UPRIVER
ENGINEERING

Bedload Sampler Top-Mounted Flap Efficiency Design

Colorado State University

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Project Sponsors

LETTER OF ACKNOWLEDGEMENT

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EXECUTIVE SUMMARY

Pressure difference bedload samplers have been known to produce biased bedload estimates since the early 20th century. Due to the complexity of eliminating unwanted bed scooping in data samples, bedload samplers have been rendered inadequate. Until 2020, there were no methods or devices developed to reduce bed scooping. In 2017, Tetra Tech and the CSU Hydraulics Lab pioneered an effort to design an attachable prototype for the BLH-84 pressure nozzle to reduce scooping. Conclusion of the project in 2020 yielded a successful first step in reducing bedload sampler scooping. While the project was determined successful, there were still many steps to develop the "top-mounted flap" prototype into an effective solution to reduce scooping (Tetra Tech & Colorado State University).

Beginning with the previous "top-mounted flap" design, Upriver Engineering was awarded the opportunity to further develop the prototype on the BL-84 sampler. Improving the flap required two engineered systems working conjointly on the bedload sampler and USGS E-crane to increase usability. To begin the design process, key objectives and constraints were developed to help guide brainstorming. Once the design criteria was established, 7 alternatives were developed through the use of morphology charts. Each alternative was then evaluated by a pugh matrix to determine the best starting design from the 7 alternatives. This process yielded the "truss" door attachment and the "secondary manual push-pull" reel for improving, and controlling the top-mounted flap.

For the truss and push pull reel, an iterative design approach was taken to continuously develop the designs from unaccounted for errors. This method heavily used additive manufacturing to make incremental changes until the design was ready for final manufacturing. Concluding the initial prototyping phase, the truss and reel systems were manufactured at the Engineering Research Center (ERC) machine shop. Once the truss was fully manufactured, a force test was administered to evaluate the pulling effort required to fully open the top-mounted flap. Results from the force test showed that the truss design was inadequate for achieving the design objectives. With the assistance of the ERC machinists, a new pulley prototype was designed and fabricated to replace the truss design. Administering the same force test methods as the truss, the new system successfully reduced the top-mounted flap pulling force by 24%, which surpassed the design objective of 20%. After conducting a flume force and horizontal displacement test, the pulley design proved to be sufficient for increasing the effectiveness of the top-mounted flap.

Fabricating the push-pull secondary reel was the most time intensive portion of manufacturing. When the reel was finished, multiple observational tests were performed to evaluate usability. Conclusion of these tests revealed that the secondary reel has potential to accurately control the pulley system, however, due to sufficient flows in the Cache La Poudre River the dial was not fully calibrated. Furthermore, experiments also revealed that the reel synchronization belt added complexity to the crane system and needs further development.

Conclusion of this project resulted in a fully functional top-mounted flap pulley system, and a promising secondary push-pull reel. The total cost of this project was estimated at $8,963 for all of the materials used and ERC machinists labor. Based on the results of this project, further improvements are necessary for the secondary reel to effectively control the top-mounted flap.

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HISTORY AND BACKGROUND

Sedimentology is “the study of natural sediments and the processes by which they were formed” (Middleton et al., 2003). While practice of sediment analysis preceded the 1900’s, it was generally categorized as an aspect of stratigraphy. It was not until the 1920’s that sedimentology became professionally recognized. Conferences and the creation of a new journal, the Journal of Sedimentary Petrology, led to its acknowledgement in America and paved the way for recognition around the world. River sediment sampling itself entails collecting a representative sample to analyze mineral composition, hydraulic conductivity, and particle distribution size of aggregates in river transport. It is also an essential tool for designing hydrologic solutions to siltation. Across the numerous subdivisions of sedimentology, the transportation of sediment is highly relevant to hydrologic study. Bedload transport is a common topic of fluvial sedimentation and fluvial sedimentology. It is of particular interest in assessing river characteristics and an important factor in projecting sediment discharge (Rivers, 2007). Most importantly, bed-load transport plays a role in flooding, quality of aquatic life, and water quality (Ghani et al., 2013).

Since collecting dynamic bedload sediment data from rivers and streams leads to a greater hydrological understanding, various sediment sampling devices have been developed to collect the amount of particles in motion along the riverbed. In the early 1900’s, bedload samplers were developed as a method of trapping sediment that “slides, rolls, or skips along in almost continuous contact with the streambed” (Hubbell, 1964). Early sampling methods included basket / box type systems that collected data by retaining sediment in a basket from the reduction in flow velocity. Another early sediment sampling technique used was the pan method. This technique positioned a triangular pan on the stream bed to allow bedload sediment to fall through the openings on the top of the pan. However, the geometry of basket and pan samplers decreased flow velocity at the sampler entrance. A reduction in entrance flow velocity caused sediment to be “diverted from or deposited at the sampler entrance,” ultimately leading to decreased efficiencies (Hubbell, 1964). In 1940, pressure-difference sediment samplers were developed to trap dynamic bedload sediment from the streambed by equalizing the velocity of both the entrance nozzle and stream flow. This mechanism allows sediments transporting in high velocities to slow down in the sediment sampler and be captured in a mesh bag which is attached at the rear end of the entrance nozzle. Ultimately, equalizing flow that passes through the entrance nozzle of the sampler allowed for a decreased percentage of diverged sediment (Hubbell, 1964).

Today, pressure-difference sediment samplers are still used to capture particles in incipient motion. Pressure-difference bedload samplers range from handheld devices to large reel and pulley systems to allow for data acquisition in a multitude of river sizes. While methods of suspending bedload samplers vary between different spatial scales, the BL-84 bedload sampler is primarily used to collect particle samples in large fast moving rivers. BL-84 samplers, as displayed in Figure 1, have an hydrodynamic shape that is composed of steel and aluminum and weighs thirty-two pounds. Furthermore, they are designed to collect sediment up to 1.5 inches in upper mean flow velocities of 10 feet per second (USGS, 2018).

By vertically suspending the device from a bridge or raft over a large river, a crane, reel, pulley, and cable system are used to manually control the position of the sampler (Tetra Tech & Colorado State University).

Figure 1. *BL-84 Bedload Sampler*

While pressure-difference bedload samplers are the most widely-used devices for directly measuring the physical bedload transport in rivers and streams, there is still substantial error in the collected data due to uncertainty. Sources of uncertainty arise from hydraulic forces thrusting the suspended sampler into the riverbed, scooping unwanted bed sediment. Current practices rely on equipment operators to evaluate scooping-induced biases to sediment samples purely on expertise-based intuition. Scooping of unwanted bed sediment is not just a recently identified issue; since bedload samplers were introduced in the early twentieth century, scooping has been the main hindrance in providing accurate data.

PROBLEM STATEMENT

In 2017, Tetra Tech contacted the United States Geological Survey's (USGS's) Hydrologic Instrumentation Facility (HIF) to request information on possible equipment available to prevent river bed scooping in bedload samplers during field tests. HIF staff informed Tetra Tech that no equipment currently exists for bedload samplers. In order to prevent bed scooping within current bedload samplers, Tetra Tech partnered with Colorado State University's (CSU's) Hydraulics Lab to launch a FISP funded project to design an attachable door mechanism. During the start of the project, Tetra Tech and CSU designed four alternative door attachments for a handheld bedload sampler. After design evaluations, Tetra Tech and CSU decided to select the "top-mounted flap" design, as displayed in Figure 2, as the final design for the bedload sampler door attachment. After manufacturing the top-mounted flap door, the design was tested repeatedly in the Colorado State University Hydraulics Laboratory's flumes. The controlled experiments were conducted primarily to evaluate the hydraulic efficiency, and point velocities around the flap to determine fluvial biases created by the door attachment. Once the laboratory hydraulic testing was over, the door attachment underwent field tests to measure the functionality of the door system (Tetra Tech & Colorado State University, 2021).

Conclusion of the field test and the overall design effort yielded an operable door attachment that reduced potential bias introduced by bedload sampler scooping. However, the effort lacked a mechanism for operators positioned on a bridge or raft to operate the door flap with the sampler on the bed of a river. Further tests also revealed problematic flap closing situations in which larger sediment prevented complete closure of the attachment. Field testing also confirmed that the connection position between the door and cable produced excessive pulling forces to fully open the flap (Tetra Tech & Colorado State University, 2021).

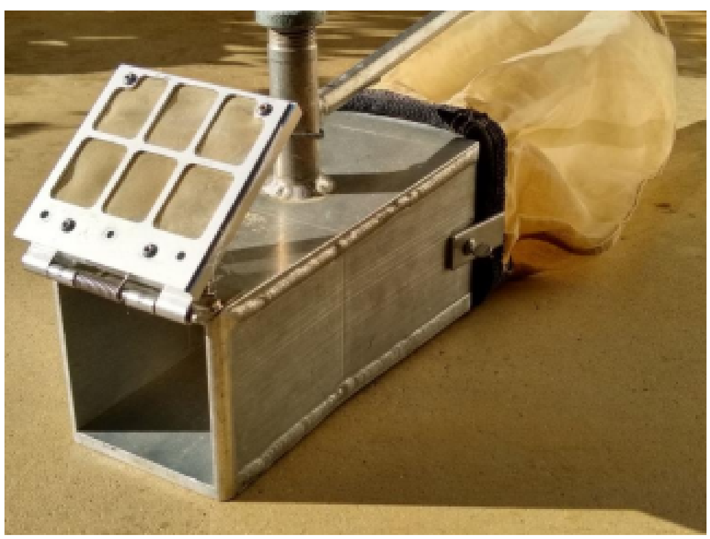

Figure 2. *Tetra Tech's and CSU's Top Mounted Door Flap Prototype*

OBJECTIVES AND CONSTRAINTS

The design objectives were determined to improve Tetra Tech's and CSU's top-mounted flap. Key findings and considerations from the "Development and Testing of a Pressure-Difference Bedload Sampler Attachment to Mitigate Scooping" report were examined. From this study, three main future considerations were identified once the top-mounted flap design efforts of top-mounted flap ended:

1. Excessive pulling forces required to open the door flap during testing.
2. Uncertain data quality due to debris trapped in flap during testing
3. The top mounted flap was not compatible with the BL-84 bedload sampler and reel system.

With these three overarching considerations at the forefront of the design process, two design goals were created: improve door flap efficiency and useability and increase product reliability. The design goals were further broken down into ten design objectives. Each design objective contains a level of priority, measurement method, objective direction, baseline, and target. This structure was used to develop the design objectives that are specific, measurable, and attainable. Table 2 below describes the design objectives:

Table 1. *Design Objectives*

Objective	**Priority***	**Measurement Method**	**Objective Direction**	**Baseline**	**Target**
Goal: Improve door flap attachment efficiency and useability					
Reduce excessive pulling force when opening flap	5	Force gage (lbs, N)	Minimize	18.2 lbs	20% reduction
Minimize effort that operator uses during duration of test to hold open flap	5	Lab testing (seconds holding flap open)	Minimize	Duration of test	10 seconds
Degree of flap fully open during test	4	Lab observation testing	maximize	180	210
Notify operator of debris caught in flap during cycle	5	Lab observation testing	Maximize	Fail	Pass
Mount reel on a USGS Type E heavy duty crane	5	Lab testing	Optimize	Fail	Pass
Route door flap cable from door flap attachment to reel	4	Lab testing	Optimize	Fail	Pass
Maintain minimal BL-84 horizontal movement during test	3	Flume Test	Maintain	1"	1"

*****(5 is the highest – 1 is the lowest)*

Table 1 (continued). *Design Objectives*

Objective	Priority*	Measurement Method	Objective Direction	Baseline	Target
Goal: Increase product reliability					
Maintenance	3	Component selection analysis	Optimize	1 year	2 years
Functionality in specified conditions	4	Flume testing	Maximize	0°C water	0°C water, gravel, and sand,
Durability (waterproofing, corrosion, fatigue, mechanical wear)	3	Material selection analysis	Maximize	Current durability	Current durability

**(5 is the highest – 1 is the lowest)*

While developing the objectives, the design constraints were also established to set the requirements for the future prototype. After conducting a "customer requirements" survey with project liaison David Pizzi to the FISP— located in Appendix A — nine key constraints were identified. Apart from the cost constraint, the baseline for all the requirements was the standard practices currently used for BL-84 sampling. In order for the design to be usable, the prototype must not obstruct with the operators standard sampling practices, and interfere with the BL-84 sampler, USGS Type E - heavy duty crane, USGS E-reel, and cable routing methods. The sampling practices considered when developing these constraints were: quick assembly, responsive movements of the cable deployed BL-84, and easy deployment and ascension of the BL-84. Furthermore, design constraints were developed from the hydraulic impact of added components. The components placed on the BL-84 will certainly have a hydraulic impact, therefore designing components that minimize the sampler movement is crucial. Table 2 below contains the design constraints along with the metric and limit of each constraint:

Table 2. *Design Constraints*

Constraint	Metric	Limit
Flap must be opened fully during each test	Degrees	180
Attachments on the reel apparatus do not interfere with normal operability during sampling	Pass/Fail	Pass
Flap cable does not interfere with bedload sampler suspension cable during operation	Pass/Fail	Pass
Suspension cable max diameter	Inches	1/8"
All hardware should be as streamlined as possible	Y/N	Y
Waterproof	Y/N	Y
Size	Y/N- must be able to fit on bedload sampler apparatus	Y
Assembly- all pieces must be able to be readily attached and detached from a cable-deployed BL-84	Y/N	Y
Cost	$	8,000

METHODOLOGY

Following the completion of the design objectives and constraints, each team member was tasked with preparing an alternate design to allow for greater diversity and innovation for the final design. This approach benefits the quality of each design concept by encouraging all team members to explore the spectrum of design technicalities and creativity with the considerations of achieving most of the objectives. Moreover, all team members were assigned to develop a Morphology Chart. The Morphology Chart is a critical component to the mechanical design process, as the chart aids in the brainstorming process and ends with the development of an alternative design. Below in Figure 3, is an example of a completed chart; a matrix that allows sketches of different concepts for a key function. Eight key functions were identified for each team member to design based on the identified constraints and objectives. The essential functions included: attach cable system to reel apparatus, route cable from reel system to door attachment, attach cable to gate, adjust cable position on bedload sampler, hold door open once the door flap is at proper sampling angle, indicate debris caught in flap during closure, power source, and synchronization.

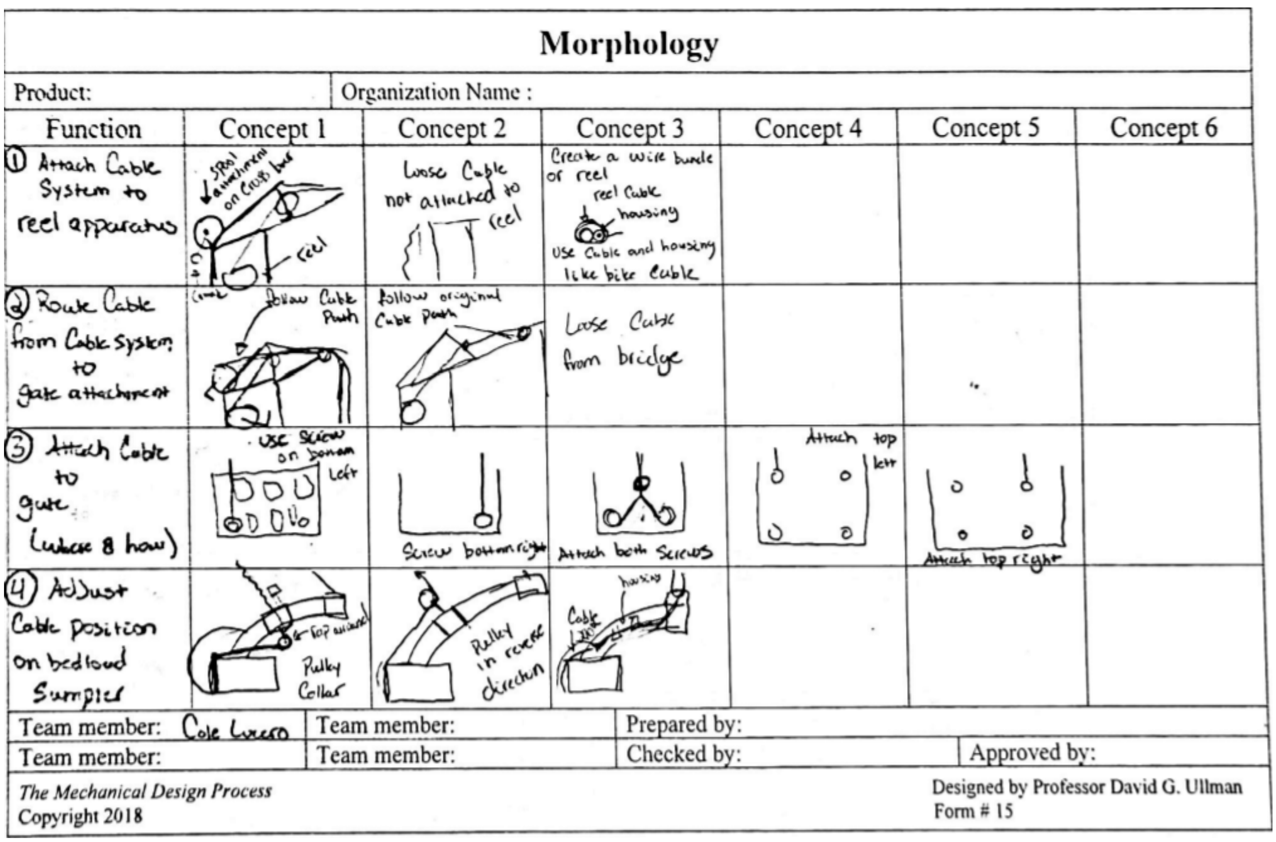

Figure 3. *Example of Morphology Chart*

Following the completion of each team member's morphology chart, seven initial and innovative design alternatives were created. Schematics were made to illustrate the design functionality of the prototypes.

Alternative 1: Truss Gear Lock

Alternate 1 takes the concept of a car's armrest to make for a unique gear locking mechanism. As the line would be pulled to lift the door flap, the gear would lift with the gate, locking its position if the user were to let go of the line. Furthermore, as the door flap reached its apex, the gear would unlock and lower back to its original starting position via the spring. The gear would be attached to the original hinge of the door flap. Figure 4 shows the gear locking system.

