Final Design Review

W12 Towing Safety Mechanism

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Statement of Disclaimer

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Abstract
Our team was tasked with creating a system that automatically disconnects the direct drive of our towable auger, the Dirt Dawg, when the machine is ready to be towed. Since our Critical Design Report (CDR), the team made detailed designs for the systems we need to ensure fail-safe and easy automation of the Dirt Dawg and its direct drive system. We needed the best way for us to translate the motion of our hitch handle to the gear system. The team found that bike brake cables would be a direct translation of motion and offer no resistance regardless of its path. Next, we determined a complete redesign of the front handle was unnecessary, and we were better suited to upgrade the current model to be our front anchor for the cable. We have included our designs, verification, and recommendations for the future. With all this information, our sponsor should be able to replicate our design with ease.
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1 Introduction
To finalize our project, our primary objective was completing our manufacturing, installing all our systems onto the auger, and then testing. Manufacturing consisted of water jetting the brackets and 3D printing guides for the cable subsystem. Once manufacturing had concluded, installation began which is described in detail below. Finally, we began testing our systems to determine how long they would last, what adjustments needed to be made, and any future recommendations we would put forth. When these pieces came together, we determined that our design specifications have been met and you will find our discussions on how we would further improve the design in the future.

2 Design Overview
This section contains a description of our project and only our project. It is important to note, there is a previous senior design project that added to the sponsors original product. We are only adding the fail-safe portion and mounting it to the new direct drive system given to us by the previous senior project team. Also described in this section is major changes made to the final design since the CDR.

2.1 Design Description
Our design consists of 3 subsystems: the cable, tongue, and direct drive subsystems. Each of these are connected via brackets that either hold the cable housing, or the cable itself. The tongue subsystem is near the hitch and what the user interacts with. It consists of a physical barrier to the hitch, a handle, two cable brackets, a pin that locks it in place and two mounting pieces that attach it to the product. The cable subsystem is what connects the tongue subsystem to the direct drive. It consists of routing clamps, a bike cable, and its housing. Finally, we have the direct drive subsystem. This subsystem is where our project overlaps with the previous senior project group. The direct drive subsystem consists of a bolt, a bracket, a spring, and a bike cable crimp.

Our design works by utilizing the rotation of the tongue subsystem. When the hitch is uncovered, as seen in Figure 1, the cable is extended, thus pulling the cable which is attached to the dog tooth gears from the previous project team. This disengages the direct drive subsystem allowing the user to tow the product without risk of damage to the hydraulic motor. When the user wants to use the direct drive, they will rotate the subsystem down to cover the hitch, thus preventing towing. In the disengaged position, the cable is in a less extended position, thus allowing the spring to push the dog tooth gears back into the engaged position, thus allowing the hydraulic to be used to drive the product around.
2.2 Design Changes Since CDR
Since CDR, we decided to change the side bracket in the tongue system because the current panel did not have the correct dimensions to support the pin. We used CAD to design a new panel that will effectively lock and stay in place when the lever is moved. We also planned to create a hand-brake system to allow the user to easily remove and place the pin in the desired position. We were to place a bike brake on the handle of the lever so that when the brake is pulled, which is attached to the locking pin via cable, it will remove the pin for ease of use. However, we decided against this because we could not find a bike brake with the dimensions for the predesigned lever which is crucial to the manufacturability of the product. Instead, we created a detailed guide on how to add the bike brake to the lever for our sponsors to follow if they decide to use our idea.

3 Implementation
Our design decisions were significantly swayed by ensuring our system is easily repeatable for our sponsor. We used off-the-shelf parts wherever we could and sourced all our raw materials through our sponsor. This lead the team to sourcing a lot of our components from the bicycle industry. This allowed for high quality and reliable parts that can be acquired easily. While our sponsor has sufficient manufacturing capabilities, all of our custom parts can be replicate easily using commonly available tools and processes.

3.1 Procurement
All parts used in the manufacturing of our project can either be purchased online or found at local retailers. For the team’s convenience, we purchased numerous parts from local stores, however, all pieces related to bicycle machinery can be found on large online retailers such as “jensonusa.com”. The team also used a few different metal stock plates, all of which were purchased from McMaster-Carr. Their part numbers can be found in Appendix C. Finally, small hardware bits were used to fasten different systems.

