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Frame

By

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In Collaboration With:
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ABSTRACT

The Automotive Industry faces extreme safety concerns during the vehicle lifting process, how can these safety concerns be mediated for the personals in the automotive industry during this process? A revolutionary vehicle jack (“The Auto-Jack”) was developed to remove all unnecessary safety concerns that are presented to the user during the vehicle lifting process. Removing the user from having to position a standard vehicle jack and/or jack stands underneath the vehicle once the vehicle is lifted will eliminate all safety concerns surrounding user inflicted failure. A hydraulic circuit is used to operate the Auto-Jack, this allows the user to operate the jack from a safe distance. A vehicle jack with a larger surface area will eradicate all possibilities of collapse or malfunctions to take place during the lifting process. The Auto-Jack frame has a closed vertical height of under 0’-4”, which allows the user to drive the vehicle over the jack and operate it from a safe distance. A standard vehicle jack is capable of lifting one tire off the ground efficiently, while the Auto-Jack successfully can lift an entire car with the ease of button and also maintains a safe working environment. The following tests were conducted to ensure the success of the Auto-Jack: met the 5000-lb compressive strength requirement, over 2’-0” of surface area contact improves safety, ease of use, less than 0’-2” of sway when 50-lbs of side load is applied at full lift height, overall frame weight of less than 75-lbs, and vertical lift height of over 2’-0”. The practical engineering tests proved the Auto-Jacks effectiveness in the automotive industry.
INTRODUCTION

a. Description:
The primary problem for mechanics and automotive enthusiasts is the risk associated with lifting and securing a vehicle with conventional jack stands. Often times improper jacking/jack stand installation results in the vehicle collapsing unexpectedly. When this happens, the personal near/under the vehicle can be seriously injured or killed. From an engineering standpoint this problem can be minimized through the application of a new redesigned vehicle lifting system.

b. Motivation:
The primary motivation behind this project is the need to improve safety in an automotive environment. The conventional method for lifting cars is not only time consuming but can be unsafe in many circumstances. A device that can quickly lift and secure the rear/front end(s) of a vehicle without requiring the user to get under the chassis of the vehicle will improve overall safety.

c. Function Statement:
This jack frame must be able to lift and securely support the weight of the front/rear end(s) of a vehicle; it must also be safe for the user to install/remove from under the vehicle.

d. Design Requirements:
The following design requirements will be met in our initial design.
- This jack frame must weigh under 50lbs to ensure the user can position it under the car with ease.
- The jack frame will also have a maximum compressive strength of 5000lbs to ensure it will safely lift the rear/front end(s) of the vehicle without failure.
- In addition the pins in the device arms need to move freely and support up to 2500lbs per pin.
- The jack frame must have a horizontal distance of less than 4 feet to universally fit under any type of standard vehicle.
- The frame must deflect less than 1.0” when subjected to the 5000-lb loading.
- The frame must have a collapsed height of less than 6 inches to sufficient fit under the chassis of most vehicles.

e. Engineering Merit:
The functionality, safety, and efficiency of the Auto-jack frame are the overall emphasis for this project. The weight, ease of use, vertical rise ability, and strength of the Auto-jack frame are the substantial factors contributing to the success of the design.

The Auto-jack frame is responsible for supporting the overall load applied from the vehicle; the max load that was determined was 5000-lbs. This 5000-lb load was determined by vehicle weight research (max weight of all types’ vehicles, cars, trucks, SUV’s, etc.). This is the loading constant that will be used throughout the analysis of the Auto-jack frame. Engineering merit was used to determine the selection and size of square stock needed to support this 5000-lb loading.

Stress, deflection, and force equations: \( \sigma = \frac{My}{I} \), \( \sigma = \frac{F}{A} \), \( \tau = \frac{V}{A} \), \( \delta = \frac{qL^4}{6EI} \) are used to determine...
the thickness of steel square stock needed, compressive stress, force in link arms, deflection in the frame due to bending, normal stress due to bending, and shear stress in the link arm pins. The material selection in the frame is extremely critical in order to maximize the weight of the Auto-jack frame without sacrificing the ultimate strength. In addition to these attributes the overall cost of materials is another contributing factor.

**f. Scope of this effort:**
The scope will only include the framework, pins, hydraulic adapters, and joints of the vehicle jack.

**g. Success Criteria:**
The success depends on the final performance of the Auto Jack safely lifting the test vehicle within our set design requirements. The success of this project can be measured/determined by testing to see if the auto-jack effectively and safely lifts the vehicle.

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**Design & Analyses**

**a. Approach:**
The design arose after seeing multiple injuries and fatalities occur from improperly lifting and supporting vehicles with standard jack stands during maintenance. A standard jack stand only has approx. 2-inches of surface area actually in contact with the vehicle during maintenance, this creates an opportunity for vehicle slippage and other stand related malfunctions to happen. Another issue stated previously is the aspect of time consumption in using standard jack stands. The approach to this design was centered about the safety and application of lifting a vehicle, create a design that is hydraulically/pneumatically powered and doesn’t require any user to maneuver jack stands or put themselves in an unsafe working environment. The square frame design that the Auto Jack features creates a jack to vehicle contact area of nearly 2 feet, this is over a 1200% safety increase from conventional jack stands.

**b. Design Description:**
The design pictured below features a 1020 steel square stock frame with steel square stock link arms that are connected via steel dowel pins. A hydraulic cylinder is pinned between the two middle link arms; the hydraulic cylinder is a dual acting system meaning it produces the same force to both extend and retract the hydraulic cylinders stroke. The design uses the force of the cylinders retraction to pull the link arms closer together forcing the top frame to rise, ultimately lifting the vehicle. The angled link arms give the jack a greater vertical lift as the horizontal cylinders strong is retracted.
c. Benchmark:
Another device that has been developed to address this problem is the Safe-Jack Gator Jack (Part # 88M-SJGA0403). While this jack does in fact lift the vehicle there is a big safety issue with this device. The compact size of the Safe-jack is comparable to our Auto-jack, but again this jack only lifts 1 quarter of the vehicle (meaning you would need 4 of these). The main problem with this device is the overall safety of the jack, the Safe-jack has a very minimal pad in which the vehicles rests on, it also doesn’t have any sort of locking mechanism to take the strain away from the hydraulics while the user is working on his vehicle. In addition to the safety, the cost of this device is extremely high, a device like this sells for around $1300.00. A device lacking in safety but yet has a very high expense is not rational; instead a much safer, cheaper, and effective device will take this vehicle lifts place in the auto industry. The Safe-Jack Gator Jack is pictured below for reference.

![Safe-Jack Gator Jack](image)

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d. Performance Predictions:
With the square frame design that the Auto-jack encompasses it is predicted that this jack will be cheaper to manufacture and have more vehicle to jack contact meaning a safer working environment. The Auto-jack will also be capable of lifting the entire rear/front end 2 feet off the ground, while the Safe-Jack Gator Jack is only capable of lifting the vehicle 18.25-inches off the ground. The Safe-Jack Gator Jack possesses the same flaws that conventional jack stands have, the contact plate that the vehicle rests on is only 2” x 2”, and this creates a huge safety issue. The Auto-jack frame has a nearly 2-foot contact plate with the vehicle; meaning if the vehicle is bumped or jerked there is no chance of slippage or collapse.

e. Description of Analysis:
The analysis starts by calculating the reactionary forces on the jack frame itself, since the jack frame is symmetrical the reactionary forces are equal but in opposite directions (Newton’s 3rd Law). The reactionary forces on the frame calculated will be used to determine the forces exerted on the link arms; these are normal forces due to bending. Analysis can be done to determine the minimum thickness of each part needed to support these forces. Each analysis always starts with a free body diagram to give a visual representation of the goal/task.

f. Scope of Testing and Evaluation:
The overall testing and evaluation will consist of the success of the jack frame, does the frame meet the requirements and successfully lift the vehicle. The testing will be completed by using a test vehicle to determine if the jack is capable of lifting the test vehicle. The success can be evaluated by the performance and capability of the Auto-jack.

**Upper/Lower Frame Analysis:**
The frame is composed of AISI 1020 square stock; this material was selected using an appropriate decision matrix. This material was chosen because of its weight to strength ratio and the overall availability and cost of material. The analysis process below shows how the thickness of the material was determined.

**Requirements:**
The upper/lower frame must support a maximum compressive loading of 5000-lbs.

**Analysis:**
Since the upper frame needs to support a maximum loading of 5000-lbs, it was necessary to calculate the reactionary forces in the frame. It can be assumed that since it is a distributed load there will be two 2500-lb vertical forces (y-direction) directly on where the link arms are mounted to the upper frame.

**Design Parameters:**
The thickness including the safety factor of 1.5 was calculated to be 0.01026, which isn’t a standard thickness of square stock. So a standard thickness will be used of 0.120. This means the final dimensions of square stock needed to support the 5000-lb loading is 1” x 1” x 0.120”.

**Documentation:**
The analysis for this requirement can be found in Appendix A-1, A-2, and the drawing of the frame assemblies can be found in Appendix B-10, B-11.

**Link Arm Analysis:**
Pins located at each bracket and joint connect the link arms to the upper and lower frame, reference the analysis in Appendix A-4. The link arms must support the 5000-lb loading without buckling, the 5000-lb force is a linear load applied directly on the link arms since these are the only attributes supporting the frame itself.

**Requirements:**
The upper and lower link arms must be able to lift and support a load of 5000-lbs.

**Analysis:**
Symmetry is present in the jack frame; since every aspect of the frame is in equilibrium the 5000-lb loading will be divided in half only producing a 2500-lb load on each link arm. The reactionary forces in the link arms go as follows \( F_x = 1562.5\text{-lbs} \) and \( F_y = 2500\text{-lbs} \). These forces will be used when calculating the overall thickness of material needed to sustain the 2500-lb loading.
Design Parameters:
After completing the analysis a thickness 0.06816-in, after applying the safety factor the new recorded thickness is 0.10226-in which isn’t a standard thickness so rounding up to 0.120-inches (standard size) was necessary. The overall dimensions of the square stock for the link arms is 1” x 1” x 0.120”. These dimensions will withstand greater than 2500-lbs with a safety factor of 1.5 applied to the overall thickness.

Documentation:
The analysis for this requirement can be found in Appendix A-4 and the drawing of the link arms can be found in Appendix B-6.

Link Arm Bracket Analysis
The link arm brackets are welded 2-inches apart at the center of the lower and upper frame, there are a total of 8 brackets to support the 8 link arms. To keep consistency in the design and abundance of materials the brackets are made of AISI 1020 Steel plate.

Requirements:
The brackets must be able to support a vertical compressive loading of 2500lbs.

Analysis:
The bracket is subjected to normal bending stress meaning the force is acting perpendicular to the cross-sectional area of the bracket. In order to determine the thickness of the bracket it was necessary to determine the ultimate stress of the AISI 1020 steel dowel pin, this stress was determined to 57249 psi. The stress in the bracket can be formulated to be $\sigma = \frac{F}{A}$, where $F$ = the force applied on the cross-sectional area, and $A$ = to the cross sectional area. The $\sigma$ (stress) and the $F$ (force) in the equation are known so now the thickness can be solved in the area formula.

Design Parameters:
The determined thickness was solved to be 0.0873-inches, applying a safety factor of 1.5 resulted in a final thickness of 0.13095. For machining purposes and tolerances the thickness value was rounded to 0.15 for ease in manufacturing.

Documentation:
The green sheet analysis can be found in Appendix A-6, A-7, and the drawing of the bracket can be found in Appendix B-5.