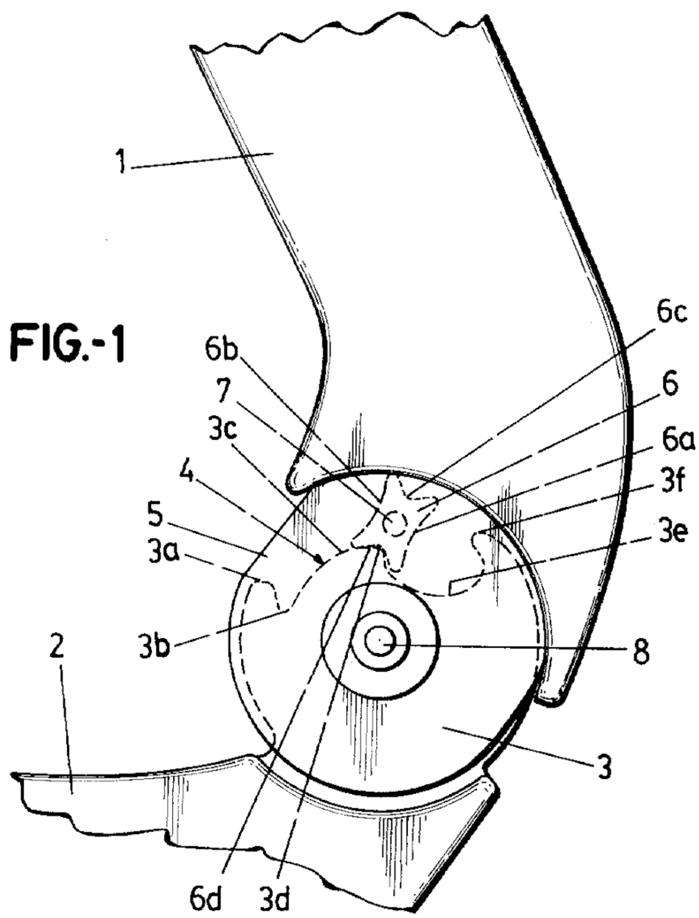

Figure 4. *Gear Locking Mechanism (EPS, 1995)*

Additionally, the main concept of this design is to utilize a truss system and two pulleys to help lift the door flap. As seen in Figure 5 below, one of the pulleys would be attached via a plastic clip to the original hinge. This allows the pulley to move with the attachment when the door is raised to the pulley's length. The pulley and hinge would move together until it hit the top-tube of the BL-84 sampler. The second pulley would remain stationary on top of the top-tube and would be connected via a collar.

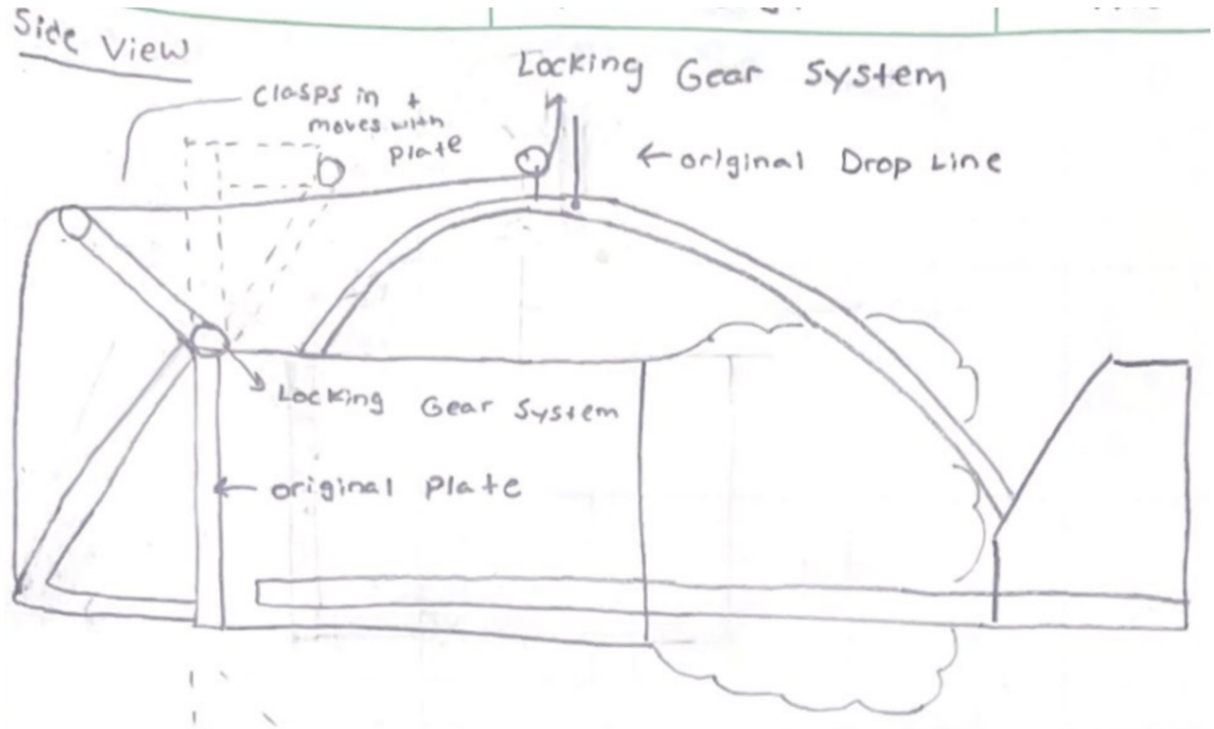

Figure 5. *Locking Gear System*

Alternative 2: Push-Pull Actuation System

Alternative 2 takes the concepts of common bicycle cable and housing for cable brakes to design an efficient way to open the door flap. An electric actuation system would be mounted under the current E-reel on a crane to eliminate the need for a secondary reel. This would be done by attaching a rotation motor to a slider crank mechanism to push and pull the door flap attachment cable housed inside the bedload sampler cable. The slider crank mechanism is further depicted in Figure 6 below:

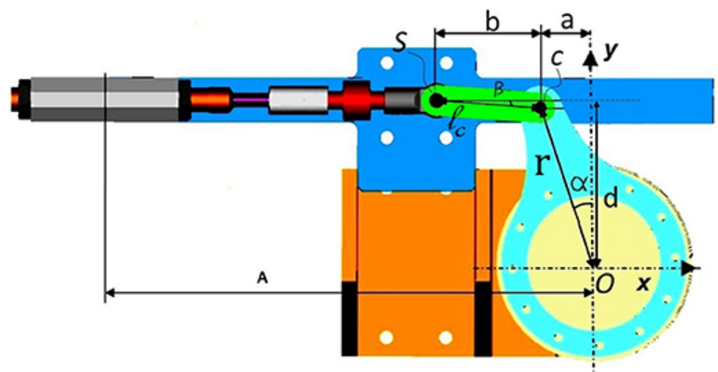

Figure 6. *Slider Crank Mechanism (Grosu et al., 2018)*

Furthermore, the main concept of this design would be the door flap cable housed inside of the bedload sampler cable. This design was inspired by the fact that the current bedload sampler cable has an inner copper wire that is outlined by a thicker aluminum cable. Alternative 2 proposed replacing the inner copper cable with a plastic housing and smaller inner aluminum cable. Plastic housing between the two cables would allow for the inner cable to move independently from the outer cable when the bedload sampler is fully suspended. Since the inner cable would be able to move inside the plastic housing and aluminum cable, the electric motor and crank would be able to lower and raise the door flap.

Another unique feature of this design would be the utilization of an encoder inside the E-reel. An encoder would track the position of the spool for the duration of the test. Since the encoder would track the number of revolutions of the spool, the cable length that props the door attachment ajar could be converted to the number of spool revolutions. Cable length would then be displayed on a seven segment display for the operator to ensure the door flap is fully open and closed.

Alternative 3: Push-Pull Manual Reel

Alternative 3 was included as a secondary approach to the E-reel. Replacing the actuation system with a regular hand reel system provides a manual option for the previous design. A secondary reel would be attached under the original reel on the crane as well as a push-pull cable. This cable is housed in the bedload sampler where a costume design model could be operated easily when rotating the crankshaft without the risk of entanglement. In addition, having two reels which operate as two separate cables (Main cable: Bedload sampler and Secondary cable: Door flap) are merged into a single line which connects to the door flap on both ends. In regards to the gate's open/close indication, cable length measurements would calculate whether or not the door is completely closed or open during testing. Therefore, if an operator were to have a misreading of the cable length then this could lead to an immediate indication that the door flap is still ajar. Figure 7 displays the second reel alternative concept and design.

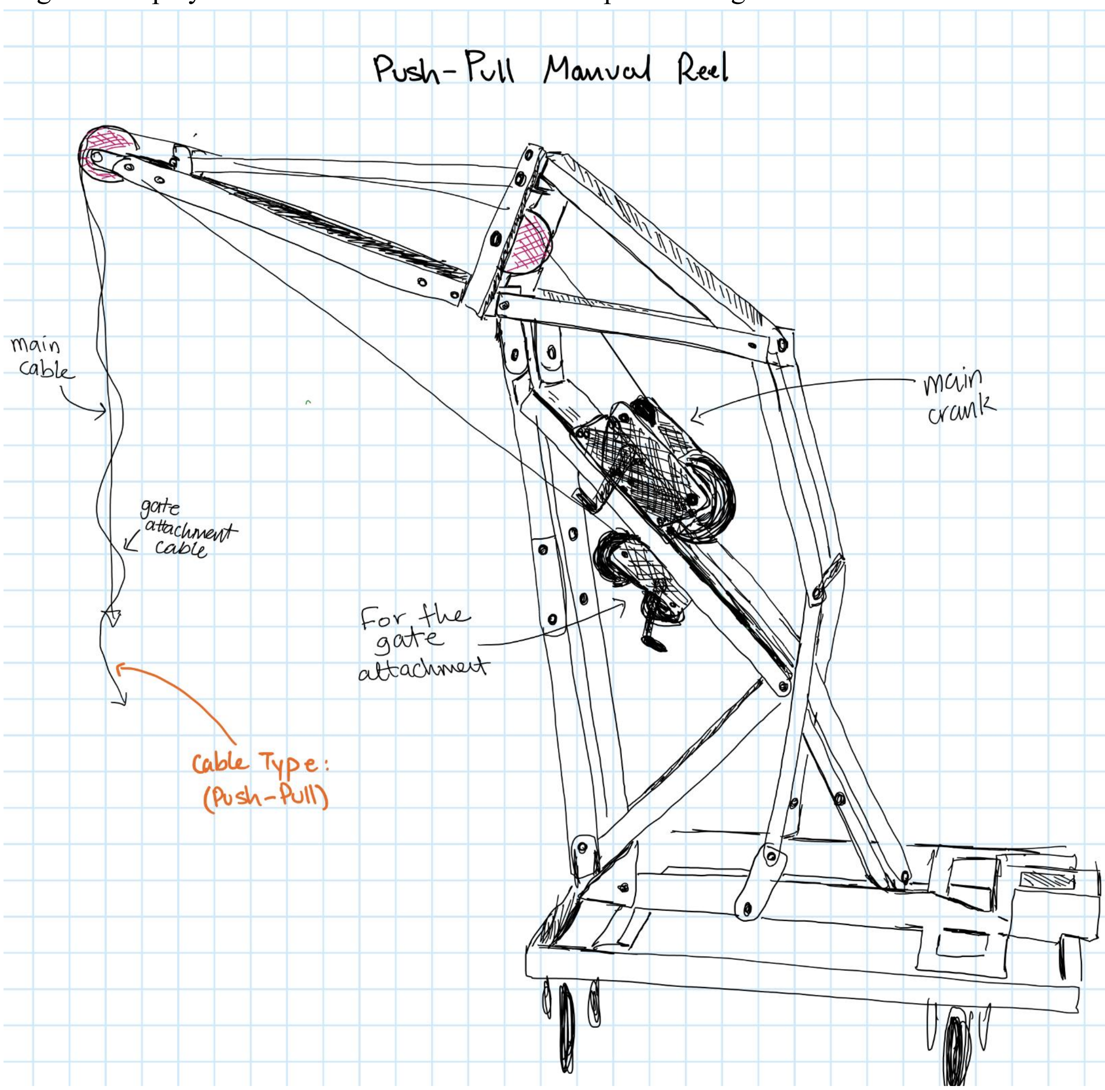

Figure 7. *Push Pull Manual Reel*

Alternative 4: Bar Cage (Truss System)

A truss-styled door flap was proposed in order to minimize the mechanical force required to open the gate. A cage of aluminum rods provides stability, durability, and a lightweight material. The door cable is split into two directions and attached to the extended corners of the truss on each end. The permanence of this attachment is reduced by using a separate frame that will attach to the door using the existing screw holes. This allows for the rods to be welded to the external frame and avoid modification onto the original door flap. A rod connecting the side trusses takes a parabolic shape so that door clearance is maximized. The unique shape is designed to combat lateral forces on the truss while avoiding contact with the top tube of the BL-84 as seen in Figure 8.

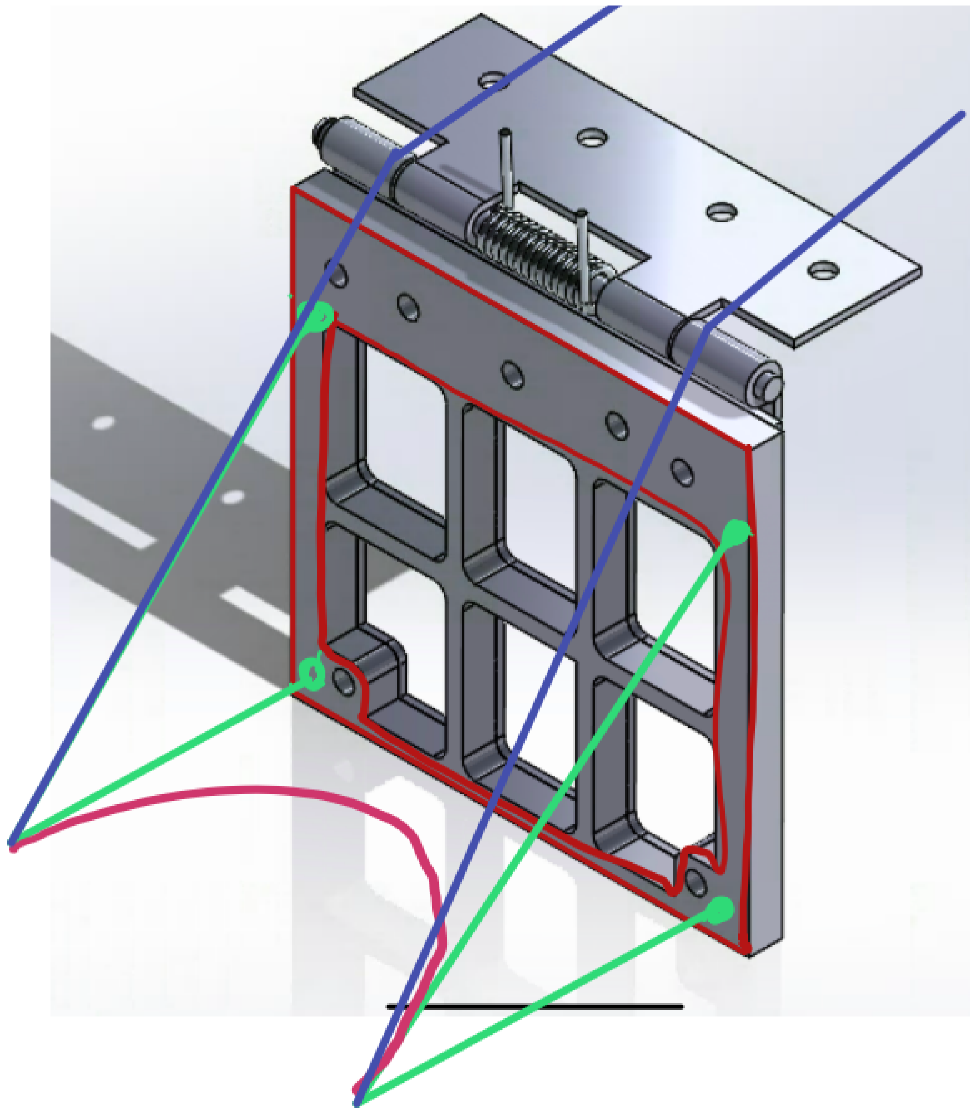

Figure 8. *Truss System on Door Flap*

Alternative 5: Garage-Pulley

Alternative 5 makes use of a separate cable and pulley system to raise the trap door, allowing it to slide upwards. The pulley is situated directly above the door to facilitate movement to the connection of the body of the sampler device in all three scenarios. This cable system runs up the length alongside the primary cable used to lower the BL-84 mechanism; this can be operated manually or by means of a battery/motor. A unique element of this design concept is the involvement of added tubing, equipment around the pulley system for water flow protection or possible channel debris. Figure 9 below depicts a side view of the trap door alternative.

