Get-A-Grip

Melis Jensen, Andrew Chin, Daniel Glick, Nachum Twersky and Alexa Ocel

The authors are with the Department of Mechanical Engineering, Columbia University, New York, NY (alo2142@columbia.edu, mj3105@columbia.edu, ajc2323@columbia.edu, nt2638@columbia.edu, dig2115@columbia.edu). This material is based upon work developed in the MECE E3420 / E3430 Engineering Design Courses

***Abstract*— Get-A-Grip: A revolutionary device enhancing gym accessibility for Individuals with grip disabilities. Grip disabilities affect approximately 5-10 percent of adults globally, significantly limiting their ability to perform various exercises safely and comfortably. Addressing this challenge, our team has developed "Get-A-Grip," an innovative device designed to secure a user's grip on gym equipment while redistributing weight across the forearm and facilitating easy release. This device comprises a compression sleeve, adjustable straps for a snug fit, and a toothed strap with a locking mechanism that enables users to attach to and detach from barbells and dumbbells effortlessly, using minimal grip strength. The locking mechanism is tested to withstand forces up to 2000N, ensuring safety and durability under ASTM standards. Unique to Get-A-Grip, the device's design includes a cushioned interior to prevent wrist strain and an easy-release feature that allows detachment by a simple wrist rotation. Our prototype iterations have demonstrated the device's effectiveness in enhancing gym accessibility, making it a transformative solution for those with grip disabilities, thus empowering them to engage in strength training exercises without fear of injury.**

I. Introduction

For decades now, scientists and researchers alike have come to the generalized conclusion that exercise and activity promotes both longevity and well-being. In fact, increased activity lowers the risk of several chronic conditions including heart disease, hypertension, diabetes, osteoporosis, some types of cancer, and cognitive decline [1]. Those benefits sound attractive enough, however further research into the long term benefits of physical activity has shown enhanced benefits specific to weight training. As Mayo clinic describes, weight training can help strengthen the bones, increase metabolism through fat maintenance, and even help manage chronic conditions such as obesity, heart disease, and arthritis. This involves integrating activities involving free weights, weight machines, and cable suspension training. An average healthy adult should "Do strength training exercises for all major muscle groups at least two times a week [2])." This regimen is supported further by a study published in Dtsch Arztebl Int. expressing that the continuation of these habits into elderhood has beneficial effects on the psychological process of aging [3].

However, a paramount issue prevents most adults from adopting this healthy lifestyle later in life. By the time adults reach the age of 60 years old, over 5% of adults report weak grip strength and another 13% have moderate grip strength. This loss of muscle only intensifies with age as over the next 15-20 years, the study shows that over 19% of Americans have completely weakened grip strength and another 34% have only intermediate grip strength [4]. In addition to natural loss of muscle over time, a large amount of the US population struggles with grip strength ailments caused by unexpected conditions such as arthritis, carpal tunnel, and the physical restrictions after strokes and heart attacks. To picture the scope of these hand disabilities:, over 52 million people in the United States have arthritis [5] four to ten million people have carpal tunnel syndrome [6], and over 795,000 people have a stroke each year [7]. Of the 795,000 people that experience a stroke, around 30 percent of people develop impaired range of motion in their hands [8].

What is left is a paradoxical problem. As Americans age, the importance of exercise and integrating weight training into a weekly lifestyle increases, but the ability to implement the lifestyle decreases due to loss of grip strength with age. Lifting weights or using gym equipment is reliant on one's ability to grip. To combat this issue, the fitness industry needs to be fixed from the inside out. The archaic nature of gym equipment has not catered toward the demographic of people that need the exercise but lack the physical ability to start lifting on their own.

This paper proposes a novel weight-lifting device that will make the gripless feel limitless in the gym. By utilizing ratchet technology, this mechanical wrist device will allow for safe, hands free connection and release from any standard sized gym bar/weight. With a $1500 design budget and a timeline of about eight months, a 4340 steel alloy based prototype was developed and tested. This complete prototype was able to complete various pulling exercises within reasonable weight limits in the gym. The brace could assist with exercises such as: pull-ups, rows, reverse curls, and lat pull-downs.