Upper and Lower Link Arm Pin Analysis
Pins support the link arms on the upper and lower brackets, there is a total of 8 pins. These pins are composed of AISI 1020 Steel as previously stated in past analysis. The diameter of the pin is directly proportional to the allowable load of the system, as the diameter increases the allowable load will increase as well. A diameter needs to be specified and standard pin size needs to be selected. The analysis below solves for the final diameter of the link arm pins that will support the 5000-lb loading.

Requirements:
The upper and lower pins must be able to support a vertical compressive loading of 2500lbs.

**Analysis:**
The upper and lower link arm pins are in double shear and are subjected to a 2500-lb compressive force (pushing directly down causing the bend to bend inward from the center). The goal of this analysis is to determine the diameter of the pin needed to withstand this loading. The first step was to determine the maximum shear stress that AISI 1020 Steel can support before fracture, this was found to be 41000 psi. The next step was to determine the maximum shear physically calculated from the free body diagrams of the pin itself. The formula used to determine the diameter of the pin is, 
\[
\tau_{pin} = \frac{V}{A},
\]
this equation was rearranged to solve for the diameter within the area function. The final equations looks like this, \[
\frac{\pi}{4} (D^2) = \frac{V}{\tau_{pin}},
\]
solving for D will produce the final diameter of the pin needed to support the load.

**Design Parameters:**
The diameter of the 1.25” AISI steel dowel pin was determined to be 0.19702-inches. Applying the safety factor of 1.5 will formulate a final diameter of 0.29553-inches, this is still not standard size so a pin sizing chart was used to arrive at a final diameter of 5/16-inch. To keep consistency within the jack frame and to promote the physical appearance of the frame, a pin size of 0.40-inch was selected.

**Documentation:**
The analysis for this part can be found in Appendix A-9, and the drawing the pin can be found in Appendix B-4.

**Jack Frame Bare Weight Analysis**
The overall jack frame weight is a crucial aspect to the frames success, if the frame is to heavy then the user won’t be able to position the frame beneath the car. The bare jack frame weight that is determined includes all pins, link arms, link arm connectors, brackets, and upper and lower frame components.

**Requirements:**
The jack frame must weigh under 50-lbs

**Analysis:**
This is one of the last analyses completed simply because all the other material aspects needed to be known before the weight analysis could be completed. Obtaining the weight from all the Solidworks drawings was the quickest and most efficient way to determine the overall weight of the system. The calculated/obtained weights goes as follows, upper frame = 10.61-lbs, lower frame = 11.09-lbs, link arm brackets = 0.1493-lbs*(8 brackets), link arm pins = 0.07-lbs*(8 pins), middle connector pins = 0.17-lbs*(4pins), welds = 0.072-lbs*(4 ft.), and link arms = 2.57-lbs*(8 arms). Adding all of these weights together will produce an overall weight of the bare jack frame.
**Design Parameters:**
The final calculated value was 48.15-lbs which exceeds the set requirement of 50-lbs. Meeting this requirement aids in the success of the final jack frame, being under 50-lbs allows the user to maneuver the jack with ease.

**Documentation:**
The final analysis can be found in Appendix A-11, the drawings of the jack frame can be found in Appendix B-12.

**Jack Frame Closed Height Analysis**
The overall closed height of the jack frame is a crucial aspect to the frames success, if the frames closed height is above 6-inches the jack frame will not be able to fit underneath the vehicles chassis. The closed height is when the hydraulic cylinder is fully extended and the jack frames link arms are resting between the frame.

**Requirements:**
The jack frame must have a closed height of under 6-inches.

**Analysis:**
To determine the closed height of the jack frame it was necessary to know all the materials dimensions before completing this analysis. The closed height will include the extrusion of the brackets beyond the upper and lower frame as well as the height of the upper and lower frame. The overall height can be calculated by simply computing, \( H = 1" \) (lower frame) + 1” (upper frame) + 0.25” (lower bracket) + 0.25” (upper bracket), these are the only variables that will attribute to height because the link arms are resting inside the lower frame.

**Design Parameters:**
The final calculated value for overall closed height was 2.50” which exceeds the set requirement of 6-inches. Meeting this requirement aids in the success of the final jack frame, having a closed height of less than 6-inches will allow this jack to be compatible with most standard vehicles.

**Documentation:**
The final analysis can be found in Appendix A-12, the drawings of the jack frame can be found in Appendix B-12 (final assembly drawing).

**Link Arm Length Analysis:**
The length of the link arms are extremely important in the overall success of the jack frame, if the link arms are to short the requirement of lifting the vehicle vertically 2-feet will not be met, and if the link arms are to large the jack frames horizontal length will be too long and the frame won’t be able to fit under standard vehicles.

**Requirements:**
The link arms must be long enough to provide a vertical lift of at least 2-ft.
Analysis:
The link arm length is the most important feature of this frame, finding equilibrium where vertical height and horizontal length are minimized but still meet requirements is crucial. In order to find the desired height of the jack frames/link arms trigonometry was used heavily throughout this analysis. Since the frame is completely symmetrical it was only necessary to find the desired length on one side of the jack frame. The analysis started by guessing and checking values, plugging in values for cylinder stroke, vertical height, and solving for link arm length. The final value test yielded a vertical height that met the design requirement and an overall efficient horizontal length. The final test:
Cylinder stroke = 13.25”, Link arm = 21.25”, \( H = \sqrt{(21.25)^2 + (13.25)^2} \). The cylinder stroke was determined by the size of cylinder needed for this project (pre-determined).

Design Parameters:
The overall length of the link arms needed to efficiently lift the vehicle 2-ft off the ground will be 21.25”, this gives a lift height 34.86”. The equation above only takes into account half of the frame, the final \( H \) calculated from the above equation needs to be doubled to take into account the rest of the hydraulic cylinder and the other side of the jack frame. The final design parameters include: length of link arm = 21.25”, vertical height = 34.86”, cylinder stroke = 13.25”.

Documentation:
The analysis for this requirement can be found in Appendix A-10 and the drawing of the link arms can be found in Appendix B-6.

Deflection in the Upper Frame:
Although the material thickness and dimensions are already determined for the square stock (previous analysis) for the upper and lower frame, it is necessary to calculate the deflection in the beam to verify the upper frame will not deflect too much causing the frame to fail. The square stock that was pre-determined was 1” x 1” x 0.120”, these dimensions will be used for further deflection analysis.

Requirements:
The upper frame must not deflect over 1-inch.

Analysis:
The upper frame is prone to deformation so maximizing the materials strength and design is extremely important. Before solving the deflection formula it was necessary to the modulus of elasticity and the moment of inertia of the cross sectional area of the square stock. The modulus was determined through research to be \( E = 29700 \) ksi and the moment of inertia was \( I = 0.05553 \). Once these values were determined the deflection in the beam was calculated using \( \delta_B = \frac{qL^4}{8EI} \), the \( L \) in this equation is the length acting perpendicular to applied load, and the \( q \) in the equation is the distributed load of 5000-lbs.

Design Parameters:
The overall deflection in the beam was calculated to be 0.8793, since the frame is symmetrical and there is another side of the frame so the value needs to be divided in half to take into account the entire upper jack frame. The final value after being computed for the full jack frame is a deflection of 0.4396-inches, which is well below the desired design requirement.

**Documentation:**
The analysis for this requirement can be found in Appendix A-2 and the drawing of the link arms can be found in Appendix B.

**Middle Link Arm Connector Pins:**
The middle connector pin supports the link arms, hydraulic cylinder, and the loading of the vehicle; each pin will support a loading of 2500-lbs because of frame symmetry. The analysis below explains how the diameter of the middle connector pin was determined.

**Requirements:**
The middle connector pins must be able to support a loading of 2500-lbs.

**Analysis:**
The middle link arm pins are in double shear and are subjected to a 2500-lb compressive force (pushing directly down causing the bend to bend inward from the center). The goal of this analysis is to determine the diameter of the pin needed to withstand this loading. The first step was to determine the maximum shear stress that AISI 1020 Steel can support before fracture, this was found to be 41000 psi. The next step was to determine the maximum shear physically calculated from the free body diagrams of the pin itself.

The formula used to determine the diameter of the pin is, \( \tau_{pin} = \frac{V}{A} \), this equation was rearranged to solve for the diameter within the area function. The final equations looks like this, \( \frac{\pi}{4} (D^2) = \frac{V}{\tau_{pin}} \), solving for D will produce the final diameter of the pin needed to support the load.

**Design Parameters:**
The diameter of the 10.50” AISI 1020 steel dowel pin was determined to be 0.19702-inches. Applying the safety factor of 1.5 will formulate a final diameter of 0.29553-inches, this is still not standard size so a pin sizing chart was used to arrive at a final diameter of 5/16-inch. To keep consistency within the jack frame and to promote the physical appearance of the frame, the pin size of 0.40-inch was selected.

**Documentation:**
The analysis for this requirement can be found in Appendix A-8 and the drawing of the middle connector pins can be found in Appendix B-7.

**Length/Width of upper and lower frame:**
The length of the upper and lower frame are crucial to the success of the jack frame, if the upper and lower lengths are too large the jack frames horizontal distance wont fit between the wheel well of the vehicle. In order to determine the total horizontal jack frame length it was necessary
to determine the link arm length, since the horizontal length is directly proportional to the vertical lift.

**Requirements:**
The jack frame must have a horizontal length of no greater than 48-inches.

**Analysis:**
The analysis for this requirement was very simple; it was first necessary to determine the length of the link arms. The calculated horizontal length of the link arms was half the distance of the fully closed hydraulic cylinder, which ended up being 28.50”. The total distance from the left side middle joint to the right side middle joint when the hydraulic cylinder was fully extended was 44-inches, this full extension produced a vertical height lift of 2-ft.

**Design Parameters:**
After determining the total horizontal distance of 44-inches when the hydraulic cylinder was fully extended designing the lower frame horizontal length was simple. The final dimensions of the lower frame were calculated to be 48-inches long by 12-inches wide. These dimensions allowed the link arms rest between the lower frame generating a smaller closed vertical height.

**Documentation:**
The analysis for this requirement can be found in Appendix A-11 and the drawing of the length and width of the frame can be found in Appendix B-1, B-2, and B-3.

**Performance Predictions:**
After completing the above analyses this jack frame proves 85% more efficient than the benchmark for this project. The bare jack frame will weight below the set design requirement of 50-lbs and be able to lift and support the 5000-lb vehicle over 2-ft vertically. On top of these predictions based upon the analyses the jack frame will be able to lift at a rate of 4-inches per second, which means the entire jack frame will reach its vertically height limit of 2-ft in 6-seconds. For further performance predictions refer to the performance analysis in the methods and construction section of this report.

**METHODS & CONSTRUCTION**
**Description:**
The jack frame was conceived after an ample amount of time researching jack frame technology and injuries relating to jack frame failure. The analysis above proves the theoretical efficiency of the jack frame itself, but the overall manufacturing and construction of the device still needs defining. Below incorporates how the construction process will be completed and how each part will be manufactured/bought/assembled. The goal here is to attempt to manufacture/assemble all parts using the resources provided from CWU. The assembly of the jack will take part in 4 sections, section 1.) The lower and upper frame will be assembled/welded; this is the foundation of the jack. 2.) The brackets will then be welded to the upper and lower frame. 3.) The link arms will be assembled with the pins and placed into position, the cotter pins will also be push fitted through the drilled holes in the link arm pins. 4.) The final step in the assembly process is to
assemble the middle connector pins and the hydraulic cylinder and make sure the components are tight with little to no movement in the center of the jack. The overall jack is composed of 36 parts, with 3 subassemblies (refer to the parts list below for further part information).

