Therapeutic Mechanical Horse Project
Final Design Review (FDR)

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Jack’s Helping Hand

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Abstract

This project team created a simple mechanical model of a horse that disabled children could ride on to feel more comfortable partaking in equine therapy. This project was sponsored by Jack’s Helping Hand as part of their equine therapy program. The team went through the entire design process of researching, ideating, prototyping, and testing to create the final product. Finite element analysis of the structural members of the horse was performed. The forces used in that model were later validated through testing of the strength of those same members after manufacturing. In the end, a self-actuating single degree of freedom horse was constructed primarily of wood and was successfully ridden by well over a hundred people at the senior expo. Since this project was entirely based on the idea of making its user more relaxed and comfortable, the positive feedback received at the expo was evidence of the project’s success.
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1 Introduction
This year-long senior project entails designing, manufacturing, and testing a mechanical horse for use in assisted riding applications. Jack’s Helping Hand (JHH) is a local, non-profit organization that provides physical therapy and programs to improve and enrich the lives of children with special needs. Sponsors Leslie Orradre and Bonnie Burt (chairwoman and event coordinator, respectively) reached out to Cal Poly to expand upon their Little Riders program. The program provides therapeutic riding to the children, helping them improve core strength, balance, coordination, and confidence. Therapeutic riding is a physical therapy that utilizes riding a horse to improve physical and social abilities. The Little Riders program comes alongside a few drawbacks and limitations. Two of the biggest concerns are the wear on the JHH lesson horses and the various levels of experience of the riders. To make therapeutic riding more accessible, JHH has partnered with our team to create an alternative way of providing the experience of riding a horse to those who may benefit from such an approach. Our team consists of Zachary Barnishan, Carson Roff, Broghan Martin, and Lydia Barnes, all mechanical engineering majors with manufacturing concentrations. Taking up the mantle of the past Mechanical Horse Senior Project teams, we have been tasked with designing and fabricating a more accessible and usable way to provide JHH with alternative, mechanical equine therapy.

This document stands as the culmination of our efforts from the past year, and contains the following information and material:
- A detailed final product design description
- The procurement and manufacturing process
- Product testing procedures and results
- A user manual describing maintenance and setup procedures

We will also be expanding upon our iteration process, the challenges we faced, and how we would continue to move forward.

2 Design Overview
The Cal Poly Mechanical Horse (CPMH) is designed to be a simple, easily maintainable product that can be used under a variety of circumstances, environments, and load cases. The following product has been developed to meet specific design criteria stated in Section 4 of this report (Figure 4.1).

2.1 Design Description
The CPMH consists of three main subassemblies: the base, the body, and the neck. These come preassembled, and all the user has to do to set up the product is disengage the locking casters, roll the CPMH to an appropriate location, and reengage the locks. To use the product, a child will step over the horse’s body with the assistance of a stepping block provided by JHH if necessary. After the child is seated and a JHH assistant gives the go-ahead to begin, the child will rock back and forth to engage the springs and begin the movement of the horse’s body and neck. To stop, the child stops rocking and the horse will automatically come to rest since the horse is not powered. The following sections go into further detail on each subassembly that make up the apparatus, explaining design iterations, material choices, and corresponding risks.

2.1.1 Base
For the base, we have elected to use a relatively heavy material (steel) to lower the center of mass and allow for the rider to rock back and forth with no worry about tipping the product over. To ensure
longevity and lower the number of parts, we have elected to weld the base together rather than rely on bolted connections (Figure 2.1). Large locking and swiveling castors were threaded into each corner, leveled, and finally welded into place.

![Figure 2.1 Welded Steel Base With Casters](image1)

The steel has been specified using finite element analysis (FEA) outlined in Figures 2.2-2.3 and is analytically ensured to support the weight of both the rider and the CPMH itself. As a parameter for the performed FEA, we placed all loading on the main pivot point. The pivot bar was subjected to a 500 lbf load (an extreme load that will allow us to have no single rider weight restriction and permit riders to have assistants on the horse with them, if necessary). The analysis revealed that the maximum bending of the pivots was only 0.003", which would not affect the structural integrity of the base component.

![Figure 2.2 FEA Deflection Results of Base with Maximum Load](image2)
2.1.2 Body
The second assembly is the body of the horse. The wooden structure is where a saddle will be affixed, and where the child will sit while using the product (Figure 2.4). It roughly emulates the natural curve of a horse’s back to both accommodate the saddle and provide the necessary contour to simulate riding a real horse. The body will sit atop the base via a machined pivot bar and two pillow block bearings (shown in Figure 2.5), and the neck component (expanded upon in Section 2.1.3) will fit into the slot in the front of the build with its own elastic bands and pivot bar.
The body will rock upon the pivot bar when the user rocks and is supported on either side by a series of springs (Figure 2.6) to provide the right amount of resistance and balance.

To design the body, a saddle provided by JHH was measured and these dimensions used to cut supporting ribbing (refer to Figure 2.7 for an interior view of the body showing this ribbing), upon which the wooden slats pictured in Figure 2.4 were affixed with screws. Using the same 500 lbf load as detailed previously, FEA was performed upon the slats. As seen in Figure 2.8, the analysis once again proved that they would hold up and not splinter or break underneath any of the load cases introduced during use. Wood material data in this analysis can be found in references [1] and [2].
Any exposed corners of the wood were sanded down and rounded, and the entirety of the body was sealed with linseed oil. Since children will likely pet the horse or grab onto the body to mount the saddle, it was imperative that splinters were removed, and the wood protected to avoid injury.

2.1.3 Neck
The neck is the last of the main subsystems. As the rider rocks, the neck is to move up and down in the rough approximation of the way a horse’s head moves during a walk. To accomplish this, an elastic band is attached to two anchoring points on the horse body (Figures 2.8-2.9). By rocking the body of the horse, the user will inadvertently change the relative position of the mounting points and thus generate a natural, “nodding” motion in the neck, allowing for a more realistic riding experience as well as integration with reins and other tacking.
Figure 2.9 Neck Mechanism Interior View, Head-On (Resistance Band Not Pictured)

Figure 2.10 Neck Mechanism Interior View, Side (Resistance Bands Not Pictured)
2.2 Design Changes Since CDR
Since the critical design review (CDR), there have only been very minor changes made to the design. In the CDR we referenced nailing the exterior panels into the supportive ribbing, and this was changed such that the panels were screwed in using wood screws. The CDR also specified the use of 6 total springs in the final product. After three springs on either side of the horse proved too stiff for rocking motion to occur, the number of springs was reduced to only four.

