Reverse Engineering Project:

Folding Music Stand

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Introduction

For our project, we selected a Nomad brand folding music stand to reverse engineer and improve upon (figure 1). This stand is composed of black powder-coated steel, ABS plastic, and rubber, with an adjustable height and base, as well as folding capacity for ease of carry. There were 35 parts excluding rivets and screws divided between three subassemblies: a frame to hold the music, a shaft to adjust the height of the frame, and a tripod to provide a stable base. As well as this tripod, the stand utilizes the additional mechanisms of clamps for sturdiness and knobs for adjustability. Its primary function is to hold sheet music at eye level so that a musician can both read and play music at the same time. Each of the subassemblies can be adjusted and folded in using a series of joints and knobs, increasing versatility of the product and reducing the size for easier portability. Our improvements target the poor sheet music carrying capacity of the stand, which is limited by the width of the frame to only two sheets, and the instability of the music on the frame itself due to the design of the frame base. Figure 2 in the appendix details the inputs and outputs of the music stand in the form of a black box diagram.

Music stands like this one are used primarily for practicing rather than performance due to their portable but flimsy nature. The market segment is enormous; according to DataUSA, 2.12 million music majors are currently in the workplace, with projected growth of 3.22%. This statistic represents only a sliver of musicians in the United States – it does not include the millions of Americans who play music without a music degree, including students still in school, those who play as a hobby, and professionals in the workplace. Music stands are a necessary component for anyone who plays off of sheet music, and even off of tablets. Because of this broad audience, a variety of customer needs must be met by a music stand. Primarily, stands must be relatively portable, lightweight and able to collapse down to a transportable size. They must also be sturdy enough to support the weight of music books, tablets, and instrument components like bows. These stands must also be adaptable to any type of musician, meaning their height must be easily adjusted. Finally, music is an expensive field, so stands must be affordable enough that anyone can afford them to help counter equity concerns.

Music Stand Background and Existing Varieties

Although music stands have been around for many years, there have been many variations and improvements, especially with material. They first were used in ancient China, and then in Europe in the 1300s. These were made of many different types of wood, and then eventually metal. The metal stands that are most common nowadays are the ones like ours with an open frame design, that can also fold and be adjusted. There are also ones that have a solid back, and these are seen more with professional use, but they are more expensive and less portable. The lengthy history of this product means that there are many varieties on the market, with improvements nowadays focusing on accessibility and ease of use for musicians while playing – many mechanisms require two hands, and while possible to set down an instrument for adjustment, it can be annoying and time consuming, especially while performing. There are many existing patents, with one of the earliest in America belonging to Carl Lehnert from 1870. However, our research did not yield any recent patents of the same design as our component. There are stands that have adjustable width but they are upwards of $30 or $40, but these require the specific purchasing of a new stand and do not appear to address the problem of music sliding off of the front.

A quick search on any e-commerce website will yield hundreds of music stand products ranging from affordable, unreliable, and cheap stands to costly, heavy, and expensive stands. We compiled a list of principal competitors who produce and have a standing in the music market; according to Gilson's Lyceum, each of them have some slight extra convenience features[1]. Cahaya's $22 option provides a detachable book stand, while with a $13 difference, Klvied's $35 stand features holes on the back of the frame, leading to a lighter weight and a hanger for your violin[2]. Wealthier musicians could invest in a similar but more highly-rated stand from Donner, Weidyudang, or Vekkia, which range from $40-$43[3]. Weiyudang's product stands out because of the addition of a phone holder that can attach onto the music stand. The majority of the products we found have a solid back, all metal, anti-rust layer, and they strongly market their added lights and additional extra features. The net weight of Donner is 1.21 kg and can hold extremely heavy objects such as a projector[4]. Weiyudang weighs about 2.6 kg, Cahaya weighs about 1.04 kg, Vekkia weighs 3.06 kg, and Levied weighs 2.49 kg[5]. Cahaya is the lightest with the best price tag while Donner has better rating a little heavier than Cahaya but overall in a better quality bracket, and the other three generally doubled the weight which makes the buyer prefer the lighter version if they want to carry the music stand around. Donner is at the top of the rank but the review from one buyer said otherwise, arguing that the music holder is made from "really thin plastic"; for them, Donner is an overpriced product with cheap materials[6]. Weiyudang could not escape the criticism also, as they got comments such as "cheap stand - cheap price" and "will not last long."[7] Cahaya is "lightweight, but fragile", Vekkia is "well built but holder is not wide enough", and Klvied is "over price for low quality". In general, we saw a need for an outstanding product that would resolve the problems mentioned above while keeping costs low. Given the