**Lower/Upper Frame Construction:**
The square stock with dimensions 1” x 1” x 0.120” is hopefully obtained from the CWU machine shop, if CWU doesn’t have the resources then it will be purchased from Fastenal. The square stock will then be mounted and cut with a table saw at 45° at the desired lengths (provided in Appendix B). This procedure will be done a total of 8 times to create all the components to build the lower and upper frame. The drawing of the upper and lower frame pins can be found in Appendix B-1 to Appendix B-4.

**Link Arm Construction:**
The link arms are made from the same AISI 1020 square stock as the upper and lower frame so hopefully when obtaining the resources there is enough square stock left for the link arms, if not then it will be purchased from Fastenal. The link arms will all be cut to a standard length of 21.25-inches using a table saw in the machine shop, the ends will then be filleted with a radius of .10-inches, and this radius isn’t set in stone as the fillet is only there for physical appearance and a smooth surface finish. The drawing of the link arms can be found in Appendix B-6.

**Bracket Construction (Part Removed from Design):**
The brackets will be purchased from APS, the bracket dimensions are Width = 1.75”, B = 1.5”, H = 1.75”, Thickness = 0.125” and are made from AISI 1020 SS. The brackets will be purchased because overall it is more cost effective and time efficient to purchase the 8 brackets rather than have to mill each bracket by hand. Purchasing the brackets will ensure quality control, as well as allow time to be spent on other components of the Auto-jack. The drawing of the bracket can be found in Appendix B-5.

**Link Arm Peg Construction:**
The link arm pegs have a 0.50” moon shape milled into the peg so the link arm sleeves can be welded flush into the moon. The pegs a manufactured from AISI 1020 Steel, the process begins by mounting the precut pegs into the milling machine and chamfer down each edge using a specialized chamfer milling tool. Tolerances were not important during the chamfering process, the chamfers were just milled to break edges and ensure the peg would slide freely into the 1” x 1” square stock.

**Link Arm Pin Construction:**
The pins are composed of AISI 1020 round stock hopefully obtained from centrals machine shop, if the round stock can’t be obtained then it will be purchased from MSC Industrial Direct Co. The round stock will be mounted in a vice and cut using a table saw or hacksaw to 1.75-inches for lower frame and 1.50-inches for the upper frame. Two small 1/8” holes will be laid out and drilled using the Bridgeport drilling machine in the machine shop. The ends of the pins will then be deburred using the bench top grinder; this creates a smooth/round edge where the pins were cut. The drawing of the link arm pins can be found in Appendix B-4.

**Middle Connector Pin Construction:**
The middle connector pins are composed of AISI 1020 round stock hopefully obtained from centrals machine shop, if the round stock can’t be obtained then it will be purchased from MSC Industrial Direct Co. The round stock will be mounted in a vice and cut using a table saw or hacksaw to 2.5-inches. The ends of the pins will then be deburred using the bench top grinder; this creates a smooth/round edge where the pins were cut. The drawing of the middle connector pins can be found in Appendix B-7.

Parts List/Labels:
The parts list, labels and budget excel sheet can be found in Appendix C-1.

Drawing Tree:
The drawing tree is broken up into two components, the frame assembly and the hydraulic assembly. The frame assembly is composed of 9 branches indicating the drawing I’Ds for each branch, the drawing tree/I’Ds and the drawings for Auto-Jack can be found in Appendix B.

Benchmark Comparison:
The jack frames size is much larger than the benchmark for this project, but the Safe-Jack Gator Jack (benchmark) is only capable of lifting 1 tire, while the Auto-jack is able to lift the entire rear-end/front-end. Although the size is roughly 50% larger the overall efficiency and safety is up 95%, with a 32” vertical height lift and square 4-foot frame the Auto-jacks performance well surpass the Safe-Jack Gator Jack. The Auto-jack also features a closed height of under 3-inches while the Gator Jack has a closed height of 7.25-inches, which is a 59% smaller closed vertical height. On top of safety and performance the Auto-Jack features a sleeker design with a powder coated shell and ball transfer wheels so no lifting is required.

Final Bare Frame Assembly:
The assembly below is the final bare frame assembly, this contains only the framework of the autojack assembly. The drawing for this assembly can be found in Appendix B-12.

Manufacturing Issues:
Lower Frame Alignment Issues:
The lower frame needs to sit perfectly flush with the ground with no variances/twists in the square stock frame. The welding process took place on a steel shop table, ideally the table should be flat and level, but after the welding process began it was clear that levelness of the frame was impacted by the table being slightly asymmetrical. The table caused the jack to lay uneven, this issue was resolved by cutting the welds, regrinding the square stock edges and placing metal shims under the lower frame components until they were level. Once the components were level the parts were tack welded to hold them in place before the final welds were made, this process ensured that the jack frame would lay plumb against the floor.

Milling Square Bar for Link Arm Insert:
A big issue was that the solid bar didn’t sit level in the milling vise, when the cutting process began it became evident that when the final cuts were made more than the desired amount of material was taken off. This material was not to spec and would no longer fit snug inside the link arm, the material had to be wasted and was unusable. The mistake that was made was attempting to mill down the whole 24” rod, to fix this issue the rod was cut into 2.5” sections (which were the size of the inserts) and then were milled down to nominal size. Undertaking the milling process in this way ensures that the entire rod is mounted into the vise and will sit level throughout the milling process. This attempt to mill down one full length piece and save time ended up costing the project more time and money in the long run.

Lower Frame Pin Hole Alignment:
The lower frame has two holes drilled on both sides with a center distance of 2.50-inches, successfully aligning these holes with the upper frame will be very difficult to do. These holes will need to be laid out on the long square stock components before the frame weldment takes place. This will guarantee the concentricity of the middle connector pins, if these holes aren’t concentric from hole layout the middle connector pins will be offset and the jack will fail. A way to ensure concentricity is to align the holes before the frame weldment takes place, the holes will be laid out and mounted into the vice of Bridgeport to ensure low tolerances.

Middle Connector Pin Alignment:
The middle connector pin alignment is derived from the lower frame pin alignment if the lower frame pins aren’t aligned from layout the middle connector pin won’t be concentric with the upper and lower link arm sleeves. To ensure that this doesn’t occur the link arms will be laid out and tack welded in place to ensure all link arms the same length and the sleeves are all concentric.

Ensuring Lower/Upper Frame Pin Alignment:
The frame hole location was a crucial aspect of the part, if concentricity wasn’t present the link arms wouldn’t mesh and the Auto-jack would fail. To ensure that the holes were drilled in the exact location in both the upper and lower frames C-
clamps were used on all four corners of frame during the drilling process. With the frames clamped together the frames were then mounted in the vise and the holes were drilled. The drilling process consisted of drilling through both frames in one pass.

**Part Modifications:**
An abundance of part modifications have been made during the construction of the final Auto-jack, the largest modification that has taken place was the removal of the link arm pin bracket (added welded pin and swinging I-bolt). The reason for this modification was to eradicate the friction coefficient, the friction in the bracket would have exerted a larger force on the pin and caused the pins life expectancy to decrease greatly, it also would have been extremely loud during operation. The new part is a machined sleeve where friction can almost be neglected due to a machined surface, and also a sufficient amount of clearance between the pin and the sleeve.

**Other manufacturing issues:**
Some other smaller manufacturing issues that occurred during this project were hole alignment for the power unit. The layout method to ensure the holes were aligned properly was extremely difficult because the holes were on the reverse of the power unit and not accessible, meaning it was a blind attempt to layout the holes efficiently.

**Figure 2-5:**
The picture to the right shows the power unit plate drilling. The issue that occurred was due to misalignment of power unit holes. The resolution was to drill the holes one std. drill size to large and use a washer to allow the bolts to not be misaligned. Drilling the holes one size to big allow the bolts to be aligned, the washer ensured the bolt wouldn’t feed through the drilled hole.

**Performance Predictions:**
The efficiency of the device is rated to be 85% more efficient than the benchmark used for this project. The efficiency is solely based on the overall lift height, weight, lift speed, and ease of using this device. Based on the calculations/analyses and Solidworks model/drawings the efficiency of this device will well surpass the benchmark device.

**TESTING METHODS**

**Strength Test Methods:**
A 5000-lb test vehicle will be used to determine if the jack is capable of lifting the vehicle 2-ft off the ground. A safe testing area will need to be arranged. A pulley system will support the car just in case the frame fails, and this will keep the car undamaged. If the jack were to fail and the pulley support system wasn’t present it could potentially cause damage to the user and the test vehicle. If this test cannot be performed and the resources cannot be acquired then a compressive test could be performed on the jack to determine if the hydraulic cylinder and frame can support a 5000-lb loading at different lift angles. This compressive test is a lot safer than using a test
vehicle but it won’t produce the same results. A testing garage has been pre-arranged to complete the initial strength and performance test.

**Alternate Strength Test:**
If the above strength test can’t be completed and alternative strength test will be done using the same 5000-lb test vehicle. This strength test will be done only lifting up half of the vehicle to ensure the jack frame will not collapse. This test is simply a safety test to ensure the final strength test will be able to be achieved without collapse.

**Sway test:**
This test is designed to determine how much the Auto-jack displaces from the top frame to lower frame when a side load is applied to the jack. This test will be conducted using the hanging scale acquired from the machine shop and anchoring it to the top of the jack frame. A variety of loads will be applied by pulling the scale horizontally, the displacement can then be measured using a square from the top frame. The jack frame should not displace more than 1 inch regardless of what the side load is (under 100-lbs set requirement).

**Hydraulic Pressure Test:**
An initial pressure test will be performed on the hydraulic cylinder before it is mounted into the jack to ensure that cylinder will be able to withstand the pressure needed to efficiently support/lift the 5000-lb loading. Refer to Hydraulic/Pneumatic part of this project for further hydraulic/pneumatic cylinder and pump testing methods.

**Overall Frame Weight Test:**
A scale accurate to the tenth of a pound will be used to test the overall weight of the jack frame, since the frame will already be assembled the weighing process will be simple. This weight test will determine if the initial design requirement was met and if the jack proves efficient.

**Overall Closed Height Test:**
This test will be completed by collapsing the frame entirely until the hydraulic cylinder is completely extended, then measuring the closed vertical height of the jack frame using a tape measure. This measurement will determine if the initial design requirement was met and if the jack proves efficient.

**Test #1 Description (Lift Height vs. Time):**
Test number one was a dry lift test (without a car), to determine if the jack was capable of meeting the 2-in/s of lift design requirement, in addition to achieving a total lift height of greater than 2 feet. The resources that were used to complete this test was a stop watch and a tape measure, the completed data sheet can be found in Appendix I-2. The first test proved the Auto-Jack’s success, once all link arms and sleeves were greased/lubricated seven test trials were performed. Throughout the seven test trials the max lift height was reached during each trial, the max lift height was measured to be 32.25-in, which is well over the 2-ft (24-in) design requirement, this is total height increase of over 34%. This height will allow the user to perform maintenance underneath the vehicle with ease. The other portion of this test focused on the time it took for the jack to reach the full lift height of 32.25-in, and the average lift per second of time. A stopwatch was used to record the total elapsed time until the jack was fully lifted, the first trial
yielded a time of 7.37-sec. After the seven trials were completed an average lift time of 7.33 seconds was calculated. Since the jack is being lifted with hydraulics and the fluid pressure is constant inside the cylinder the total time can be divided by the max lift height to determine the time it takes the cylinder to lift the jack 1-inch, this time was calculated to be 4.40-in/sec, this is well above the design requirement initially set for the jack.

