetic riveter recoil cushioning, damping and positioning system
5,572,900	Reduced recoil bucking bar

CHAPTER 2 DESIGN OF THE RIVET HELPER

2.1 Design Introduction

The first and most important step of any design undertaking is to specifically outline goals of the device. The Rivet Helper design process began with this step. The following is a list of goals that have been continually visualized throughout the design process:

- A device that allows one person to rivet large pieces of sheet metal alone
- The target customer is small scale, repair type work
- Accommodate rivet sizes from 1/16 to 5/32 in.
- Alerts the user when to stop using
- Practical size and weight with emphasis on durability and safety
- Prototype costs may not exceed \$750

The first goal has been illustrated in the background section of this text. The rivet helper device will take the place of the hand held bucking bar and eliminate the need for a second person to assist in riveting. The target customer is one who wants to circumvent the labor requirements that this problem poses. This device will not be used on assembly line or mass production applications for the building of airplane sections at companies like Boeing or Lockheed-Martin. The time, expertise, financial resources, and manpower were not available to design a device such as that, nor was the need for such a device identified. Rather, this device will be focused towards hobbyists or companies, large and small, who require such a device to do localized repair work. Since this device will have to be slightly adjusted for every rivet, it would be far too inefficient to use it on an application that required hundreds or thousands of rivets. Figure 5 on the next page shows an example of our target customer's potential application of this device.



Figure 5: Repair patch on airplane fuselage

The size of the rivet will determine the force needed to compress the rivet. Thus, our design will have to be limited to only 4 rivet sizes: 1/16, 3/32, 1/8, and 5/32 in. The device will adapt to supply the necessary force for all these rivets, which are commonly used in sheet metal applications. This device will also alert the user when to stop riveting, as to not over compress or crush the rivet, which will weaken it and lead to mechanical failure and/or failure to pass FAA inspection. Both the operator and limitations of the work area determines what constitutes a practical size and weight for this device. The lighter the device, the easier the operator will be able to use it. As with any other device or tool that is used in manufacturing settings, this one will have to be fairly durable to be able to withstand a certain amount of abuse on top of normal wear and tear.

Figure 6 shows a simplified layout of the current rivet helper design.

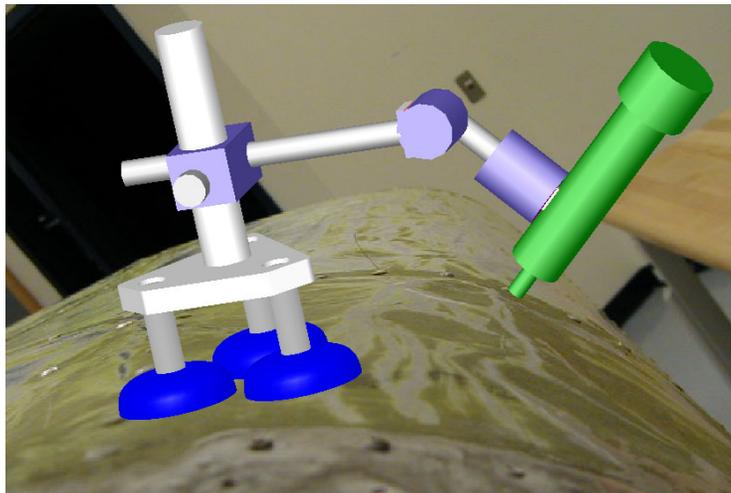


Figure 6: Rivet Helper Design Assembly

The rivet helper design was separating into three major components. In this way, individual or pairs of design group members could focus on one aspect of the design without always having to think globally. The design will be detailed and analyzed in this same way, showing the functionality of each and its contribution to the whole device.

The first component, as seen in green in Figure 6, is the bucking bar assembly. This assembly is the most critical part of the design, as it takes the place of the hand-held bucking bar and must incorporate all the criteria and requirements of the bucking bar.

The second component, as seen in white, is the positioning system of the device. An articulating arm has been chosen as a means to connect and position the bucking bar assembly to the base. This component will require the most engineering analysis due to the many forces and variables involved. All major joints are seen in light blue.