[1] Jackson, "Music Stand"
[2] See note 1
[3] See note 1
[4] See note 1
[5] See note 1
[6] Jackson, "Music Stand"
[7] See note 6

range of options on the market, we chose to focus on the affordability and portability of our product.

Disassembly

Our disassembly process was as follows: First, we unscrewed the frame knob to detach the frame and shaft, which contained the knob, washer, and a screw, then drilled out rivets in the frame which detached the frame linkages, sheet clasps, rib, bases, and joints. We then removed the rubber feet at the end of the legs and drilled out the rivets in the tripod, which detached the tripod legs and stretchers and also detached the runner from the shaft. We then sanded out the interior of the linkage knob to remove the metal dimples, detaching the linkage knob from the lower shaft which allowed us to unscrew the connector knob. We then used a mallet to slide the shaft connector off of the lower shaft, which detached the lower and upper shafts, and also to slide the shaft connector off of the upper shaft, which forced the upper shaft insert off to complete the disassembly. Figure 3 in the appendix depicts the product decomposition diagram, figure 4 labels each component, and photographs of the disassembly process can be seen in figure 5.

Product Analysis

The main function of a music stand is to hold up music. Subfunctions of a stand include its adjustable height, adjustable frame angle, adjustable base width, sheet clasps to secure music, and foldability. A graphical representation of the functions and subfunctions can be seen in figure 6. The first subfunction – the frame – includes eight different parts. First, the frame long linkage offers vertical support for the sheet music. There is one of each on either side of the main spine. Next is the frame medium and frame small linkages. These offer horizontal support for the sheet music, and also have the capability to fold inwards towards the main spine. Again, there is one of each on either side of the frame spine. The frame spine connects all the linkages as stated, and is the main area of support for the sheet music. The frame base is where the sheet music can stand up; and it is also where the long linkages and spine connect to. The sheet clasps give extra support for the sheet music, restricting the vertical and horizontal movement of the sheets. Next, the frame bracket is a small piece that connects the base of the stand to the frame joint, giving more support. The frame joint then connects the frame bracket and the subsequent parts to the upper shaft, which is the main vertical component for the shaft system. The frame knob is the last component of the main frame, and it controls the angular movement of the frame. The next subfunction is the shaft system. This contains the upper and lower shafts, a connector, and a knob. The upper shaft is the main component, as stated before, and is a part of the height adjustment system. The lower shaft is slightly larger than the upper shaft, and allows for height adjustment. The upper shaft fits into the lower shaft to allow the adjustment. The shaft connector connects the shafts together. The shaft knob is connected to the shaft connector, and can be loosened and tightened to allow movement of the shafts to adjust height. The last main sub-function contains the lower knob, which allows for the movement of the tripod. The tripod consists of three legs which are connected by the tripod runner. The runner also connects to the lower knob, which is in charge of adjusting the height and angle of the tripod legs. Also connected to the legs are three stretchers, which give horizontal support to the tripod base, and also aid in movement. To connect the stretchers to the lower shaft, another linkage knob is used. And lastly, rubber feet are used at the ends of the tripod legs to allow traction which reduces slippage and offers standing support. Another general subfunction is the ability to fold the whole stand into a compact size of about 55 cm by 12 cm, allowing for easy storage and transportation.