**Test #2 Description (Strength Test):**
The second test was the physical vehicle lift test, basically proving if the Auto-Jack is capable of lifting the test vehicle. The test vehicle being used to complete the lift test was a 2001 Ford Ranger Edge 4x4, which is the heaviest ranger Ford manufactures. Initially the tests were going to be conducted using a 2001 Honda CRV, unfortunately when mounting the gauge to the cylinder the jack wouldn’t fully close, which ultimately meant the jack wouldn’t fit underneath the CRV’s rear differential. The first trial was conducted and deemed successful the Auto-Jack was capable of lifting the rear end of the truck with ease, Approx. 1336-lbs. The force on the jack was found using the equation in Appendix G, this appendix also includes the datasheet for final completed test. After completing the test and analyzing the data it was clear to see that the pressure is linearly proportional to the weight on the jack, as the pressure in the system increases the force on the jack increases, which is what was concluded before the test was initiated. In conclusion the hypothesis generated and the success of the jack were both satisfied after completing this test. The next test will involve lifting the entire vehicle approx. 4500-lbs, theoretically since the jack is only operating at 1/3 of its capable system pressure, lifting the entire vehicle should be no issue.

**Testing Description:**
The testing process will begin on March 25, 2019, the first test that will be conducted will be the overall strength test. This test will be completed by first attempting to lift half the vehicle, if the Auto-Jack can safely and efficiently lift half of the vehicle then the full vehicle lift test will begin next. A standard car jack will be placed under the vehicle (apply pressure to the frame) to ensure that if indeed the Auto-Jack fails there will be no damage done to the test vehicle.

Once the Auto-Jack has been deemed successful and the strength tests have been conducted, the next testing method will be to test the overall extended vertical lift height. This test will be completed by measuring the vertical displacement from the bottom of the vehicles rear bumper (height difference from before/after lift). The set requirement for this is a two foot vertical lift, if the Auto-Jack is capable of lifting the test vehicle two feet off the ground the testing will proceed, but if the requirement isn’t met further modifications will need to be made to hit the design requirement.

The final testing methods include overall length measurement, this is simply done by measuring the overall horizontal length of the Auto-Jack and ensuring it fits properly underneath the chassis of the vehicle. The final test conducted will be the stability test, this test ensures the safety of the Auto-Jack when an external force is acting on the car. This test fortifies that if the car is bumped or jerked the Auto-Jack won’t collapse and the vehicle won’t slide of the jack. Similar to the strength tests a vehicle jack will be placed underneath the vehicle applying pressure to chassis while a side load will be exerted on the vehicle, if the jack appears to be sound and resists the
urge of swaying the stability test will be deemed successful. The deflection test that was originally going to be conducted was superseded by the stability test.

**Deliverables:**
Deliverables can be found in Appendix G-I of this engineering report.

**PROJECT MANAGEMENT**

**Cost & Budget:**
The entire jack frame must cost under $750 to manufacture. The overall goal is to keep the material cost below the desired amount. The material abundance will be one of the biggest contributing factors that will affect the overall cost of this project. Using AISI 1020 steel keeps the material abundance high; this type of square stock steel is extremely cheap to purchase yet yields the strength needed for the frame. Refer to Appendix C-1 for the complete budget and parts list.

**Cost & Budget Changes:**
The Auto-Jack is still well under the proposed budget for this project even though a few changes and part modifications have been made. The big change that affected the overall budget of the jack frame was the link arm insert addition; this part addition cost an additional $50.00 on top of the proposed budget. Luckily enough, the hydraulic motor system (most expensive component of this project) cost $200.00 cheaper than what was initially budgeted, this allocated some extra funds to be used on any change orders during the manufacturing process.

Another change that affected the budget was the elimination of the steel dowel pins; the dowel pins purchased were Rockwell hardened C52 pins. After further analysis it was evident that these were quenched and fully hardened pins instead of being case hardened, this ultimately meant they couldn’t be machined. The ten dowel pins were no longer being used in the project and a replacement part had to be ordered. The original cost of $29.74 had to be taken out of the original budget even though the pins were no longer in use.

Any extra funds at the end of this project will be used to further enhance the “ease of use” of the Auto-jack frame. One anticipated feature will be adding wheels to the power unit plate, this will allow for easy moving during the lifting process. These additions will be made once the Auto-jack is and deemed successful.

**Final Budget Overview:**
As of February 1st, 2019 all parts have arrived to their final destination and no other parts will need to be purchased. The total cost for the project at this point (after all parts have arrived, and all changes have been made) is $625.55, which is well under budget.

The budget has been officially revised and can be located in Appendix C-1 the final cost for the entire project is $732.94, this is $17.06 below the proposed budget of $750.00. The total cost of the bare frame was approx. $375.00, this cost is reflected in Appendix C. The final cost includes shop labor and all purchased parts, the finalized budget excludes all extra parts that central provided (i.e. gear rod, zip ties, bolts & fasteners, hydraulic fittings, and hydraulic plugs). No
other cost/budget changes should occur as the project is currently in its final state and no other modifications will be necessary.

Schedule:
The main schedule for this project is expressed in the form of a Gantt chart, the Gantt chart can be found in Appendix E. The Gantt chart is split up into three sections; the sections include Design & Analysis (Fall Quarter), Methods & Construction (Winter Quarter), and Testing (Spring Quarter). The first section of this project is presented in the form of a proposal, which includes all design, analysis, scheduling, budget, and drawings for the overall project. The next section focuses on the construction and implementation of the design of the Auto-Jack, the construction will include all drawing trees, parts and budget lists, and any manufacturing issues that arose during the construction of the Auto-Jack. The last section features the testing of the final device, which entails the description, methods, and testing processes used to determine the success of the project.

The biggest factor that will impact this schedule will be obtaining the materials within the desired time frame. A lot of square stock and round stock is needed, if central doesn’t have this metal in-house then it will need to be purchased from third party retailer in order to get the best price. This transaction will the take more time than anticipated and may affect the overall schedule of this project.

Schedule Issues/Revisions:
The project schedule has been revised as of 01/25/2019, the revisions have been added to the part construction section of the Gantt chart. The changes were made due to the fact that some of the parts are no longer being manufactured and have been eliminated from the design entirely. The link arm bracket has been eliminated and the pin applications have also been changed, these changes affected the overall schedule of the project. Time had to be allotted for the manufacturing of the new link arm inserts and the swinging I-bolts, this created a delay on the project and caused the project to be behind schedule by about a week. Extra time was spent in the machine shop to get the project back on schedule and finish the newly added components.

The project remains well ahead of schedule as of 05/08/2019, the last couple weeks have consisted of making final adjustments and finalizing the jack so that it is in presentable condition by the time source arrives. There have currently been no schedule changes in the past couple of weeks, refer to the Gantt chart for the most updated schedule if necessary. The overall testing of the Auto-jack has been successfully completed and can be located in Appendix G-I of this engineering report. There are no longer any time constraints weighing on this project as it is nearing completion, further modifications and adjustments will be made as seen necessary during the finalizing process. If any foreseen problems arise and schedule changes need to be made they will be documented.

Proposed Total Project Time:
Referring to the Gantt chart the proposed project time is approximately 300 hours of work over a span of 8 months. The proposal consisted of about 120 working hours to finish, the construction is pre-determined to take around 100 hours, and lastly testing will take around 55 working hours to finish.
Milestones:
- Finish entire proposal by Dec. 04, 2018
- Finish construction and Implementation of design by March 7, 2019
- Present a fully successful device by May 30th, 2019

Physical Resources:
- Hogue Machine Shop
- Hogue Hydraulics Lab
- Hogue Materials Lab
- Test Garage (Lake Tapps, WA)
- Hogue Technology Computer Lab
- Hogue Welding Lab

Software Resources:
- Microsoft Word
- Microsoft Project
- Solidworks 2018
- Microsoft Excel
- Wix.com Website Creator

Human Resources:
- See acknowledgements

Financial Resources:
This project has no funding and no sponsors, this device is being paid for out of pocket.

DISCUSSION

Project Progression:
This project has changed exponentially from the first design that was conceived, in the beginning the design of the jack frame featured an X-Frame design, which after further analyses was determined that this frame wouldn’t work because the vertical lift height needed couldn’t be achieved with this design. The first X-Frame design also had the hydraulic cylinder angled from the lower frame to the upper frame similar to an industrial scissor lift. Both of these components changed during the projects progression, in order achieve the design requirements the frame had to changed so that the link arms were bending outward instead of inward and also the hydraulic cylinder will now act as reverse hydraulic cylinder (stroke acting in both directions, same force pushing and pulling) resting in the middle of jack frame and completely horizontal.

Another big aspect that has been changed sporadically throughout the design of this device was the link arm mounting brackets. Initially the brackets rested on top of the lower frame and underneath the upper frame, this allowed a small increase in vertical lift, but once the analyses began it was evident that the jack frame wasn’t going to meet the closed vertical height requirement if these brackets were position this way. The brackets were then redesigned and repositioned on the jack frame so that the bracket only protruded 0.50-inches beyond the frame.
The final big change that was made during the design phase was the dimensions of the upper and lower frame. Originally the upper and lower frame were both designed using the same dimensions which were 48-inches long by 12-inches wide. As the project progressed it was evident that the link arms would not be compatible and they would fail (no space between arms for the pin). In order for the link arms to mesh perfectly the length and width of the upper frame needed to be 2-inches smaller on each component, this would allow the link arms surfaces to be coincident after assembly.

One of the biggest problems that occurred during this design was the mating issues with final assembly of the jack frame. When the middle link arm mounting rods were mated concentrically into the final assembly the device kept failing, this was due to the concentricity problem with the pinholes on the jack frame. The lower and upper frame pinholes weren’t aligned correctly from original drawings, so a jack frame redesign was needed in order to have a successful device.

**Manufacturing issues/Design changes:**
Throughout the construction phase of the Auto-jack multiple aspects of the design has changed, and an abundance of manufacturing issues have arose. The big design changes that took place were the elimination of the pin brackets due to a great amount of friction present. The brackets were eliminated and replaced by a manufactured swinging I-bolt, this bolt acts as a bearing and reduces the resisting frictional force. The other large change that occurred was the drilled pin holes on the link arms, a steel insert was manufactured to weld directly on to the swinging I-bolt, and now the link arms consist of no drilled holes. This insert reduces the localized stress concentration on the link arm pin hole.

A lot of unanticipated manufacturing issues occurred during the insert and swinging I-bolt manufacturing process. Machine mounting capabilities were one of the big problems that was overcome during the manufacturing of both of these components. A big issue was that the solid bar didn’t sit level in the milling vise, when the cutting process began it became evident that when the final cuts were made more than the desired amount of material was taken off. The square bar had to be cut down to 2.5” sections to ensure levelness when mounting it into the milling vise. A similar problem occurred with the round bar, initially the cutting process was going to be taken out using the lathe to create a smooth cut surface on each 1” section. Since a large portion of the material was sticking out of the chuck of the lathe the round bar was off balance, the solution to this problem was to once again cut the material down to 1.25” sections and face each section down to 1” +/- 0.05”.

The final design change was made on 04/10/2019 after the first test was initiated, after the first test it was evident that the jack exceeded the 50-lb initial design requirement. A modification was made to the top frame, this modification had no effect on the Auto-Jacks strength/structure it was only made to remove unnecessary weight. The modification consisted of designing a flat 12” x 12” x ¼” plate that was welded to the top of the frame, resting above the link arm gears. The long upper frame could then be cut down to a 12” x 12” section removing roughly 10-lbs of 1020 AISI square stock, this now allowed the jack to pass the weight test. After these modifications were made the final weight of the jack was just under 47.50-lbs which is 2.50-lbs lighter than the 50-lb weight requirement.
Testing Issues/Design Modifications:
The biggest design modification that was implemented after the first test was the link arm gear, without the gear the Auto-jack frame wouldn’t remain vertical when lifted. Once the gear was added to the link arms the second lift (lift height vs. time) test could be successfully completed. One issue that was addressed was the issue of rapid lift during the first 1”-2” of lift, this was due to hydraulic cylinder stroke being fully extended. When the stroke is fully extended it takes an enormous amount of pressure to begin pulling in the hydraulic rod, which causes the rapid lift and the jack to jolt. This issue was mitigated during the lift trials by starting the test with the cylinder just slightly retracted to ensure the jolt and the rapid lift won’t occur. This test method allowed a smooth lift and a more accurate set of data.