The last component of the design is the base, which is seen in blue. The base will connect the entire device to the riveting work piece, the hull or fuselage of an airplane for example. It will incorporate three vacuum cups powered by a vacuum pump, which stands alone near the device. This design fulfills all aforementioned design goals listed in the design introduction. Each component will now be fully explained in the next three sections.

2.2 Bucking Bar Assembly

The first major component of the Rivet Helper design is the bucking bar assembly. This assembly needs to supply a consistent force on the bucking bar and transfer this force to the back of the rivet. This assembly also dampens the majority of the vibrations exerted on the Rivet Helper from the active rivet gun. This assembly must also have the capability to detect when the rivet has reached an appropriate deformed level. Then communicated this information to the riveter that it is time to stop riveting. Thus the bucking bar assembly is the most essential piece of the design. This assembly, however, does not perform all the tasks required by the design problem. The rest of the design must incorporate a way to hold the bucking bar assembly in proper position during the riveting process. It is the function of the other two major components of the design to hold the bucking bar assembly perpendicular and stable. The framework or positioning system and the base of the design will compile these two components.

2.2.1 Function of Bucking Bar Assembly

This assembly has to be highly accurate in that it supplies a consistent force on the rivet. The bucking bar assembly will also reduce shock and vibration transmitted to the other components of the entire device. The purpose of this assembly is to supply an inertial force against the end of the shank of the rivet. As the pneumatic riveting gun is activated against the rivet head, it delivers a series of sharp impacts to the head of the rivet. These impacts send a shock wave down the length of the shank to the bucking bar at the other end. Due to the difference of inertia of the rivet and bucking bar, the rivet is more likely to move. However, because the rivet is contained by the bucking bar and the active riveting gun the rivet has no choice but to deform. Therefore, the rivet is compressed by this impact force in combination with the inertial force supplied by the bucking bar.

2.2.2 Design of Bucking Bar Assembly

Figure 7 is an assembly view of the final bucking bar assembly. The bucking bar assembly is comprised of several components. The first component listed is the assembly cap, which contains the spring and the bucking bar. The next component is the spring. This will allow the rivet to push the bucking bar back and also create a preloading force that is needed to keep the bucking bar on the head of the rivet. The third component listed is the bucking bar itself. The chosen bucking bar is a cylindrical steel tube which was filled with lead to decrease the size of the tube for a given mass. Its end section reduces in cross section and extends through smaller hole in the footing. It was decided to decrease the cross section of the end of the bucking bar to make it easier to center the assembly on the hole where the potential rivet will be. The cylindrical cross section was chosen so the friction from the wall of the sleeve to the bucking bar will be consistent in any orientation. The fourth listed component is the sleeve. This houses the rest of the components and is threaded on the outside on both ends. This allows the cap and the footing to be screwed on.