Manufacturers have optimized the process and reduced waste by using 2 standard sheet metal gauges to form out the majority of the parts. Frame linkages are mostly likely to be cut into shapes and drilled holes from standard sheet metal stocks (1-5,7-8, 17-18)[8]. Parts 7, 8, 17, as can be seen in figure 4, were cut out of a thicker metal sheet approximately 2.22 mm when other frame linkages 1-5, 18 where using the same thin approximately 1.44 mm. Part 4, 5, 8 were further created by pressing a few sides into appropriate angles. Part 20 was cut, molded into the appropriate shape, and press-joined with lower shaft 14. Part 20 also had holes drilled to connect with the leg stretchers. Each metal component was powder-coated to protect them from rust. All the plastic parts were most likely injection molded. Part 12 is an interference fit with the lower shaft and a clearance fit with the upper shaft. Part 11 is interference fit with the upper shaft. Part 16 connects the 3 long leg linkages and it is also a clearance fit with lower shaft to adjust the base width. Plastic injection or insert molding (applying force) are possible processes to produce parts 9, 13, 15. The metal threads in parts 13 and 15 are potentially machine screws with an oval head to be placed inside the mold first and injecting plastic later to keep the screw in place. A similar process can be predicted for part 9, though this is difficult to know without sectioning the piece. Part 19 seems to be rubber, shaped specifically to slide over the ends of the legs to provide friction between the music stand and the ground. The upper and lower shafts are made from hollow metal tubes, most likely stock components, cut to the appropriate length.

Weight Analysis

To understand the materials that made up our product, we conducted a weight analysis. We first weighed all of the individual parts in grams, obtaining the total weight of the music

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[8] Thomas, Sheet Metal Sizes

stand. Then, based on physical observations, we assigned each metal modeled component the material “steel”. On the product website, we found that the metal was specifically powder coated steel. However, since this was not an option in Inventor, the subsequent weights were off compared to the real weights. We also chose ABS plastic to be the material for the plastic parts of the stand. While these weights were comparably closer, there were still some irregularities. In the physical stand, some of the plastic pieces have metal inserts that we were unable to model correctly in Inventor, so the simulated and real weights differ there as well. Our improved extension parts were also modeled using slightly different materials than their actual material. In Inventor, the closest match to micro carbon filled nylon was thermoplastic resin, which can account for some of the weight difference. The overall difference in simulated and physical weights was about 147 grams, which is about a 16% error. A more in depth look at our weight analysis can be seen in figure 7 of the appendix.

3D Modeling

For the 3D modeling portion of the project we modeled 24 parts, excluding standard screws, rivets, and washers. As the manufacturing process utilizes standard gauge thicknesses and hole sizes, we referenced these dimensions to ones that we defined as standard. Other dimensions were directly measured and modeled, ensuring that details were accurately captured. Modeling was divided according to subassembly to ensure that all components within a subassembly fit well. After assembling the components, further measurements and adjustments were made to ensure components fit together smoothly. Pictures of 3D modeled parts and assemblies can be seen in figure 8 of the appendix.

Product Strengths and Weaknesses

As mentioned previously, the primary strength of this component is its relative inexpense, at ~$15, and its portability. Due to the materials used, it is extremely durable yet lightweight, allowing for easy transportation without concern for damage. Given the broad customer base this stand type has, this product must be highly adjustable according to the needs of the musician. The frame angle can be adjusted, the frame height can be increased or decreased, and the base width can be narrowed or widened as well.

Despite these strengths, this type of stand falters when it comes to its primary purpose of holding music. The frame is not very wide, only able to comfortably hold two pages of music side-by-side. Additionally, the flat frame base means that music can very easily slip off of the front, particularly during rapid page turns that the narrow frame width requires. Ultimately, these two factors create a highly unstable mechanism for holding and displaying music. The sheet clasps are intended to address these issues, but only are helpful with two pages of music, and must be removed and reapplied with every page turn, something that is not feasible during a performance.