3 Implementation
This section will outline all procurement, building, and assembly that was completed for the horse.

3.1 Procurement
The mechanical horse is designed to hold up against all different kinds of terrain, loading, and handling circumstances. Therefore, we strove to find materials and components that were high-quality and long-lasting. Through online research, senior design project guides, and consulting with peers, we decided to use McMaster-Carr to procure our basic mechanical components (screws, washers, and bearings), and local shops for wood and steel stock materials. McMaster-Carr is well-known for consistent and quality, well documented components, on top of their fast shipping time. All this allowed us to quickly gather materials to generate functional prototypes, and to pull SolidWorks files directly from the source for component testing. Costs were kept low by using local stores for wood and steel materials, as shipping would have been a massive cost for our budget to support.

We are grateful to have received a $2000 grant from Cal Poly’s TECHE (Transforming Engineers through Community Hands-on Engagement) lab, as Jack’s Helping Hand is a non-profit organization. This allowed us to purchase high-quality materials that would last instead of requiring further contribution from JHH.

Since our team is entirely made up of students with manufacturing concentrations, the entire assembly was able to be completed by our team with no outsourcing necessary, reducing our overall costs. The total budgeted costs for the project are summarized in our iBOM as detailed in Figure 3.1.
Due to mishaps and incorrect purchase orders that occurred during the procurement process, we ended the project with a different cost from the purchasing iBOM prediction. The true cost for the product came in (still under the $2000 grant) at $1620.64, and the full breakdown of costs per component can be found in Appendix C.

### 3.2 Manufacturing
To begin the manufacturing process of our mechanical horse project, we focused on ensuring that we did not rush the process, with a primary goal of providing excellent quality of workmanship in the build. Our materials were carefully sourced, with steel extrusions and bar stock purchased from Paso Robles...
Welding, wood and wood screws from Home Depot, bearings, casters, machine screws, nuts, and washers from McMaster-Carr, and springs and elastic bands from Eqicizer.

3.2.1 Base
Our manufacturing process began with the metal base, which was made of steel extrusions, mainly comprised of rectangular, square, and angle cross-sections. The metal came with some mill scale on it, and we knew that over time the scale would flake off – along with any paint over it – leading to rust and corrosion. To prevent this, we made a bath of vinegar and let the steel soak in it for a day. We then scrubbed the steel off with ScotchBrite abrasive pads. This led to some flash rusting on the surface, but we were able to remove it later with a wire brush. The difference between a fully cleaned steel piece and a stock piece is shown in Figure 3.2.

![Figure 3.2 Vinegar Cleaned Tube Next to Uncleaned Tube](image)

We used a thin steel blade on the Evo chop saw in Mustang 60 to cut the steel. To try to get all the center pieces to consistent lengths and maintain parallelism between the two long ends, we used a stop. Unfortunately, the stop did not work as well as planned because the chop saw had a lot of torque on start-up and vibrated vigorously, making it hard to get clamps on the table. As a result, we had to trim up some of the pieces to get a good fit.

After cutting the metal, we proceeded to tack weld the frame of the base together. We took extra care to ensure that everything was square before and after welding, which sometimes required grinding off some tacks and starting again. To put forth a quality product, we knew that patience was key in achieving good workmanship. Once the base was tacked together, we ran full weld beads across it (Figure 3.3). However, the welders in Mustang 60 had been roughly used by students all year and had various issues. One of them had a bad potentiometer that didn’t allow the adjustment of wire speed, while the other had an inconsistent wire output as the internal components seemed to bind every so often. This led to a few less-than-ideal welds that needed to be ground down afterward.
Once the frame of the base was manufactured, we proceeded to build the vertical columns that the horse’s body and neck elastic bands mounted to. These columns required a protruding 1-inch solid steel bar, which we accommodated by drilling through the top of square tubing with a step drill in the drill press. We then cut the bar stock to length on the Wellsaw Horizontal Bandsaw in Mustang 60.

With all the components made, we began to weld the vertical columns onto the base. We were careful to maintain perpendicularity and parallelism where needed between all critical components. This again led us to grind down tack welds and reweld components once we noticed they were out of square. After the columns were welded, we placed them in the rod and TIG welded the pivot bar stock to the column as pictured in Figure 3.4.
To mount the casters to the base, we used long coupling nuts that were the same 3-inch height as our base. These nuts came with a zinc coating to protect against corrosion; however, zinc cannot be welded as the fumes are toxic to inhale. To safely weld the nuts, we removed the zinc layer using the metal belt sander in the back of Mustang 60. We then tack welded each coupling in place, before discovering an issue with our tack welding method. Our first two tack welds were done on the top of the nut. This became a problem when we tried to thread on the caster, since the weld interfered with the threads on the caster and on the nut. Since it takes about 50 revolutions to get the caster stud through the nut and you can only turn half a revolution at a time with a large wrench, it took a lot of force and around 40 minutes of exertion to turn the caster and remove it. We then re-tapped the nut and used a die to clean up the threads on the caster. After that, the caster threaded in easily and we repeated the simpler process on the remaining three.

The final step was to remove the built-up rust with wire wheels and a surface conditioning tool, which we found to be the fastest way to achieve a clean surface ready for painting. We then taped off all critical features, propped the base on sawhorses, and painted the entire structure using Flat Black Rustoleum Spray Paint. The painted base and painting setup is shown in Figure 3.5. This concluded all the manufacturing on the base of the horse.

![Figure 3.5 Painting the Base](image)

### 3.2.2 Body

We began construction of the horse body with the bulkheads, which we made from ¾ inch plywood. We exported a DXF file from the SolidWorks model and brought it into Adobe Illustrator, where we prepared it for use on the laser. A guideline was etched onto each piece of plywood, which we used to set up the miter gauge or fence on the table saw to achieve accurate straight cuts as shown in Figure 3.6.
Once cut, we loosely glued all the bulkheads together using masking tape and hot glue. We then sanded them to ensure that they were all precisely the same dimensions using a hand sanding machine. Next, we marked and cut the slot for the neck mechanism in the frontmost bulkhead using the bandsaw. However, after this part was assembled, we realized that it was not square, so we had to come back and make the slot larger to make it a square cut. Finally, we lightly sanded the bulkhead edges to remove splinters.