C1	Assembly Cap
C2	Assembly Spring
C3	Bucking Bar
C4	Sleeve
C5	Footing
C6	Sensor

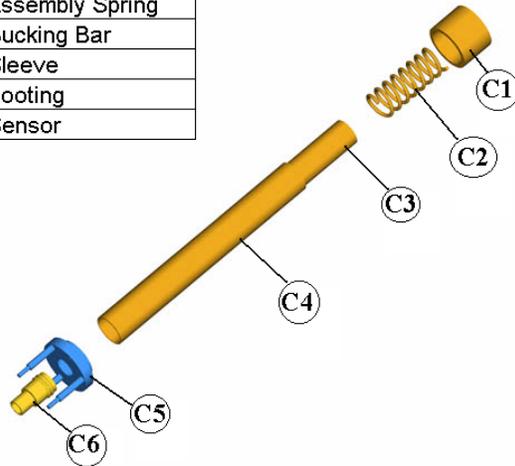


Figure 7: Exploded View of Bucking Bar Assembly

The fifth component is the footing. This allows the riveter to know that the bucking bar is exactly perpendicular to the wall as long as the three feet are touching. This is true because it takes three points to generate a plane which is perpendicular to the center axis of these three points. The last component is the sensor. The sensor remains in contact with the wall at all time by a weak spring which is in compression. The sensor performs multiple tasks. First, it has two electrical contacts. One fixed to the sensor, and the other fixed to the bucking bar. With the rivet pushed all the way in compressing the spring, the distance between these contacts is one half the diameter of the corresponding rivet. When riveting is performed the rivet deforms. This decreases the distance between the two contacts until they connect and make a complete circuit. Existing within this circuit is a power source, a light, and buzzer. The light and buzzer are to communicate to the riveter to stop riveting while the power source provides the energy. The second task for the sensor is to provide a wall so the bucking bar will not vibrate off of the end of the rivet. Experimentation with the entire design in the stages of development proved the resultant vibrations could cause the small cross section at the end of the bucking bar to walk off the rivet.

2.2.3 Spring Choice

The spring included in the bucking bar assembly is used along with the bucking bar to supply the necessary force to compress the rivets. An experiment was performed in which a spring with a known spring constant was set up in such a way it could be riveted against. Then by visual inspection, multiple runs were performed and an average of the spring deflection was calculated. Knowing the deflection and

the spring constant of the spring used we can approximate the resultant force. This force was found by experimentation to be approximately 6 lbs. The design will also need to take into consideration the possibility of the bucking bar assembly being used upside down. Thus adding the weight of the bucking bar to the spring. Knowing this information we choose to select a few different springs with a range of constants around approximated value. Then we performed trial and error experimentation with each of the different springs to determine which would be best suited.

2.2.4 Material Selection

Material selection is another important criteria of our bucking bar assembly. Steel has been chosen as the material of the bucking bar as current bucking bars used this material. Steel is much more rigid than aluminum and other materials. Therefore it will be less likely to be marked up by the riveting. The second reason is for density. This was a large consideration for our design. We desire to minimize the total size of the bucking bar assembly. Therefore, we chose to fill the steel sleeve of the bucking bar with lead which has a higher density.

2.3 Framework / Positioning System

The framework or positioning system is responsible for holding the bucking bar assembly perpendicular to the sheet metal surface throughout the entire riveting process. Failure to do so results in poor rivet quality, which would likely fail an F.A.A. inspection. Improper bucking bar orientation also increases the chance of deformation of the sheet metal. The positioning system design must also fulfill some fundamental requirements. First, it must have a connection to the bucking bar assembly that will withstand the weight of the device. Next, the positioning system must not allow vibrations from the rivet gun to propagate throughout the device. Additional vibrations could adversely effect the base. Finally, the positioning system must be able to navigate throughout a range of four to ten inches from the base with enough degrees of freedom to align the bucking bar assembly perpendicular to the sheet metal surface. The maneuverability will be especially important when working on curved surfaces or around obstacles such as a fuselage shown in the figure below.



Figure 8 – Interior of an Airplane Fuselage: This is an example of possible obstacles and curved surfaces that the riveting helper device might encounter. The positioning system must be able to hold the bucking bar assembly perpendicular to the sheet metal surface.

2.3.1 Positioning System Design

The possible designs of the frame or positioning system for the Rivet Helper vary from a centralized bucking bar assembly with multiple legs to an articulating arm. The articulating arm is the preferred design because it would accommodate multiple rivets while maintaining a fixed base by simply moving the bucking bar assembly to the next rivet. The base will consist of one or many vacuum cups that will hold the Rivet Helper to a surface by suction power. The number of vacuum cups used relates to different types of frame designs. The single articulating arm would likely be more conducive with a base of just one vacuum cup. However, the multiple leg structure would be the likely candidate for a base with a variable number of suction cups. This range varies from three to five vacuum cups depending on the type of framework or positioning system.

The multiple leg design is the contingency design for the positioning system of the Riveting Helper. If the articulating arm design did not satisfactorily meet the design specifications then the multiple leg design would have been used. This design has desirable and undesirable aspects. As stated above, the major con to the multiple leg design is that the entire device would have to be relocated for each new rivet whereas the articulating arm could accommodate many rivets while keeping the base in a rigid location. The multiple leg designs have, to its advantage, a connection from the frame to the bucking bar assembly that does not extend far from the base. The bucking bar assembly will be mounted, via to its connection, directly to the solid frame. The frame will have legs that extend off the main shaft of the body to the connection of the base vacuum cups. The legs will adjust so that the bucking bar

assembly can be positioned perpendicular to the surface of the sheet metal of various slopes. The number of legs on the framework may vary between three to five legs.