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together. While the team purchased these from a hardware store, the parts can also be found on McMaster-Carr.

3.2 Manufacturing

Remaking the swinging lever would have been unnecessary, so we decided to reuse the one provided by our sponsor. Figure 2 shows us utilizing the sand blaster in Mustang 60 to clean the rust off our handle and the two previously fabricated side plates that were mounted to the hitch. The lever creates the foundation for the rest of our design and is the thing was designed the brackets around. The lever assembly has a pending patent, so it was important to the sponsor that we use their design.

*Figure 2:* The team working together on the sand blaster to clean off rust from older parts.

To get an adequate throw length for the dog tooth gears, we needed to mount the moving bracket as far away from the stationary bracket as possible. This configuration would give us the most travel for those gears. In Figure 3 you can see how we mounted the handle to the drill press to create that hole for mounting the moving bracket. The drilling operation was difficult since the lever was already bent into shape. Going forward, the requisite hole will be included on the part model for the handle, so there will be no need to drill it after the fact since it will be cut out on the waterjet.
3.3 Assembly
The three brackets needed can all be waterjet cut out of 1/8\textsuperscript{th} inch thick 5052 Aluminum sheet metal, as seen in Figure 4. Once the brackets are cut out, the only post processing required is to tap two holes with an M10-1.00 tap to accept the barrel nuts for adjusting cable tension, and then to bend them up 90 degrees. The nice thing about the design is the relatively loose tolerances, so the bend line and bend angle do not need to be exact. This will ease reproduction and make it cheaper to mass produce if desired.
The tongue assembly uses the two smaller brackets and has a simple installation involving two mounting bolts to the lever, as seen in Figure 5. Once installed on the lever the cable system can be run through the brackets as pictured. The barrel nut is important to orient in this direction because it provides the seat for the cable housing and provides tensioning capabilities. The ferrule end of the cable is seated in the front bracket and can be run through the housing until it pops out the other end by the direct drive. Both barrel nuts need to be fully threaded into the brackets in order to give the most possible adjustment for later.
The other end of the cable needs to be fed through the barrel nut and bracket installed near the direct drive. One important installation note is to be wary of the exposed cable end. From the factory the tip is soldered and will not fray, but if you cut then attempt to reinstall the cable it tends to fray causing a lot of issues with smooth operation that can inhibit the function of the device. So, it is recommended that if maintenance is performed on the cable some solder, epoxy, or tape be applied to the cut end to avoid fraying.

Figure 6: Direct drive bracket and barrel nut

With the cable fed through the bracket the final step is to install the 3/8-inch bolt into the sliding rod. Wrap the cable around the rod and thread it through the crimp. When installing it is important to have both barrel nuts threaded fully into the brackets to give the most potential of adding cable tension later. Along these lines, ensure the lever is in its downward (covered) position because this is the position where the cable is unloaded. Once these parameters are met pull all of the slack out of the cable and crimp it tight. This procedure is the most difficult part of the installation and requires a lot of tension to be pulled on the cable while simultaneously crimping with the other hand, so it is significantly easier to perform with a second pair of hands to help. Although somewhat complex to install, once installed the barrel nuts will give all of the adjustment needed and there is no need to touch this area.
4 Design Verification

We ran two tests to ensure our project’s functionality and reliability. First, we wanted to test the cable’s ability to follow our routing scheme with the minimal force required. Since this project is going to be subject to many uses, a cycling test was also deemed necessary. In addition, we were adding a constant load to the pin which had not experienced that load in any other iteration of the project, so we analyzed the strength of the pin.

4.1 Specifications

There is one change made to our specifications table since the PDR. Our updated specifications table is shown in Table 1. That was the addition of a minimum throw length necessary for the two moving parts of the project. The cables in the direct drive and tongue subsystem have a throw length that can clear the distance necessary for movement or stop of movement. It is important to note these are minimum lengths and we have designed to exceed these marks.
Table 1: Specifications Table