Product Improvement and Solution Requirements

Music stands are used by a very specific, but very large, audience. This limits our ability to expand into other markets, but this expansion is not needed considering the already large consumer base of musicians worldwide. Considering DFMA regulations, we have to keep in mind the cost/benefit relationship, along with the actual functionality of any new parts. Given the variety of music stand varieties on the market, we decided to establish a set of specific solution requirements to narrow down the scope of our addition to the stand. We focused on addressing what we saw as the two primary weaknesses of the stand: its limited carrying capacity (2 sheets of music) and the way in which music often slides off of the front of the frame base. Additionally, our solution could not hinder the existing strengths of this stand model. The reason similar style stands are so popular is that they are inexpensive and portable. This portability is due to its light weight, sturdy materials, and compact design. Additionally, it is highly versatile, applicable to many types of musicians and skill levels.

Our Solution

With these requirements in mind, we ultimately designed a solution that is inexpensive, straightforward, and practical. As can be seen in figure 9, which depicts our 3D model of our improvement, this solution is a thin extension which can be slotted over the base. We produced two of these, one for each side of the stand. These components contain slots designed for a slight interference fit with the replacement stand that we purchased as a visual aid for our presentation, rather than the width of the original frame base, but this dimension could be easily adjusted depending on the product model it is applied to. Their primary solution is that they can be slid out from the center of the frame base to significantly extend the width of the frame and thus hold more music. The interference fit holds the components secure as these components are extended. Additionally, each component features a small front lip, preventing music from sliding off the front without visually blocking any music or preventing the musician from turning the page. On the back of each component is also a small tab with a hole, into which a rivet and metal clasp much like the one on the existing stand can be inserted. This metal clasp, rather than serving to clamp the music to the frame back, instead serves as back support when the solution is extended and music is placed beyond the edge of the original frame back. When this extension is not needed, the components can nest back over the frame base without interfering with the ability of the stand to fold up and be transported.

Working Drawings

Drawings of our individual parts, sub assemblies, and final assembly with dimensions, bill of materials, and multiple views can be found in the appendix under figure 10.

Prototyping

When designing and prototyping our improvement, we wanted to make the most lightweight, affordable, and useful addition possible. We decided to make it more of a 2-in-1 improvement, with both adjustable width and more support with a bottom lip. We first 3D modeled our idea, and then 3D printed based on the measurements of the frame base. Keeping the requirements of 3D-printing in mind, we designed and oriented our solution so that the only support material required would be underneath the tab that holds the wire, while ensuring that the circular hole on this tab was precise and the slot did not need to be filled with support material. We designed our prototype according to the frame base dimensions of a slightly different brand music stand that we purchased as a replacement for our disassembled Nomad brand so that we could assess fit and practicality of our design.

Our first design contained a slot that was too tall for our product, meaning that it fell off easily when it was extended. We then adjusted this height, creating a slight interference fit that held the piece secure on the frame base and ensured it could be compatible with different brands of music stands. Since it is 3D printed, there is increased flexibility, so it can stretch to accommodate thicker frame bases. We also wanted to take into consideration the cost, weight, and functionality of the improved base. Since it was 3D printed, and the size was relatively small, the cost was low. The mass of the add-on is only about 0.03 kg each, so the added weight to the stand is almost negligible (<8% of the total stand weight for both additions combined). As for functionality, it works exactly how we expected it to; it is easy to slide on and off, accommodates different thicknesses, and supports paper with the added lip.