After finishing the bulkheads, we moved on to the manufacturing of the slats. A plywood sheet was cut to length on the panel saw, and then all the slats were cut to width using the table saw. Finally, we added a chamfer to each slat to remove the sharp edges as illustrated in Figure 3.7.
To create the base of the body’s frame, we used common construction 2” by 4” (1.5” by 3.5” actual) boards. We cut them to length and assembled them using Deckmate screws, ensuring all holes were predrilled to reduce risk of the wood splitting. Using metal brackets and small wood screws, we attached all the bulkheads to this frame, being sure to keep the spacing accurate to the SolidWorks model and keeping all of the bulkheads in line with one another.

Unfortunately, this design was not as rigid as planned. To fix this, we manufactured some brackets out of aluminum sheet metal to support the outer side of both outer bulkheads. These were cut using a step shear, and then drilled and countersunk on a drill press. This greatly improved the overall rigidity of the design. The attached brackets are shown in Figure 3.8.

![Figure 3.8 Body with Rigid Brackets Attached](image)

To create the neck pivots, we cut two more pieces of the 2” by 4” planks using the miter saw and drilled 1-inch-deep holes in them using a forstner bit and a drill press. The final pivots are shown in Figure 3.9.
We then cut two more pieces of 2” by 4” at angles of 60 and 30 degrees using the sliding compound miter saw to make the braces for the front slotted bulkhead. However, we soon realized that this had interference with the slats that were not present in the CAD model due to lack of access to CAD models for Home Depot brackets. Thus, these bolsters needed to be cut at an uncommon compound angle. This we accomplished using a combination of hand planes and the wood belt sander. We then used screws and wood glue to attach these braces to the body as shown in Figure 3.10.

Moving on to attaching slats to the bulkhead; we used hot glue to hold the slats in place while the mounting holes were drilled and screws were sunk into the slats. The slats were all attached in this way,
except for the second from the top layer, which needed to be installed after the neck and base assembly was put together.

To make the mounts for the springs, we cut angle iron using the EVO Chop Saw and drilled holes in them using metal drill bits as well as step drills in the drill press. The large holes accommodate the springs, and the six smaller holes accommodate the mounting hardware (1/4-20 bolts, washers, and nuts) that attach the angled spring mounts to the frame.

Finally, we drilled the clearance holes for the bolts that mount the bearings to the frame of the body. This finishing the manufacturing of the body.

3.2.3 Neck
The neck was manufactured by cutting plywood to the required dimensions and chamfering it with the table saw before gluing the rectangular cross-section together. A 1.5-inch hole was drilled to accommodate the PTFE bushing that the neck rotates about. Unfortunately, the forstner bit labeled for the 1.5-inch hole was incorrect, so the hole had to be redrilled on the other side of the neck pivots to the correct location. Fortunately, the extra hole at the front of the neck did not pose any structural risk and reduced the weight of this heavier component slightly.

We fabricated the lower neck band bracket using angle iron and bar stock. The angle iron was cut on the EVO Chop saw, deburred on the deburring wheel, and drilled using metal drill bits and step drills on the drill press. Initially, the first hole was made according to the model, but the actual dimensions of the metal band were different from the CAD model, so we had to drill a hole on the other side to accommodate it. The extra holes didn’t pose any structural risk and – in fact – helped reduce the weight of the component.

The bar stock was cut using the horizontal bandsaw and deburred on the deburring wheel before being TIG welded together with the angle iron. We maintained our high standard of workmanship by grinding down tack welds and retacking components as necessary. Although the TIG welder behaved poorly and resulted in random porosity in the top of the welds, we have experienced this issue in the past on this TIG welder when working on other projects, we were able to overcome it and produce a quality product. This bracket is shown in Figure 3.11 along with the lower end of the neck, the attached elastic bands, and the angled 2” by 4” planks that support the neck pivot.
As a final step, we made a small spacer block out of plywood that attached underneath the bracket. However, after testing we found that it was unnecessary and removed it from the final product. This concluded the manufacturing of all the mechanical non-aesthetic components of the final horse assembly.

3.3 Assembly

The assembly process is fast, but requires a minimum of two people if no additional tools are used. Fortunately, this assembly should only need to be done once and only by our senior project team who understand the safety concerns and design intent of each individual component and how they interact.

To assemble the body onto the base, the pillow block bearings need to be mounted onto the base pivots aligned such that their flat sides are facing up. The body is then placed on top of the bearings and the through-bolts that mount the body onto the bearing are inserted and tightened with washers and nuts.

After this is complete, the springs need to be attached. After some initial testing, we found that the easiest way to attach the springs is to clip the carabiners onto the spring mounts on the base, lower the front down so the springs can be attached to the front of the body, and finally have one team member push the rear of the body down so that the rear springs can be attached to the base. The assembled base and body (with the four springs) is shown in Figure 3.12.

Figure 3.11 Neck Attached to Body
The final component to be assembled is the neck. Attaching the neck to the body is done by placing the pivot bar through the PTFE bushings and press-fitting the supporting 2” by 4” planks on both protruding sides of the pivot bar. The planks are then screwed onto the body of the horse and the elastic band is stretched onto the lower bracket of the neck and the upper pivot of the base. The mechanical horse assembly with all three main components is shown in Figure 3.13.
To add the final touches, we began with the wooden head. A 3D printed head was attempted, but the scaling proved to be inaccurate and reprinting was time-consuming and deemed unreasonable. Instead, wooden sheets were laser cut in the shape of a horse head and glued together with dowel rods through each layer to ensure proper alignment. To keep weight down, only the outer layers were full, while inner layers were cut such that the inside of the head was hollow. The saddle provided from JHH was affixed to the body, and reins were attached to the horse’s head. The final product with all aesthetic components is shown in Figure 3.14.

![Final Horse Assembly with Aesthetic Components](image)

**Figure 3.14 Final Horse Assembly with Aesthetic Components**

4  Design Verification

To ensure that our product fulfilled all design constraints and specifications posed by the sponsor, various tests were performed. The tests administered verified the product’s adherence to size requirements, load factors, and setup time, all detailed in Figure 4.1. The Design Verification Plan and Report (DVPR) can be referenced in Appendix D.
4.1 Specifications
Design specifications were developed with the oversight of our sponsor, JHH, and served as the targets to which the entire product was designed for.