Fig. 1: Get-A-Grip Final Prototype

To ensure that our device was up to standards for practical use in real gym environments, there were many constraints that guided our design process. These posed strength thresholds on the type of materials we used to create the wrist brace, the ratcheting technology, the strap, as well as the overall geometric shape of the device. The primary constraints for gym equipment are set by the American Society for Testing and Materials (ASTM) and the Weightlifting and Powerlifting Federation. These constraints will be further detailed in the methodology section of the paper.

II. Methods

The design and manufacturing of Get-A-Grip are categorized by its mechanical and nonmechanical components. Each component of the Get-A-Grip prototype adheres to established standards to ensure it meets the load requirements, safety expectations, and comfort needs of gym users. Initially, we focused on integrating design standards into the locking mechanism, specifically the pawl and locking rod, as illustrated below. When a user inserts the tooth strap into the locking mechanism and it's in the "locked" position, the pawl engages with the strap but cannot rotate due to its contact with the locking rod, effectively securing the strap. Conversely, when "unlocked," the locking rod moves upwards, allowing the pawl to rotate and release the strap.

The paramount standard for gym equipment is ensuring the product is strong enough to hold the maximum extrinsic loads of the gym environment. As well as being an ethical concern for gym user's safety, there is legal liability involved with injuries due to broken gym equipment. As far as how large the reactionary force of the device should be to prevent these problems, an analysis of various gym movements was done. For this device, the maximum load situation was estimated for a 200lb male doing a deadlift. From various sources, the average expected deadlift amount was 290 pounds [9]. Converting this number to a force, the maximum user applied load is estimated to be around 1300 Newtons. Then, per ASTM rule 5.2.1, the total reactionary force needed is estimated by Formula 1. In this equation, F_{test} equates to the experimental loading applied to test robustness of the system, W_p is the proportionate amount of the user's body weight being applied to the machine component being tested, F_a is the maximum user applied load at the point of user contact with the machine for the maximum capacity of the machine, and S is the factor of safety desired [10].

$$F_{test} = [W_p + 1.5F_a]S \quad (1)$$

To use this formula, a FOS of 2.5 is recommended but to err on the side of caution, a factor of safety of 3 was used. Additionally, given that a deadlift is not utilizing any of the user's weight, Wp can be taken as zero which resulted in an estimated reactionary load of 2000 Newtons (rounded up). This is the estimated force threshold that needs to be implemented for the manufactured device to handle the estimated maximum load in the gym environment. This posed very important constraints on the point of contact for the pawl. As a very small (1.5 inch) rod, the material in which the part was manufactured had to be quite strong. To satisfy these load requirements, 4340 alloy steel was chosen as the ideal material for its high yield strength of 740-1860 MPa [11]. In addition to the pawl, the locking rod within the mechanism also required high yield strength due to its direct contact with the pawl while the device is experience load increase. For this reason, both parts were to be machined out of 4340 steel for a quality high strength mechanism. To ensure that these parts were strong enough with these force transfers, finite element analysis was done to confirm that the parts fit the 2,000 newton requirement with a factor of safety of 3 (6000 Newtons). These analysis results will be provide in the following section.

A. Arm Brace and Attached Strap

While our design primarily revolves around a mechanical locking mechanism, the non-mechanical elements like the arm brace and fabric strap are key to the product's comfort and functionality. Thus, we meticulously adhered to relevant standards and regulations, including standard forearm dimensions and barbell diameters, during the design process.

For the arm brace construction, our goal was to accommodate the broadest range of forearm sizes. We used the Compression Therapy and Exercise guide as a reference, which lists an average forearm length of 6.27" and a wrist radius of 3.9" [12]. Aware that these averages might not suit everyone, we included a compression sleeve at the base of the arm brace to prevent slipping and adjust to larger forearms. The compression sleeve's strength of 30 mmHg fits within the guide's recommended range of 23-46 mmHg [13].

In designing the fabric strap that secures to barbells or fitness equipment, we considered weightlifting standards, specifically the typical barbell diameter of 28 mm, extending up to 30 mm [14]. A 30 mm diameter translates to a circumference of 94.2 mm. With this circumference in mind as well as considering the necessity for the strap to be fed through the ratcheting lock mechanism, we chose a strap length of roughly 200 mm Using the strength requirements outlined previously, we selected a propylene fabric for the strap due to its cost-effectiveness and a load capacity of 1800 lb-f (or approximately 8000 N), ensuring it can handle a maximum load of 2000 N without risk of failure [15].