Project Documentation:
All project documentation can be found in the Appendix of this proposal; the documentation includes drawings, analyses, schedule, parts/budget lists, safety hazard forms, etc. If reference material is needed, please refer to the Appendix of this engineering report.

Project Risk Analysis:
There is a substantial amount of risk that takes place during the construction of this device, the risks range from welding risks, to jack collapse and hydraulic leaks. Always following the proper PPE standards will minimize the risks present, as well as always having a certified/authorized individual overseeing the testing processes. If compliant with these standards the risk factors present during the construction will be minimized. There was no risk present during the design phase of this project, the risk analysis hazard sheet can be found in Appendix J of this engineering report.

Next Phase:
The next phase of this project is the construction of this device; the build process will begin January 3rd, 2018. The process will begin by contacting manufactures/ordering the materials for the Auto-jack. Once all the parts/materials are purchased and shipment has arrived the building process will begin.

CONCLUSION

The final Auto-Jack frame was able to meet all design requirements by the end of the design phase; the jack frame also surpassed other features than the benchmark used for this project. The overall budget for this device came in well under the benchmark; this means that further physical appearance upgrades will be made if time is plentiful. The biggest innovation that was made during this project was the safety features of this device; the safety features include the 3-foot frame surface to vehicle contact area, as well as the quick disconnect air hose adapters. The sturdiness and ductility of the Auto-jack will allow the user to operate this device without having to worry about jack stand failure and vehicle slippage. The Auto-jack minimizes almost all risk factors that are present when lifting a vehicle.

The Auto-jack is capable of lifting the vehicle at a rate of 4-inches per second; this is twice as fast as the leading benchmark. The Auto-jack also features a user-friendly appearance with minimal operations, the user can simply place the jack under the car and the let the hydraulics do
the rest. This device cuts the time and operational skills down to a minimum, while keeping safety its number 1 priority.

On top of this device meeting all set design requirements this project also meets all the parameters for a successful senior project.
1. Shows substantial engineering merit in stress analysis, reactionary forces, and structural design.
2. The size and cost of this project is within the parameters and resources available
3. Proves efficiency in design, teamwork to principal investigator

Final Device Performance Increase:
1. Jack lift speed increased by 50%
2. Operational process was cut down by 30% (ease of use)
3. Safety was increased by 100%
4. Lift capacity increased by 27% of the benchmark
5. The cost of the final device decreased by 40% of benchmark

ACKNOWLEDGEMENTS

Central Washington University – Provided the use of the Machine Shop, Materials Lab, Welding Shop, Hydraulics Lab, and logistics to successfully achieve the final device.

Dr. Craig Johnson – Central Washington University: Provided guidance throughout the design phase of this project.

Dr. Charles Pringle – Central Washington University: Provided guidance throughout the design phase of this project.

Jeunghwan Choi – Central Washington University: Provided guidance throughout the design phase of this project.

Ted Bramble – Central Washington University: Provided assistance with access to the machine and provided guidance in manufacturing processes for this device.

Sponsors: No sponsors were present for this project.
A-1: Solving for the support forces that the link arms provide to the top frame.
A-2: Solving for the Deformation in the top frame using the deflection formula

**Given:**
- Weight of car
- Load on Jack
- Dimensions of beam
- \( E = 29,700 \, \text{ksi} \)
- AISI 1060 Steel

**Find:** Maximum deflection of the beam

**Method:**
1. FBD
2. Use Appendix for constants
3. Find Inertia
4. Solve for \( S_B \)

**Assumptions:**
- Weight of the device is negligible

\[
S_B = \frac{qL^4}{8EI}
\]

\[
I = \frac{A_h^4}{12} - \frac{a^4}{12}
\]

\[
I = \frac{(\text{in})^4}{12} = \frac{(0.374225 \text{ in}^2)^4}{12}
\]

\[
I = 0.03768 \text{ in}^4
\]

\[
S_B = \frac{138.9 \text{ #/in} (17 \text{ in})}{8 (29700000 \text{ psi}) (0.03768 \text{ in}^4)} = 0.87927 \text{ in}
\]
A-3: Shear and moment diagrams for the continuation of A-2
A-4: Solving for the square stock thickness needed to support the desired 5000# load

\[ \Sigma F_y = 0 \]
\[ B_y - 2500 \# = 0 \]
\[ B_y = 2500 \# \uparrow \]

\[ A_x = -1562.5 \# \]
\[ A_x = 1562.5 \# \]

\[ \Sigma M_c = 0 \]
\[ -2500 \# (17in) - B_x (9.64in) = 2500 \# (4in) + 2500 \# (19in) = 0 \]
\[ B_x = -1562.5 \# \]
\[ B_x = 1562.5 \# \]

\[ \text{Symmetry} \]

\[ A = \sqrt{2500^2 + 1562.5^2} = 2932 \# = A \] (in)

\[ \text{Solving for thickness needed:} \]
\[ \sigma = \frac{M}{I} \Rightarrow I = \frac{M}{\sigma} \]
\[ I = (2in)(2500 \#)(0.25in) = 0.0205 \text{ in}^4 \]
\[ \frac{60900 \text{ psi}}{60900 \text{ psi}} \]

\[ I = A^2 + A^2 \]
\[ 0.0205 \text{ in}^4 = \frac{A^2}{12} + \frac{A^2}{12} \]
\[ A^2 = 0.734 \]
\[ A = 0.9318 \text{ in} \]
\[ 1 - 0.9318 \text{ in} = 0.06816 \text{ in thick} \]

Thickness of square stock needed

\[ 0.06816 \text{ in} \]

\[ \text{Thickness} \times SF = 0.06816 \text{ in} \times 1.5 = 0.10226 \text{ in} \]

*Use standard size 1\times1\times0.120".*
A-5: Solving for the cylinder and stroke size needed to support the 5000# load
A-6: Determining the minimum thickness needed for AISI 1020 Bracket

Given:
- Design Req. and Safety Req. (Bracket must withstand 5000 lb load)
- Bracket Design
  - Pin size = 0.50" (from manufacturer)
  - Link arms force $F_a = 1562.5 \text{ lb}$
  - Force $F_f = 2500 \text{ lb}$
- Material AISI 1020 Steel
  - Flange Face Width = 0.50-in
  - $SF = 1.5$

Find:
- Thickness of bracket needed to support arm loading.

Assume:
- Weight can be neglected
- Bracket in double shear

Solution:

Methods:
1.) FBD
2.) Solve for reactions (V/Iz diagram)
3.) Shear Stress in Bracket
4.) Solve for Bracket thickness

Normal stress in bracket (double shear):

$$\sigma = \frac{F}{A}$$

$$\sigma_{1020 \text{ steel}} = \frac{57249 \text{ psi}}{2500 \text{ lb}}$$

57249 psi = 2500 lb

$$0.5(+) = 0.04367 \text{ in}$$
$$0.5$$

$$SF \times 0.0873 \text{ in} =$$

$$+ = 0.13075 \text{ in}$$

Minimum thickness needed:

Thickness = 0.13075 in
A-7: Bracket re-design (After further design this bracket proved incompatible with device)

Given:
- Design Req. and Safety Req. (Bracket must withstand 5000-lb loading)
- Bracket Design
- Pin size = 0.40 in
- Link arm force \( F_x = 1662.5 \) lb
  \[ F_y = 2500 \] lb
- Material AISI 1020 Steel
- Front face width = 1.25 in
- SF = 1.50

Find:
Thickness of bracket needed to support arm loading

Assume:
- Bracket weight can be neglected
- Bracket in normal bending stress

Solution:

Method:
1) FBD
2) Solve for reactions (V, M diagram)
3) Normal stress in bracket
4) Bracket thickness

Normal stress in bracket
\[ \sigma = \frac{F}{A} \]
\[ \sigma_{max} = 57249 \text{ psi} \]
\[ \frac{57249 \text{ psi}}{0.625 \text{ in}} = 2500 \] lb
\[ \frac{57249 \text{ psi}}{0.625 \text{ in}} \]
\[ \frac{0.625 \text{ in}}{0.625 \text{ in}} = 0.00367 \text{ in} \]
\[ + = 0.06987 \text{ in} \]
\[ SF \times + = 1.5 \times 0.06987 \text{ in} \]
\[ + = 0.1048 \text{ in} \]

Max stress = 1250 lb

Max moment = 781.25 lb-in

Min thickness = 0.1048 in

A-8: Determining diameter of middle link arm connector pins

Given:
- Design Req and Safety Req. (Pin must withstand 5000-lb load)
- Pin design
- Link arm spacing and dimensions
- Link arm force $F_x = 1562.5\ \text{lb}$
  $F_y = 2500\ \text{lb}$
- Material = AISI 1020 Steel
- $SF = 1.50$

Find:
Pin $\varphi$ to support loading

Assume:
- Weight can be neglected
- Pin in double shear

Solution:
\[
\begin{align*}
1562.5\ \text{lb} &\rightarrow 1562.50\ \text{lb} \\
2500\ \text{lb} &\rightarrow 2500\ \text{lb}
\end{align*}
\]
Shear in pin = 2500 lb = $V$

Method:
1. FBD
2. Normal Stress
3. Diameter of pin

\[
\gamma' = \frac{V}{A}
\]
\[
\gamma' = \frac{2500}{\pi (D^2)}
\]
\[
41000\ \text{psi} \left(\frac{\pi}{4} (D^2)\right) = 2500\ \text{lb}
\]
\[
\frac{\pi}{4} (D^2) = 0.06098
\]
\[
\sqrt{D^2} = 0.07764\ \text{in}
\]
\[
D = 0.27863\ \text{in}
\]
* Min Required diameter

\[
1.5 \times 0.27863\ \text{in} = 0.41795\ \text{in} \text{ after } SF
\]

Standard size = 0.50"

Answer:
Min Required $\varphi = 0.41795"$

Tolerance:
Manufacture tolerance 0.005"
A-9: Determining the minimum diameter needed for link arm pins

**Given:**
- Design Req and safety Req. (Pin must withstand 5000 # load)
- Pin Design
- Bracket size and dimensions
- Link arm's Force: $F_x = 1562.5 \#$
- Material AISI 1020 steel
- SF = 1.5

**Find:** Pin $d$ to support loading

**Assume:**
- Weight can be neglected
  - Pin in double shear

**Solution:**

$$d = \sqrt[3]{\frac{41000 \times 1250}{0.030488}} = 0.19702 \text{ in}$$

**D**: $0.19702 \text{ in} 	imes 1.5 = 0.29553 \text{ in}$

*Standard pin size = 5/16 1020 steel, Dowel pin*
A-10: Determining the overall link arm length

Given:
- Frame Dimensions
- Lift Height Needed (Vehicle lift)
- Angle of link arms
- Square Stock Dimensions

Find:
Link arm length needed to lift the vehicle greater than 2 ft off the ground.

Method:
1.) FBD
2.) Create triangles w/ Frame
3.) Determine Angles / Sides
4.) Solve for the Vertical Component

Solution:

First value test
Cylinder stroke = 15°
Vertical height = 12 in
Link arm L = ?