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Specification Description</th>
<th>Requirement/Target</th>
<th>Requirement Pass/Fail?</th>
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<td>Product Weight Requirement</td>
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<td>PASS</td>
</tr>
<tr>
<td>2</td>
<td>Rider Weight Restriction</td>
<td>175lbs/rider</td>
<td>PASS</td>
</tr>
<tr>
<td>3</td>
<td>Rider Height Range</td>
<td>3’6” to 6”</td>
<td>PASS</td>
</tr>
<tr>
<td>4</td>
<td>Product Footprint</td>
<td>2ft by 6ft</td>
<td>PASS</td>
</tr>
<tr>
<td>5</td>
<td>Load Factor</td>
<td>300lbs</td>
<td>PASS</td>
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<td>6</td>
<td>Saddle Height</td>
<td>38”</td>
<td>PASS</td>
</tr>
<tr>
<td>7</td>
<td>Appearance Survey</td>
<td>10/10 rating goal</td>
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<tr>
<td>8</td>
<td>Use Survey</td>
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<td>9</td>
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<tr>
<td>11</td>
<td>Cost of Materials</td>
<td>$2000 maximum</td>
<td>PASS</td>
</tr>
</tbody>
</table>

*Figure 4.1 Summary of Design Specifications*

4.2 Testing and Results
For each design specification a test was performed following procedures outlined in Appendix E, the results of which are included in Appendix D. Each test had only two results: pass or fail. If the horse failed, it would entail going back, redesigning, rebuilding, and retesting until a “pass” was achieved.

4.2.1 Weigh the Final Design
For the first test, the product was weighed and would pass if it was less than 130lbs and so long as it can be lifted by two people. Since the horse weighed 110lbs, it passed this test.

4.2.2 Measure Final Design Footprint Width and Length
The second test involved the product footprint, and to ensure it was below the allotted storage area of 2ft by 6ft. After measuring the steel base’s frame, the test was passed with a product footprint of 1.9ft by 5.75ft.

4.2.3 Two-Rider Test
To ensure the horse was able to support anyone who used it, we tested its response to two riders (an equivalent of 300lbs total). When the horse was able to hold the weight without breaking or deforming, the third test was passed.

4.2.4 Saddle Height
The height of the saddle was fixed at a maximum of 38” to accommodate shorter riders and the use of a JHH step that cannot be altered. After measuring the maximum height of the top of the body to the floor, the height passed the test at 37.5”, just short of the maximum.
4.2.5 Appearance and Use Surveys
Because the horse will be used primarily with children, we decided to perform an appearance survey to ensure the horse looked non-threatening and professional. We also wanted to make sure the users were comfortable so a use survey was also conducted. The participants were asked to rank the horse on a scale of 1-10 on both accounts, with 10 being the best appearance/most comfortable. To pass, the average score across all participants must be above 7/10. With a 9.5, the horse passes the survey.

Everyone who rode the horse enjoyed the experience, even those who were initially hesitant to get on. We passed the use test with an average score

4.2.6 Spring Constants
The most important test was ensuring the spring constants of all six springs used were sufficient to facilitate the proper rocking motion and not require an excessive amount of balancing. To measure the spring constants, each in turn was hooked up to a tensile tester and stretched an inch (24.4mm). The resulting force (N) was observed and recorded in Appendix E. A sample of the tensile tester graph outputs can be seen in Figure 4.2. After data was collected, the resolution uncertainty of the tensile tester was recorded for both displacement and force. Then a t-test was conducted with 5 degrees of freedom on both the force measurements and the displacement measurements. This yielded the nominal values for both and their statistical uncertainties. Root-sum-squaring the statistical uncertainty and resolution uncertainty yielded the total uncertainty for both force and displacement. Propagating these values through the fractional uncertainty equation solved the total uncertainty of the spring constant for this set of springs. The nominal values of force and displacement were used to find the nominal spring constant. For specific numbers and equations, refer to Table E.1 in Appendix E. The springs all passed under a constant of 27 lbf/in.

4.2.7 Measure Pinch Points
Pinch points were spotted early as a concern with all the moving parts on the horse. To make sure the children would be safe holding onto the neck (a common place to steady oneself), the gap between the neck and the body must be above a distance of 1.5”. With a measurement of exactly 1.5”, there is enough room for a finger or two to rest or hold without being pinched or injured.
4.2.8 Tipping Test
Finally, due to the rocking motion of the entire horse, testing was done to make sure the horse did not tip over with any possible out-of-plane loading forces. By testing worst case mounting possibilities as documented in Appendix E, the horse passes the tilt test and proves the center of gravity was engineered low enough so as to not fall over while in use or while stored.

4.2.9 Reflection
Although all tests were passed, we noted that if something had failed it would be difficult to alter the design to retest. For example, if the saddle height was too tall, fixing it would entail disassembling the horse body from the base, cutting through the steel beams, reaffixing welded components, recoating exposed steel, and reassembling. After reflection, if we were to redo the project we would be sure to measure or test continuously throughout the building process to catch any issues that could have arisen.

Once again, all test outlines, procedures, and results can be found in Appendix E.

5 Discussion & Recommendations
This section will go over the results of the project and our recommendations for next steps and any continuation of the project in the future.

5.1 Discussion
Through the year of working on this project, our team was humbled and proud to be a part of a nonprofit organization such as JHH. We were able to learn more about the families that JHH assists, and how to view the world with more attention to the plethora of accessibility concerns that may not be evident at first glance. The act of riding a horse is not accessible to many, and we sincerely hope to give those who are unable to ride an experience that resembles the real thing as closely as possible. Most of all, we hope that more students are interested in assisting JHH with future projects to help those in need.

5.2 Recommendations and Next Steps
If we were continuing this project, we would like to find a way to incorporate optional motorized rocking. While the sponsor specified self-propulsion as a top priority, it became evident from the use survey that smaller children would not be able to rock the horse themselves. Introducing optional motorized capabilities would further broaden those who can benefit from the horse.

Along similar lines, more time on the project would allow us to research and develop mechanisms that move the horse along more axes (side-to-side instead of only rocking back and forth). With this, we can emulate the true gait of a horse more closely and create what could be a replacement entirely for equine therapy if a child is unable to ever make the jump to riding a real horse.