B. Linkage Bars

A linkage system connects the arm brace to the locking mechanism, using wrist force to unlock the ratchet. When the user extends the wrist, a rod within the locking mechanism shifts, enabling the locking pawl to rotate and release the tooth strap. The design accommodates an average wrist rotation of 75-90 degrees, as noted by Healthline [16]. However, to cater to potential wrist mobility issues, we set the rotation requirement at a more accessible 25-30 degrees. We confirmed that the linkage can rotate under 30 degrees while still pulling the locking rod up by 3 mm. For safety, we based our calculations on a 15 mm displacement requirement. The minimum required distance from the arm brace's pivot point to the locking rod is approximately 37 mm, illustrated in Fig. 2. Using this distance, and a 15 mm translation requirement, trigonometric ratios helped us determine a safe wrist rotation angle of 24 degrees, as detailed in Equation 2. This angle is also effective on the opposite side of the pivot point, interacting with the wrist. Considering an average hand depth of 40-41 mm, we calculated a linkage length from the pivot point to the wrist of about 100 mm using Equation 3 [17]. These measurements were refined through iterations following 3D printing and testing of the assembly, focusing on both dynamics and comfort.

$$sin^{-1}(\frac{15}{37}) \quad (2)$$

$$\frac{41}{sin(24)} \quad (3)$$

C. Supporting Materials

Additionally, various adhesives were required to fasten parts together. For example, to permanently press fit bearings into the connecting linkages, we used JB Weld because of its optimal strength and fast-drying bond. To adhere the

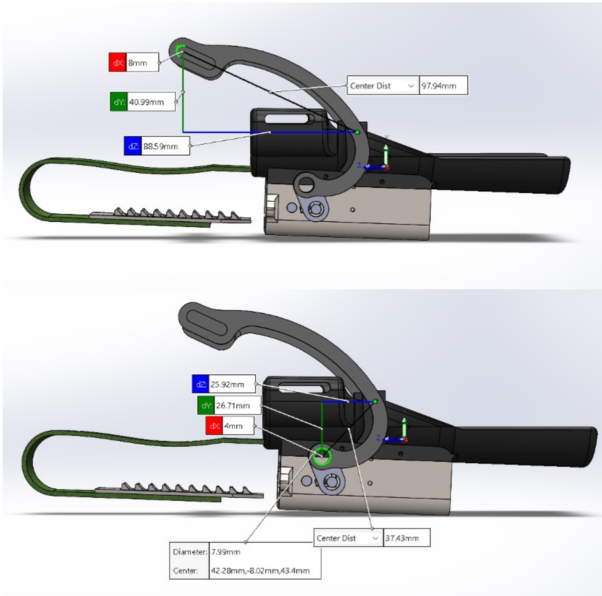
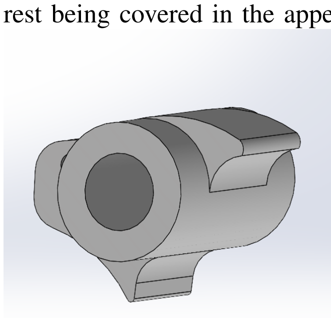


Fig. 2: (a) Min Distance Pivot Point to Wrist and (b) Min Distance Pivot Point to Locking Rod

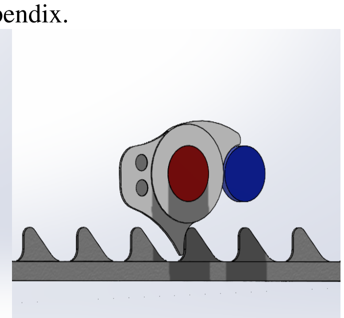
Propylene fabric strap and various paddings to the arm brace, we used 3M Scotch-Weld adhesive. Unlike JB Weld, 3M's Scotch-Weld adhesive can be used with propylene fabrics.

D. Finite Element Analysis

Many of the parts undergo high forces relative to their size. Therefore, many of the parts went through FEA (Finite Element Analysis) to determine how they would perform. This portion will only cover the FEA of the most complex part geometrically, the pawl illustrated in Fig. 3a, with the rest being covered in the appendix.