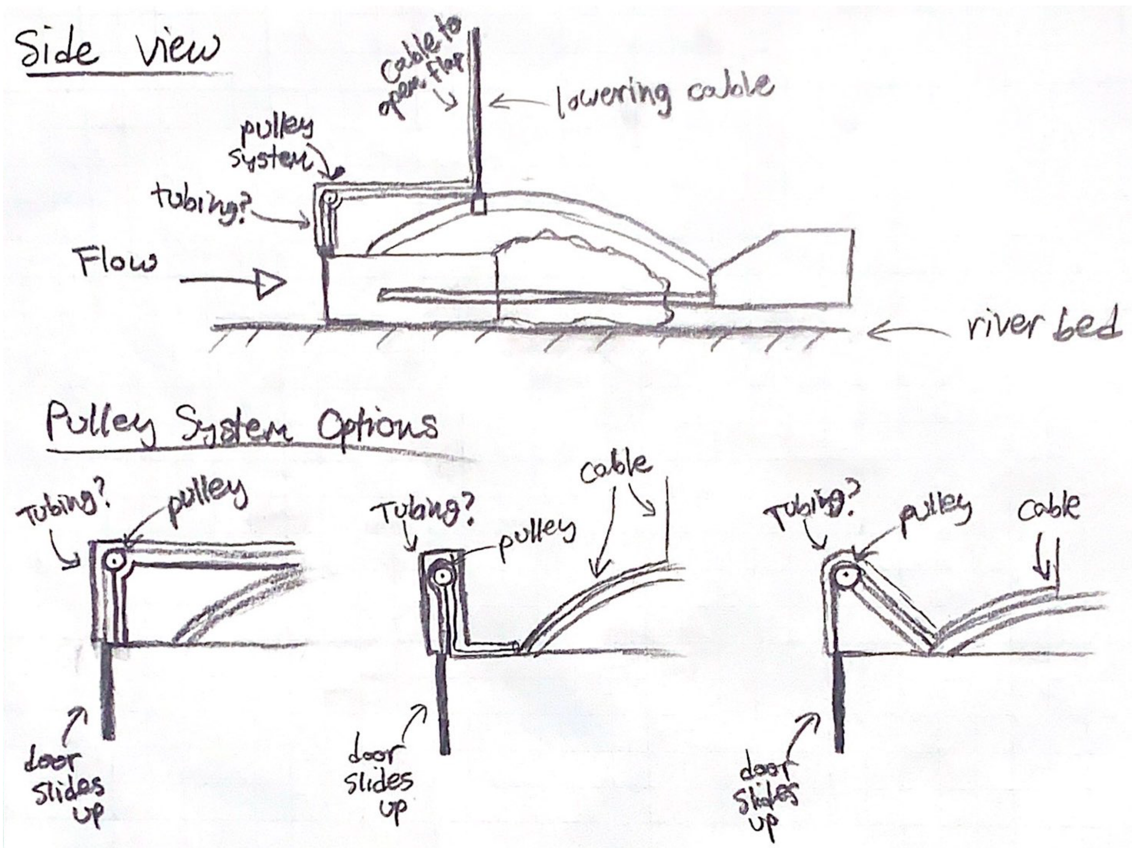

Figure 9. *Garage-Pulley System*

Alternative 6: Garage

Alternate 6 utilizes a release door acting as a garage door cover on top of the filter. As shown below in Figure 10, a filter will still be detachable but the additional garage door is held together via clasps. A pulley system will attach at the top of the garage allowing the user to manually pull the cover off of the filter up the sliding ramp. A wire is looped through a welded hole attached at the top of the garage to provide a point load force to pull upward to open the door. This wire is optimized to spread the pull force to reduce the amount of friction on the metal plate above the gate. Furthermore, the ramp is welded at a specific angle to allow the door to open and close to expose the filter. The clasps will be attached to the bedload sampler to facilitate movement and hold the garage in place. Lastly, the final system will attach the wire through loops allowing for less friction when pulling the garage in an upward motion.

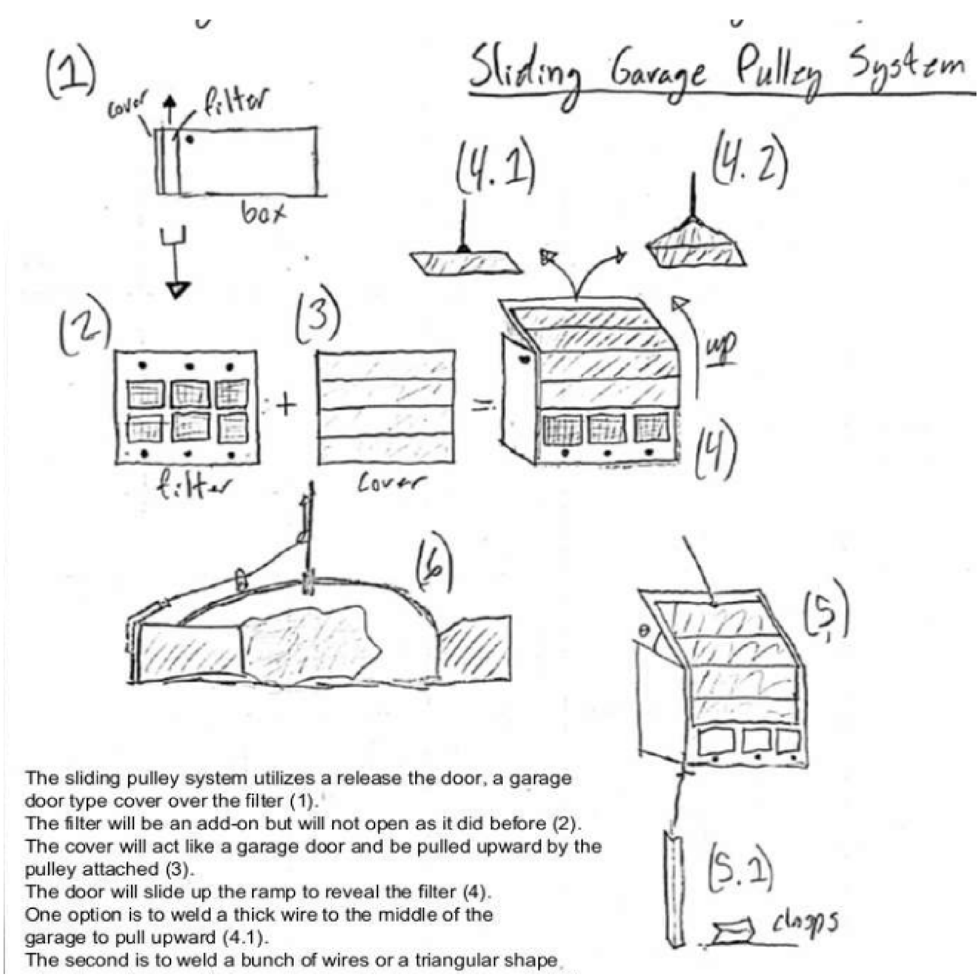

Figure 10. *Sliding Garage Pulley System*

Alternative 7: Stilts

Alternative 7 incorporates the gravitational weight of the bedload sampler to open the door which is attached to a set of guiding rods. Figure 11 below shows the design alternative of seven silts. The first drawing shows the closed mesh position. As the sampler is lowered to the river making contact with the riverbed, the weight of the sampler pushes the door open guided by piston-like tubing. When the sampler is raised, the door slides closed with no external input from the operator. This design was not chosen due to the lack of control of opening the door. A significant hindrance this design has is the inability to collect samples within the water column and not solely on the riverbed.

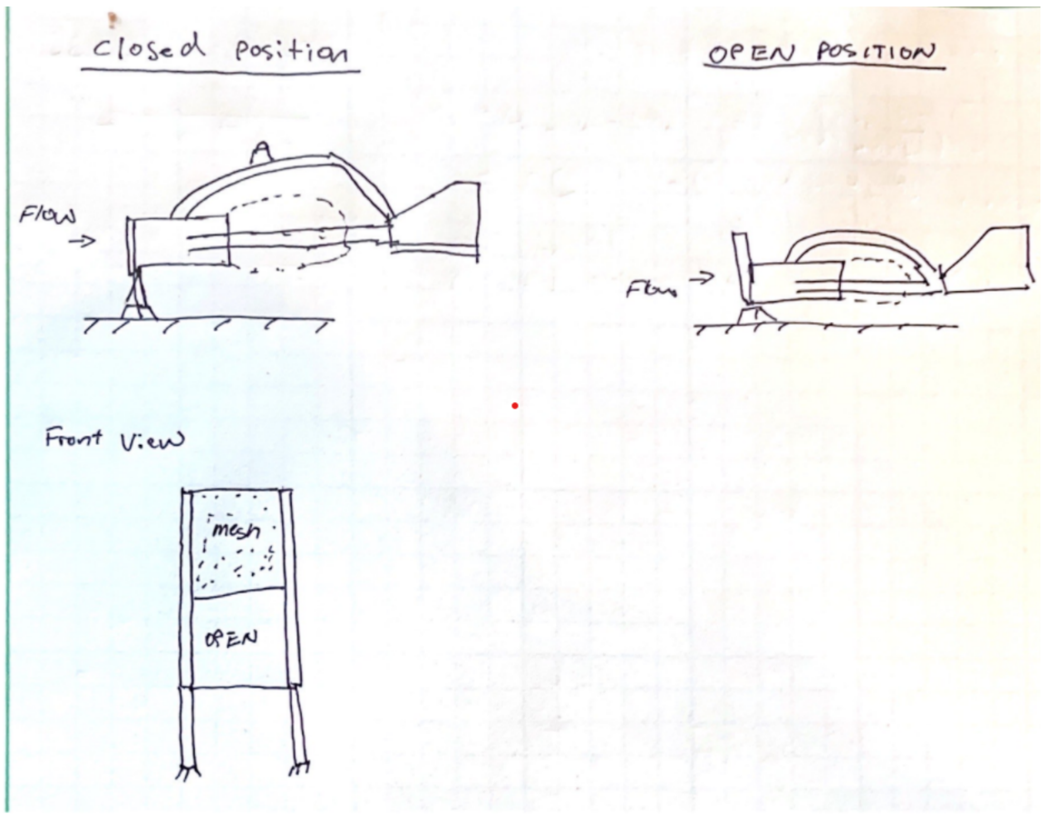

Figure 11. *Stilts Sketch Design*

After the seven alternative designs were proposed, a Pugh Matrix was created to analyze the alternatives and determine the final design. A Pugh Matrix is a way to analyze conceptual design alternatives based on an established set of criteria. All concept evaluation is conducted against a benchmark and repeated until a clear winner is established.

Optimizing the functionality of each alternative, a rating scale from negative five to five was used for each design criteria; negative five being considerably worse than the baseline for each design function, and five being considerably better than the baseline for each design function. The Pugh Matrix analyzes each alternative on a weighted criteria basis. After the design criteria, weights, baseline, and alternatives are included in the matrix where the team collectively rates each alternative. Once the alternative designs have been rated, the design with the highest weighted score is elected as the new benchmark design.

The Pugh Matrix was chosen to rate the seven alternatives because the table helps build a consensus amongst team members when rating the alternatives. Group discussion and evaluation on each alternative helps to avoid pitfalls of “falling in love with a flawed design,” and elects the solution with the overall “ideal solution.”

Before the Pugh Matrix criteria selection, a clear benchmark had to be established to evaluate each alternative. Since the scope of work builds upon the existing Tetra Tech and CSU door flap attachment, the baseline of the Pugh Matrix was the functionality of the top mounted flap attachment. Currently, the top mounted flap door is only available for handheld bedload samplers, which impacts the baseline for the reel criteria. A key assumption for the baseline of opening the door flap was that the operator manually pulls the door open with a cable unconnected to the reel system; this assumption impacts the baseline for the reel criteria.

Two sets of design criteria were established, one for the reel, and another for the gate. For the door flap the design criteria was established as: durability, required opening force, constructability, weight, volume, range of motion, hardwear streamline, maintenance, and operability. Conversely, the design criteria for the reel was established as: durability, required torque, constructability, weight, volume, cable routing to sampler, no interference, maintenance, operability, and door indication. After the design criteria was established, weights for all the criteria were set and each alternative was collectively criticized. The results of the Pugh Matrix are displayed in Table 3 and Table 4 below:

Table 3. *Door Flap Pugh Matrix*

Design Criteria	Weight	Baseline	Truss Gear Lock	Pulley-Collar	Single Bar	Bar Cage	Tubing + Garage Pulley	Garage	Stilts
Durability/ Corrosion	5	0	2	0	0	3	-2	-2	1
Required Opening Force	5	0	2	0	0	-1	3	4	4
Constructability / Mountablity/ Assembly	4	0	4	0	0	4	-4	5	1
Weight (low)	1	0	3	0	0	1	4	3	2
Volume	2	0	2	0	0	1	-1	3	1
Range of Motion (interfere w/ operability) (functionality)	4	0	-1	0	0	-3	-2	-3	-3
Harewear Streamline	3	0	2	0	0	1	-1	0	0
Maintenance	4	0	4	0	0	4	-4	4	-4
Operability	5	0	0	0	0	3	4	2	-1
Total	33	0	18	0	0	13	-3	16	1

Table 4. *Reel Pugh Matrix*

Design Criteria	Weight	Baseline (No Reel)	Push Pull (Elec-Act)	Push Pull (Manual) (Secondary Reel Crank System)
Durability/Corrosion/WP	5	0	-2	3
Required Opening Force	5	0	5	2
Constructability/ Mountability	4	0	-4	1
Weight (low)	1	0	-3	-1
Volume	2	0	-3	-1
Cable Routing to Bedload	5	0	3	3
No Interference	5	0	5	5
Maintenance	4	0	-2	-1
Operability	5	0	1	3
Door Indication	5	0	5	5
Total	41	0	5	19

After the conclusion of both Pugh Matrices, alternative designs, “gear-lock”and “secondary reel system”, were collectively elected to be the baseline starting designs. The “gear lock” design excelled in constructability, weight, and low maintenance, which ultimately made for a preliminary design concept. For the reel system, theoretically, the push-pull actuation system worked extremely well. However, after thorough analysis, a lack of reliability and complexity made for a purely mechanical secondary system the clear winner.

Once the two baseline designs were decided by the team, a meeting was held with David Pizzi, to verify designs properly fit into the scope of work. During the meeting, David expressed great interest and enthusiasm towards the baseline designs. Once a verification was made from David, prototyping could properly be started with full assurance of the design being within the scope.

Afterwards, teams of two were formed in order to commence operations in designing the voted concepts. The first team was focused on the flap attachment, ensuring that the lock gear system would eventually work and not hinder the samplers’ performance during testing. The second team was responsible for designing an efficient reel system on the crane which is considered the most important part of the whole apparatus design. In addition, the reel system will be responsible for opening/closing the flap door and providing door operating indication.

However, after careful evaluation of the voted concepts, both teams decided to enhance their design functionality with various other alternatives which were inspired by the original concept. For the initial design, the door attachment team decided to go ahead and apply the bar-cage truss system instead of the lock gear mechanism due to: operability, simplicity of design, minimal complexity, cheapness of manufacturing, and most importantly serving the same purpose as the original voted concept. In addition, the truss system would not take up any surface area on the bedload sampler. The design is to be operated in ways which do not interfere with the sampler’s other components other than the flap itself. The trusses will be welded on small plates screwed on the sides of the flap attachment; any welding on the original sample components is avoided. This provides the operator with maintenance privileges and all components may be replaced or removed without having to be concerned about permanent pieces. A U-shaped shaft will be welded to the ends of each truss. This allows the design piece to gain a large opening while being pulled open by having the curved shape wrapped on the top pipe above the sampler.

The second team took a similar approach for developing the secondary reel system. One of the essential aspects of the design was the flap opening/shutting indication. Creating a distance indicator dial attached to the reel system to inform the operator for when the attachment is ajar. The new concept of the dial was to assure a 1:1 ratio between the dial’s indicator rotation and the rotation of the reel gears. The reel team was then able to manage a ratio that is close to a 1:1 ratio and maintain correct gear sizes. Gear mechanics were considered and orders were placed to be used in the design assembly in solidworks to create a visual simulation.

INITIAL DESIGN ANALYSIS

Initial Truss Design

Once the gear locking truss concept was selected from the Pugh Matrix, prototyping commenced. After mapping out the concept, the locking mechanism was removed to increase simplicity and to eliminate future functionality problems. This approach was taken after the realization that sand and dirt will cause the locking mechanism to jam during field tests. Once this change was made, the gear locking truss design was renamed as the "Truss Design".

After these changes to the design were made, a SOLIDWORKS model was created for visual representation, 3D printing, and machine drawings. Figure 12 below shows the first CAD model created for the truss design.

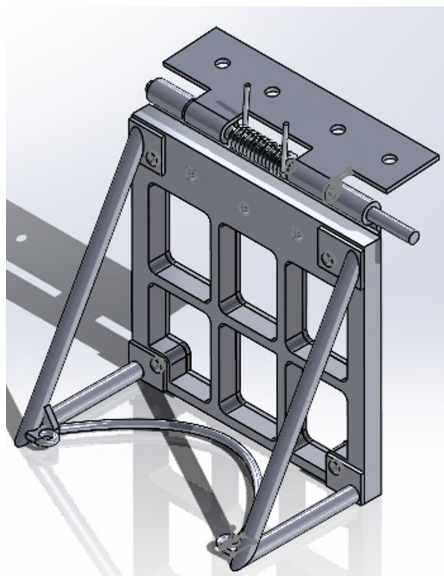

Figure 12. *Initial Truss Design*

The truss design, as represented in Figure 12, consists of two side rods extending two inches out from the flap attachment to provide a lever arm to amplify the input force to open the gate. In addition, the bottom sides of the rods have hole placements for cable attachments on both ends of the truss design. Having two cables assembled on each side of the truss was hypothesized to eliminate any unwanted rotational forces from just the use of a single cable. Another incorporated feature of the truss was the U-shaped piece, which connects the two side rods to mainly ensure force support and was made to be "wrapped" around the top-tube of the bedload sampler to allow maximum flap opening.

Once the CAD model was created multiple 3D prints were created using the PLA extrusion printers. The 3D prints helped refine dimensioning and tolerance before shop drawings were created. Following an iterative additive manufacturing approach, the design was proposed to the CSU Engineering Research Center (ERC) machine shop for manufacturing. Following a thorough design review changes were made to the shapes of the side rods and base plate. These changes were suggested by the ERC machinists to improve manufacturability and to reduce costs. Figure 13 below shows the final CAD model produced before manufacturing.

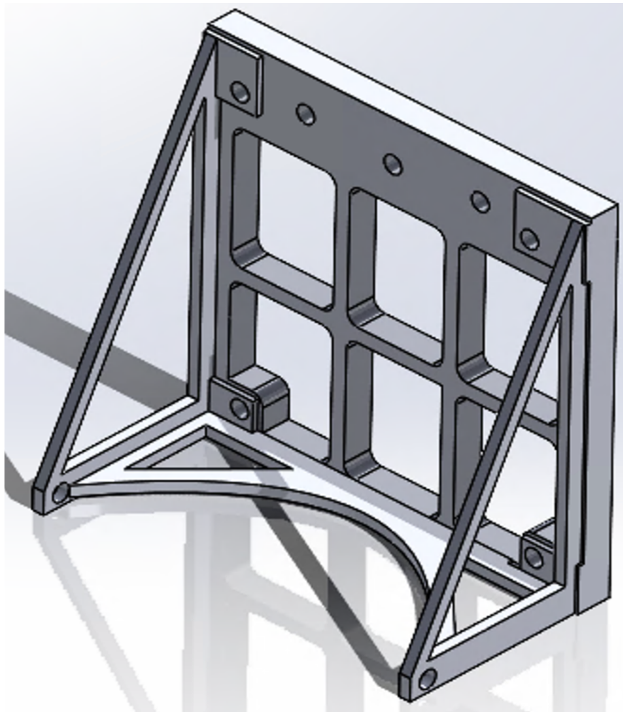

Figure 13. *Final Truss Design*

Following the finalization of the CAD model and shop drawings, the truss design was manufactured at the ERC. The truss was fabricated with a thin sheet of 6061 aluminum. The aluminum sheet was cut using a waterjet, and then bent and welded into shape. Holes were drilled into the truss to allow for quick attachment and detachment from the top-mounted flap. The two images shown below in Figure 14 display the final truss prototypes.