<table>
<thead>
<tr>
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<th>Target</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
</tr>
</thead>
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<td>Cost</td>
<td>$2000</td>
<td>MAX</td>
<td>L</td>
<td>A</td>
</tr>
<tr>
<td>Weight Difference</td>
<td>+150 lb.</td>
<td>MAX</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>Percent Reliability</td>
<td>100%</td>
<td>—</td>
<td>M</td>
<td>A, T</td>
</tr>
<tr>
<td>Operation Time</td>
<td>3 min</td>
<td>MAX</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>Minimum Gear Clearance</td>
<td>0.05”</td>
<td>Min</td>
<td>L</td>
<td>A, T, I</td>
</tr>
<tr>
<td>Product Life</td>
<td>15 years</td>
<td>MIN</td>
<td>H</td>
<td>A, T</td>
</tr>
</tbody>
</table>

Our other change was removing gear shroud width from the specifications table; we found it was not integral to the design as we previously thought. Other specifications remain the same as in the PDR other than the product life, which was raised significantly. All other specifications were exceeded.

4.2 Testing and Results
Before implementing our design, we wanted to make sure the concept was worth the effort. One important test we ran was checking the movement of the cable within its housing. The goal in this pass/fail test was to test the friction imparted on the cable, and whether modifications needed to be made to make it run smoothly. Luckily, the cable housing showed little to no change no matter how sharp our routing was, even in an unrealistic position like Figure 8.

![Figure 8: One of the test configurations for cable friction test.](image)

We also were subjecting the pin to a load it was not under before. Due to this change, we used Finite Element Analysis (FEA) to ensure the pin could handle this new load and found no worry of failure in the pin. This meant we could move on with our design. The FEA results is depicted in Figure 9.

![Figure 9: FEA results](image)
Over time, bike cables are known to stretch. We needed to ensure our design, which relied on a bike cable to satisfy our project’s end goal, did not stretch out of the acceptable range. To test the cable’s stretching, we simply cycled the system hundreds of times, as it would see this type of use in the field. The results of this test are depicted in Table 2. We hypothesized the cable would stretch for the first few hundred cycles, then stabilize at a certain length. Notice here that Gear-To-Gear Clearance is any extra space the gears have past the minimum throw length.

Table 2: Cycling Test Results

<table>
<thead>
<tr>
<th>Cycle Number</th>
<th>Gear-to-gear Clearance</th>
<th>Pass/Fail</th>
<th>Difference</th>
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<td>0</td>
<td>0.2175 in.</td>
<td>PASS</td>
<td>N/A</td>
</tr>
<tr>
<td>250</td>
<td>0.0900 in.</td>
<td>PASS</td>
<td>0.1275</td>
</tr>
<tr>
<td>500</td>
<td>0.0550 in.</td>
<td>PASS</td>
<td>0.0375</td>
</tr>
<tr>
<td>750</td>
<td>0.000</td>
<td>FAIL</td>
<td>0.0550</td>
</tr>
</tbody>
</table>

After about 750 cycles, the dog tooth gears no longer were reaching minimum throw length, so we cut the test short. What we found was our failure condition was not the cable stretching. Instead, it was the brackets that failed. Moreover, it was only the brackets on the lever side of the cable that were found to be the ones failing. The bracket on the direct drive side of the cable, made of the same material and thickness, showed no signs of deterioration even after hundreds of cycles. The reason for the failure of the lever side brackets is unknown to us, but likely has to do with the additional movement the lever causes those brackets to deal with. All in all, while the fail-safe system worked as intended, the lifespan of our additions is not up to par. In addition, care must be taken after a certain number of cycles to ensure the brackets are not bending, for that could nullify the point of the project completely.
5 Discussion & Recommendations
Although the design works as intended, there are some limitations and failures we found that are cause for concern. The most glaring of them all is the lifespan of the project. 750 cycles are not enough for a lifetime of 15 or more years. Other possible upgrades could be considered to further enhance reliability or ease of use. Changing materials is the main point we wish to emphasize, because the project will be subject to harsher conditions than experienced in our project room for this year. A material change is essential to the brackets on the lever that blocks the hitch because these are the parts that failed when we cycled the project.

5.1 Discussion
Our design functions as planned, which is good because this was the simplest design we could come up with. Even with all our iterations and failures we only spent about $205, but if one were to mass produce the system, we would estimate each unit to be less than $50 to implement. Our project is completely analog meaning there are no electronic features that could fail. It also can be modified, as the cable is flexible and can be routed in any fashion, should it be useful. Lastly, the project is easily repeatable. The only custom fabricated parts are the routing clamps and the cable brackets. Everything else used was off the shelf parts. All in all, the simplest design proved to be the superior one.