(a) CAD Model of Pawl



(b) Pawl Mechanism

The mechanism that surrounds the pawl is shown in Fig. 3b The pawl sits on a 303 stainless steel rod (red) and is held in its 'primed' position by using springs. When under load, the toothed plate pulls back on lower portion of the pawl causing the pawl to rotate into the locking rod (blue). Once locked, the pawl is fixed in place, while the toothed plate and locking rod enact a force on it.

As mentioned previously the pawl is expected to undergo a maximum force of 2000 Newtons and adhere to a minimum factor of safety of 3. As shown in Fig. 4 The pawl has a force from the locking rod, and the toothed plate. Both are

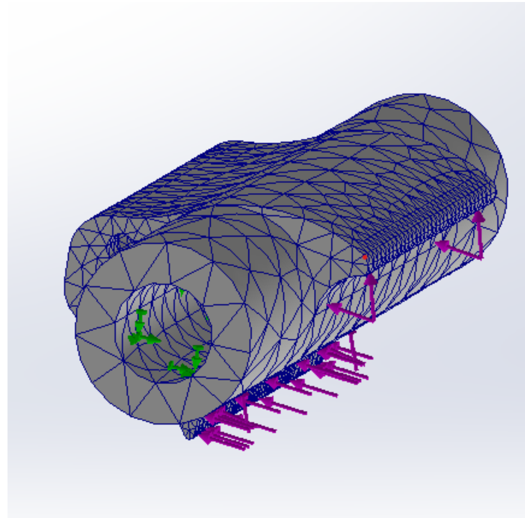


Fig. 4: Forces and constraints placed on the pawl for FEA

set to a magnitude of 2000 Newtons. Since the pawl is fixed in place by these 2 forces it was fixed in place around the center rod. Lastly, a mesh convergence study was done to ensure the accuracy of the simulation results.

E. Real World Testing

Since the users wrist is the force that releases the mechanism, testing was needed to be done to determine the forces required to push on the wrist bar. We assumed early on that the amount of force needed to release the mechanism would be proportional to the amount of weight the user is lifting. To test this, increasing weights were lifted using the Get-a-Grip while a force gauge was attached to the release bar as shown in Fig. 5 . This test was done from 15 to 40 pounds (6.8 to 18.1 Kg). Once the weight was lifted off the ground, the release mechanism was pulled and the max force needed was recorded.

Fig. 5: Input vs Output Force Testing

III. Results

A. Finite Element Analysis Results

The results of the mesh convergence study are shown in the chart below in Table I. With a maximum percentage error of 1.5 we can be assured that our FEA results are accurate and the overall geometry of the pawl isn't skewing the data.

TABLE I: Max Stress Values at Different Nodes Amounts

Node Amount	Max Von Mises Stress (Pa)
17,893	8.870×10^7
23,758	8.914×10^7
31,579	8.824×10^7

As shown in Fig. 6. The Maximum Von Mises stress is $7.99 \times 10^7 (N/m^2)$ which is well below the yield strength of the 4340 alloy as mentioned above. The focus of the stress is on the bottom protrusion that interacts with the toothed plate. further testing must be done to see how the part will react with asymmetrical loading. However, with the current design the pawl has a minimum Factor of Safety of 5.178 as shown in Fig. 7.