Figure 14. *Manufactured Truss Prototypes*

Initial Pulley Design

A pulley attachment was designed once the prototyping of the reel was underway. The pulley attachment was determined as a necessary part of the design to provide a smooth cable guide on the bedload sampler. One major concern of the door attachment was cable management and routing from the reel to the door. Meeting this need created a pulley collar, designed to effectively guide the cable to the flap attachment.

The pulley collar was modeled after a simple removable collar. A collar was chosen because of the ease of assembly, detachability, and adjustable orientation. A pulley was added to the collar to rotate the flap attachment cable from a vertical orientation coming from the crane to a horizontal orientation connecting to the gate. The device would allow the door cable to be fixed on the BL-84 near the bedload sampler cable to eliminate the possibility of the wires getting tangled. The pulley was designed to freely rotate around a shaft to eliminate lost mechanical energy. Furthermore, a divideder was designed to route the split section of the door cable to the composite section of the cable. The pulley collar was modeled in SOLIDWORKS and is displayed in Figure 15 below:

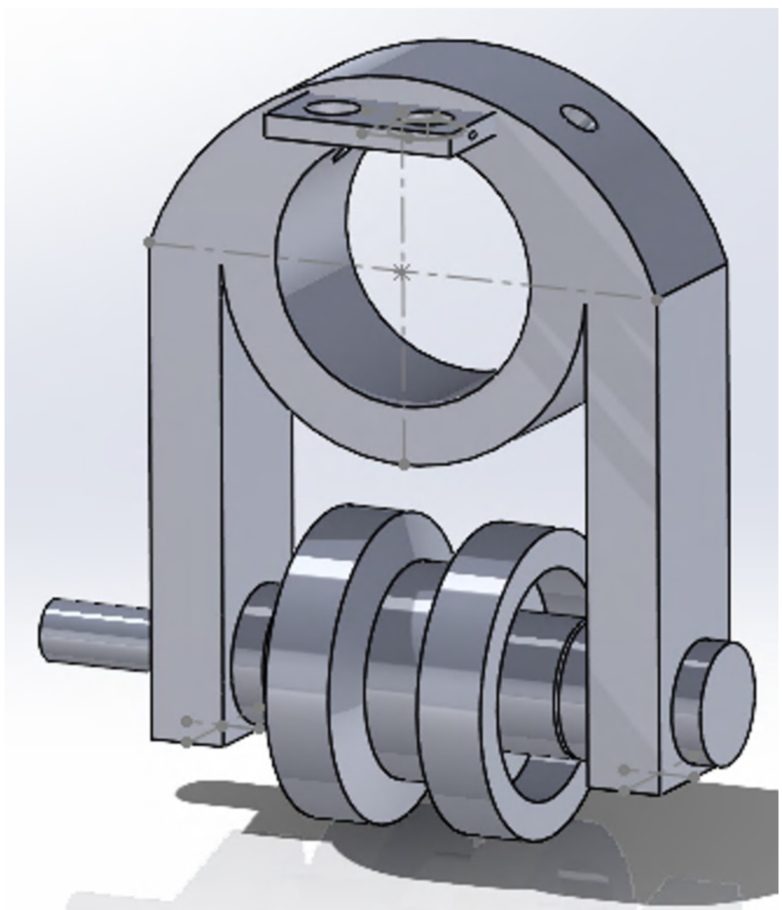

Figure 15. *SOLIDWORKS Pulley Attachment*

Following the completion of the pulley attachment CAD model, shop drawings of the part were taken to the ERC for fabrication. The body of the pulley was chosen to be manufactured from 6061 Aluminum primarily due to cost, machinability, availability, and durability. Furthermore, two bolts were used to clamp the top and bottom pieces of the body for easy attachment as seen in Figure 16 and 17 below. A steel bolt was used as the axle for the delrin pulley. Delrin was the selected material for this application primarily because of the self-lubricating material properties. The materials selected for the pulley attachment helped achieve the design objectives of durability and constraint of cost.

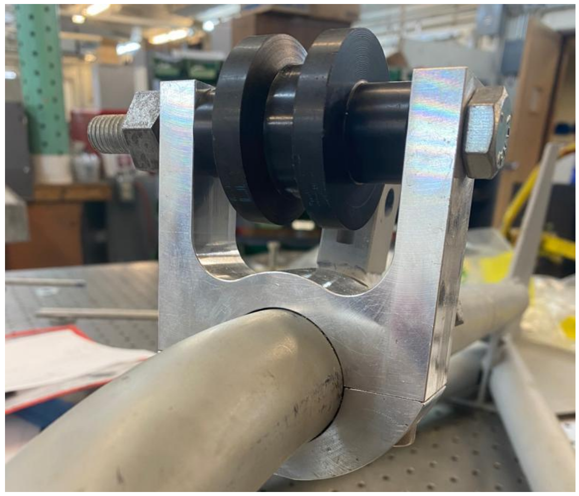

Figure 16. *Fabricated Top-Tube Mounted Pulley*

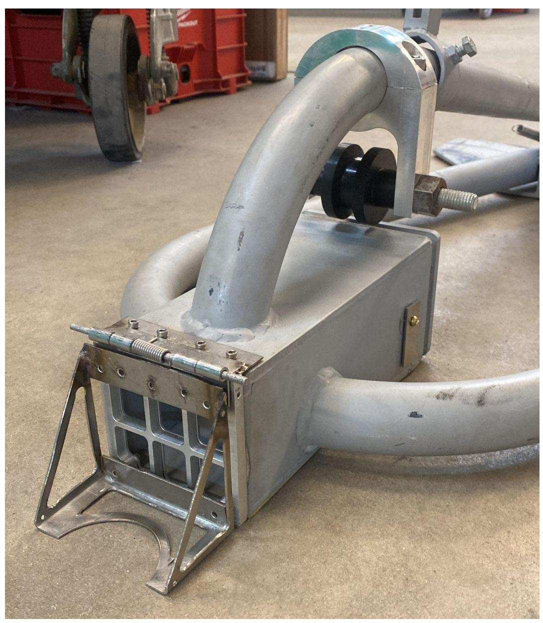

Figure 17. *Fabricated Top-Tube Mounted Attachment*

Initial Design Testing

After the truss and pulley attachment were manufactured, testing commenced to evaluate the design's functionality. The main objective for the truss and pulley attachment was to reduce the force required to fully open the top-mounted flap on the BL-84 sampler. A twenty percent reduction was set as the goal for the design, as mentioned in the "Objectives and Constraints" section. This testing objective, a force test was required for the original top-mounted flap and for the truss attachment mounted on the top-mounted flap.

For the force test as displayed in Figure 18, a Hanson model 895 hanging scale, displayed in was used to measure the force required during each test. The mechanical force gauge was chosen primarily because of the ability to measure a vertical pulling force. Accurately measuring the force exerted during each test consisted of a slow motion camera. For each testing variation, ten force tests were performed and recorded. With the sample size of ten tests, the average force was calculated and used for analysis.

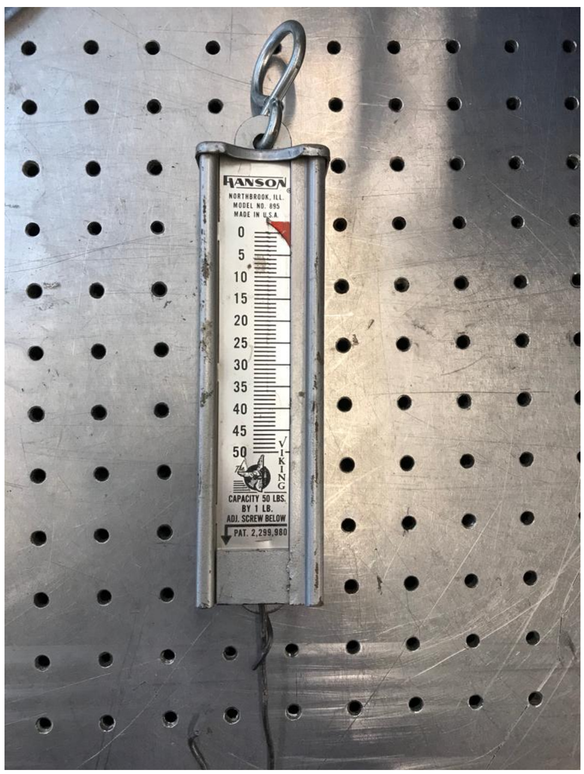

Figure 18. *Hanson Model 893 Scale*

Three testing variations were analyzed to determine the effectiveness of the top-mounted flap design. The first variation was the top-mounted flap with the pulley attachment. This variation was used to set the baseline force required to open the flap. For this test, the pulley attachment was used to properly route the cable to the flap. Since the top-mounted flap was not previously compatible with the BL-84 sampler, there was not an established way to route the cable from the reel to the flap. Considering this, the pulley attachment was added to keep the cable alignment consistent among all the force tests. Figure 19 below presents the testing position for the first variation test. Once the testing position was determined, ten force tests were performed and recorded. Figure 19, also presents a plot of the force points recorded along with the calculated mean force of 18.2 lbs.

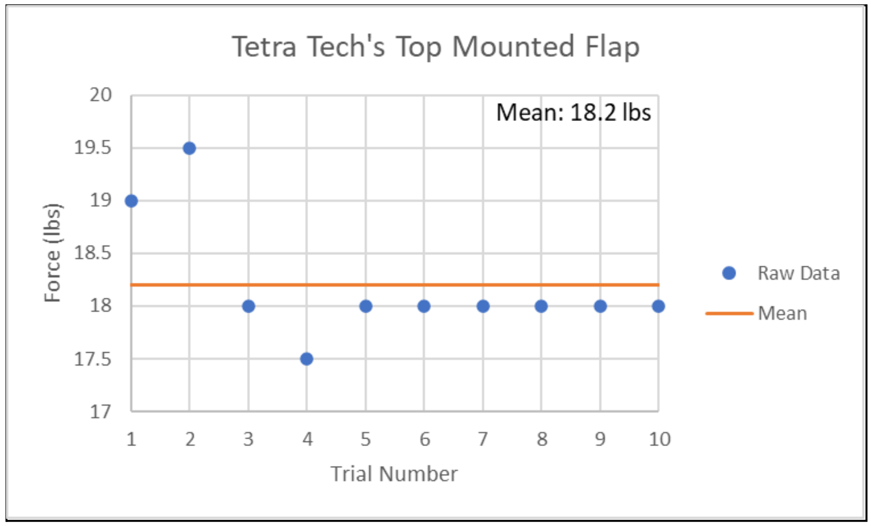

Figure 19. *Test 1 - Force Results From Top-Mounted Flap*

During the top-mounted flap force test, the max pulling force to open the flap was observed only when the flap was approximately ninety degrees open. Once the flap crossed the ninety degree threshold the force dramatically decreased and the flap was thrust into the top-tube. As a result of the large magnitude of force when the flap was less than ninety degrees open, the pulling force would lift the BL-84 off the ground. For that reason, the team member performing the force test was required to stand on the BL-84 side-tubes to prevent the sampler from lifting off the ground. The reason the force magnitude was the highest when the flap was less than ninety degrees open, was the fact that the cable was positioned against the hinge of the flap. Since the cable was resting on the fulcrum, the force applied through the cable was almost parallel to the face of the flap. However, when the flap was opened more than ninety degrees, the cable would lift off the hinge and the cable would orient the resultant force almost perpendicular to the gate. When the cable was oriented with a greater perpendicular resultant, the pulling force would drastically decrease. Discovering this relationship changed how the top-mounted flap and truss prototypes were analyzed and was crucial for the next design iteration. Figure 20 shows how the resultant force changes as the flap's physical position when the cable is pulled open.

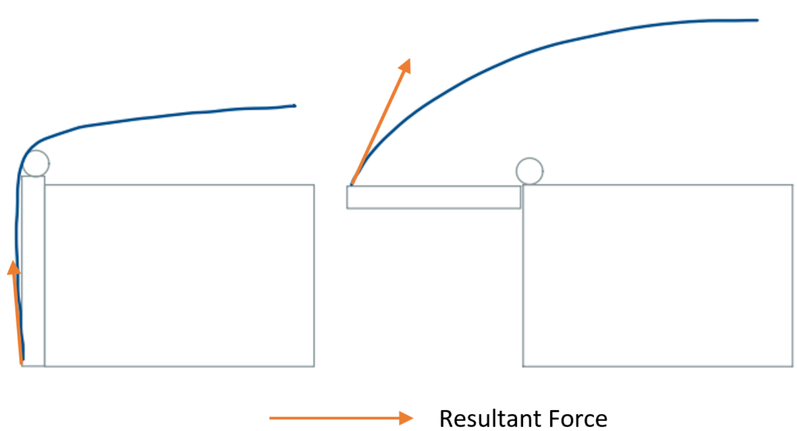

Figure 20. *Resultant Force Sketch*

Following the top-mounted flap test, two force test variations were conducted on the truss and pulley attachment. Test two's first variation positioned the pulley attachment below the top-tube of the BL-84, while test three's second variation positioned the pulley above the top-tube. These two approaches were taken to determine how the orientation of the pulley attachment affected the pulling force.

Test two followed the same procedure as the top-mounted flap test described above. This test resulted in nearly double the pulling force compared to Tetra Tech's design at a mean of 33.1 pounds, and had the worst performance out of the other positions. Figure 21 displays the data point graph from the position two testing.

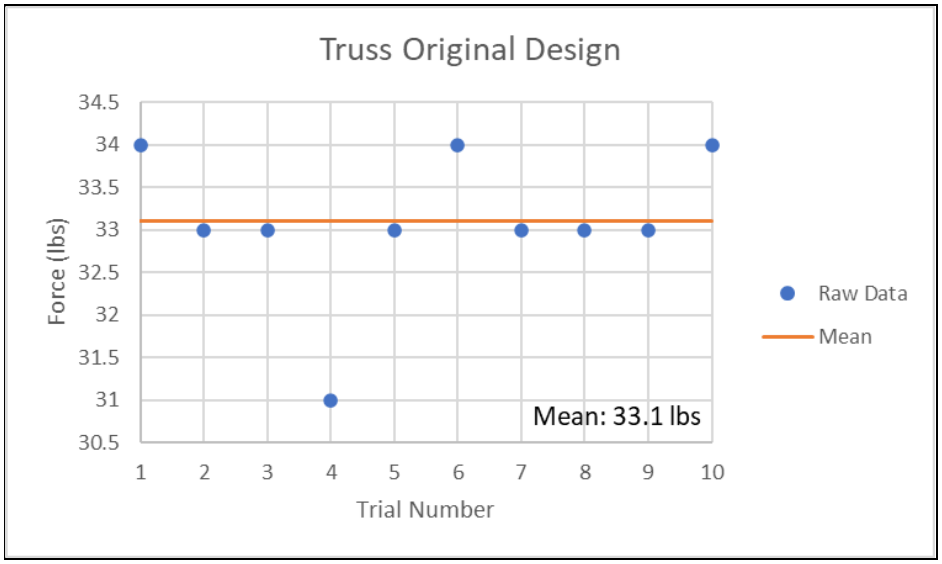

Figure 21. *Test 2 - Truss Design (Pulley Oriented Downwards)*

Test three also followed the same procedure as the top-mounted flap and test two. After collecting ten force data points, the mean pulling force was calculated as 21.6 lbs, as represented in Figure 22 below. In conclusion, this test determined that rotating the pulley attachment one-hundred-and-eighty degrees reduced the mean force by 11.5 lbs, and the truss attachment does not achieve the design objectives. After analyzing the truss prototype, key design flaws were identified. First, the length of the truss did not extend the cable far enough to change the resultant force orientation. During testing, similar problems were present as described in the top-mounted flap test. The max force required to open the flap still occurred at angles smaller than ninety degrees, and once the cable detached from the fulcrum, the truss would trust into the top-tube. Second, the use of two cables added unwanted friction to the system. Since the cable branched from the same pulley, the cables ran along most of the top-tube. When the cable was tensioned, significant friction was created between the cables and top-tube.

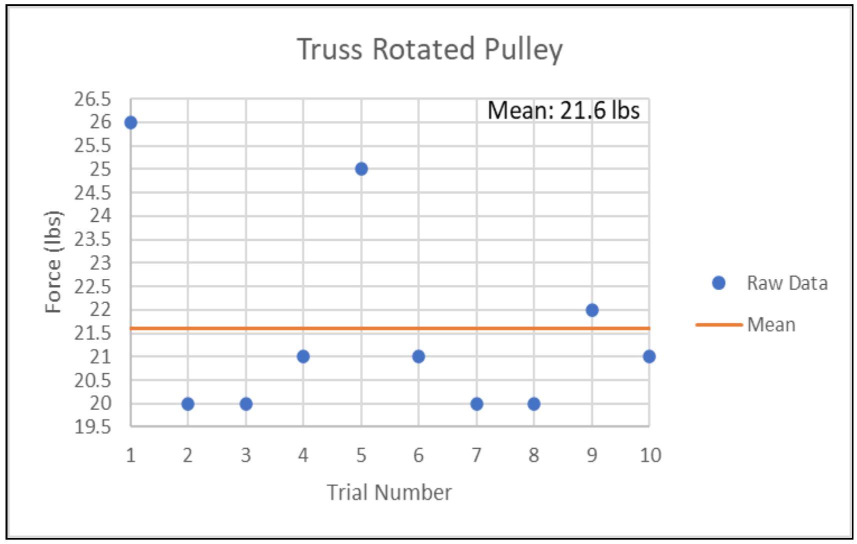

Figure 22. *Test 3 - Truss Design (Pulley Oriented Upwards)*

After thorough analysis of the truss design, the mean pulling force could be reduced if the pulley attachment was resigned. While reducing the friction forces in the system could reduce the required force to open the gate, the maximum force would still lift the BL-84 of the bed during sampling. Due to this problem a different approach from the truss was required.