5.2 Recommendations and Next Steps
The most critical issue is our choice of materials. Following the theme of “simpler is better” we chose mostly cheap and easy to work with materials for the benefit of reproducibility. The most glaring weakness is the brackets on the lever near the hitch. Those brackets were our failure mode as discussed in our testing and results section. The easiest fix for this would be switching from aluminum to steel. Another fix would be changing the geometry to better support the bracket in the direction of bending. The bracket near the direct drive is also made of aluminum, however showed no signs of failure. Another part of the project where the material can be changed is the routing clamps. We chose to 3-D print these parts because of ease and price; they are shown in Figure 10. The epoxy held up well for the time we had it, but for increased longevity and durability, we recommend switching to welded routing clamps.
When thinking about customer experience using the product, one issue stood out: you need two hands to engage and disengage the hitch. Our idea to fix this was to add another bike cable. The plan was to add a generic bike brake handle to the lever that would pull the pin out and allow the lever to move from one position to the other, as seen in Figure 11. The only fabricated part necessary would be a bracket on top of the pin to force the cable to pull the correct direction. The pin itself would need to be modified in these conditions as well. The cable would need to be connected to the pin for this idea to work, so a hole would need to be drilled in the pin that the cable could be mounted to. All of this would have been a lot of fabrication for the time we had remaining when we thought of this. In addition, we could not find a bike brake that fit on the lever handle. The project still fulfills its purpose without this addition, but it would make using the product easier.

*Figure 11: Potential placement for bike brake that would enable one-handed operation.*
6 Conclusion
After our testing and operation, the auger is now towable while making sure that the direct drive system will not be damaged. Previously, the system required significant manual input from the end user that would not have been foolproof. With the cable connecting the tongue handle near the tow hitch to the plunger system connected to the direct drive, it is impossible to hitch the auger to a vehicle while the dog teeth gears are still connected. The system in functional and simple, but we believe small, yet significant improvements can be made easily. As previously discussed, a bike brake handle connected to the locking pin would allow users to operate the system with one hand and reduce confusion. While the lifetime of the brackets is fair, we believe a different material would be an improvement and reduce maintenance costs. As it stands, the whole system is reliable and far superior to the electronic systems we considered given the outdoor use of the auger. However, with the small adjustments we recommend for the future, the lifespan of our system would greatly increase.
7 References


Senior Design Project Success Guide. (2023, April).


Appendix A – User Manual

Safety Hazards and PPE:
- Ensure the Dirt Dawg is off when changing direct drive position.
- Wear safety glasses during maintenance.

Moving direct drive from engaged to disengaged:
1. Bring the Dirt Dawg near the towing vehicle using the self propulsion.
2. Turn off the engine.
3. Remove the pin from its locking position and move the lever to uncover the tow hitch.
4. Ensure the locking pin is secured in the pin hole. The lever should look like this before moving onto the next step.

5. Attach the tow hitch to the towing vehicle.

Moving direct drive from disengaged to engaged:
1. Detach Dirt Dawg from towing vehicle.
2. Remove the pin from its locking position and move the lever to cover the tow hitch.
3. Ensure the locking pin is secured in the pin hole. The lever should look like this before moving onto the next step.

4. Turn on Dirt Dawg and use as needed.
Maintenance:
If the device is no longer operational, the first step is to troubleshoot and try and find the root cause of the issue. Check all moving parts such as the cable and lever pivot.
If the cable is broken, it should be obvious, and simply purchase a new road bike brake cable of standard length from any local or online bicycle parts retailer. Install exactly the same as the initial assembly.

If the cable is not broken, but is no longer pulling the dog teeth far enough to fully engage/disengage them, the tension is probably out of spec. It is a known phenomenon with new braided cables that they stretch small amounts in the first few months of operation. This is precisely why we included barrel nuts on both ends of the cable routings. To increase cable tension, turn the front barrel nut by the hitch receiver anti-clockwise to essentially unthread it from the bracket. Do this as much as needed until the dog teeth disengage with a margin of greater than 0.25” from the direct drive. This is the desired clearance to make sure there is no chance of contact while trailering. If more tension is needed, repeat the procedure with the second barrel nut by the direct drive. If both adjustments do not solve the issue, the cable probably has some other issue with it and should be examined, or it may not have been installed correctly as new.