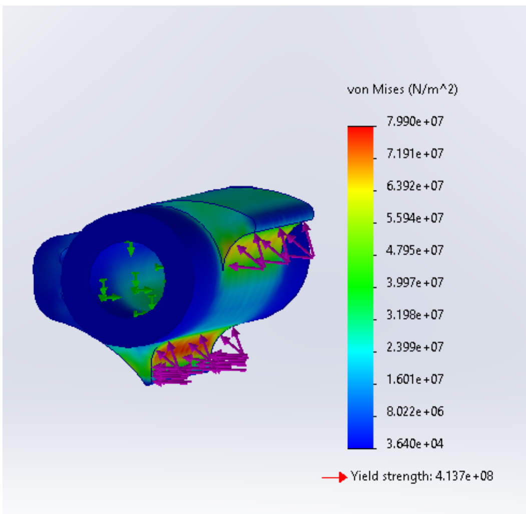


Fig. 6: FEA Results

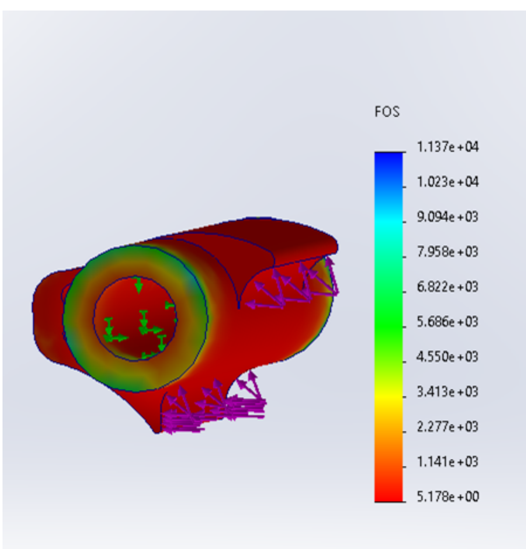


Fig. 7: Factor of Safety Plot

B. Real World Testing Results

The data from the input vs output force testing showed that with the tested weight increase, the required force remained roughly the same. To be sure, the original assumption that this relationship would be linear was tested by running a linear regression. With a calculated r-squared value of 0.0189, the linear correlation proved to be very weak. As shown in Fig. 8, the required force fluctuated between 0.8 - 1.2 pounds (.36 - 0.54 Kg).

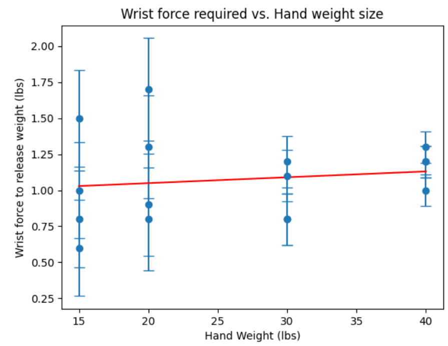


Fig. 8: Testing wrist force

In terms of the product's comfort, the team's plan was to include sufficient padding at the end of the brace to both make the brace more comfortable under load and help users further avoid injury. For the prototype, we used glue to fasten household foam to the brace in order to ensure we could try something else if we weren't satisfied. When it cured however, the glue dried into hard chunks that tended to dig into the users arm and made the wear-ability worse. The team is thinking about better ways to fasten foam onto the brace that wouldn't pose this issue. We are also looking at different varieties of foam to select one that best reduces impact and increases the overall comfort of the final product.

We took the product to some users at the gym to get initial feedback and got the following responses. People felt the product was intuitive. It's easy to get on and use with little to no learning curve. They had no issues engaging the mechanism release and were generally impressed with the performance of the product. With that being said, trusting a device to hold up your weight goes against one's intuition and users found themselves shifting their weight towards the uninjured arm out of caution. We suspect that as users get comfortable with the product and build trust in its strength, this pattern will go away.

IV. Discussion & Conclusion

A. Interpretation of Results

The factors of safety of the pawl, tooth plate, and locking rod seen in Fig. 7, 12, and 15, respectively, calculated within SolidWorks and Fusion 360 are well above the safety factor of 2.5 prescribed by the gym equipment regulation safety standards. As mesh convergence was achieved in each study these results ensure that our ratcheting locking mechanism will not fail when subjected to three times the worst case loading of 2000N, or 6000N. Note the equivalent weight in pound force is equal to about 1350 lbs. Therefore, from our calculation we are confident that Get-A-Grip will not fail during a user's lifting experience even under the most extreme loading conditions.

Further as seen in Fig. 8, as the applied load on the tooth strap increased, the force required by the user's wrist to unlock it increased minimally, ranging from 0.8-1.2 lbs of force. While unexpected, this result proves extremely favorable for our device as the user will always be able to easily disengage the locking mechanism no matter the weight with which they are lifting.

B. Analysis Errors

One of the common issues faced within our FEA of the ratcheting pawl and pawl rod was the presence of artificial stress concentrations. These were created as a result of the split lines introduced into the models to simulate the fixed geometry of our real world system. This was solved within the pawl by filleting the harsh corners of the models at the ends of the cylindrical faces and around the split lines. This broke the artificial corner conditions allowing for mesh convergence to be reached, which proves the robustness of our analysis.