Two designs for the articulating arm were conceived, an entirely mechanical arm and a pneumatic arm. Both designs allow the operator to adjust the arm and then tighten all joints simultaneously. The pneumatic articulating arm design will be used for the Rivet Helper because the mechanical arm is overly complex. The mechanical design incorporates too many moving parts and needs a clutch to pick up the slack of the screw tightened joints. The figure below shows the complexity of the mechanical arm design.



Figure 9 – Mechanical Articulating Arm: The mechanical arm design is overly complex with too many moving parts.

Figure 9 shows the mechanical articulating arm is a complex design. A ball joint connects the bucking bar assembly, in green, to a shaft which is screw tightened by the handle above it, in gray. The rotation of the handle also causes the shaft to rotate which in turn tightens the screw at the ball joint, in green, above the base, in blue. Although this design meets the necessary design requirements it is far from ideal. The complexity of the design would make it hard to manufacture and maintain, driving up costs for the manufacturer and ultimately the consumer.

The single articulating arm design consists of a connection to the base at one end and a connection to the bucking bar assembly at the opposite end. The articulating arm system will have some joints that allow it no less than four degrees of freedom to meet the design requirement. The articulating arm has the advantage of servicing many different riveting areas with just one location of the base. This ability contributes to this design is that the vacuum cup does not need to release the vacuum hold, be relocated, and then have the vacuum reapplied.

The final designs for the articulating arm were conceived, a pneumatic arm. The design allows the operator to adjust the arm and then tighten all joints simultaneously. The pneumatic articulating arm design will be used for the Rivet Helper. The pneumatic articulating arm design will be used for the Rivet Helper because it meets the design requirements and has many advantages over the mechanical articulating arm. The pneumatic arm has three joints; one sliding joint above the base and two ball joints.

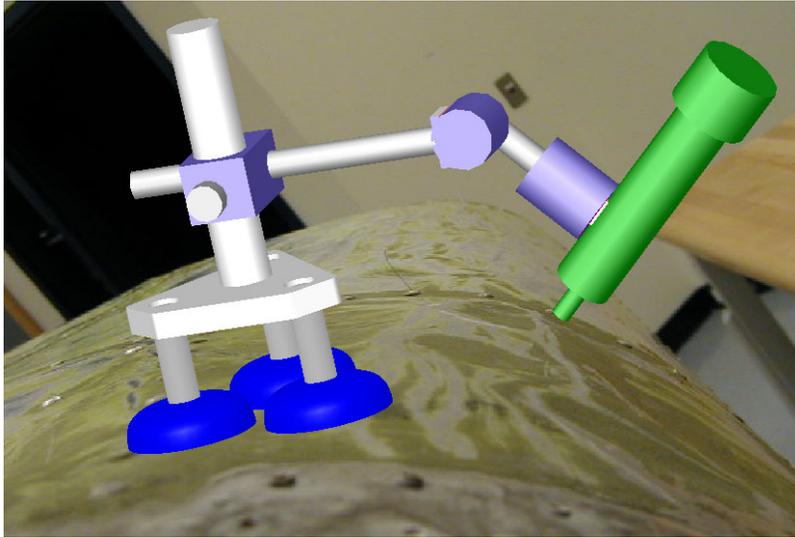


Figure 10 – Joint Placement in Pneumatic Arm: The placement and type of pneumatic joints allow for five degrees of freedom.