Conclusion

Music stands are a highly-used product, necessary for musicians across the world. Our specific music stand brand is highly versatile, inexpensive, and portable, thus our solution needed to maintain these strengths, while improving upon the stand's primary purpose of holding music. Our improvement is straightforward and practical; its design makes it robust, it does not take up significant extra space, it is inexpensive to manufacture, and it efficiently addresses the two primary issues that we found with the original stand. The 3D printed nature of our component means that it is flexible, allowing it to fit on a wide variety of stand types regardless of brand. Given the low cost of the stand, we concluded that our solution must also be very low cost, otherwise consumers would merely purchase a new stand. This design does not appear to be overly complex, but this is its primary virtue. For such a straightforward, versatile product, a straightforward, versatile addition was necessary.

Appendix

Figure 1. (Depicts the Nomad brand folding music stand that we chose to disassemble and improve upon)

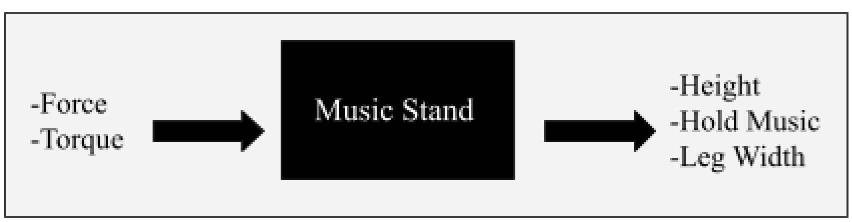

Figure 2. (A black box diagram detailing the inputs of force and torque on the music stand, which then adjust the height, leg width, and ability of the frame to display music)

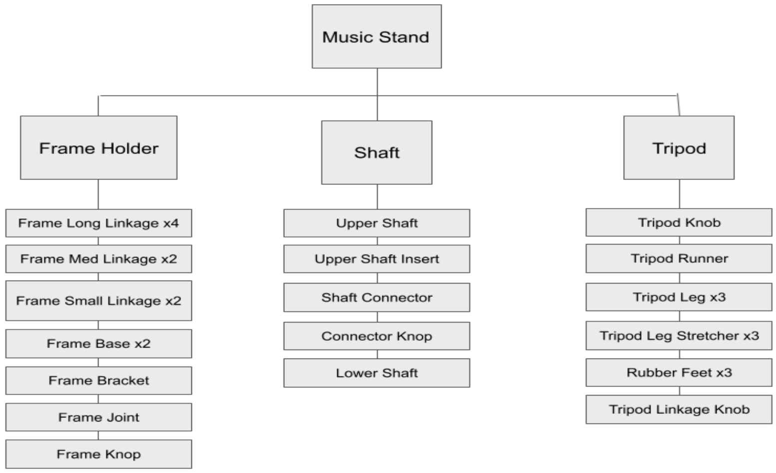

Figure 3. (Depicts a product decomposition diagram divided between the three subassemblies)