If there is excessive friction causing the direct drive to be sticky and not move when actuating the lever, first add some Tri-Flow oil to the cable. Do this by squirting the oil inside both housing ends and actuating the cable to try and work it onto the cable. Tri-flow is a light oil with low viscosity that is known to not corrode or otherwise alter the brake cable, any other oil may be used at your own risk. If the cable is still sticky, there is a chance the cable has unwound and has stray strands inside the housing impeding motion. Disassemble if problems persist, and if the cable has started to unwind replace it as trying to fix it could endanger the structural integrity.
Appendix B – Risk Assessment

Y 1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points? **We will attempt to prevent this by adding housing to revolving parts so they cannot be easily accessed.**

N 2. Can any part of the design undergo high accelerations/decelerations?

N 3. Will the system have any large moving masses or large forces?

N 4. Will the system produce a projectile?

N 5. Would it be possible for the system to fall under gravity creating injury?

N 6. Will a user be exposed to overhanging weights as part of the design?

N 7. Will the system have any sharp edges?

N 8. Will you have any non-grounded electrical systems?

N 9. Will there be any large batteries or electrical voltage (above 40 V) in the system?

N 10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?

N 11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?

N 12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?

N 13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?

N 14. Could the system generate high levels of noise?

Y 15. Will the device/system be exposed to extreme environmental conditions such as fog?

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humidity, cold, elevated temperatures, etc.? Our prevention efforts for rust will be using rust resistant materials and applying a coat of paint to materials that are not rust resistant.

N 16. Is it possible for the system to be used in an unsafe manner?
### Appendix C – Final Project Budget

#### Overall Project Bill of Materials

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<td></td>
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<td>Cable Housing</td>
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<td>$</td>
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<td>-</td>
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<td>$7.00</td>
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<td>$65.92</td>
<td>McMaster</td>
<td></td>
<td>18-8 Stainless</td>
<td>91831A127</td>
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<tr>
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<td>2</td>
<td>$0.36</td>
<td>$0.72</td>
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<td>$4.92</td>
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<td>.125&quot; 5052 Al 6&quot;x24&quot;</td>
<td></td>
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<tr>
<td>3</td>
<td>13810</td>
<td>1/2&quot;-13, 1&quot; Long Hex Head Bolt</td>
<td>1</td>
<td>$8.81</td>
<td>$8.81</td>
<td>McMaster</td>
<td></td>
<td>18-8 Stainless</td>
<td>92240A712</td>
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<td>3</td>
<td>13720</td>
<td>1/2&quot;-13 Nylock Nut</td>
<td>1</td>
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<td>$6.40</td>
<td>McMaster</td>
<td></td>
<td>18-8 Stainless</td>
<td>91831A137</td>
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</table>

**Total Parts: 50**
## Final Project Bill of Materials

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Item Description</th>
<th>Vendor</th>
<th>Vendor's Part Number</th>
<th>Item Cost</th>
<th>Shipping and Tax</th>
<th>Total Cost</th>
<th>Method of Purchase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cable</td>
<td>Foothill Cyclery</td>
<td>-</td>
<td>$14.99</td>
<td>$1.31</td>
<td>$16.30</td>
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<td>2</td>
<td>Barrel Nuts</td>
<td>Foothill Cyclery</td>
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<td>$2.00</td>
<td>$0.18</td>
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<td>Cable Housing</td>
<td>Foothill Cyclery</td>
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<td>$36.00</td>
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<td>$39.15</td>
<td>Reimbursement</td>
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<td>4</td>
<td>Sheet Steel</td>
<td>McMaster-Carr</td>
<td>1388K69</td>
<td>$59.22</td>
<td>$5.18</td>
<td>$64.40</td>
<td>Company Order</td>
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<td>5</td>
<td>Bracket Fasteners</td>
<td>Ace Hardware</td>
<td>-</td>
<td>$4.40</td>
<td>$0.39</td>
<td>$4.79</td>
<td>Reimbursement</td>
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<td>Cable Fasteners</td>
<td>Ace Hardware</td>
<td>-</td>
<td>$5.42</td>
<td>$0.47</td>
<td>$5.89</td>
<td>Reimbursement</td>
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<td>7</td>
<td>Washers</td>
<td>Home Depot</td>
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<td>$23.28</td>
<td>$1.69</td>
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<td>8</td>
<td>Aluminum Sheet</td>
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<td>9</td>
<td>Locking Pin</td>
<td>McMaster-Carr</td>
<td>8692A14</td>
<td>$23.43</td>
<td>$2.05</td>
<td>$25.48</td>
<td>Company Order</td>
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</table>