Figure 10 provides an example of joint placement in the pneumatic arm. The first sliding pneumatic joint is located above the base, in blue, and allows the arm to move back and forth along the main shaft. The sliding joint will utilize a pneumatically engaged clutch that holds the joint in place. A pneumatic ball joint attaches the arm to the bucking bar assembly shown in green. This joint will allow the bucking bar assembly to be perpendicular to the axis of the rivet. A second pneumatic ball joint is located towards the center of the arm, acting as an elbow, allowing for movement throughout the four to ten inch range. Both of the ball joints are tightened simultaneously using pneumatics pressure. This is a great advantage of the pneumatic arm because it allows the user to tighten all of the joints at once by applying a vacuum or pressure to the joint. The Rivet Helper is already utilizing pneumatics in the design

of the base therefore additional lines can be run to the joints so that the user can loosen or tighten the joints by simply turning a valve.

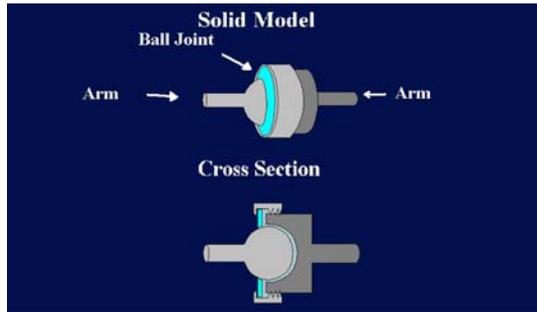


Figure 11 – Pneumatic Ball Joints: The pneumatic ball joints have multiple degrees of freedom and are easily adjusted.

2.3.2 Positioning System Engineering

The pneumatic joint is composed of a ball, similar to that of a standard ball joint, which is held in place by a ring and cap as seen in Figure 11. O-rings will be used to insure the fittings are air tight. Movement of the ball is opposed by a force relative to the frictional coefficient between the ball and the inside surface of the joint. This coefficient will be important when determining the material of the ball and housing of the joint. The frictional force must allow the ball to move around freely inside the joint when pneumatics is not active on the joint. However, once the pneumatics power are activated for the joints, the frictional force must be able to withstand forces imposed on the joints such as axial loading, moments of inertia, and vibration. Theoretical calculations will not be sufficient for this design of the joint because it is nearly impossible to account for and quantify all of the forces that will be acting on the joint. Therefore, experimentation will be done to properly design the pneumatic joints and arrive at a final design. Various factors for the joint include size of the ball, material, pneumatic force applied to the joint, and area inside the joint where pneumatics are applied. The pneumatic force will depend upon whether vacuum or pressure is applied. Pressure is preferred because it provides sufficient force, which is a excellent safety issue in the design. In fact, the pneumatic gun utilizes compressed air while riveting so pressure is a viable option. An example calculation demonstrates how these factors effect the performance of the joint. One can calculate the amount of force a locked joint can handle using the following equation:

$$M = \mu * F * R \quad \text{where: } M = \text{Moment of friction}$$

μ = Coefficient of radial friction

F = Pneumatic force

R = Radius of ball

The pneumatic force is found by multiplying the pressure applied to the joint by the area inside the joint over which it is applied. For instance, assuming a frictional coefficient of .55 for rubber on metal, a Pneumatic force of 50 pounds, and using a ball with a one inch radius the joint can handle approximately 28 inch*pounds. A prototype of similar dimensions was constructed but does not hold 28 inch pounds. This reinforces the necessity of using experimentation as a means of designing these joints.

2.4 Base

2.4.1 Function of Base

The base has a simple function. It must withstand gravitational forces on the weight of the design, and any resulting forces applied through the riveting process.

2.4.2 Design of Base

Specific design considerations for the base are evident given the previous description of the other components. Because the design of this device accounts for the interior of an airplane, the clearance and reach height of this device becomes an important variable. Obstacles may exist in the path of an arm system if it were to be positioned off of the floor. These obstacles can be seen in Figure 12 as it displays the inside of a typical airplane fuselage.



Figure 12: Fuselage Interior



Figure 13: Fuselage Exterior

Aluminum is the primary metal to be riveted with the aid of this device. Therefore, the possibility for a magnetic base is eliminated. With a large surface curvature to consider, the group designed for radii of up to, and including, fifteen inches; the approximate radius of a fifty-five-gallon drum. Figure 13 shows a curved surface of an airplane. The base design was narrowed down to two

options: one 5 inch suction cup which will support the entire device, or 3 3-inch suction cups attached to a central aluminum base. The three suction cup design gives the device additional stability, because it does not rely on one single suction cup to adapt to a curved surface, it uses three suction cups that can better adapt to the surface curvature and hold the device stable.