If our product was to be produced in high volumes in the future, we would opt for easier materials to machine. The base would remain as-is, but elements like the body and the head would need to be standardized to shapes easily mass-machined (such as full half-ovals for supportive ribbing, as opposed to the tedious polygon shapes). The head was hand-glued layer by layer, so an injection-molded plastic head would remove the hours of work that were put into that segment of the build.

If we were to fully redo the project, we would make sure to set up more time with our sponsor to test the horse at the JHH facility with those who would be using it. Due to scheduling issues, it was difficult to
coordinate times with not only the senior project team and the sponsor, but with the schedules of JHH families. From the beginning, we would build the product we have currently, but have made sure to immediately begin testing with the end users and changing the design if necessary.

6 Conclusion
Beginning in 2020 with a team of eight members, this project has gone through a very long and unusual past. JHH provided the same design criteria that our team received, but once the final product was revealed it was clear miscommunications and misunderstandings occurred. Even so, JHH was committed to their cause to help those unable to fully utilize their equine therapy program, restarting the project with our team in September of 2022. Learning from the past year’s issues, our team ensured a clear and open partnership was maintained between JHH and the project. We made sure each step was signed off and reviewed by Mrs. Burt, and that we were progressing towards the desired result. In doing so, we hope we exceeded our sponsor’s expectations.

This project will truly help those in need of an extra helping hand. Not only will the horse assist with confidence, strength, balance, and fine motor skills, but it will provide a fun and exciting experience to children and young adults who may not be able to experience horseback riding. We sincerely hope that Jack’s Helping Hand will continue to use our product for years to come and help countless children in the process.

7 References


8 Appendices
Appendix A – User Manual
Appendix B – Risk Assessment
Appendix C – Final Project Budget
Appendix D – Design Verification Plan & Report (DVPR)
Appendix E – Testing Procedures
Appendix A – User Manual
Please read the following user manual in its entirety to ensure safe and proper setup, use, and storage of the mechanical horse.

Setting Up the Horse
To set up the mechanical horse, first disengage the locks on all four castors. Roll the horse to the desired location, ensuring the surrounding area is clear and the land is level enough such that all four castors are in contact with the ground. Reengage the locks. Push the horse to ensure the castors are locked properly. If the horse rolls or moves, re-engage and check all four castor locks. Remove the protective cover from the horse and place in an area away from the product.

OPTIONAL: Add saddle, reins, or any other desired tack to the horse.

Using the Horse
Once properly prepared, the horse is ready for use. Do not ride alone! Always have an assistant present.
No PPE is required.
To mount:
1. Place stepping block next to the horse base (optional for shorter riders)
2. Swing one leg over the back of the horse, sitting down on the saddle or middle of the body structure.
3. Remove the stepping block if used in step 1, and place it in an area away from the product.
To use:
1. Rock forwards and backwards on your hips in a rhythmic motion to generate a rocking motion.
2. Continue rocking as long as you want to use the product.
3. To stop, slowly cease your rocking motion.
To dismount:
1. Ensure the horse has come to a complete stop.
2. Place stepping block next to the horse base (optional)
3. Anchor one foot upon the stepping block.
4. Swing other leg over the back of the horse and step away.

Storing the Horse
When storing the horse, or for any amount of time when the product is not being moved, ensure that all four castors are locked. Place the protective cover over the horse body, head, and neck. Store in a dry, covered area.

Maintenance
This product was designed to not require maintenance. With proper storage and use of the protective cover, there is no need for extensive upkeep. An optional dry brush can be performed over the horse exterior to remove any accumulated dust. If a component were to break, please reach out to our team via the emails provided in this report. Replacement parts (such as springs) can be ordered using the Final Project Budget (Appendix C) provided in this report.
### Appendix B – Risk Assessment

#### Mechanical Horse

<table>
<thead>
<tr>
<th>Item Id</th>
<th>User / Task</th>
<th>Hazard / Failure Mode</th>
<th>Initial Assessment</th>
<th>Risk Level</th>
<th>Risk Reduction Methods / Control System</th>
<th>Final Assessment</th>
<th>Risk Level</th>
<th>Status / Responsible / Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1-1</td>
<td>Common tasks</td>
<td>mechanical / pinch point Hands being stuck into the gap between neck and body.</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Read enclosures / barriers. Guards and hard stops will prevent any child from pulling their hands in areas where they could be pinched.</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1-2</td>
<td>operator Common tasks</td>
<td>mechanical / machine instability.excessive side to side rocking may tip horse over</td>
<td>Serious Remote</td>
<td>Low</td>
<td>prevent energy buildup. Staff members supervising the riding child will prevent the child from rocking excessively from side to side.</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-1-1</td>
<td>maintenance technician parts replacem.</td>
<td>mechanical / pinch point Replacing the springs could lead to getting pinched as they are stretched or released suddenly.</td>
<td>Minor Likely</td>
<td>Low</td>
<td>Restricted users</td>
<td>Minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-1-2</td>
<td>maintenance technician parts replacem.</td>
<td>mechanical / machine instability. If the springs are not taken off of one side of the horse it will want to snap down on the opposite end. This could potentially whoever is working on the horse.</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>prevent energy buildup.</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-2</td>
<td>maintenance technician periodic maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-1-1</td>
<td>passer by / non-user work near to / near machinery</td>
<td>mechanical / crushing Someone standing or passing the horse could be injured by the moving horse body.</td>
<td>Serious Remote</td>
<td>Low</td>
<td>standard procedures Not Applicable</td>
<td>Serious</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-2-1</td>
<td>passer by / non-user walk near machinery</td>
<td>mechanical / crushing Someone passing the horse could be injured by the moving horse body.</td>
<td>Serious Remote</td>
<td>Low</td>
<td>standard procedures</td>
<td>Serious</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix C – Final Project Budget