This issue, however, persisted with respect to the pawl locking rod. Note that the FEA simulation study was conducted within Fusion 360. Despite our attempts to fillet the harsh corners, artificial stress concentrations remained within our study, preventing mesh convergence. The pawl rod was therefore simplified in geometry to a rod of identical material and equal diameter and length. This can be justified by the fact that the main load bearing section of the pawl rod shown in 13 is a simple cylindrical rod. Identical applied loads and fixed geometries were assigned to the rod and the FEA was conducted within SolidWorks and mesh convergence was found. This gave us the confidence that our actual pawl rod of slightly more complex geometry would not fail within as it had a factor of safety greater than 3.

C. Literature

Literature, including that of ”Specification for fitness equipment” dictates that the factor of safety can be determined by equation 1 [10]. Analytical calculations with our prescribed loading of 6000N produced an expected safety factor of 3. In comparison, however, our SolidWorks simulations yielded factor of safety values that, as stated before, were greater than 3. This can be attributed to the complex and specific geometries of the pawl and pawl rod which distribute applied loads in unique ways. Nevertheless, this confirms that our numerical calculations follow the theory outlined by the equation[1].

D. Shortcomings & Improvements

One thing we did not account for is the possibility of the slot on the mechanism housing getting worn down over time. Due to limited testing resources, we could not cycle the product more than 100 or so times and it’s possible that after some time the housing could get worn down and the mechanism could develop slop. In fact, significant jamming of the locking mechanism was observed due to this oversight. Fortunately the incorporation of ample lubricant was able to ensure against this as the locking mechanism now functions smoothly, without any error. Despite this, more testing of the device to its breaking point and the inclusion of a warranty up to that threshold are action items we seek to pursue in the future. The arm brace which was laser sintered from nylon powder is also not necessarily very strong. Further an accidental drop of a sizable weight on it could possibly damage it. When running tests (FEA or in person) we only tested the products viability while it was being worn by the user but not if it were on the floor and a weight was dropped on it. To account for this, the design could be modified by using a stronger material for the brace that would be strong enough to withstand the impact of an accidental weight drop on it.

As for other possible improvements, the team would like to better the user experience with regards to unlocking our ratcheting mechanism and making the lifting experience more comfortable and easier for the user. While our linkage mechanism was effective in disengaging our locking mechanism, formal calculations or simulations were not conducted to ensure its integrity under extreme loading capacity. Rather only empirical testing was conducted with the maximum weight of 80lbs (about 360N) applied to the system. Thus, for future improvements we plan introduce a gear train to make our linkage mechanism more robust. The utilization of a gear ratio to amplify the input force that the user’s wrist exerts when unlocking our ratcheting mechanism will ensure that the user will always be able to release themselves from the bar, regardless of the weight they are lifting. Additionally, we aim to line portions of the arm brace with silicone and continue to experiment with more ergonomic arm brace geometries to improve overall comfort. We plan to use casting of silicone 20A to fabricate padding-like structures to line the portion of the arm brace which interface with the user’s wrist. We believe that it will be able to replicate the cushioned functionality of foam while resisting deformation over time. Last, we aim to add a magnet system to align the the tooth strap with the ratchet entryway for easier engagement. There are existing versions of this type of system used in other applications and we could incorporate a similar system here to make our product even easier to use.

Through our rigorous analysis we have successfully brought Get-A-Grip to life. Combining a rated safety factor of 3 and above with an ergonomic, comfortable and easy to use mechanism, Get-A-Grip allows for limitless potential within the gym. With this groundbreaking device, users with grip disabilities will finally have the ability and confidence to engage in pulling exercises with ease. Not only can they lift upwards of 2000N, or about 450lbs, all without any use of their grip, but they can also easily detach themselves from the bar in use with a simple backwards flexion of their wrist. The archaic nature of the fitness world, and gyms especially, have notoriously been known for discouraging users who have come to see it as a world of ”I can’t”. With Get-A-Grip, however, we have laid the foundation for turning their worlds of ”I can’t” into ”I can” for those with grip disabilities and even other avid gym goers.