FINAL DESIGN ANALYSIS

Final Design - Flap Door Pulley System

Following the completion of the initial design assembly and testing, the truss design did not achieve the set design objective. In addition, the cable had to be pulled with a measured force of 25-30 lbs into a narrow angle. This setback was immediately evaluated and resolved with the machinists' support at the ERC. The solution suggested adding a pulley on one end of the door flap hinge to rotate the door flap directly around the shaft. Apart from this, the pulley had a large enough diameter to provide sufficient space for the cable to be pulled to the door flap’s full potential. The hinge pulley was fabricated out of aluminum and was designed with a small pin extruded from its' edge, inserted into a drilled hole made on the side of the door flap. This ensures that the door flap is able to rotate with the pulley during operation. Figure 23 shows the extruded pin from the pulley and placement on the side of the door flap.

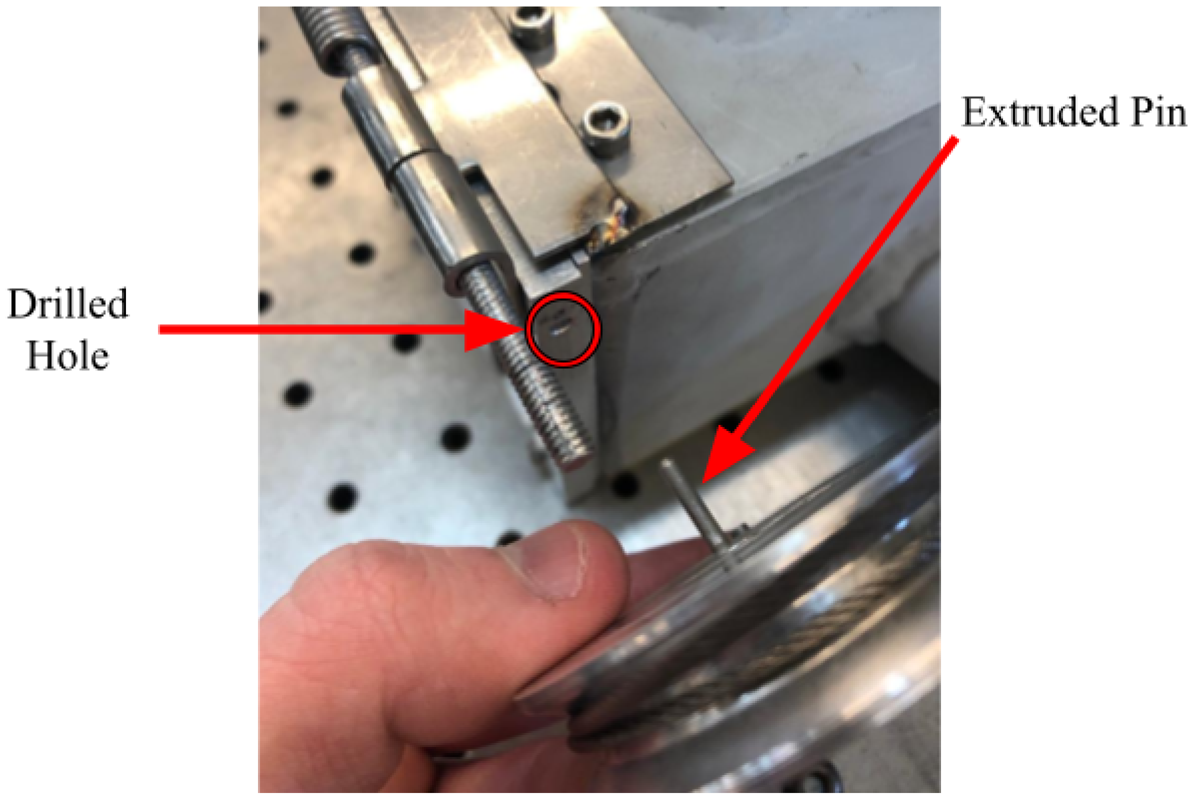

Figure 23. *Final Design - Pulley Hinge Extruded Pin Placement on Door Flap Attachment*

Another incorporated feature on the pulley hinge is a fixed pin inserted across its outer wall to secure the cable from unwrapping. The rigidness of the small pin was strategized to be set in a specific location to account for not blocking the cable route when pulling and rotating the pulley upwards. The pin was tested to observe all the possible cable blockages on the hinge pulley, which occur when operating the door flap. Therefore, when the door flap is shut, the bottom side of the pulley is a suitable location to add the small pin and allow for cable clearance when operating. Figure 24 and Figure 25 display the fixed pin on the pulley hinge and the assembled pulley on the door flap hinge, respectively.

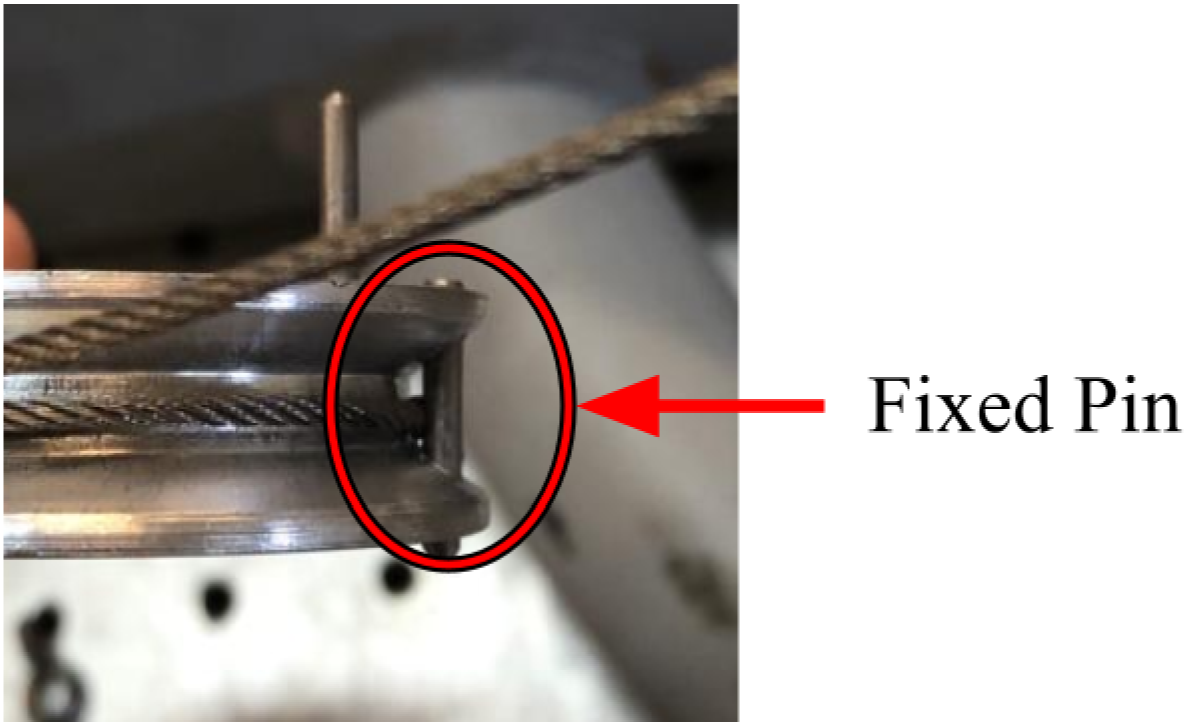

Figure 24. *Final Design - Fixed Pin on Pulley Hinge*

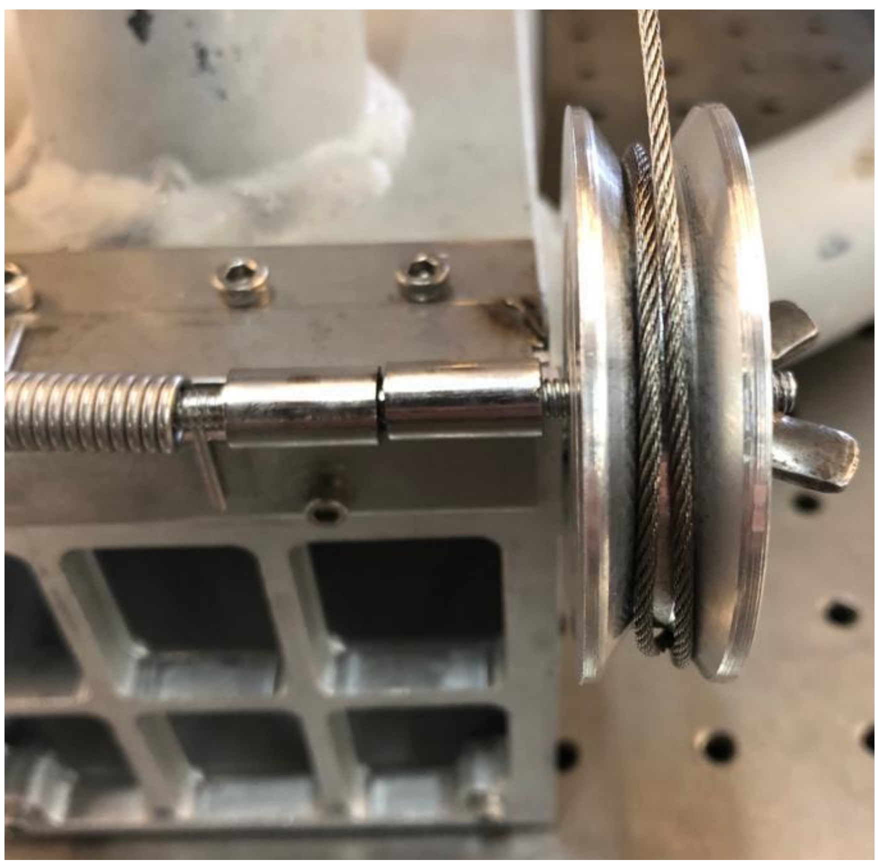

Figure 25. *Final Design - Assembled Pulley on Door Flap Hinge*

Furthermore, when routing the cable from the side positioned hinge pulley to the middle positioned top tube mounted pulley, the cable was noticed to line up in an angle. Visually, the misalignment was easily assumed to cause minor pulling force issues. Therefore, the top tube mounted pulley has been altered to where the Delrin pulley was replaced with another fabricated aluminum pulley and assembled on the outer side of the mount. The purpose of this modification is to assure the pulley mount is directly aligned with the flap pulley to achieve linear routing for the cable. Moreover, pulling forces will be less difficult when transmitting rotations in one axis. An aluminum sleeve was assembled on the tube pulley to ensure the routed cable is in place, serving a similar purpose of the fixed pin from the hinge pulley. Figures 26 and 27 display the newly modified tube mounted pulley and an overall look of the final design assembly on the bedload sampler.

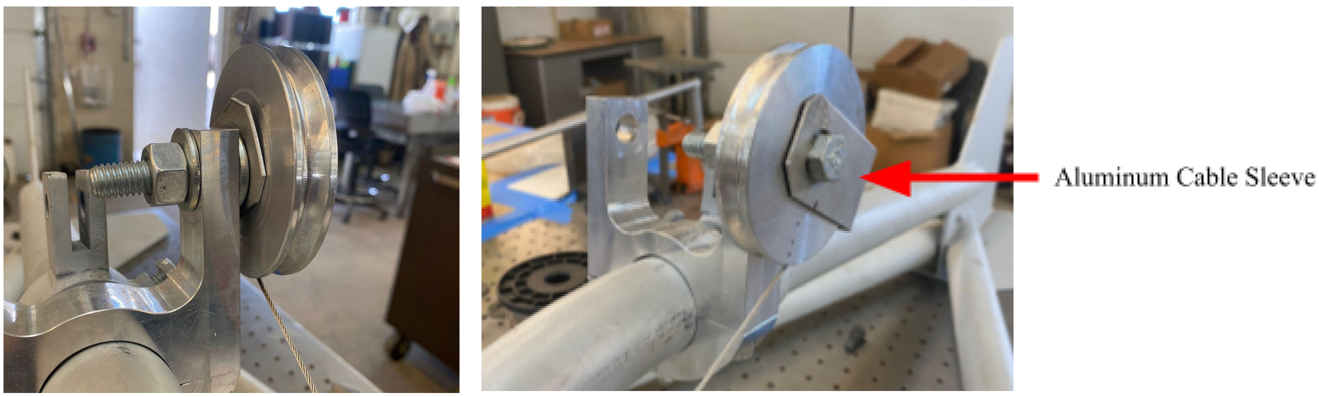

Figure 26. *Final Design - Modified Tube Mounted Pulley*

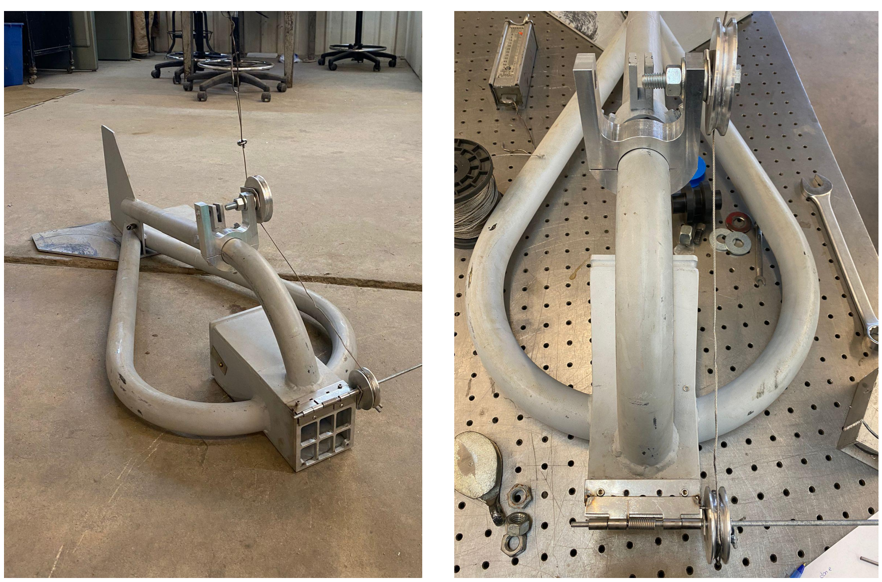

Figure 27. *Final Design - Door Flap Pulley System Assembled on Bedload Sampler*

Final Design - Secondary Reel System

Beginning from the Reel Pugh Matrix, the manual secondary reel concept was chosen to take part in the final project design. Further design developments were discussed with respect to achieving the design objectives and ensuring design effectiveness. For sufficient operability, the secondary reel concept was inspired by the USGS E-Reel system, used by Tetra Tech to lower/lift the bedload sampler, in regards to its overall shape and functionality. Additional features have been included to enhance the secondary reel design efficiency like a custom made distance indicating dial, ratchet locking key, and double belt pulley. Moreover, The secondary reel is positioned linearly under the USGS E-Reel so as to fit on the crane and attain reeling synchronization when deploying the bedload sampler. This placement was specifically selected to provide simplicity during field testing whilst managing two different reel systems. Although the reel is suggested to keep the crane less trafficked with components for portability, weight was a neglected matter based on the fact that the secondary reel is rested on a cart and only mounted to support suspension. Figure 28 showcases the completed 3D CAD model of the final secondary reel system design.

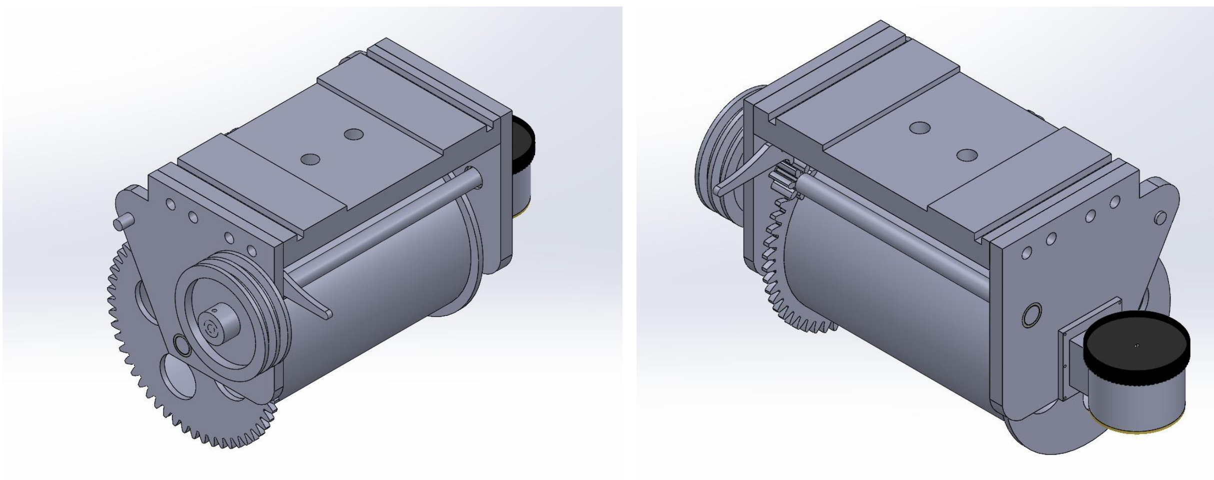

Figure 28. *Final Design - Complete 3D CAD Model of Secondary Reel System*

Fabrication of the secondary reel was heavily reliant on utilizing 6061 Aluminum. Aluminum can obtain several benefits including machinability, corrosion-resistance, durability, and cost efficiency. Another main reason for selecting aluminum to fabricate is because of its lightweight feature compared to other durable metals. This attribute reduces the access load on the portable crane when assembled with the USGS E-Reel which is made out of Steel. The methods and construction of the secondary reel consist of envisioning and designing four sub-assemblies to achieve optimization, which include reel framing, a primary shaft, a secondary shaft, and a costume-made distance indicating dial. Investments on certain materials were made to accommodate project budget constraints. Furthermore, the Engineering Research Center (ERC) machine shop was used for fabrication to reduce production costs.

1- Reel Framing

A three-framed reel cover is designed to carry all the sub-assemblies with the capability of mounting on the crane. All frames have been fabricated by utilizing a CNC milling machine. Labeled CAD models of each frame are displayed in Figure 29. Frame one, the "Top Mounted Frame", was fabricated to be attached to the crane's L-shaped bars by fastening to a rectangular plate. Furthermore, indentations above frame one account for fitting correctly on the L-shaped bars. Shown in Figure 30 is the assembly of the reel framing on the crane. Frame two, the "Driving Frame", is responsible for carrying the main components of controlling the reel mechanism with a handheld crank, a double-belt pulley, and a ratchet gear lock. Frame three harbors the dial elements in a gear pocket which is significant for aligning the dial cover to the frame to ensure accurate gear meshing. Frames two and three hold both the primary and secondary shafts to account for the gear transmission and spool rotation. Moreover, both frames have been press fitted with needle bearings to support all shaft rotations.