<table>
<thead>
<tr>
<th>Person</th>
<th>Order No.</th>
<th>Total</th>
<th>Description</th>
<th>Vendor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lydia's Orders</td>
<td>1</td>
<td>$43.69</td>
<td>Resistant Neck Bands</td>
<td>Wooden Horse Co.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$120.81</td>
<td>6x Springs + Spring Clips</td>
<td>Wooden Horse Co.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$238.52</td>
<td>Permanently Lubricated Mounted Ball Bearing</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$15.12</td>
<td>Zinc Yellow-Chromate Plated Hex Head Screw</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$15.68</td>
<td>High-Strength Steel Hex Nut</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$13.05</td>
<td>Grade 9 Steel Washer</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$22.73</td>
<td>Grade 9 Steel Washer</td>
<td>McMaster</td>
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<tr>
<td></td>
<td></td>
<td>$25.36</td>
<td>High-Strength Steel Hex Nut</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$20.49</td>
<td>Zinc-Plated Alloy Steel Socket Head Screw</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$35.04</td>
<td>Zinc-Plated Steel Coupling Nut</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$371.03</td>
<td>Swivel Caster with 4&quot; Long Threaded Stem</td>
<td>McMaster</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>$13.97</td>
<td>Grade 9 Steel Washer</td>
<td>McMaster</td>
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<td></td>
<td></td>
<td>$13.98</td>
<td>High-Strength Steel Hex Nut</td>
<td>McMaster</td>
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<tr>
<td></td>
<td></td>
<td>$42.54</td>
<td>Ultra-Low-Friction Dry-Running Sleeve Bearing</td>
<td>McMaster</td>
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<td>Broghan's Orders</td>
<td>1</td>
<td>$290.22</td>
<td>Steel Tubing and Plywood</td>
<td>Home Depot / Welding Supply</td>
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<tr>
<td></td>
<td>2</td>
<td>$148.78</td>
<td>Plywood and Hardware</td>
<td>Home Depot</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>$65.13</td>
<td>Sewing Supplies</td>
<td>Walmart</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>$10.86</td>
<td>Canvas Drop Cloth</td>
<td>Harbor Freight</td>
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<tr>
<td>Carson's Orders</td>
<td>1</td>
<td>$21.14</td>
<td>Flat Black Spray Paint</td>
<td>Home Depot</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$3.56</td>
<td>Dowel Rod</td>
<td>Home Depot</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>$59.95</td>
<td>Lumber</td>
<td>Home Depot</td>
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<tr>
<td>Zach's Orders</td>
<td>1</td>
<td>$28.99</td>
<td>Horse Tack</td>
<td>Tractor Supply Co.</td>
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<table>
<thead>
<tr>
<th>Total Remaining Funds</th>
<th>Total Spent</th>
<th>Max Budget</th>
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<tr>
<td>$379.36</td>
<td>$1,620.64</td>
<td>$2,000.00</td>
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# Appendix D – Design Verification Plan & Report (DVPR)

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Specification</th>
<th>Test Description</th>
<th>Acceptance Criteria</th>
<th>Test Responsible</th>
<th>Test Stage</th>
<th>SAMPLES</th>
<th>TIMING</th>
<th>TEST RESULTS</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Product Weight</td>
<td>&lt;120 lbs</td>
<td>Carson</td>
<td>1</td>
<td>Sys</td>
<td>4/16/2023</td>
<td>4/22/2023</td>
<td>10 lb lift</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Product Footprint</td>
<td>&lt;24 x 60</td>
<td>Carson</td>
<td>1</td>
<td>Sys</td>
<td>4/18/2023</td>
<td>4/20/2023</td>
<td>2.4 x 5.5 ft</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Load Factor</td>
<td>Does not yield</td>
<td>Zach</td>
<td>1</td>
<td>Sys</td>
<td>4/20/2023</td>
<td>Passed</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Saddle Height</td>
<td>&lt;38 in</td>
<td>Zach</td>
<td>1</td>
<td>Sys</td>
<td>3/24/2021</td>
<td>5/23/2021</td>
<td>37.5 in</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>Appearance Survey</td>
<td>&gt;7/20</td>
<td>Lydia</td>
<td>1</td>
<td>Sys</td>
<td>4/25/2023</td>
<td>5/23/2023</td>
<td>9.5 Average</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>Use Survey</td>
<td>&gt;9/10</td>
<td>Broghen</td>
<td>1</td>
<td>Sys</td>
<td>4/16/2023</td>
<td>5/23/2023</td>
<td>9.4</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>Setup Time</td>
<td>&lt;30 min</td>
<td>Broghen</td>
<td>1</td>
<td>Sys</td>
<td>4/16/2023</td>
<td>5/23/2023</td>
<td>5 min</td>
</tr>
<tr>
<td>8</td>
<td>FMEA</td>
<td>Spring Constant</td>
<td>450 lb</td>
<td>Broghen</td>
<td>1</td>
<td>Sys</td>
<td>4/21/2020</td>
<td>5/23/2021</td>
<td>2700 lb/in</td>
</tr>
<tr>
<td>9</td>
<td>FMEA</td>
<td>Pinch Points</td>
<td>&gt;1.5 in</td>
<td>Lydia</td>
<td>1</td>
<td>Sys</td>
<td>4/16/2023</td>
<td>5/23/2023</td>
<td>Exactly 1.5 in</td>
</tr>
<tr>
<td>10</td>
<td>FMEA</td>
<td>Tip or Tilt</td>
<td>Does not tip</td>
<td>Zach</td>
<td>1</td>
<td>Sys</td>
<td>4/21/2020</td>
<td>5/23/2023</td>
<td>Did not tip</td>
</tr>
</tbody>
</table>
Appendix E – Testing Procedures

**Test Name:** Weigh the Final Design

**Purpose:**
This test ensures that we have made the horse within the acceptable weight limits. Our design criteria specified the design being lifted by two volunteers (in case of the castors locking up).

**Scope:**
This test will involve weighing the final horse design.

**Equipment:**
Mechanical Horse (Fully Assembled)
Scale

**Hazards:** Drop hazard.

**PPE Requirements:** Close-toed shoes required.

**Facility:** Bonderson

**Procedure:**
1. Lift horse up with two group members
2. Carefully place the horse onto the floor scale
3. Record weight measurement

**Results:**
- Pass Criteria: Horse is less than 130 lbs.
- Fail Criteria: Horse is more than 130 lbs or is unable to be lifted by two people.

**Test Date:** 5/16/2023

**Test Results:** PASS  **Weight Measurement:** 110 lbs.

**Performed By:** Carson Roff + Broghan Martin
**Test Name:** Measure Final Design Footprint Width and Length

**Purpose:**
This test verifies that the horse design will have an acceptably small footprint, so as to fit within storage areas at the JHH facility.