V. Appendix

A. Toothed Plate

We followed the same method for the toothed plate as we did the pawl. In this case, The toothed plate was held fixed at the bottom, with the force of 2000N acting on a single tooth as shown in Fig 9. The results of the convergence study are shown below in Fig 10. Lastly are the Von Mises stress plot 11, and FOS plot.12 7

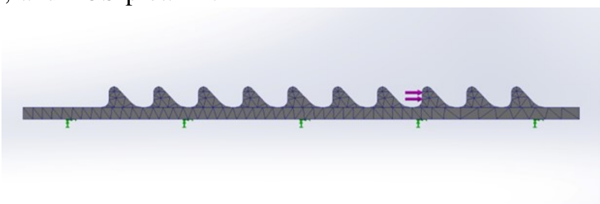


Fig. 9: Toothed Plate Mesh and Forces

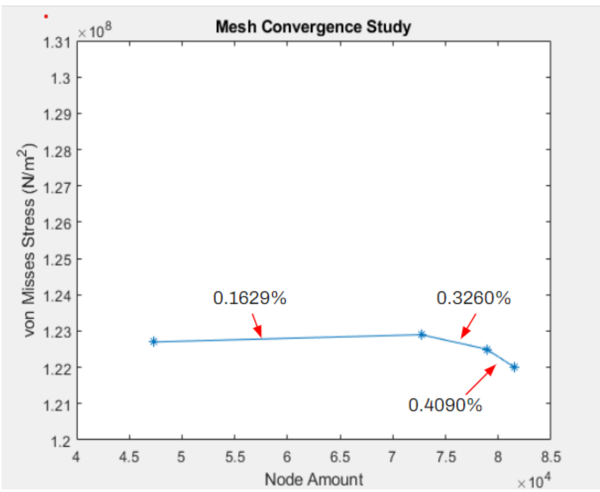


Fig. 10: Toothed Plate Convergence Study Result

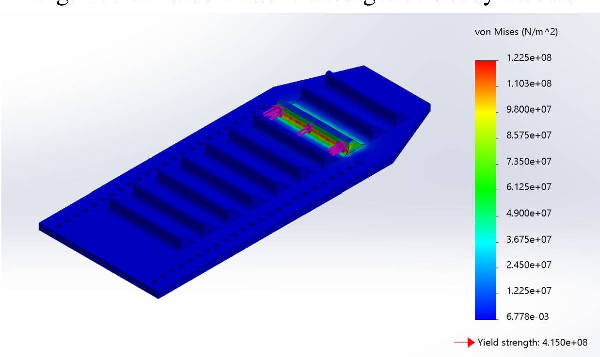


Fig. 11: Toothed Plate FEA

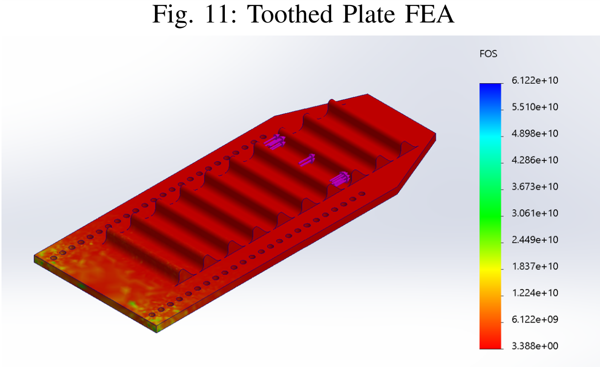


Fig. 12: Toothed Plate FOS

B. Locking Rod

As mentioned above, the locking rod was slightly more difficult to setup an FEA.This was due to the directional forces that act on the rod from the pawl and it required the use of split lines. This created a corner condition which caused our mesh convergence to fail, as well as result in incredibly high stress at the invisible corners. This locking rod was also designed in Fusion360 and the FEA could not be done in SolidWorks. In this case, The locking rod was held fixed where it interacted with the release bar, with the force of 2000N acting on it at a 45 degree angle as shown in Fig 13. Lastly are the Von Mises stress plot 14, and FOS 15