The device must be easy to move. Therefore, the design must have a base with simple relocation characteristics. The design allows a single person accomplish a task that was not previously possible without assistance. We are focused on fulfilling the act of completing the task instead of marketability and ease of use. Given that we will be able to complete the act, it makes sense to make the product as functional as possible. This in turn leads to designing the base to be as easy to move as possible, as it may undergo many movements during the riveting of two sheets. Therefore a powered vacuum system will be implemented as the base.

2.4.3 Experimentation of Base

Results of experimentation show that the high degree of surface curvature is not an issue for power vacuum systems. Group experiment shows that the powered vacuum cups can hold high loads. These high loads will provide a high factor of safety for the device. Using a powered vacuum system, the device can mount locally to the rivet. This will reduce the size of the frame system. The design of the frame system will also need a vacuum pump. The group has obtained a vacuum pump that puts out approximately negative ten psi. Another option for a vacuum source was to use a Venturi Vacuum Generator (see Appendix C). These use compressed air to generate a vacuum. However, they required mounting close to the area that needs suction and can be very loud. Operation with a silencer registers nearly 70 decibels. For these reasons the Venturi Vacuum Generator was not chosen as an optimal solution.

The design team chose to use a powered vacuum system. To best accommodate the requirements of the device, this vacuum cup will have a stabilizing frame on the inside of the cup similar to Figure 14.



Figure 14: Stabilizer Inside Vacuum Cup

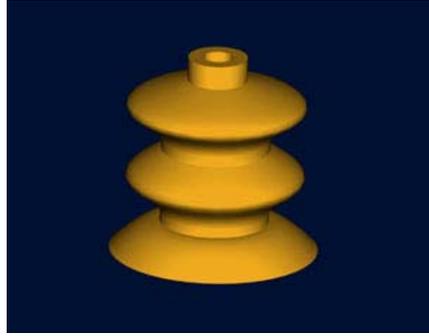


Figure 15: Vacuum Cup

A single arm will be attached to the base through the center axis of the aluminum plate, which is also connected to the three suction cups. This will ensure that when the suction cup is under pressure it will push the stabilizing system firmly against the wall and prevent wobbling. The vacuum line of the suction cup will go through a hollowed-out stud that attaches the suction cup to the central aluminum plate. The vacuum line is then channeled through this plate, joining all three airlines to a central valve to simplify the air hose setup. Figure 15 shows the proposed vacuum cup.

2.4.4 Engineering of Base

The design team has made calculations to ensure that the design will be strong enough to support the load of the device and force exerted upon it during riveting. The vacuum pump at negative ten psi on the available area between the cup and surface yields the net suction force of the base. Therefore, three 3-inch cups, with a half inch stabilizing rings in each, operating at negative ten psi, yields a suction force of approximately 160 pounds. This excessive allowable force gives the design a high factor of safety in supporting the device. Experiments have also shown this force not to be too much for the Aluminum sheet metal to handle, i.e. the suction does not cause the sheet metal to flex a great deal. Based on the criteria mentioned above, the vacuum cup design best fits the design needs. While the cups can be purchased, the stabilizing braces were machined.

2.5 Electrical Components

In addition to the aforementioned mechanical designs, there is an additional electrical component to the Rivet Helper. The electrical system will serve 3 purposes: the first is to have a local switch to turn the vacuum pump on and off. This will make it easier for the riveter to turn the vacuum pump on or off

while he or she is holding the device close to the fuselage, instead of reaching for an AC cord to pull it out of the outlet. The second function is to have an easy on/off switch to lock down the pneumatic joints. Since the two ball joints and one of the linear slides is locked with pneumatics and a solenoid valve, a single on/off switch makes it easier for the riveter to position the device and lock it down with one step. The third function of the electrical system is to connect the sensor of the bucking bar assembly to an alert system, consisting of a visual light and a audio buzzer, to tell the riveter when to stop riveting.