**Scope:**
This test involves measuring the dimensions of the horse with a tape measure and recording the final measurements.

**Equipment:**
Mechanical Horse (Fully Assembled)

**Hazards:** N/A

**PPE Requirements:** N/A

**Facility:** Bonderson

**Procedure:**
1. Using tape measure, measure length of horse base
2. Record value
3. Repeat steps with the width of the base

**Results:**
- Pass Criteria: Width is less than or equal to 2ft, AND length is less than or equal to 6ft.
- Fail Criteria: EITHER measurement extends past maximum value.

**Test Date:** 5/16/2023

**Test Results:** **PASS**
- Length: **5.75 ft.**
- Width: **1.6 ft.**

**Performed By:** Broghan Martin
**Test Name:** Use two riders with an equivalent weight of at least 300 lbs

**Purpose:**
This test ensures the horse does not collapse or yield with a maximum load of two people.

**Scope:**
Two group members will sit on the horse to test the strength and yield limits.

**Equipment:**
Mechanical Horse (Fully Assembled)
Broghan
Zach

**Hazards:** Collapse of the horse. Falling. Pinch points.

**PPE Requirements:** Floor mats, safety glasses, close-toed shoes.

**Facility:** Bonderson

**Procedure:**
1. Set up mechanical horse as would be done at JHH facility
2. Have Broghan and Zach sit on the horse, one at a time, without supporting their weight elsewhere
3. Listen/look for cracking or yielding
4. Have Broghan and Zach get off the horse
5. Inspect for any damage

**Results:**
Pass Criteria: No damage.
Fail Criteria: Visible damage to the horse body.

**Test Date:** 5/16/2023

**Test Results:** PASS

**Performed By:** Group
Test Name: Measure Saddle Height

Purpose:
This test verifies that the horse design will have the required saddle height.

Scope:
This test involves measuring the dimensions of the saddle with a tape measure and recording the final measurement.

Equipment:
Mechanical Horse (Fully Assembled)

Hazards: N/A

PPE Requirements: N/A

Facility: Bonderson

Procedure:
1. Using tape measure, measure height of saddle to the top of the saddle seat
2. Record value

Results:
Pass Criteria: Saddle height is less than 38in and preferably 36in.
Fail Criteria: Saddle height exceeds 38in.

Test Date(s): 5/16/2023

Test Results: PASS
Height Measurement: 37.5in.

Performed By: Zach Barnishan
**Test Name:** Have users perform appearance survey

**Purpose:**
This test utilizes volunteers and users to provide feedback about the aesthetics of the mechanical horse and ensure it is professional and welcoming in appearance for all.

**Scope:**
This survey collects opinions, scores, and comments about the overall appearance of the horse as designed.

**Equipment:**
- Mechanical Horse (Fully Assembled)
- Clipboard
- Pen
- Printed survey results table

**Hazards:** N/A

**PPE Requirements:** N/A

**Facility:** Various (JHH office, Cal Poly parking lot, Bonderson, etc.)

**Procedure:**
1. Lead volunteer to mechanical horse
2. Allow volunteer to look at horse
3. Record initial comments
4. Ask volunteer to rate the aesthetic of the horse on a scale from 1-10, with 10 being the best
5. Record rating
6. Ask for final comments and opinions
7. Record any final comments

**Results:**
- Pass Criteria: Mean appearance survey score is >7/10.
- Fail Criteria: Mean appearance survey score is <7/10.

**Number of Volunteers:** 11 (must be >10)

**Test Date:** 5/16/2023

**Test Results:** **PASS** Score: **9.5/10**

(table on next page for printability)
<table>
<thead>
<tr>
<th>Volunteer #</th>
<th>Appearance Survey Score (/10)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>No horse head? (was not attached yet)</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>Liked the look of the wooden frame</td>
</tr>
</tbody>
</table>

**Performed By:** Lydia Barnes
Test Name: Use Survey

Purpose:
This test utilizes volunteers and users to provide feedback about the ease of use of the mechanical horse and ensure it fulfills its purpose.

Scope:
This survey collects opinions, scores, and comments about the performance of the horse.

Equipment:
Mechanical Horse (Fully Assembled)
Clipboard
Pen
Printed survey results table
Bonnie

Hazards: N/A

PPE Requirements: N/A

Facility: Various (Bonderson High Bay, JHH facility, etc.)

Procedure:
1) Print out survey for Bonnie to keep copies of
2) Give Bonnie the following procedure to follow when compiling data:
   a. Allow client to use the horse
   b. Record any comments
   c. Ask user to rate their experience of using the horse on a scale from 1-10, with 10 being the best
   d. Record rating
   e. Ask for final comments and opinions
3) Repeat procedure for any further users

Results:
Pass Criteria: Mean appearance survey score is >9/10.
Fail Criteria: Mean appearance survey score is <9/10.

Number of Volunteers: 5 (must be >4)

Test Date(s): 6/2/23

Test Results: PASS  Score: 9.4/10

(table on next page for printability)
<table>
<thead>
<tr>
<th>Volunteer #</th>
<th>Use Survey Score (/10)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/10</td>
<td>Felt like riding a real horse to girl ~9yo</td>
</tr>
<tr>
<td>2</td>
<td>8/10</td>
<td>Very small boy ~2yo could not rock it himself, but loved sitting and an assistant facilitated the motion</td>
</tr>
<tr>
<td>3</td>
<td>10/10</td>
<td>Self-explanatory to use once he had seen others use it. Very fun</td>
</tr>
<tr>
<td>4</td>
<td>10/10</td>
<td>Could fit two children at once (~7yo ea) and ride comfortably, self-propelled</td>
</tr>
<tr>
<td>5</td>
<td>9/10</td>
<td>Felt very close to the gait of a horse according to horseback rider</td>
</tr>
</tbody>
</table>

**Performed By:** Lydia Barnes
**Test Name:** Setup Time Test

**Purpose:** This test will measure the time it takes to set up the mechanical horse to make sure it is easy to use.

**Scope:** This test is constrained only to the set up of the horse once it is fully assembled by the team, it is not meant to measure how long the manufacturing processes take.