L = \sqrt{12^2 + (15)^2} = 19.21 in

Second value test (26° cylinder)
Cylinder stroke = 13.25°
Link arm = 21.25°

height = \sqrt{(21.25)^2 + (13.25)^2} = 26.93 in

Answer:
Actual Link Arm Length = 21.25 in
Vertical lift height = 34.86 in
Closed Cylinder Length = 28.5 in
A-11: Determining overall weight of bare frame (without hydraulics)

Given:
- Diagram with all dimensions
- Square stock dimensions (determined from analysis)
- Material = AISI 1020 steel
- Bracket weight from Solid Works drawing
- Pin weight from Solid Works drawing
- Upper/Lower Frame Dimensions

Find:
Overall weight of bare frame (without hydraulic cylinder or mounting rod)

Method:
1.) Determine the # of each part
2.) Obtain weights from Solid Works
3.) Total weight of frame

Solution:

Upper/Lower Frame

- Upper Frame weight
\[ W = 10.61 \text{ lbs} \]
- Lower Frame weight
\[ W = 11.09 \text{ lbs} \]

Link Arm Brackets

Total Brackets Needed = 8
Weight of 1 Bracket = 0.1493 lbs
Total Bracket weight = 0.1493 lbs x 8
\[ \text{Total weight} = 1.194 \text{ lbs} \]
A-11: Weight calculations continued...

Link Arm pin

- Total # of pins needed = 8
  - Weight of (1) pin = 0.07 lbs
    - Total weight = 0.56 lbs

Middle connector pins

- Total # of pins needed = 4
  - Weight of (1) pin = 0.17 lbs
    - Total weight = 0.68 lbs

Welds

- Est. Weld weight per ft = 4 ft of welds = 4.8 inches
  - Total # of feet of weld = 0.072 lbs
    - Total weld weight = 3.456 lbs

Link Arms

- Total # of Link arms needed = 8
  - Weight of (1) Link arm = 2.57 lbs
    - Total weight = 20.56 lbs

Total weight of Frame

- Weight of Base Frame = 21.7 lbs + 1.194 lbs + 0.56 lbs + 0.68 lbs + 3.456 lbs + 20.56 lbs
- Weight = 48.15 lbs

Answer:

- Total weight = 48.15 lbs

Tolerance:

- +/- 1 pound
A-12: Closed Jack Frame Height (Vertical Height)

Given:
- Jack Frame Open Dimensions
- All Jack Component Dimensions

Find:
Closed Jack Frame height

Solution:
Overall closed length

\[
\text{Overall closed length} = 1'' + 1'' + 0.50'' = 2.50''
\]

Answer:
Overall closed height = 2.50 inches

Tolerance:
Part tolerances ± 0.05 inches
Drawing Tree

D = Drawing Number in Appendix B

- Lower Short Side 45° Square Stock
- Lower Short Side 45° Square Stock
- Upper Long Side 45° Square Stock
- Upper Short Side 45° Square Stock
- Welds
- Link Arms
- Link Arm Pins
- Middle Connector Pins
- Cotter Pins

Hydraulic Cylinder
- Mounting Rod
- Pneumatic Motor/Pump
- Check Valve
- Quick Disconnect Hose

Frame Assembly

Auto-Jack Vehicle Lift
Appendix B

B-1: Lower frame angled square stock part drawing 12” side
B-2: Lower Long Square stock side components
B-2: Upper Long Square stock side components (Revision)
B-3: Upper Frame Short Side Component

OPERATION NOTES:
1. CUT MATERIAL TO LENGTH USING MITER SAW ANGLED TO 45 DEGREE
2. REMAINING END IS MITERED TO 45 DEGREE
3. SAW ANGLED TO 45 DEGREE
4. ENDS MATCH EXCEPT FOR OTHER COMPONENTS

NOTES:
1. SQUARE STOCK SYMMETRICAL
2. COMPLETE MATCHING COMPONENTS
B-4: Link arm pin drawing
B-6: Link Arm Drawing
B-7: Link Arm Middle Connector Pins
B-8: Link Arm Peg
B-9: Pin Sleeve
B-10: Upper Frame Subassembly
B-11: Lower Frame Subassembly
B-12: Hydraulic Line Guide (Feeder)
B-15: Final Jack Frame Assembly
## Appendix C-D

### C: Budget list

<table>
<thead>
<tr>
<th>Item ID</th>
<th>Item Description</th>
<th>Item Source</th>
<th>Model/SN</th>
<th>Price/Cost</th>
<th>Quantity</th>
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**Total Parts:** 6

---

### D: Parts List

**Tyce’s Manufactured Parts List**

- (2) Link Arm Insert x 16
- (1) Cylinder Clevis Sleeve
- (1) PWR Unit Cart Plate
- (1) Cross Rods x 2
- (1) Hydraulic Line Guide
- (1) Differential Plate

**Total Parts:** 7

**Nick’s Manufactured Parts List**

- (1) - Lower Frame Short x 2
- (1) - Lower Frame Long x 2
- (1) - Upper Frame Short x 2
- (1) - Upper Frame Long x 2
- (1) - Link Arm Pins x 8
- (1) - Link Arms x 8

**Total Parts:** 6
# Appendix E

## E-1: Gantt Chart: Finalized Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
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<th>Duration (incl. HW)</th>
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<td>2b. Link Arm</td>
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</tr>
<tr>
<td>6d. Assemble Rod and Cylinder</td>
<td>Sat 2/2/14</td>
<td>Sat 2/2/14</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drone Calibration</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7a. Set Parameters</td>
<td>Sat 1/24/14</td>
<td>Mon 1/27/14</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7b. Design Test &amp; Score</td>
<td>Tue 1/28/14</td>
<td>Sat 2/1/14</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>7c. Flight Performance</td>
<td>Sat 2/1/14</td>
<td>Sat 2/1/14</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>7d. Make Test Sheets</td>
<td>Wed 2/5/14</td>
<td>Fri 2/7/14</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>7e. Fluid Analysis</td>
<td>Fri 2/14/14</td>
<td>Sat 2/15/14</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7f. Instrumentation</td>
<td>Wed 2/20/14</td>
<td>Wed 2/20/14</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>7g. General Test</td>
<td>Thu 2/15/14</td>
<td>Thu 2/15/14</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7h. Perform Flight Test</td>
<td>Fri 2/15/14</td>
<td>Sat 2/16/14</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>7i. Take Night Flights</td>
<td>Wed 2/20/14</td>
<td>Wed 2/20/14</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7j. Update Website</td>
<td>Sat 2/22/14</td>
<td>Sat 2/22/14</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drone Deliverables</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8a. Drift Report</td>
<td>Wed 2/26/14</td>
<td>Wed 2/26/14</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8b. Draft Report Draft</td>
<td>Sun 2/2/14</td>
<td>Wed 2/12/14</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>8c. Write Report</td>
<td>Wed 1/22/14</td>
<td>Tue 2/1/14</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>8d. Make Final Outline</td>
<td>Sat 2/1/14</td>
<td>Sat 2/1/14</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>8e. Create Presentation</td>
<td>Sat 2/1/14</td>
<td>Sat 2/1/14</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>8f. Check Out Deliverables</td>
<td>Sat 2/2/14</td>
<td>Sat 2/2/14</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>8g. Test and Check Deliverables</td>
<td>Sat 2/2/14</td>
<td>Sat 2/2/14</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>8h. Update Website</td>
<td>Sat 2/15/14</td>
<td>Tue 2/24/14</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>8i. Print CD</td>
<td>Sat 1/15/14</td>
<td>Tue 1/30/14</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Subtotal: 33.50
Appendix F
F-1: Expertise and Physical Resources

Matt Burvee:
Provided guidance during the manufacturing process, as well as helped determine where and what materials to order. Matt also offered design modifications and changes that would help improve the performance of the Auto-jack. In addition to his guidance he also physically welded some more complex aspects of the jack.

Physical Resources Acquired:
- Hydraulic fittings
- Hydraulic plugs
- Rear differential square stock and plate
- Weldments

Charles Pringle:
Provided design expertise and manufacturing information during the entire project, In addition to the revision and critique of this engineering report. Charles Pringle also provided the background and information needed for this project to come together.

Craig Johnson:
Provided design expertise and manufacturing information during the entire project, In addition to the revision and critique of this engineering report. Craig Johnson also provided the background and information needed for this project to come together.

Ted Bramble:
Offered hydraulic knowledge and helped determine which fittings would be the most useful and beneficial for this project. He also provided guidance through the testing phase and helped set up a pressure system to determine the pressure in the system.

Physical Resources Acquired:
- High pressure PSI hydraulic gauge

Central Washington University:
Central Washington University provided the scholastic environment that allowed this project to be successful. Without the laboratories and workrooms that central Washington University had to offer this project would have been implausible.

Physical Resources Acquired:
- Computer lab
- Hydraulics lab
- Metallurgical Lab
- Machine Shop
- Senior project work room
Appendix G

Datasheet #1 for Strength Test

Test Vehicle: 2001 Ford Ranger Edge 4x4
Curb Weight: 3599-lbs
Lift Location: Rear Hitch post

Reason for lift location: With the pressure gauge attached to the cylinder the jack was unable to close fully and be placed underneath the vehicles differential so an alternate lift location was needed.

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Pressure, P1 (psi)</th>
<th>Force (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1700 psi</td>
<td>1335.18-lbs</td>
</tr>
<tr>
<td>2</td>
<td>1200 psi</td>
<td>942.50-lbs</td>
</tr>
<tr>
<td>3</td>
<td>2200 psi</td>
<td>1727.88-lbs</td>
</tr>
<tr>
<td>4</td>
<td>2000 psi</td>
<td>1570.80-lbs</td>
</tr>
<tr>
<td>5</td>
<td>1950 psi</td>
<td>1531.53-lbs</td>
</tr>
<tr>
<td>6</td>
<td>1800 psi</td>
<td>1413.72-lbs</td>
</tr>
<tr>
<td>7</td>
<td>1100 psi</td>
<td>863.94-lbs</td>
</tr>
</tbody>
</table>

Equation to solve for Force:

\[
F = P_1 \left( \frac{\pi (d_2^2 - d_1^2)}{4} \right)
\]

P1 = Pressure read from gauge
\(d_2 = 2\)-in
\(d_1 = 1\)-in
Appendix G-2

Test Datasheet

Datasheet #2 (Lift Height vs. Time)

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Total Lift Height (in)</th>
<th>Total Lift Time (sec)</th>
<th>Inch/Sec of Lift</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.25-in</td>
<td>Lift: 7.37-sec</td>
<td>Lift: 4.38-sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower: 7.99-sec</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>32.25-in</td>
<td>Lift: 7.55-sec</td>
<td>Lift: 4.27-sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower: 8.04-sec</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>32.25-in</td>
<td>Lift: 7.44-sec</td>
<td>Lift: 4.33-sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower: 8.22-sec</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>32.25-in</td>
<td>Lift: 7.12-sec</td>
<td>Lift: 4.53-sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower: 8.15-sec</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>32.25-in</td>
<td>Lift: 7.26-sec</td>
<td>Lift: 4.44-sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower: 8.75-sec</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>32.25-in</td>
<td>Lift: 7.31-sec</td>
<td>Lift: 4.41-sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower: 7.89-sec</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>32.25-in</td>
<td>Lift: 7.29-sec</td>
<td>Lift: 4.42-sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower: 7.96-sec</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Lift Time (sec)</th>
<th>7.33-sec</th>
<th>Average Inch/Sec of Lift</th>
<th>4.40-in/sec</th>
</tr>
</thead>
</table>
Appendix G-3

Horizontal Length, Closed Vertical Height, Overall Frame Weight

Datasheet #3: This datasheet expresses the data that was formulated after the first test.