Our design requires the use of a simple circuit with few components. These components can be seen in the wiring diagram in Figure 16.

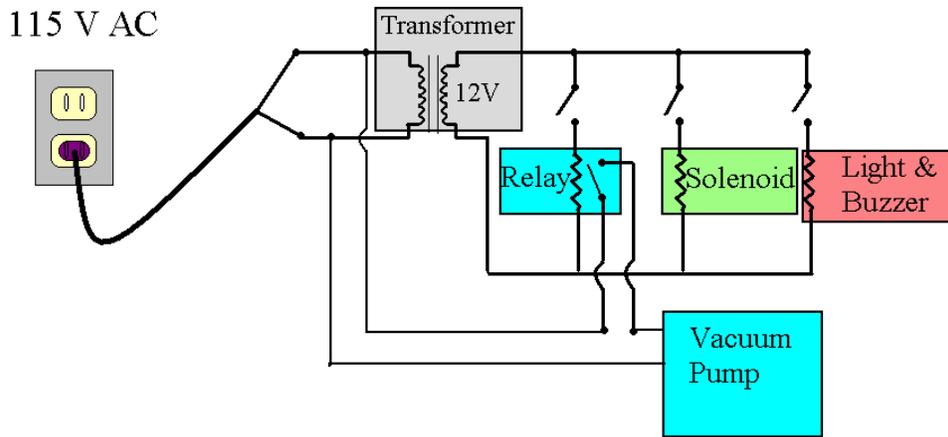


Figure 16: Wiring diagram of the rivet helper

Our vacuum pump required the use of 115V. However our light, buzzer, and solenoid were designed to use 12 Volts. Therefore a transformer was used. This will also keep the high voltage out of our switches and away from the end of the bucking bar. Then the three switches were hooked up in parallel with each other, but in series with their respective components. The first switch seen is used to activate a relay to turn on our vacuum pump. This switch was mounted locally to the base for easy operation. The second switch locks up the joints in the arm. It does this by activating a solenoid which opens compressed air to each of our joints. This switch is located on the bucking bar assembly so a user can line up the bucking bar and then flip the switch. The third and final switch is our sensor which is

located at the end of the bucking bar assembly and activates a light and buzzer which the appropriate deformation is reached.

2.6 Design Discussion

Since the beginning of the design process, the rivet helper has been divided into the three discussed components: bucking bar assembly, framework, and the base. The bucking bar assembly was the first to be designed and finished, since that design did not change for any design concept that was discussed. The only minor debatable issues, related to the bucking bar assembly, were the decision on the sensor. This included choosing the sensor type, and also the means in which the operator was alerted.

The frame of the design has been by far the most challenging. Many ideas were discussed for this component, and the deciding factors were first the main goals of the project, as discussed in the design introduction. The next step of the decision-making was minor attributes that would make the design more appealing above and beyond the necessary ones. This design would benefit from the rivet helper being able to reach multiple rivets without having to disengage the vacuum and move the entire assembly. This decision steered the design more to the articulating arm, as opposed to a solid frame system, which would require the device to be moved for each rivet. Designing this articulating arm was a heavy undertaking by the capstone design group. A frame system would have been fairly easy to design to maneuver and lock. An articulating arm is very complicated because it requires 5 degrees of freedom to maneuver the bucking bar assembly into place, and all 5 degrees have to be locked tight for the effectiveness of the design. This component of the design will be thoroughly tested to validate the analysis and design of this text.

In deciding on the frame, it also affected the decision for the base. While the suction cup concept was decided early on in the design process, the number of cups and their size was dependant on the frame design. A solid frame would require 3-5 cups of a smaller size, an articulating arm just one large one. Lastly, several efforts were made to eliminate the need for a vacuum pump for the base. Research was done to find other means that would use air pressure instead of a separate vacuum pump. This would be beneficial because it not only eliminates the need for the extra pump and electricity, but it uses an airline, which is already present in the work area that is used for the pneumatic riveting gun.