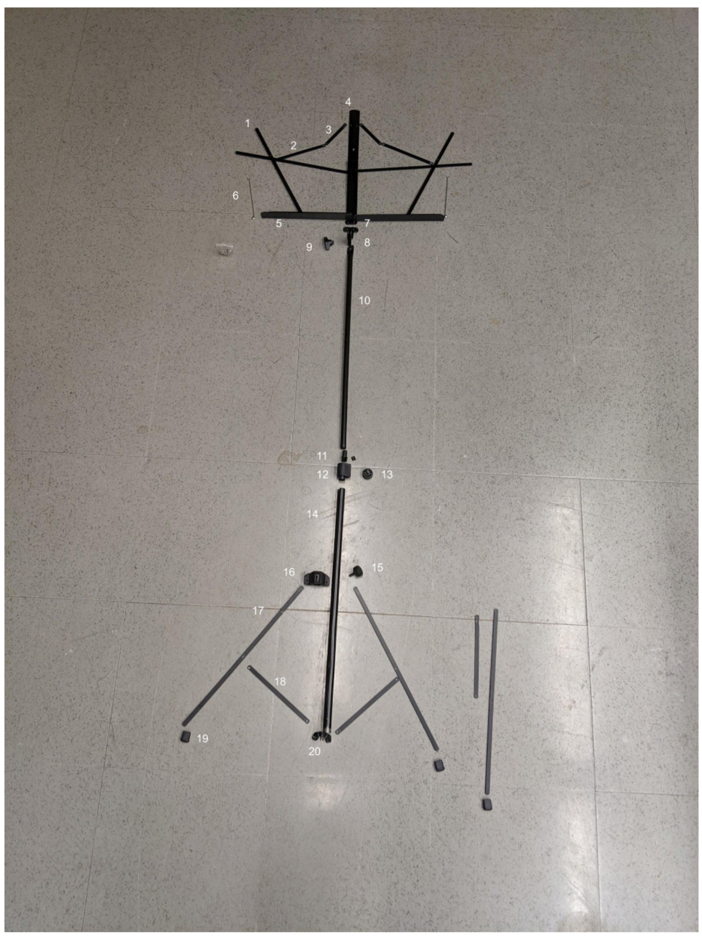

Figure 4. (The disassembled stand with each component numbered)

Figure 5. (Some images of the disassembly process, including the removal of rivets from the frame and the detachment of the upper and lower shaft)

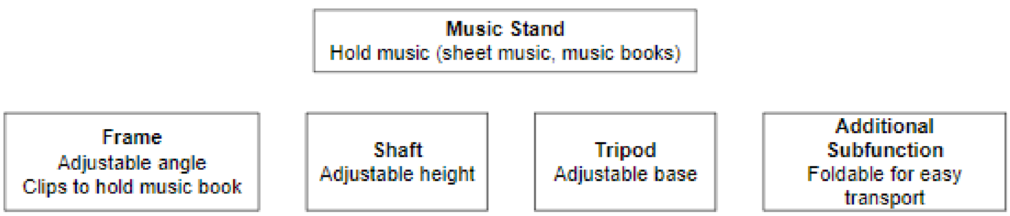

Figure 6. (Breaks down the functions and subfunctions of the music stand and subassemblies)

	Full	Frame	Shaft	Tripod	Extension
Actual (g)	**924.6**	367.2	266.2	225.2	66
Estimated (g)	**777**	256	247	180	94
Difference (g)	**147.61**	111.2	19.21	45.2	28
% Error	**16.0%**	30.3%	7.2%	20.1%	42.4%

Figure 7. (Table of actual and estimated weights of sub-assemblies with percent errors)