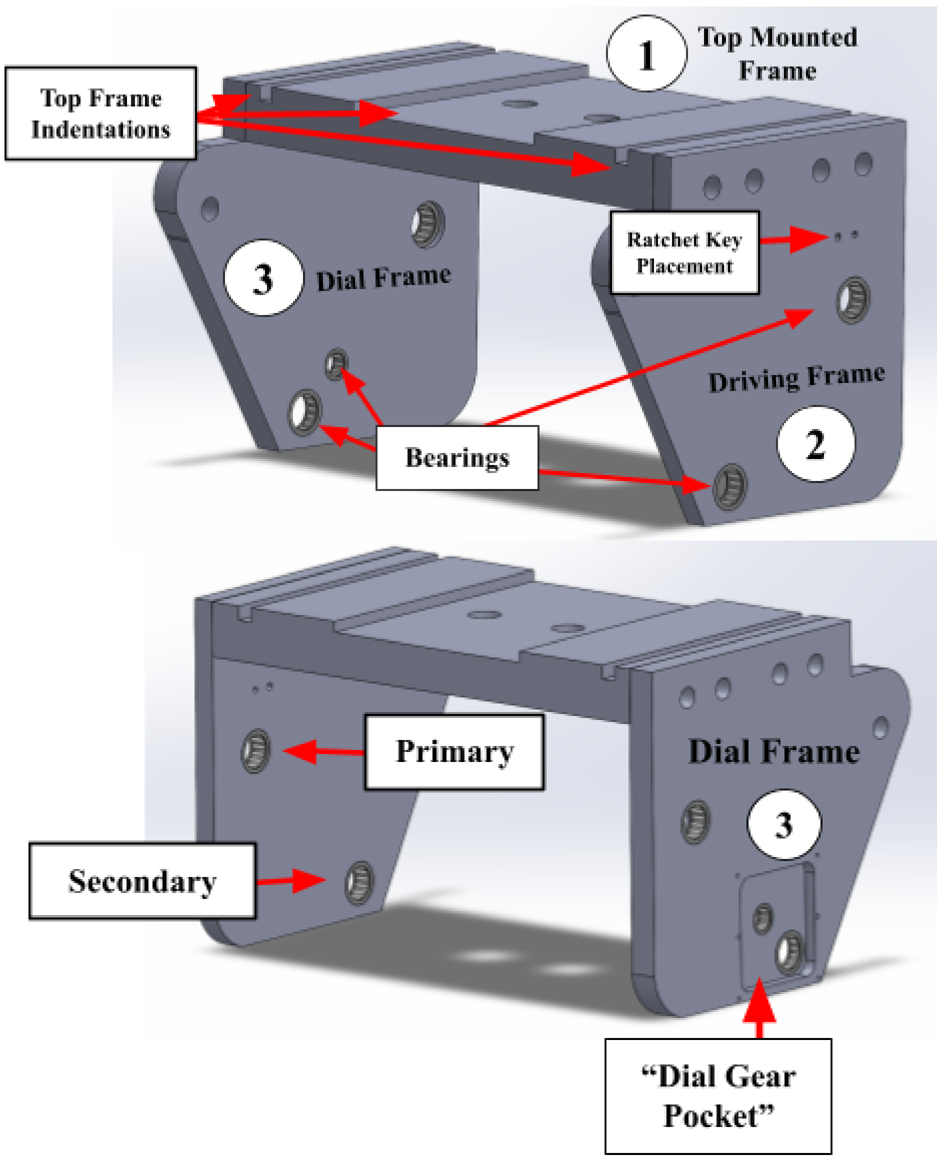

Figure 29. *Final Design - Reel Framing*

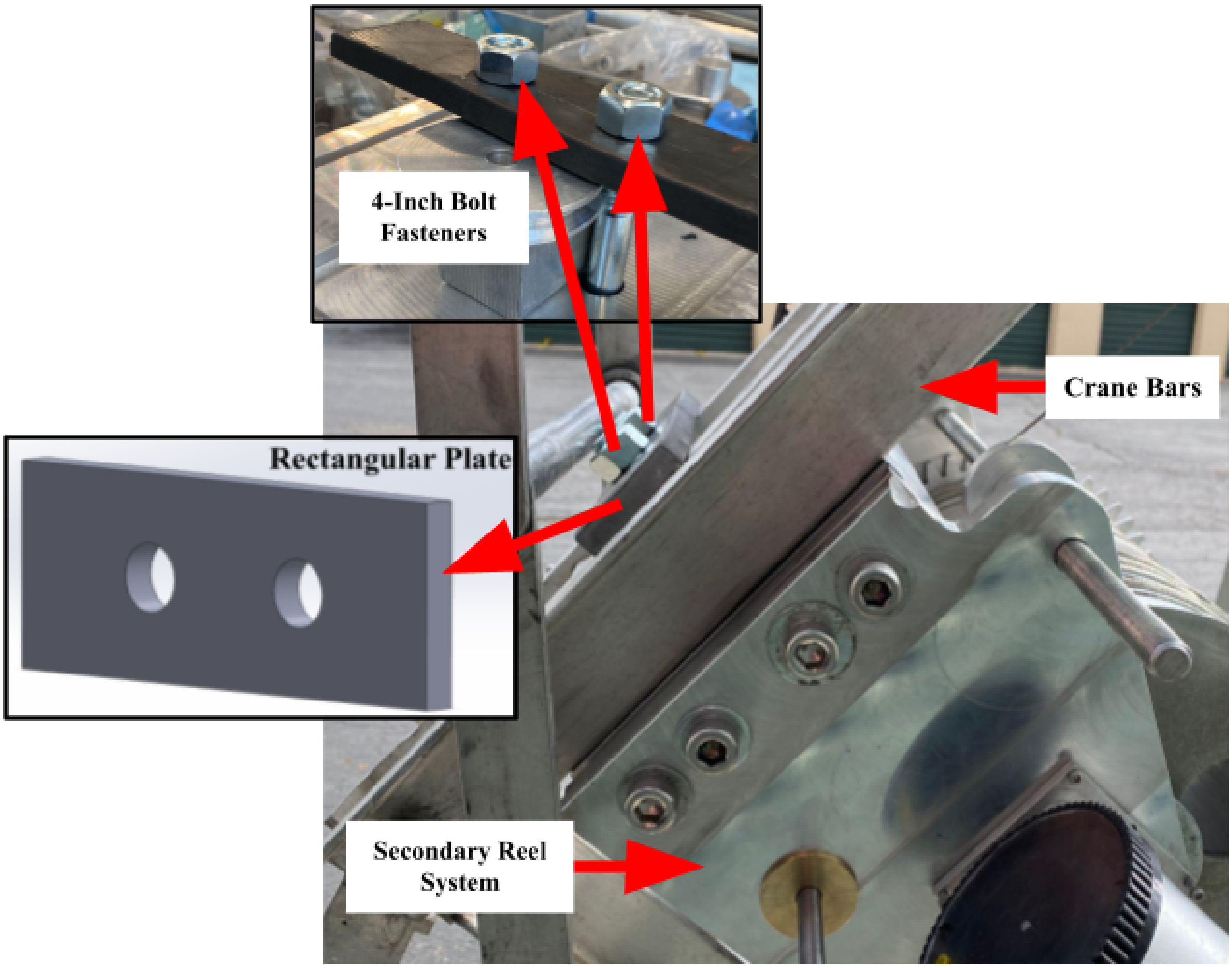

Figure 30. *Final Design - Reel Framing Crane Assembly*

2- Primary Shaft

In the first frame, the primary shaft is the main source of manual movement. A double belt pulley is attached to the primary shaft and can be operated by a handheld crank. Adding the double belt pulley to the secondary reel allows for a direct connection to the USGS E-Reel. This connection is important for achieving reeling synchronization for both the bedload sampler and door flap cables. In addition, the synchronization concept allows both cables to be reeled together without causing both systems (bedload sampler and top-mounted flap door) to incline during suspension. Furthermore, the two double belt pulleys can be synchronized with a 15545 V belt. The double belt pulley for the secondary reel was 3D printed and assembled for operating due to cost and time constraints. 3D printing was a great approach for custom designing the pulley to be press fitted on the primary shaft and for cutting down machinery expenses. Figure 31 displays the reeling belt connection between the two reel systems.

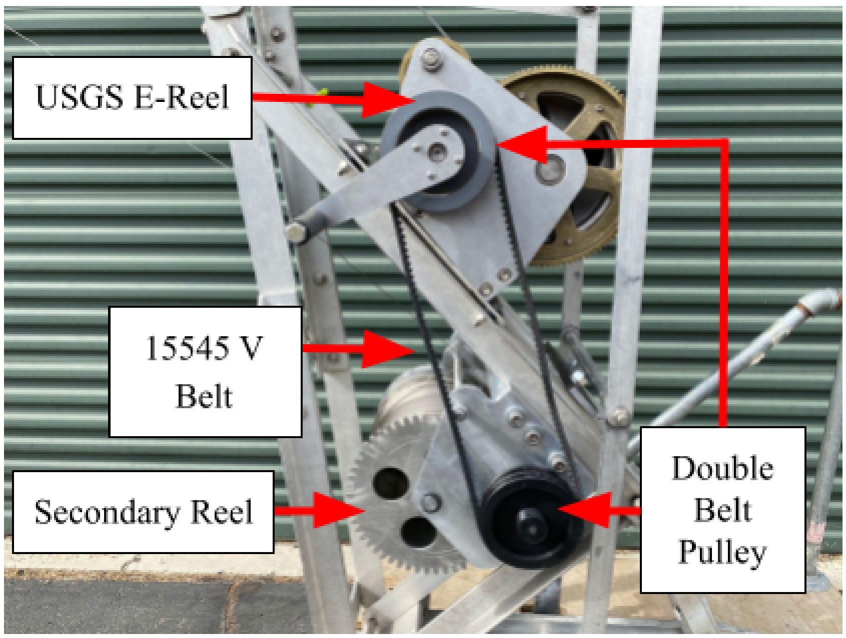

Figure 31. *Final Design - Reeling Belt Connection*

Assembled on the primary shaft is a custom made 7-tooth pinion (driving) gear, which meshes with a custom made 54-tooth (driven) gear. The 54-tooth gear is welded to a spool in order to directly reel the top-mounted flap cable. The large difference in gear teeth accomplishes a gear ratio of 7.71:1. This ratio is significant because the ratio matches the 7.71:1 gear ratio from the USGS E-reel to ensure that when the bedload sampler is reeled up, the cables move at the same speed. A ratchet mechanism was added to the 7 tooth gear to reduce the effort required to control the top-mounted flap during testing.The ratchet is operated by a loaded spring and can be adjustable for holding the spool in place after reeling. This mechanism ensures the operator that the top-mounted is fully held open during the duration of the test. Figure 32 displays a 3D CAD model of the assembled primary shaft components. Figure 33 shows the assembly of the machined primary shaft components.

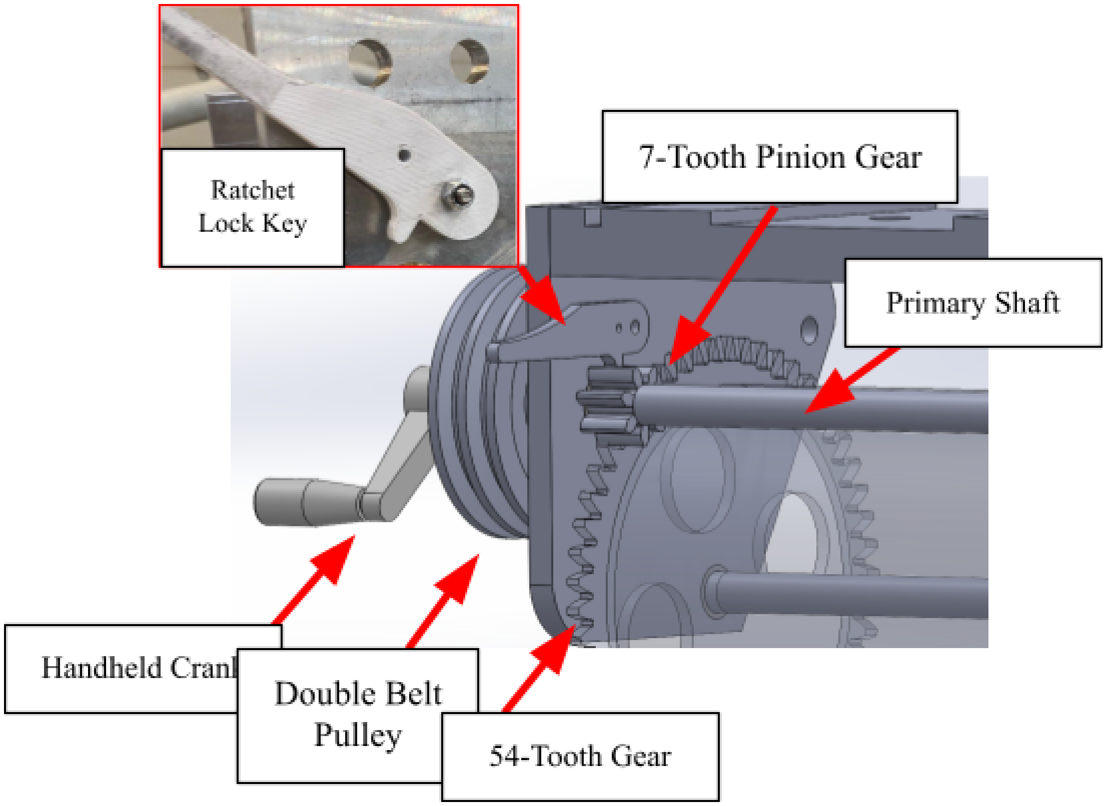

Figure 32. *Final Design - 3D CAD Model of The Primary Shaft Components*

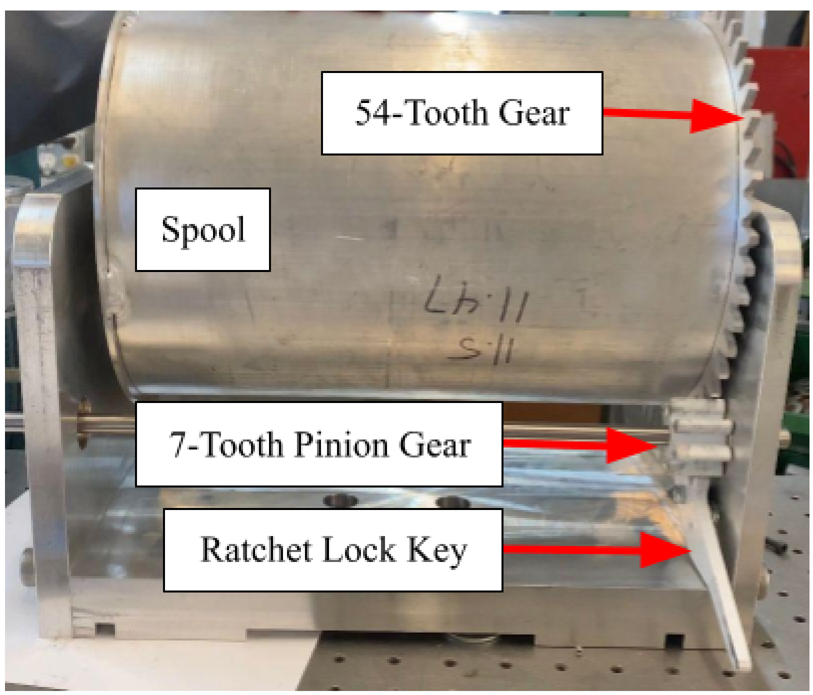

Figure 33. *Final Design - Machined Primary Shaft Components*

3- Secondary Shaft

In order to stabilize the spool within the frames, a secondary shaft was inserted to provide structural support which is represented in Figure 34. The ends of the shaft were tightly secured to the 54-tooth gear (1) and the circular plate (2), thus ensuring the spool rotates codependently with the shaft when reeling. The secondary shaft is also a vital component to the distance-indicating dial, in which it is utilized to transmit rotational motion to the dial's interior gears. Additionally, an inverted bushing was fabricated, using a lathe, on one end of the shaft for securing a 12-tooth pinion gear. The attached pinion is then assembled to the pocket to initiate the gear train leading into the dial. For fitting purposes, the pocket was designed to have the exact depth as the pinion's thickness. This accomplishes a leveled surface to which the dial cover can be easily installed without adjustment issues.