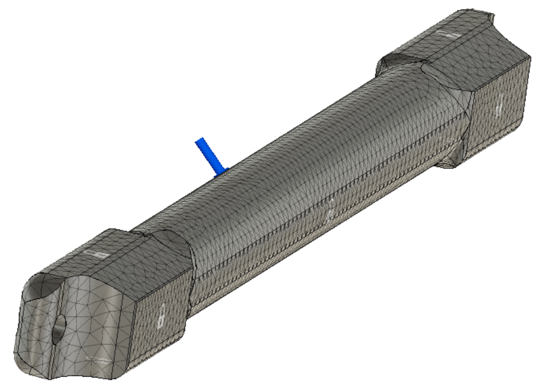


Fig. 13: Locking Rod Mesh and Forces

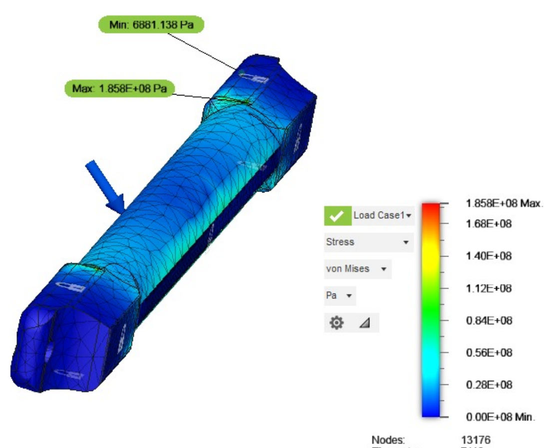


Fig. 14: Locking Rod FEA

References

[1] "Harvard school of public health: Healthy longevity," *Harvard School of Public Health*, 2022.

[2] S. M. Pruthi, "Strength training: Get stronger, leaner, healthier," *Mayo Clinic: Health and Lifestyle (Fitness)*, 2023.

[3] F. Mayer, S.-R. Friederike, C. Anja, M. Cassa, S. Muller, and J. Scharhag, "The intensity and effects of strength training in the elderly," *National Library of Medicine*, 2011.

[4] A. P. Looker and C.-Y. P. Wang, "Prevalence of reduced muscle strength in older u.s. adults: United states, 2011–2012," *National Center for Health Statistics*, 2015.

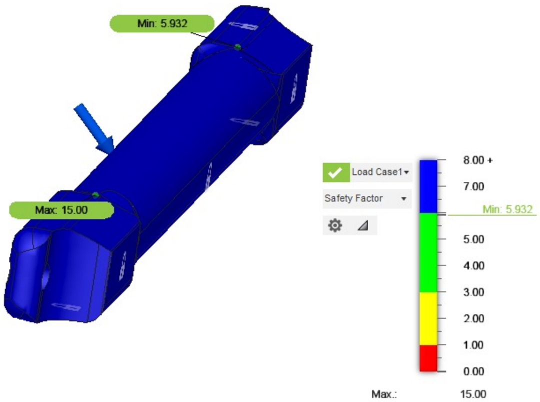


Fig. 15: Locking Rod FOS

[5] "Arthritis," *National Center for Chronic Disease Prevention and Health Promotion*, 2023.

[6] "Surprising statistics about carpal tunnel syndrome," *BrownMed*.

[7] "Thumb and finger movement is reduced after stroke: An observational study," *Centers for Disease and Control Prevention*, 2023.

[8] M. Heroux, J. Cheetham, S. Potts, and J. Diong, "Thumb and finger movement is reduced after stroke: An observational study," *National Library of Medicine*, 2019.

[9] *Deadlift Standards for Men and Women." Strength Level, strengthlevel.com/strength-standards/deadlift/lb*. 2024.

[10] F08 Committee, "Specification for fitness equipment," tech. rep., ASTM International, West Conshohocken, PA, 2008.

[11] G. Pomeranz, R. Mott, S. Wendel, S. Anderson, S. Falkowski, R. Wolff, and J. Waintraub, "Consolidating two NSF online materials and information resource centers for manufacturing and engineering technology education," in *2008 Annual Conference & Exposition Proceedings*, ASEE Conferences, 2020.

[12] *Size Guide - Graduated Compression Arm Sleeves." Gloves for Therapy by Veturo, glovesfortherapy.com/pages/size-guide-graduated-compression-arm-sleeves*. 2024.

[13] V. V. Service, *What Is Mmhg and What Compression Level Is Right for You?" VIM & VIGR, vimvigr.com/blogs/our-blog/what-is-mmhg-how-to-choose-compression-socks#: :text=Class 1: 10-15 mmHg*. 2024.

[14] Rules, *International Weightlifting Federation RSS 092, iwf.sport/weightlifting_/rules*. 2024.

[15] *How to Guide to Strapping Equipment." SJF Material Handling Inc., www.sjf.com/strapping.html*. 2024.

[16] E. Hersh, "Wrist flexion: What's normal, what's not and exercises to improve it," *Healthline*, 2019.

[17] S. Frothingham, "Average hand size: For adults, children, athletes, and more," in *Healthline, Healthline Media*, 2019.