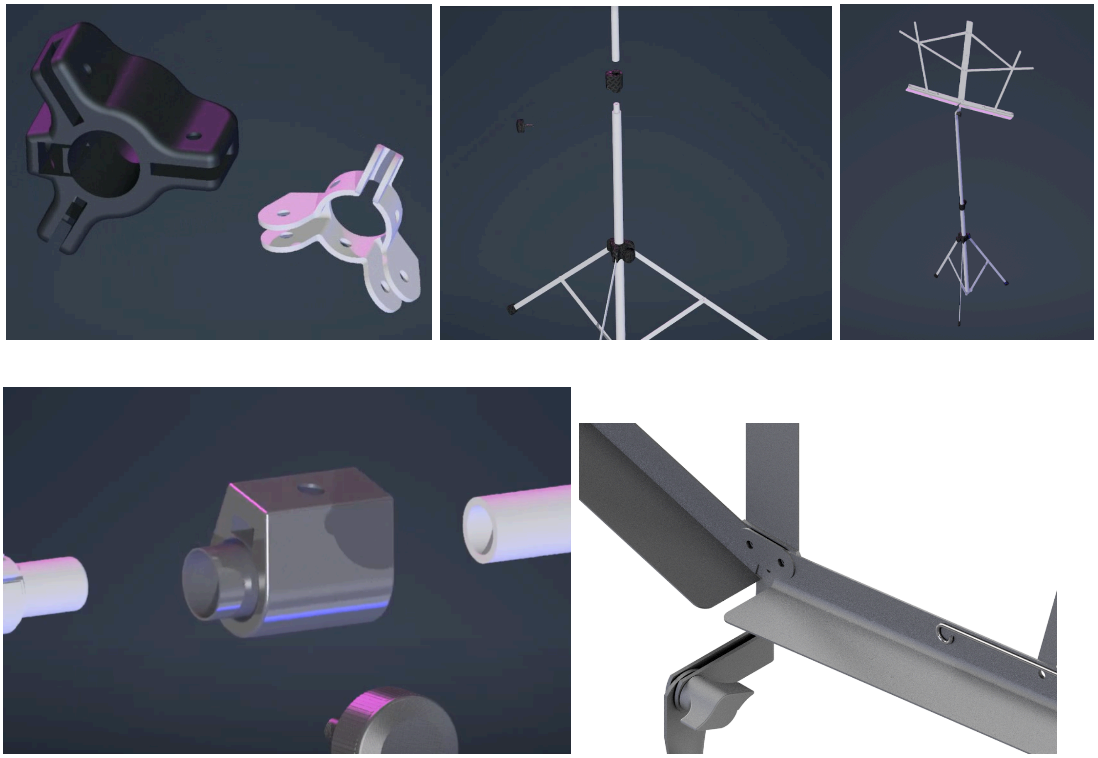

Figure 8. (Depictions of 3D modeled parts)

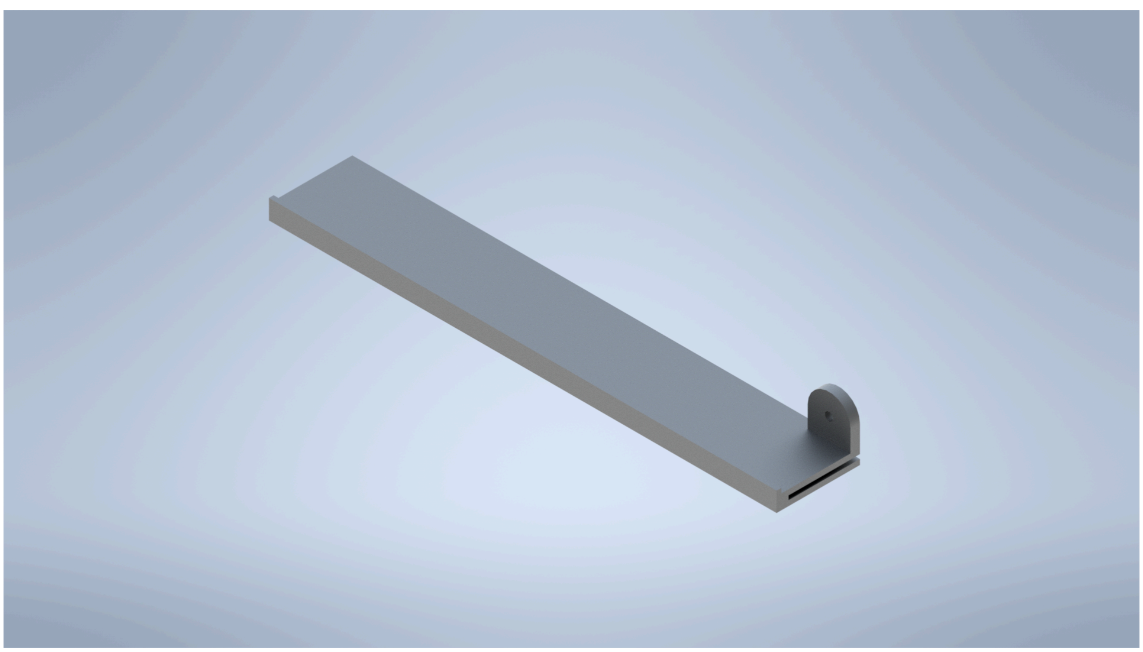

Figure 9. (3D depiction of improvement)

Figure 10. (24 drawings)

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