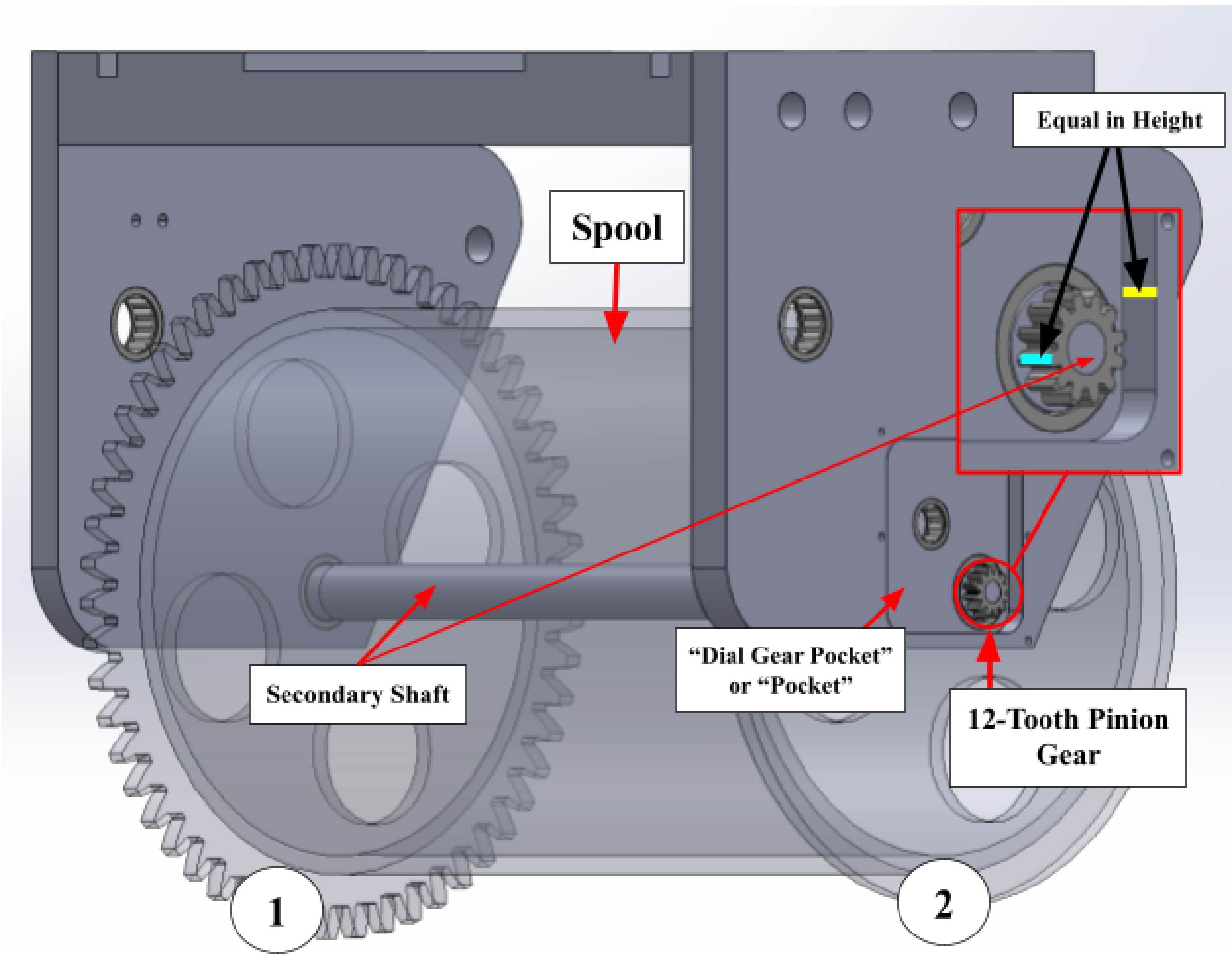

Figure 34. *Final Design - Secondary Shaft Features*

4- Distance-Indicating Dial

Inside the pocket area, the 12-tooth pinion gear drives a compound gear that consists of a 40-tooth spur gear and a 24-tooth bevel gear. A dial cover is then attached to conceal the gears which is a combination of three pieces: A dial mounting plate, a tunnel hub, and the dial cover tube, which are represented in Figure 35. In order to mesh the dial gears properly, the cover is placed in a location where the 24-tooth bevel gear would have the correct center distance to another 12-tooth pinion gear inside the dial. Bevel gears are an advantage for transmitting gear movement into the dial gear train. In addition, bevel gears also connect shafts whose axes are oriented at a 90 degree angle to each other. In this case, the dial is placed face up towards the top-mounted frame to be visible for the operator.

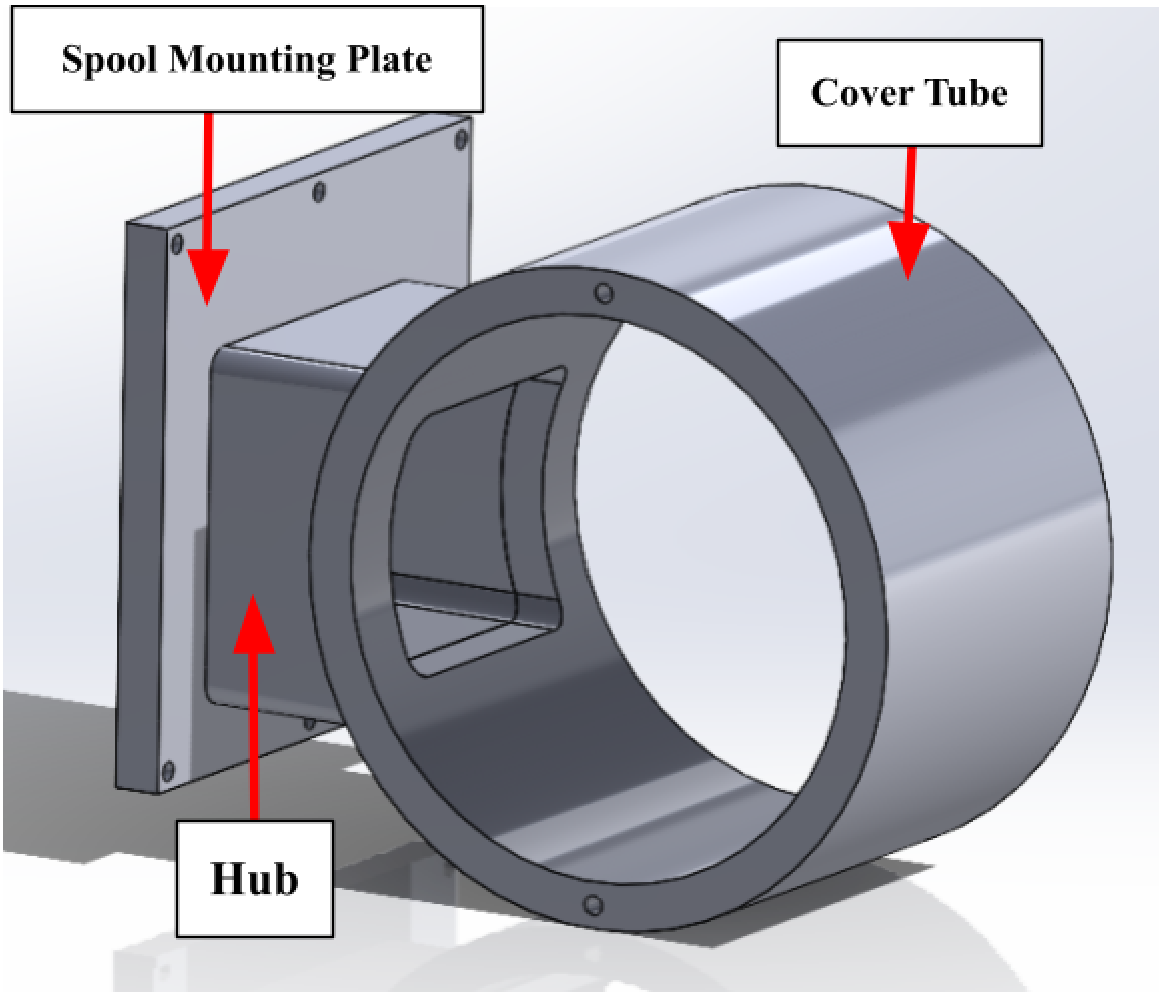

Figure 35. *Final Design - Dial Cover (Exterior)*

Gear dynamical transmissions had been crucial throughout the process of designing the dial gear train. The goal was to achieve a synchronized ratio closest to a 1:1 trade-off between speed and torque. In addition, dial readings, during field tests, are likely to be accurate and could provide the operator with unbiased data to analyze. Certain gear formations have been incorporated within the dial to transmit the 54-tooth gear motion with a speed reduction, yet still deliver an equal trade-off. To do so, compound gears are utilized to create the dial gear train due to the ability of shifting speeds from the input to the output in a single axis. The number of teeth selected for each dial gear has been calculated to estimate a close ratio from the spool rotation. The first compound gear, in the secondary reel system, is the 54- and 12-tooth gears. The dramatic decrease in gear sizes was purposefully done to match the gear ratio of the USGS E-reel.Then, a 40-tooth gear is installed into the dial gear pocket to mesh with the 12-tooth pinion gear to largely reduce the rotational speed directly from the spool. This was an approach to gradually reintroduce the rotational speed of the spool into the dial due to the change of shaft directions. Therefore, a 24-tooth bevel gear was then assembled to the 40-tooth gear to create a second compound gear. The bevel gear was a beneficial add-on since it is able to change the directional rotation of the dial gear train. The bevel gear was included to moderately increase the speed to which a 12-tooth bevel pinion gear is then incorporated to further raise the speed once more. After a sufficient gear trail to transmit the spool rotation, the rotational speed of the dial needle is equalized by adding two 18-tooth spur gears and two 36-tooth spur gears. To further illustrate the equalization, the first 36-tooth gear is installed behind the 12-tooth pinion and creates a third compound gear. Next, the first 18-tooth gear is inserted to mesh with the neighboring first 36-tooth gear, and shares an axis with the second 36-tooth gear; thus creating a fourth compound gear. Lastly, the second 36-tooth gear is meshed with the second 18-tooth gear which acts as the dial needle. Figure 36 displays the 3D CAD models of the dials' compound gear train.

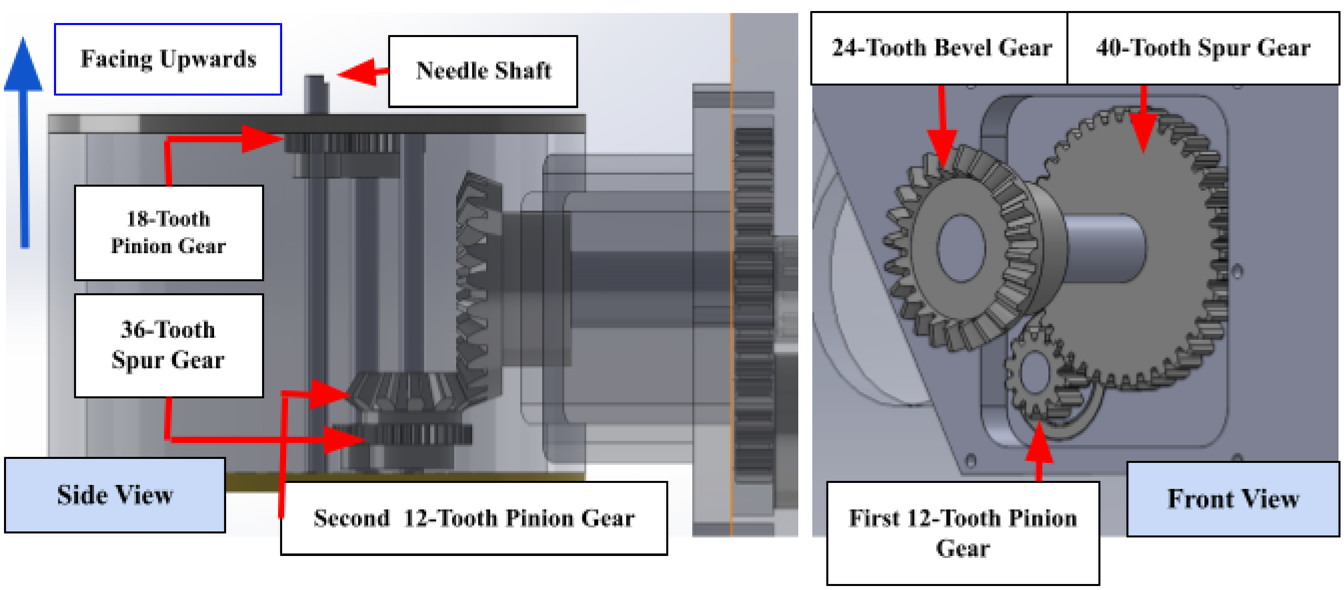

Figure 36. *Dial Gear Train*

Dial Mounting Plates and Cover

Two identically fabricated plates are attached onto the dial brims and consist of three placement holes each. The plates play a vital role in ensuring all the interior gear shafts are perfectly spaced out to achieve proper gear meshing. All gear shafts rely on enclosed ball bearings to reduce friction and grant axle support. For maintenance purposes, bearings on the back plate are press fit to secure the shafts on one end of the dial, and the bearings on the front plate are slip fit to permit easy detachment. This awards the operator with installation simplicity. Figure 37 displays a 3D CAD model of the dial psnitonal plates.

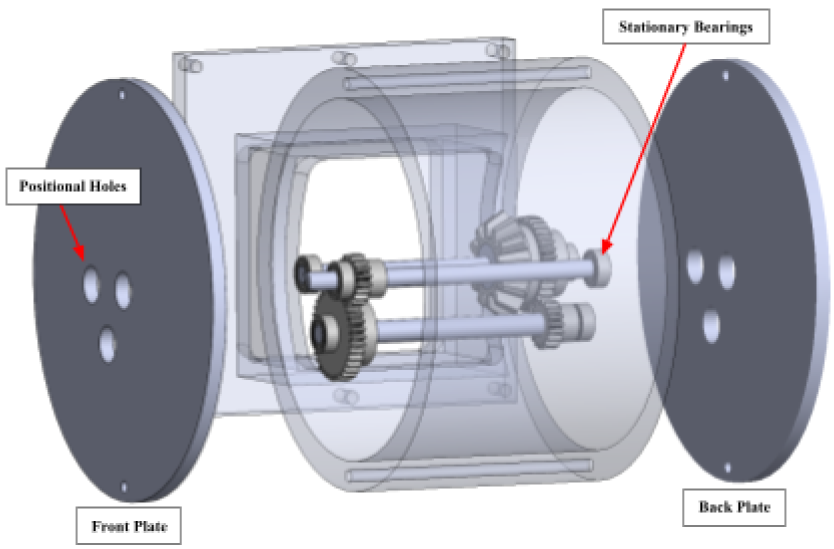

Figure 37. *3D CAD Model of Dial Plates*

For distance indication and zeroing, a "dial cap" was designed and 3D printed out of PLA. Zeroing the dial is crucial for accurately determining the position of the flap during the test, thus the method to zero the dial needed to be quick and easy. The dial cap zeroing concept was based on the rotating cover used in dial calipers. A set screw was tapped into the needle cover to allow the operator to tighten the screw when the dial was zeroed. When the dial needs to be zeroed, the operator simply untightens the screw and rotates that cap until the dial is properly zeroed. Figure 38 below displays the dial cap with the applied set screw.

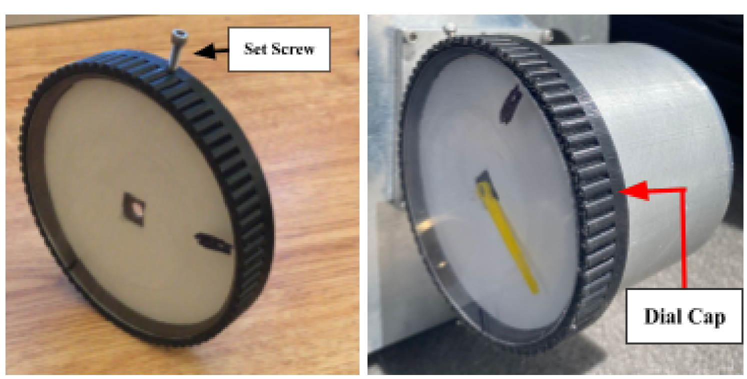

Figure 38. *Dial Cap with Set Screw*

FINAL DESIGN TESTING - DOOR FLAP ATTACHMENT

1. Force Gauge Test

Force testing was performed to determine if the side pulley design, as discussed in the "flap door pulley system," reduced the maximum required pulling force. A Hanson model 895 hanging scale was again utilized for each force test. Following the same procedure used in the initial design testing, 10 force tests were performed and recorded for the side pulley design. Further force testing was conducted in a flume to measure the pulling force at different flow speeds.

After 10 force test trials with the pulley design were conducted, the average force required to open the door was calculated to be 13.9 lbs, as represented in Figure 39 below. Compared to the average force of the original top-mounted flap, the pulley system reduced the required pulling force by 24%. This experiment revealed that the pulley system achieved the 20% force reduction design objective. Additionally, the door flap fully opened to a 210 degree angle during every force test, which achieved the "210 degrees of flap" position design objective.

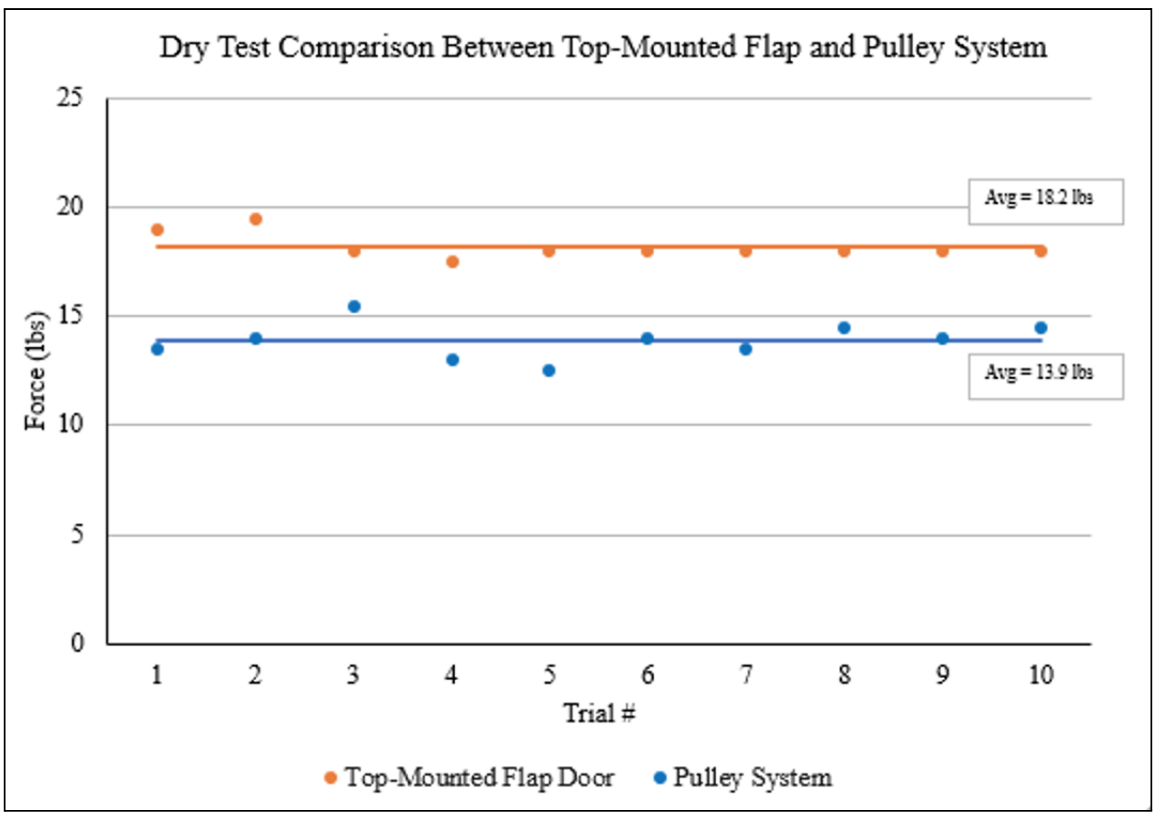

Figure 39: *Final Force Test to Open Door Flap*

Furthermore, the force test also revealed that the maximum pulling force required did not change with the angle of the top-mounted flap. The force applied to open the door was observed to be a constant pulling force independent of the angle of the flap. Since the pulley translates the pulling force of the cable into a moment about flap hinge, the flap smoothly opens to the open position without moving the bedload sampler.