CHAPTER 3 CONCLUSION

The previous sections have summarized the different parts of the design of the Rivet Helper. Early on experiments were conducted that ultimately led the group to make decisions on choosing particular designs for each section. After selecting the respective pieces and completing a prototype the group was left with concerns about extraneous effects which may inhibit the design from working. Therefore further experimentation with our prototype was made which resulted in adverse conditions of the combination of the vibration and preloading which caused the bucking bar to walk off the end of the rivet during riveting. Steps were then implemented to correct this undesirable effect. One such step was to eliminate a degree of freedom that was not needed. This was done by putting a slot on our main arm cylinder. It was seen in testing that this was a weak point in the arm and would rotate during riveting. We needed to use a cylinder of thicker cross section to have it be structurally stable with the slot. It was then decided that if we have to change the beam entirely, to also shorten it by an inch and a half. This will limit the range of our design but as we found during experimentation our joints could barely handle the existing range.

The other step made to correct the issue was to change the design of our sensor. Our initial design consisted of an easily replaceable pin which remained stationary against the wall at all time. This was then replaced by a sleeve which enclosed the end section of the bucking bar. This provides a wall around the bucking bar which the rivet cannot escape from. Another consideration is the deflection of the airplane wall, or other material being riveted, under the loading of our device. If the wall of the airplane deflects under the loading then it will not provide a stable surface. The corrections made for the previous issue help to combatant this problem. In addition our existing design of the sensor keeps the sensor against the wall at all times. Therefore when the bucking bar deflects when the rivet is pushed in the sensor will not move. Thus correcting any issue wall deflection could incur.

In summary, experimentations were performed which lead the team to decide on the particular design. Engineering calculations were made to generate the engineering drawings necessary to build our prototype. These calculations were generated using worst case scenario thinking. Our prototype was made and then experimented on. Faults were found with the design from prototype testing. The design was then altered to overcome these faults. Overall, the proposed design completely fulfills the design problem criteria. Efforts were made to make the design easy for a person to use, which includes the position of the switches for the pneumatics of the device. This device completely allows a single person to easily rivet where two people were previously needed.

Appendix A - Cost analysis for the Rivet Helper

Cost Analysis plays a very important factor in purchasing and manufacturing any device. Not only to make our device function but also to make this device more affordable and more marketable to meet the customers financial expectation. The Rivet Helper is mainly concern with raw materials excluding a vacuum pump. The total cost to purchase these materials excluding the cost of machining is approximately \$732.46, which is under our required spending budget. In fact, more than 44% of the cost goes toward purchasing the vacuum pump. This calculation has calculated and shown on an excel table below.

Bill of Materials	
Description	Price
Bucking Bar Assembly	
1 ½ inch Dia steel 1 ft.	\$30.03
1 ½ inch I.D., 2 inch O.D. Aluminum 1ft.	\$34.25
Springs	\$10.47
Articulating Arm	
¾ inch cylindrical aluminum rod 6 ft stock	\$31.98
Aluminum stock to make joints 1 ½ in Dia 1 ft.	\$29.13
Ball Joints Mat'l	\$15.00
Base	
Plate for stabilizing base	
½ inch thick 8 inch by 8 inch aluminum stock	\$ 35.70
Aluminum arm ¾ inch Dia 1 ft long	\$ 25.13
Vacuum pump	\$ 325.83
Salenose Valve	\$ 34.99
Electrical	
Anodizing	\$ 75.00
Electrical Box	\$ 24.99
2 Relays	\$ 9.98
Transformer	\$ 9.99
Miscellaneous	
Air Hose/Line	\$ 9.50
Electrical	\$ 15.49
Hardware	\$ 15.00
Total	\$732.46

Appendix B – Venturi Vacuum Cup



Appendix C – List of Equations

1) shear stress due to torsion: $\tau = (T \cdot a) / J$

2) bending stress: $\sigma = (M \cdot c) / I$

3) Friction Locked Joints: $F = (T \cdot \nu) / (\nu \cdot d)$

4) Spring Force: $F = k \cdot \delta$