<table>
<thead>
<tr>
<th>Closed Vertical Height (in)</th>
<th>Overall Weight (lbs.)</th>
<th>Horizontal Length (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.50”</td>
<td>47.60-lbs</td>
<td>3’-11” (47”)</td>
</tr>
<tr>
<td>Initial Design Req.</td>
<td>Initial Design Req.</td>
<td>Initial Design Req.</td>
</tr>
<tr>
<td>6”</td>
<td>50-lbs</td>
<td>48”</td>
</tr>
<tr>
<td>Efficiency Increase</td>
<td>Efficiency Increase</td>
<td>Efficiency Increase</td>
</tr>
<tr>
<td>25%</td>
<td>4.80%</td>
<td>3.1%</td>
</tr>
</tbody>
</table>
Appendix H
H-1: Blank Evaluation Sheets

Datasheet #1 for Strength Test

Test Vehicle: 2001 Ford Ranger Edge 4x4
Curb Weight: 3599-lbs
Lift Location: Rear Hitch post

Reason for lift location: With the pressure gauge attached to the cylinder the jack was unable to close fully and be placed underneath the vehicles differential so an alternate lift location was needed.

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Pressure, P1 (psi)</th>
<th>Force (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Equation to solve for Force:

\[ F = P_1 \left(\frac{\pi(d_2^2 - d_1^2)}{4}\right) \]

P1 = Pressure read from gauge
\[ d_2 = 2\text{-in} \]
\[ d_1 = 1\text{-in} \]
Appendix H-2

Test Datasheet

Datasheet #2 (Lift Height vs. Time)

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Total Lift Height (in)</th>
<th>Total Lift Time (sec)</th>
<th>Inch/Sec of Lift</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Lift Time (sec)</td>
<td>Average Inch/Sec of Lift</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix H-3

Horizontal Length, Closed Vertical Height, Overall Frame Weight

Datasheet #3: This datasheet expresses the data that was formulated after the first test.

<table>
<thead>
<tr>
<th>Closed Vertical Height (in)</th>
<th>Overall Weight (lbs.)</th>
<th>Horizontal Length (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Design Req.</td>
<td>Initial Design Req.</td>
<td>Initial Design Req.</td>
</tr>
<tr>
<td>6”</td>
<td>50-lbs</td>
<td>48”</td>
</tr>
<tr>
<td>Efficiency Increase</td>
<td>Efficiency Increase</td>
<td>Efficiency Increase</td>
</tr>
</tbody>
</table>
Introduction:
The Auto-Jack, in order to be deemed successful and to prove the legitimacy of this device needs to meet a certain set of design requirements initially stated in this engineering report. The design requirements that will be tested and proved are total frame must weigh under 50-lbs, the jack frame must support a vertical compressive loading of up to 5000-lbs, the frame must deflect less than 1.0” when subjected to vehicle loading, the overall horizontal length must be under 4’-0”, and the vertical height when the frame is entirely collapsed must be less than 6.0” high. These design requirements need to be satisfied in order to prove the success of the Auto-Jack, the parameters of interest are explained in the design requirements above. Through thorough analysis completed previously in the analysis section of this engineering report a set of predicted parameters have been formulated, refer to Appendix A1-A12 for these parameters.

The tests that will conducted will be based around the design requirements for the Auto-Jack, the first test being ran will simply be a weight and horizontal span test. This test directly confirms if the jack was designed and engineered around the design requirements initially established. Following this test will be a lift height vs. time test; this will prove the overall efficiency of the jack, if it can reach its max height at a speed of more than 2.0” per second. The last test features the vehicle lift test that will ultimately prove if the Auto-Jack is successful. This test will require a test vehicle that will be lifted from different locations under the vehicle, varying the load until the max compressive strength design requirement is achieved. If the Auto-Jack passes all tests and satisfies the set design requirements, then the engineering merit has been accomplished.

Schedule:
The testing of the Auto-Jack will be completed over a 5-week period, consisting of three major tests, in addition to multiple minor tests that will satisfy all initial design requirements. The first test will begin April 4th, 2019 and be completed by April 9th, 2019, this test will conclude if the Auto-jack is functional, and if its weight, height, and lift parameters have been met, this test can be referenced from the Gantt chart provided in Appendix E (task #’s 7b-7d) of this engineering report. The second and third test completion dates can also be referenced in Appendix E, refer to the Appendix for a detailed outline of completion dates and start dates for testing.

Method/Approach:
The resources needed to complete the four tests at hand include a multitude of both physical and external resources. Below is a detailed list including resources needed for each test conducted, the extra costs for test items have also been outlined in the budget located in Appendix C.

Test #1 Resources (Overall Weight/Length/and Collapsed Height Test):

Physical:
- Standard Tape Measure
- Bathroom Scale with Weight Capacity up to 300-lbs
- Testing location (senior project work room)
External:
- Datasheet (located in Appendix G)
- Efficiency Equation

People:
- Tyce Vu

Costs:
- No initial costs were applied to complete this test

**Test #2 Resources** (Overall System Efficiency/Lift Height vs. Time):

Physical:
- Standard Tape Measure
- Phone Stop watch
- Testing location (senior project work room)

External:
- Datasheet (located in Appendix G)
- Efficiency Equation
- Microsoft Excel 2010

People:
- Tyce Vu

Costs:
- No initial costs were applied to complete this test

**Test #3 Resources** (Compressive Loading Strength Test):

Physical:
- Standard Tape Measure
- High PSI Pressure Gauge
- Testing location (Nick’s Apartment Parking Lot)
- Hydraulic Fitting Reducer 3/8” to ¼” Male to Female
- 2001 Ford Ranger Edge 4x4 Test Vehicle
- Cell phone used for video footage

External:
- Datasheet (located in Appendix G)
- Microsoft Excel 2010
- Microsoft Word 2010
- Force Equation (Calculating force on jack using pressure read of gauge)
- Efficiency equation calculating total efficiency of system
People:
- Tyce Vu
- Matt Burvee (Provided guidance during the testing process)

Costs:
- Hydraulic reducer fitting cost of $5.41, this is the cost for the fitting needed to attach the pressure gauge to hydraulic cylinder, and this initial cost can also be located in the budget section of this engineering report.

Test procedure overview:
Test #1 (Overall Weight/Length/and Collapsed Height Test)
The testing procedure is different for each of the tests, the first test (Overall Weight/Length/and Collapsed Height Test) was a basic test simply using a tape measure to measure the horizontal span, collapsed height, and placing the jack onto a bathroom scale to determine if the jack met the design requirements. The precision for this test was measurements to the nearest 1.0”, and a weight tolerance of +/- 2.0-lbs, after running this test it was evident that the Auto-Jack met the first set design requirements. The next two tests took a bit more time to set up, and had a few more steps to successfully complete the tests.

Test #2 (Overall System Efficiency/Lift Height vs. Time):
The testing procedure included set up, the actual test being run, and the tear down of the test. A couple of extra parts needed to be manufactured in order to complete this test, but these modifications required no additional costs. The first modification that needed to be made before the testing began was a wood frame needed to be implicated to prevent the link arm gears from coming into contact with the floor and damaging the gear teeth. Once this frame was mounted to the existing metal frame the test set up could begin.

Set-up (Precautionary Measures):
1. Ensure the hydraulic power units wiring is tight and no loose wires/terminal connections are present.
2. Fill the reservoir entirely with fluid and prime the system (operate the hydraulic cylinder until the lines are filled with hydraulic fluid).
3. Refill the reservoir after the system has been primed.
4. Test the hydraulic power unit and the hydraulic cylinder to ensure smooth operation before running the test.

Operational Limitations:
One operational limitation that will remain present during this test is the cylinder retraction jump if the test is ran when the jack is completely collapsed. In order to remain a set of smooth test trials the tests were conducted with the jack 2” lifted (the cylinder stroke already slightly retracted) this prevented the jack from having the spike in pressure and causing the jack to jump/jolt when the hydraulic cylinder begins retracting.

Precision/Accuracy:
The precision of this test is extremely accurate, with a time tolerance of +/- 1.0-seconds, the reason this test can be completed with such accuracy is due to the help of Tyce Vu. One person was in charge of operating the hydraulic system and the jack while the other individual focused on operating the stopwatch and recording the data.

Data analysis/presentation:
The data for this test can be found in Appendix G or by referencing the results/deliverables section at the end of this testing report.

Test #3 (Vehicle Lift Test/Deflection Test):
The testing procedure included set up, the actual test being run, and the tear down of the test. A couple of extra parts needed to be purchased in order to complete this test, these additions cost $5.41 and affected the overall budget of this project. The first part that needed to be ordered was a 3/8” male to ¼” female hydraulic reducer fitting, this fitting was required in order to attach the pressure gauge onto the cylinder.

Set-up (Precautionary Measures):
1. Ensure the hydraulic power units wiring is tight and no loose wires/terminal connections are present.
2. Fill the reservoir entirely with fluid and prime the system (operate the hydraulic cylinder until the lines are filled with hydraulic fluid).
3. Refill the reservoir after the system has been primed.
4. Use plumbers tape and screw the pressure gauge into one of the two available hydraulic cylinder ports.
5. Test the hydraulic power unit and the hydraulic cylinder to ensure smooth operation before running the test, and also make sure there are no hydraulic leaks present.

Operational Limitations:
One operational limitation that was addressed once the hydraulic pressure gauge was attached to the cylinder was that the jack would no longer retract below 10.5”, this was due to the bulky hydraulic pressure gauge. This limitation prevented the jack from being placed under the rear differential of the test vehicle, another vehicle testing location had to be identified. Underneath the 2001 Ford Ranger’s hitch was the best alternative testing location, this location provided enough clearance to lift the vehicle smoothly and provided extra safety during this test. This was the only limitation present during this vehicle lift test.

Precision/Accuracy:
The precision of this test wasn’t as accurate as it should have been, the pressure gauge used in the test was faulty and only provided three reasonably accurate readings. The pressure gauge wouldn’t hold a constant pressure value throughout the lift, the gauge needle would increase sporadically while lifting and then return back to zero once the jack stopped lifting, but this shouldn’t be the case because there is constant pressure even when the jack has stopped moving and is just supporting the weight of the vehicle.

Data analysis/presentation:
Testing Procedure for Vehicle Lift Test

Summary/overview:
The strength test ultimately determines if the Auto-Jack is capable of lifting and supporting a 5000-lb compressive loading. The test will be completed using a variety of loads slowly increasing in weight to create a safe testing environment and to ensure the Auto-Jack can lift the items successfully before lifting the test vehicle. A series of sub tests will also be completed during this testing process, the sub tests include: deflection test, hydraulic pressure test, and lift time. These subtests are crucial to the success of the strength tests, if these subtests aren’t satisfied the overall strength test won’t succeed. A total of 7 trials will be completed using increments of 500-lbs increasing weight after each trial is completed. After each trial the jack will be returned to its original state and the loading will be removed from the Auto-Jack.

Time/Duration:
The duration of the test will be approximately 2 hours, extra time will be allotted for setup and teardown, overall the entire test time should span no longer than 4 hours.

Place:
The testing will take place in an empty gravel or asphalt parking lot (since the Auto-Jack is portable testing can be completed pretty much anywhere) the exact location hasn’t been specified at this time.