**Final Project Cost:** $215.13

The cost for the entire project, including all prototypes and the final design, was $454.25 out of our $2,000.00 budget. To manufacture one system for the Dirt Dawg, it would cost $215.13, but with materials bought in bulk, the cost would be significantly cheaper than for one system.
### Appendix D – Design Verification Plan & Report (DVPR)

<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Test Description</th>
<th>Measurements</th>
<th>Acceptance Criteria</th>
<th>Required Facilities/Equipment</th>
<th>Parts Needed</th>
<th>Responsibility</th>
<th>Start date</th>
<th>Finish date</th>
<th>Notes on Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Friction in bike cable, (Inspection)</td>
<td>Put cable in housing. Hold cable in a tight. Push/pull the cable to test ease of action. Compare to ease of action to that of the cable when it is held straight.</td>
<td>Estimate friction of cable in housing</td>
<td>Does the cable move smoothly?</td>
<td>Procedure performed in Bonderson-108. Safety glasses required.</td>
<td>Cable and cable housing</td>
<td>Grant</td>
<td>4/25/2023</td>
<td>4/25/2023</td>
<td>The cable moved very similarly when in a tight loop versus a straight line. Therefore, the cable is considered to move smoothly and passes the test.</td>
</tr>
<tr>
<td>2</td>
<td>Shear stress in locking pin, (Test)</td>
<td>Design pin in CAD or upload file if available. Modify part as needed. Measure force required on pin by the lever and direct drive spring. Apply these forces to the pin in SolidWorks and record stress. Compare to standard yield strength of material and calculate uncertainty analysis.</td>
<td>Yield strength or deformation under stress</td>
<td>Will the pin support the force necessary?</td>
<td>SolidWorks.</td>
<td>Locking Pin</td>
<td>Ava</td>
<td>5/2/2023</td>
<td>5/9/2023</td>
<td>The stress that the pin will experience from the system is less than the yield strength of the material.</td>
</tr>
<tr>
<td>3</td>
<td>Longevity of cable system under repetitive use, (Simulation)</td>
<td>Roll the direct drive from the engaged to disengage position by moving the lever to cover and uncover the tow hitch, respectively. Repeat 100 times.</td>
<td>Estimate the durability of the cable-spring interaction.</td>
<td>Will the cable support the repetitive forces put on it by the direct drive system?</td>
<td>Procedure performed in Bonderson-108. Safety glasses required.</td>
<td>Complete system prototype</td>
<td>Ava</td>
<td>10/19/2023</td>
<td>11/27/2023</td>
<td>There was no physical change in the cable after undergoing repetitive usage. The complete system prototype worked as expected.</td>
</tr>
</tbody>
</table>
Appendix E – Test Procedures

**Test Title:** Fail-Safe Dog-Tooth Travel Clearance Test  
**Test Goals:** Determine number of cycles the system can undergo before failing to fully disengage the direct drive.

**Test Safety:**

<table>
<thead>
<tr>
<th>Safety Concern</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinch Points</td>
<td>• Label pinch point</td>
</tr>
<tr>
<td></td>
<td>• Avoid pinch points</td>
</tr>
</tbody>
</table>

**Test Equipment Required:**

- Safety glasses – for all attendees
- Measuring Tape
- Calipers

**Test Procedure**

1. Begin with the hitch cover lever in the engaged position (covering the hitch).
2. Verify the dogtooth gear is completely meshed and the spring is completely extended.
3. Push lever into the disengaged position, revealing the hitch.
4. Measure the distance dogtooth gear traveled.
5. Measure the difference in spring length (it was fully extended and should now be compressed).
6. Ensure there is at least 0.15 inches of clearance between each gear.
7. Move the lever back into the engaged position such that the dogtooth gears fully mesh.
8. Repeat steps 3-7 until failure (gears no longer clear).