**Equipment:**
Stopwatch

**Hazards:** None

**PPE Requirements:** None

**Facility:** JHH facilities

**Procedure:**
1) Place the mechanical horse in its place of long term storage.
2) Start the stop watch and ask Mrs. Burt or another JHH associate to set up the horse.
3) Wait and observe until Mrs. Burt or another JHH associate has set up the horse and stop the stopwatch.

**Results:**
PASS / FAIL of setup time of the horse compared to the benchmark of 10 min to set up.

**Test Date(s):** 6/2/23

**Test Results:** PASS  Time: 5 mins

**Performed By:** Broghan Martin
**Test Name:** Test spring constants with final springs

**Purpose:** This test will measure the spring constant of the several springs we used in the creation of our concept prototype.

**Scope:** This test is constrained only to compression springs for use in the Mechanical Horse project.

**Equipment:**
Intron or other tensile tester

**Hazards:** Accelerated particles from broken or snapped springs.

**PPE Requirements:** Safety glasses since experiment will be conducted in the shop. Close-toed shoes.

**Facility:** Mustang 60

**Procedure:**
1) Zero the Intron.
2) Place test spring in Intron.
3) Manually job spring extension to 1.0 inch.
4) Read and record force exerted and displacement from Intron readout.
5) Repeat steps 1-4 for each subsequent spring.

**Results:**

*Table E.1: Spring force and displacement from Intron*

<table>
<thead>
<tr>
<th>Spring #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (N)</td>
<td>120</td>
<td>123</td>
<td>118</td>
<td>127</td>
<td>123</td>
<td>124</td>
</tr>
<tr>
<td>Displacement (mm)</td>
<td>25.401</td>
<td>25.400</td>
<td>25.402</td>
<td>25.400</td>
<td>25.401</td>
<td>25.400</td>
</tr>
</tbody>
</table>

Intron force graph resolution: 1 N
Intron displacement resolution: .001 mm

A t-test will be conducted using collected data to find a range of values that the true spring constant for these springs would be predicted to fall. The general uncertainty propagation equation (below) will be used for uncertainty propagation on the uncertainty for the force measurement and the displacement measurement.

\[
\delta f = \sqrt{\left(\frac{\partial f}{\partial x_1}\delta x_1\right)^2 + \left(\frac{\partial f}{\partial x_2}\delta x_2\right)^2 + \cdots + \left(\frac{\partial f}{\partial x_n}\delta x_n\right)^2}
\]

The uncertainty calculations performed for this test can be viewed in Figure E.1 on the following page.
### Data

<table>
<thead>
<tr>
<th>Spring Force</th>
<th>Spring Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>120.02</td>
<td>25.401</td>
</tr>
<tr>
<td>123.11</td>
<td>25.4</td>
</tr>
<tr>
<td>118.05</td>
<td>25.402</td>
</tr>
<tr>
<td>127.14</td>
<td>25.4</td>
</tr>
<tr>
<td>123.04</td>
<td>25.401</td>
</tr>
<tr>
<td>124.08</td>
<td>25.4</td>
</tr>
</tbody>
</table>

### Nominal Values

- **Mean**: 122.538715\(\text{N}\), 25.40066666\(\text{mm}\)
- **Std dev**: 3.181519553, 0.000816497

### Statistical Uncertainty

- 95% confidence: 6.199410662, 0.001591

### Resolution Uncertainty

- 0.01, 0.001

### Total Uncertainty

- 6.199418727, 0.00187917

### Fractional Uncertainty

- 0.050591446, 7.39811E-05

### Uncertainty Propagation

**Equation I will be using:**

\[ u_k = (u_F^2 + (-u_d)^2) \]

### Fractional Uncertainty of K

\[ u_k = 0.0505915 \]

### Nominal Value of K

- K\(=\) 4.624 N/mm
- Uk\(=\) 0.244 N/mm

### In English Units

- K\(=\) 26.571 ± 1.394 lbf/in
- Maximum Spring Stiffness: K\(=\) 27.965 lbf/in

---

**Figure E.1: Uncertainty Propagation Calculations Spreadsheet**

**Test Date:** 4/28/2023

**Test Results:** PASS

**Performed By:** Broghan Martin, Zach Barnishan, Carson Roff
**Test Name:** Neck Mechanism Gap Measurement

**Purpose:**
Defining the minimum gap between the neck and the body allows us to minimize pinch points and ensure fingers won’t get stuck.

**Scope:**
This test determines what the minimum gap would be between the top of the body and the upper face of the neck mechanism when the system is pushed up against the hard stops.

**Equipment:**
Caliper
Horse Body
Horse Neck Mechanism

**Hazards:** Pinch points end up pinching fingers.

**PPE Requirements:** N/A, but refrain from putting hands in pinch point areas.

**Facility:** Bonderson

**Procedure:**
1) Have a team member pull the horse neck mechanism back until it hits the hard stop
2) Have a second team member use a caliper to measure the gap between the top of the neck mechanism and the middle slat on the body

**Results:**
Pass Criteria: Distance is greater than or equal to 1.5”.
Fail Criteria: Distance is less than 1.5”.

**Test Date:** 5/16/2023

**Test Results:** PASS

**Gap Measurement:** 1.5in.

**Performed By:** Carson Roff
Test Name: Perform Tilt Analysis

Purpose:
This test verifies that the mechanical horse does not tip over when mounting and dismounting the saddle.

Scope:
This test analyses the center of gravity of our mechanical horse and verifies that the base was designed with the correct CG location.

Equipment:
Mechanical Horse (Fully Assembled)  
Ratchet straps  
Carabiner  
Chain  
Mass Sim (variable weight)  
Thick floor pads

Hazards: Tipping resulting in falling and injury.

PPE Requirements: Thick floor pads

Facility: Bonderson

Procedure:
1. Place the floor pads on the floor at the tilt test side of the horse
2. Run the ratchet straps around the body of the horse in line with the saddle
3. Attach the carabiner to the ratchet straps at the side of the horse
4. Loop the chain through the mass sim
5. Attach the chain to the carabiner
6. Add additional weight until the horse tips sideways

Results:
Pass Criteria: 170 lbs. does not result in tipping.  
Fail Criteria: The horse tips over at or under 170 lbs.

# Samples to Test: 1

Test Date: 5/16/23

Test Results: PASS

Performed By: Broghan Martin, Zach Barnishan, Carson Roff