Resources Needed:
The resources needed to complete this test will a pressure gauge that will be implemented directly into the hydraulic circuit loop; this will detect the operating pressure of the hydraulic circuit. The other necessary materials needed are listed below:

Physical Resources:
- Engineering ruler/tape measure
- Stopwatch
- Test area (flat level ground, cement or asphalt will do)
- Data sheet to record trial data
- 3500-lb test vehicle (this is the average weight of most family size vehicles, so this is the size of vehicle the strength test will completed with. Although the Auto-Jack is capable of lifting and supporting much more this is a good benchmark to reach before attempting to lift the full 5000-lb loading).
- High Pressure gauge (PSI)
- 3/8” to ¼” fitting reducer

Calculations/Data Needed:
Equations to calculate Force: \( F = P_1 \left( \frac{\pi (d_2^2 - d_1^2)}{4} \right) \) (Since the system pressure will be measured using the pressure gauge the actual force on the jack can be calculated, a force of around 500-lbs is desired for each increment)

- \( d_2 = \text{Piston } \varnothing = 2" \)
- \( d_1 = \text{Rod } \varnothing = 1" \)
- \( P_1 = \text{Pressure from Gauge} = \text{To be determined from first trial} \)

Human Resources Needed:
- Tyce Vu will be supervising and ensuring safety precautions are taken during the set of trials.

Process:
1. The first step in this process is to ensure the jack is functioning and the resources needed have been acquired. To test the functionality of the jack use the yellow control pad and test that the up arrow lowers the jack and the down arrow raises the jack (the arrows are reversed because the cylinder is operating in the opposite direction, as the stroke is retracted the jack will begin to lift). If further reference is needed Figure 1.1 below shows the control pad that will be used.

   **Figure 1.1:** Hydraulic power unit control pad. Down arrow retracts the hydraulic cylinder, while the up arrow extends the cylinder.

2. Once familiar with the hydraulic control pad drive the test vehicle over the jack, or slide the jack underneath the vehicle until it is positioned so that the greatest amount of surface area of the jack will be in contact with the vehicle. The best way to do this would be to align the jack horizontally underneath the rear or front axels. View figure 1.2 below to see the best positioning of the jack.

   **Figure 1.2:** The red boxes in the figure represent where the Auto-Jack should be placed.

3. After the jack has been placed under one of the two locations depicted in the previous step, it is time to run the first trial. The first trial will consist of loading the jack vertically
with 500-lbs, before beginning ensure the pressure gauge reads 0 and you have placed yourself with the power unit a safe distance away from the car and the Auto-Jack. (The hydraulic lines were intentionally cut long so the user could operate the jack from a safe distance).

4. Once the user is a safe distance away from the vehicle and everything has been double checked, it’s time to begin the first trial. Push the down arrow and hold it down until it begins to apply pressure onto bottom of the vehicle (this can be seen from the hydraulic pressure gauge on the power unit) once the pressure begins rising above 215-225 psi slowly release the down arrow and read the pressure from the pressure gauge. (The 215-225 psi was determined from completing the pressure calculation above using the constant variables). Note: Since the weight added is increasing by 500-lbs each time, the working pressure from the current trial is doubled to determine the pressure needed for the next trial.

5. The user can repeat steps 3-4 for the next 6 trials, while slowly applying more weight each trial. After each trial ensure that the datasheet is being filled out after each trial. If the user completed the first trial successfully the next 6 trials can be done easily and safely.

6. After the trials have been completed and the data has been recorded it is time to safely remove the jack from underneath the car, and clean up any other resources used during the trials.

7. Datasheet for this test can be located in Appendix G

**Deliverables/Testing Results:**

Test #1 (Overall Weight/Length/and Collapsed Height Test):
Test 1 yielded a weight of 52.50-lbs, a total horizontal length of 3’-11”, and closed vertical height of 4.50”, which means the Auto-Jack has successfully passed 2/3 of the first test. After further modifications and design overview slots were cut into the bottom frame to reduce weight, these slots didn’t affect the overall strength of the structure. Once the slots were cut into the frame the total weight was reduced down to 47.60-lbs. The initial parameters set were a total closed height of less than 6”, total frame weight of 50-lbs, and a total horizontal length of 4’. The Auto-Jack efficiencies can be calculated to be…
50lbs - 47.60lbs = 2.40lbs
\[
\frac{2.40lbs}{50lbs} = 4.80\% \text{ weight decrease}
\]
\[
4.50/6.00 = 25\% \text{ closed height decrease}
\]
\[
47in/48in = 3.1\% \text{ horizontal length decrease}
\]

In conclusion, test #1 yielded an overall efficiency increase of 32.9\% from the original design requirements determined at the start of this project. This efficiency increase yields a high standard of engineering merit in the design, analysis, and manufacturing of this project. The datasheet for test #1 can be found in Appendix G of the engineering report.

**Test #2** (Overall System Efficiency/Lift Height vs. Time):
Test 2 yielded an average lift height of 4.40-in/sec, and average dry lift time of 7.33-sec. The design requirement for this test that needed to be satisfied was a lift speed of at least 2.00-in/sec; the Auto-Jack proved 56.0\% more efficient than the set design requirement. Initially calculated in the analysis section of this report was a lift speed of 4.00 inches per second, which is very close to the physical value determined by the test. This test not only proved the accuracy of the analysis but also the precision during the testing process. The datasheet for this test can be located in Appendix G-2.

In conclusion, test #2 yielded an overall efficiency increase of 56.0\% from the original design requirements determined at the start of this project. This efficiency increase yields a high standard of engineering merit in the design, analysis, and manufacturing of this project. The datasheet for test #2 can be found in Appendix G-2 of this engineering report.

**Test #3** (Vehicle Lift Test/Deflection Test):
Test 3 yielded a max vehicle lift weight of 2500-lbs, with a system pressure of 1950 PSI, this pressure is nearly half of the max pressure the entire system is capable of. The reasoning behind not maxing the system out is to provide added safety while operating the Auto-Jack, this also provides a vehicle weight safety factor. Initially the design requirement was to lift the entire vehicle (5000-lbs), but after further design reviews and analyzing the system, it would be unsafe to lift the entire vehicle off the ground with only one jack. Although the Auto-Jack is incapable of lifting the entire car safely, it is capable of lifting the vehicles rear differential nearly 3’-0” off the ground with less than 1.00” of deflection in the frame, it is also supports up to a 100-lb side load. This stability and allowable side load aids in the safety of the Auto-Jack (which is the Auto-Jacks major requirement), this means that if the operator accidently bumps the vehicle during maintenance/repair the Auto-Jack will not collapse and the vehicle will not slip off the jack. Although the Auto-Jack, because of safety concerns isn’t capable of lifting the entire vehicle the equation below proves that theoretically the jack is capable of lifting well over 2500-lb load. The equation below expresses the theoretical pressure at 5000-lbs and the maximum allowable load when the system pressure is maximized.

\[
F = P_1 \left(\frac{\pi (d_2^2-d_1^2)}{4}\right)
\]
5000 = \( P_1 \left( \frac{\pi (2^2-1^2)}{4} \right) \)

\( P_1 = 3937.00 \text{ psi} \) which exceeds the pressure capable in the system

**Allowable Load on the Auto-Jack**

\[ F = P_1 \left( \frac{\pi (d_2^2 - d_1^2)}{4} \right) \]

\[ 3900 = P_1 \left( \frac{\pi (2^2 - 1^2)}{4} \right) \]

\( P_1 = 3063.63 \text{ psi} \) which is the maximum system pressure

The maximum load that the Auto-Jack is capable of lifting safely is roughly around 3900-lbs, this is less than the 5000-lb design requirement, but no standard vehicles rear-end is more than the 3900-lb weight requirement.

In conclusion test #3 (Vehicle lift test/Deflection test) yielded a deflection of less than 1.00” when the vehicle was fully lifted, and provided data that supports the calculations above. The vehicle lift test that was presented was only ran using half of the test vehicle with a total weight of 2500-lbs on the Auto-Jack. For further reference of the test being ran and the data collected refer to datasheet in Appendix G-1.
**Appendix J: Job Safety Analysis Sheet**

---

**JOB HAZARD ANALYSIS**
*(Frame Welding)*

<table>
<thead>
<tr>
<th>Prepared by: Nick Stadelman</th>
<th>Reviewed by:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approved by:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location of Task:</th>
<th>CWU Power Lab/Welding Lab – Hogue 130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Equipment / Training for Task:</td>
<td>Proper Welding and Ventilation Practices</td>
</tr>
</tbody>
</table>

**Personal Protective Equipment (PPE) Required**
*(Check the box for required PPE and list any additional/specific PPE to be used in “Controls” section)*

- [ ] Gloves
- [ ] Dust Mask
- [x] Eye Protection
- [x] Welding Mask
- [ ] Appropriate Footwear
- [x] Hearing Protection
- [x] Protective Clothing

*Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.*

<table>
<thead>
<tr>
<th>PICTURES (if applicable)</th>
<th>TASK DESCRIPTION</th>
<th>HAZARDS</th>
<th>CONTROLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire feed welding frame</td>
<td>Hazardous Fumes</td>
<td>Use fume hood and ventilation to control the fumes, if welding outside make sure you are downwind from the fumes</td>
<td></td>
</tr>
<tr>
<td>Wire feed welding frame</td>
<td>Toxic Substances on Surface</td>
<td>Cleaning welding surfaces to ensure no toxic substances are present before welding process begins</td>
<td></td>
</tr>
<tr>
<td>Welding top frame</td>
<td>Fire Hazard</td>
<td>Ensure that the top frame is away from anything flammable during welding process</td>
<td></td>
</tr>
<tr>
<td>Welding top frame</td>
<td>Eye Danger</td>
<td>Use welding mask at all times</td>
<td></td>
</tr>
</tbody>
</table>
Appendix K
K-1: Final Resume

NICHOLAS STADELMAN
Nick.stadelman23@gmail.com  |  (360) 771-1788
3348 S 10th Way, Ridgefield, WA 98642
https://stadelmann8.wixsite.com/autojack

PROFESSIONAL SUMMARY
Compelling, motivated, and performance driven engineering professional with an exceptional blend of leadership, business, design, and industry knowledge. I am seeking an entry-level position where I am able to utilize my expertise and provide quality services for a reputable company.

SKILLS
- Outstanding team leadership skills
- Skilled in Solidworks (CSWA)
- Strong verbal communication
- Microsoft Office Suite
- Expert problem solver
- Self-motivated

- Quick to learn, and excellent with attention to detail
- Proficient with cost analysis spreadsheets
- Excellent in AutoCAD 2D & 3D design

WORK HISTORY
AutoCAD Technician  |  Central Washington University - Ellensburg, WA
06/2017 - CURRENT
I currently work with other mechanical engineers and project managers on design-based projects, my roles consist of:
- AutoCAD 3D & 2D models with no guidance
- Designing and implementation of utility systems
- Reviewing work place safety protocols
- Managing multiple projects on a schedule
- Writing technical emails and memos to achieve a goal
- Gathering documents for pre-bid construction meetings
- Surveying using Trimble GPS systems
- Responding to customer requests via telephone and email

Maintenance Specialist  |  City Of Oregon City, Parks Department - Oregon City, OR
06/2016 - 09/2016
My roles consisted of:
- Basic construction skills (electrical & irrigation repairs)
- Grading with a tractor
- Concrete drilling, concrete repairs, and concrete pouring
- Solving construction based problems promptly and proficiently
- Following safety protocols while operating equipment
- Worked directly with the community, clients, and management to achieve a goal

EDUCATION
Central Washington University, Ellensburg, WA
Bachelors of Science: Mechanical Engineering Technology, Cumulative GPA: 3.35
Coursework in Statics, Strength and materials, Thermodynamics, Fluid dynamics, Technical dynamics, Applied heat transfer, Mechanical design, Calculus, Finite element analysis, and also completed a year long senior project where I designed, manufactured, and tested a new and improved mechanical device.