**Test Results:**

<table>
<thead>
<tr>
<th>Cycle Number</th>
<th>Gear-to-gear Clearance</th>
<th>Pass/Fail</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.2175 in.</td>
<td>PASS</td>
<td>N/A</td>
</tr>
<tr>
<td>250</td>
<td>0.0900 in.</td>
<td>PASS</td>
<td>0.1275</td>
</tr>
<tr>
<td>500</td>
<td>0.0550 in.</td>
<td>PASS</td>
<td>0.0375</td>
</tr>
<tr>
<td>750</td>
<td>0.000</td>
<td>FAIL</td>
<td>0.0550</td>
</tr>
</tbody>
</table>

Table 1. Travel Distance Measurements (in.)
<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Engaged</th>
<th>Disengaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Drive</td>
<td><img src="image1" alt="Engaged" /> <img src="image2" alt="Disengaged" /></td>
<td><img src="image3" alt="Engaged" /> <img src="image4" alt="Disengaged" /></td>
</tr>
<tr>
<td>Tongue</td>
<td><img src="image5" alt="Engaged" /> <img src="image6" alt="Disengaged" /></td>
<td><img src="image7" alt="Engaged" /> <img src="image8" alt="Disengaged" /></td>
</tr>
</tbody>
</table>

Table 2. Photographs of Gear Clearance Tests
**Test Name:** Pin Yield Strength  
**Purpose:** Test the yield strength of the pin to ensure that it will not deform under forces by the system.  
**Scope:** This test will encompass the singular spring-loaded pin used to lock the tongue lever in place.

**Equipment:**  
1. Spring-loaded pin CAD file  
2. Computer with SolidWorks

**Hazards:** N/A

**PPE Requirements:** N/A

**Facility:** We can operate the test in the room where class is held.

**Procedure:** (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures)  
1) Measure forces placed on pin by the lever and cable using a force gauge.  
2) Download the CAD file of the selected spring-loaded pin from McMaster website.  
3) Open the file in SolidWorks, create a new simulation, and assign material as stainless steel.  
4) Create a mesh, add fixed points, and add forces to simulate the force of the system.  
5) Run the simulation and record deformation and vonMises stress of the pin.  
6) Compare the value of vonMises stress to yield strength of stainless steel.  
7) If vonMises stress exceeds the yield strength of stainless steel, assign a different material and repeat steps 4-7.

**Results:** Pass Criteria, Fail Criteria, Number of samples to test, Design analysis equations/spreadsheet with uncertainty. Comment on how Uncertainty Analysis will be completed.  
- Pass Criteria: vonMises stress must be less than the maximum stress the material can handle. Deformation must be deemed insignificant to the performance of the system.  
- Failure Criteria: vonMises stress is greater than the maximum stress allowed by the material and deformation is significant.  
- No analysis required after testing. Just data collection.  
- Uncertainty analysis will be done on the sensitivity to different parameters.

**Test Date(s):** June 8, 2023

---

W12 Towing Safety Mechanism
Test Results:

**Figure A1.** Failure mode and effects analysis (FMEA) of pin vonMises stress. The maximum value is 19.37 psi.

**Figure A2.** Failure mode and effects analysis (FMEA) of pin deformation. The deformation value is $0.1859 \times 10^{-6}$ in and considered negligible.
**PIN YIELD STRENGTH TESTING**

\[ \sigma_y = 200 \text{ MPa} = 29752.7 \text{ psi} \]

> YIELD STRENGTH OF STAINLESS STEEL.

\[ \sigma_y \gg \sigma_m = 19.37 \text{ psi} \]

PIN WILL WITHSTAND STRESSES FROM SUBSYSTEMS.

**UNCERTAINTY ANALYSIS:**

FORCE GAUGE RESOLUTION: 0.1 lbf.

UNCERTAINTY \( (0.1) + (2) = 0.05 \) lbf

MEASURED FORCES ON PIN = 9.8 ± 0.05 lbf

**NOTE:** FOR EXTRA SECURITY, PIN WAS TESTED WITH 20 lbf.

**Figure A3.** Uncertainty and numerical analysis for pin stress test.