2. Flume Test

Flume testing was conducted for two primary purposes; first, to quantify the amount of force required to open the designed door, and secondly to determine if the design produced unwanted horizontal displacement from hydraulic drag. For this experiment, a 2ft wide recirculating sediment flume at the ERC was used. The BL-84 sampler with the top-mounted flap, and side pulleys mounted were placed in the flume. The first test conducted was a force test, where the same procedure was used in the force gauge test described above. During the flume test, 6 different flow velocities of 1.63, 1.85, 2.15, 2.46, 3.48, and 3.70 ft/s were used to determine the amount of force required to open the door attachment. For each flow velocity, 5 data points were collected to determine the mean force required to open the flap door. Figure 40 below displays the amount of force required to completely open the top-mounted under the respective flow velocity:

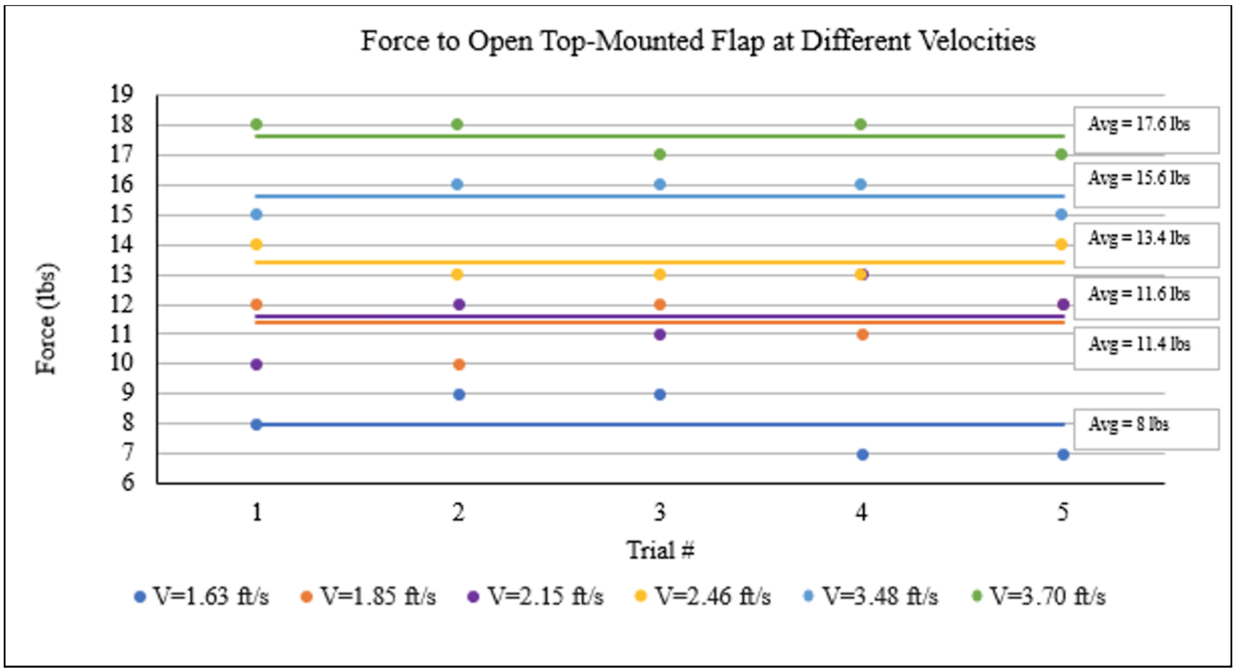

Figure 40: *Force to open Upriver's Door Flap Attachment*

From Figure 40, the average forces required to open the Upriver side pulley flap attachments were 8 lbs, 11.4 lbs, 11.9 lbs, 13.4 lbs, 15.6 lbs, and 17.6 lbs for each flow velocity, respectively. The flume testing yielded results that show that the amount of force required to open the flap increases as the flow velocity increases. However, with a flow of 3.70 ft/sec acting upon the surface area of the top-mounted flap, the force required to open the flap was lower than the force required to open the original top-mounted flap without flow.

3. *Movement of BL-84*

The second experiment performed in the flume was a displacement test to track BL-84 movement under flow conditions. One challenge that was encountered was decreased visibility during operation, due to the recycled sediment creating turbid conditions. In order to trace the sampler movement during the drift testing, two large metal rods were attached to the nozzle which would stick out of the water. The metal rods above the water surface served as the tracking point for the BL-84 sampler during the test. Figure 41 below shows the setup of a DSLR camera mounted on a tripod, which was used to collect footage of the tests. The video was then imported into Tracker - a tool for physics video analysis - and the movement of the metal rods was compiled. Video was recorded in MP4 format and the desired frames from each test were selected. As seen in Figure 42, the video scale and initial tracking point was then set. A total of 12 data points were collected per test by advancing the video in increments of ten frames. Specific points on the rods were tracked during this time while Tracker tabulated the data. The finished data was then exported to excel to compare indicator rod movement versus velocity.

Figure 41 : *DSLR camera setup on flume*

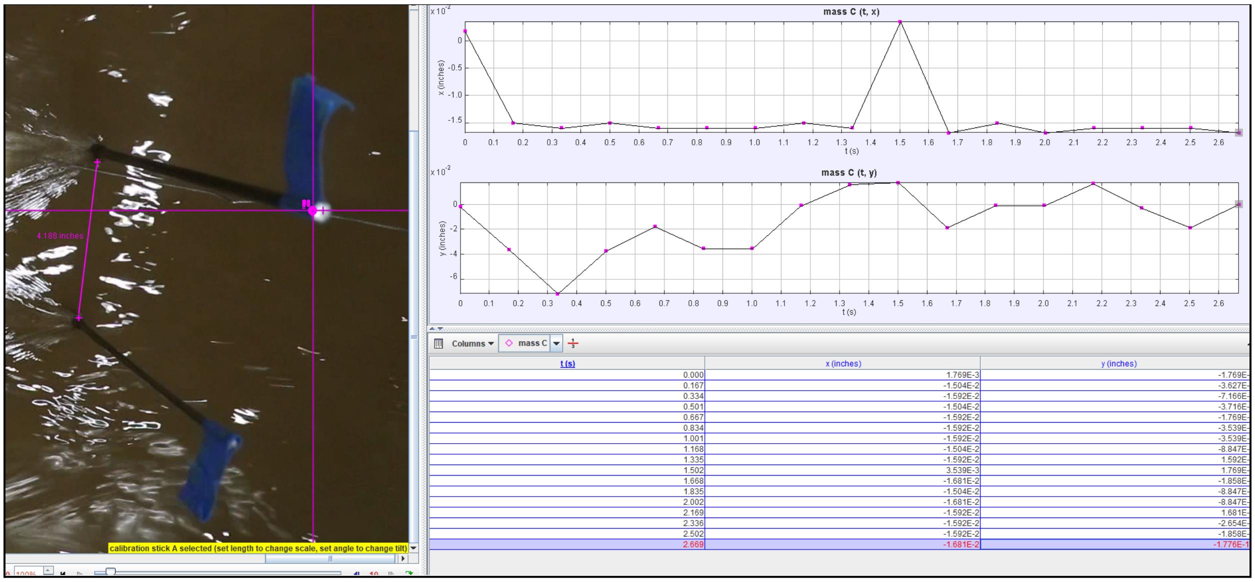

Figure 42 : *Tracker Data*

From Figure 43 below, the 2.15 ft/s flow velocity test had the greatest total displacement with 0.38 inches and the 1.63 ft/s flow velocity had the smallest total displacement with 0.15 inches. Speeds higher than 2.15 ft/s exhibited progressively decreasing total displacements, with the 3.70 ft/s test having only 0.24 inches. A correlation between flow rate and BL-84 drift is unlikely, based on the recently noted information in conjunction with the indiscriminate paths. Rather, vibrations from the water are likely responsible for variations in indicator rod movement. At speeds higher than 2.15 ft/s, the water force is believed to have provided the rod's stabilization; which explains the greatest total displacement at 2.15 ft/s. Regardless of the cause of the indicator rod movement, the displacement which occurred is insignificant at a maximum 0.072 inches. These findings suggest that the addition of the pulley attachments do not affect the drift of the BL-84 underwater. This finding reveals that the pulley attachment achieved the design objective of limiting the BL-84 sampler to a horizontal displacement of 1 inch.

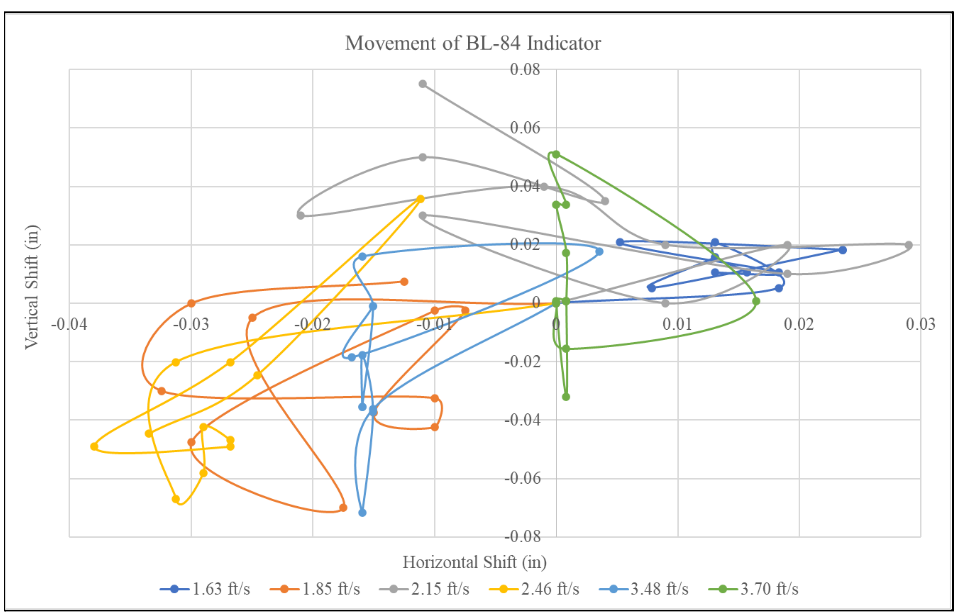

Figure 43: *Movement of Bl-84 Indicator*

DESIGN EVALUATION

After laboratory and observational tests were performed, the design objectives and constraints developed were able to be fully analyzed. For the pulley system developed for the Tetra Tech and CSU's top-mounted flap attachment, the result of the design was a success. As described in Table 5 below, the pulley system attachment achieved all of the design objectives established before brainstorming began. The pulley system is a simple, effective solution to increasing the usability of the top-mounted flap on all bedload samplers.

Table 5. *Pulley Design Objectives Results*

Objective	Objective Direction	Target	Result
Pulley Attachment System			
Reduce excessive pulling force when opening flap	Minimize	20% reduction	24% reduction
Maintain minimal BL-84 horizontal movement during test	Maintain	1”	0.38”
Degree of flap fully open during test	maximize	210	210
Route door flap cable from door flap attachment to reel	Optimize	Pass	Pass
Functionality in specified conditions	Maximize	0°C water, gravel, and sand	Pass

For the designed reel system, the prototype has the potential to achieve all of the proposed design objectives. However, due to seasonal constraints, the dial was unable to be properly calibrated and tested. In order for the dial to be properly calibrated, hydraulic conditions similar to regular field tests need to be present. Due to the extremely low flow conditions in the Cache la Poudre river during the spring, the BL-84 sampler would not have been subjected to the same flow velocities and depths normally present when bedload samplers are used. High flow conditions are imperative for calibrating the dial properly because of the added hydraulic forces on the cable. Since the diameter of the cable wire is 1/16” ,the cable easily bends. Hydraulic forces present with high flow rates will have a major impact on removing bends from the cable. Until the BL-84 sampler is subjected to high flow conditions, the dial will not be able to be accurately calibrated.

While the dial still needs to be calibrated to determine the overall effectiveness of the reel, the prototype did meet two of the proposed design objectives. Once the reel was fully manufactured, the prototype was placed under the USGS E-reel successfully. Since the reel fit in the allotted space in the crane, and aligned perfectly with the E-reel, the mountability objective was completed. Furthermore, the addition of the locker mechanism to the 7-tooth pinion gear eliminated any effort required by the reel operator to hold the flap fully open during the duration of the bedload sample.

During the design phase of the reel, material and components were selected in a way that accounts for maintenance and durability during the life cycle of the reel. The reel was primarily made out of 6061 Aluminum, however, the 7-tooth pinion gear, crank pulley, and needle cover were 3D printed out of PLA plastic. These components were 3D printed due to their machining difficulty, time constraint, and cost. Since these parts are 3D printed, their durability is uncertain for their intended use. Further field tests would help determine how often the 3D printed components would need to be replaced to maintain maximum performance. For this reason, the maintenance and durability objectives need further testing. A list of all the reel design objectives is located below:

Table 6. *Reel Design Objectives Results*

Objective	Objective Direction	Target	Result
Reel System			
Minimize effort that operator uses during duration of test to hold open gate	Minimize	10 seconds	Locker mechanism. No effort required
Mount reel on a USGS Type E heavy duty crane	Optimize	Pass	Pass
Notify operator of debris caught in flap during cycle	Maximize	Pass	Calibration required
Maintenance	Optimize	2 years	Further testing required
Durability (waterproofing, corrosion, fatigue, mechanical wear)	Maximize	Current durability	Further testing required

Following the analysis of the design objectives, the design constraints were examined for the entire system. Out of the 9 constraints established, 8 of the design constraints were met, as shown in table 7 below. All of the functional constraints relating with the existing USGS E crane, and reel were satisfied after the proper testing was conducted. However, the cost constraint for the project was not met, and will be discussed in the cost analysis section below:

Table 7. *Design Constraints Results*

Constraint	Metric	Limit	Result
Flap must be opened fully during each test	Degrees	180	180
Attachments on the reel apparatus do not interfere with normal operability during sampling	Pass/Fail	Pass	Pass
Flap cable does not interfere with bedload sampler suspension cable during operation	Pass/Fail	Pass	Pass
Suspension cable max diameter	Inches	1/8”	1/16”
All hardware should be as streamlined as possible	Y/N	Y	Y
Waterproof	Y/N	Y	Y
Size	Y/N- must be able to fit on bedload sampler apparatus	Y	Y
Assembly- all pieces must be able to be readily attached and detached from a cable-deployed BL-84	Y/N	Y	Y
Cost	$	$8,000	$8,963

Cost Analysis

Before the manufacturing phase of the project, the FISP technical committee established an $8,000 budget to manufacture and test all of the required final design components. Taking this into account during the design phase, 3D printing was heavily utilized for the dial to cut down iteration costs. Entering into the manufacturing phase of the project, the only accumulated expenses were the 2 rolls of PLA 3D printing filament, which equated to $60. Due to the team's limited manufacturing experience, the reel, truss, and pulley system were decided to be manufactured at the ERC machine shop. This decision was made based on ERC machine shop experience, and prior connections with the Civil and Environmental Engineering department.

For this project, the machinists were contracted out at a rate of 55 $/hr. This hourly rate accounts for the machinist labor as well as the cost to use the machine shop. Once the manufacturing phase began, the ERC machinists started with an initial design review before manufacturing the truss, reel, and pulley designs. Following the design review, the machinists fabricated the reel, truss, and pulley attachment. Once the machinists started manufacturing the reel, bearings, gears,and shafts had to be purchased for the dial and reel. The bill of materials for the purchased parts can be found in Appendix B.

Once all the components were fully fabricated, the full cost of the project was determined. The cost of the project consisted primarily of the ERC machine shop labor costs and the components purchased for the reel. The ERC machinists worked a total of 154.5 hours on the project, which equated to a total cost of $8,498. The sum of all purchased materials for the project equaled a cost of $465, and is represented in the appendix. The grand total of this project was determined to be $8,963.

FUTURE RECOMMENDATIONS

After testing and a thorough analysis, Upriver Engineering recommends to the FISP technical committee these recommendations to further the development of a system that effectively removes bed scooping in bedload samplers:

1. Properly calibrate the dial under hydraulic conditions normal to testing. If difficulties are encountered calibrating the dial, the thickness of the flap cable should be increased to remove unwanted slack in the system.
2. Manufacture reel double belt pulley out of aluminum. For this project, the double belt pulley was 3d printed out of generic PLA to cut down on machining costs, and to quickly make the pulley for testing.
3. Fabricate the 7 tooth pinion gear out aluminum or nylon. Due to manufacturing complexity, the 7 tooth pinion gear could not be manufactured. This was due to the gear not reaching the minimum number of gear teeth for a 14.5 degree pressure angle spur gear. Due to this constraint the gear either needs to be 3D printed out of aluminum or nylon 3D printed to meet durability requirements.
4. To make the secondary reel smoothly function with the USGS E-reel, the pulley mechanism needs to be advanced. While the current design properly functions, to make the transition from independent reel use to synchronized reel use, the pulley concept needs to be further developed.

CONCLUSION

During the 2021-2022 year, Upriver Engineering worked together to come up with and create a new and improved design for opening Tetra Tech's BL-84 flap door, that mitigates scooping, as part of a project funded by FISP. Following an initial research phase, which involved identifying some of the main objectives to hit and constraints to take into account with this project, the team set right to work on determining a set of viable solution alternatives. These different alternatives were compared by means of a pugh matrix, with truss gear lock and push pull secondary crank designs coming out on top for the flap and reel systems respectively. This is because, as mentioned previously, the team realized the project could be split into two separate systems working hand in hand to accomplish the overall goal, and thus split off into two groups to tackle these different systems/parts in parallel. Over the next few weeks, Upriver Engineering accomplished a number of different tasks associated with bringing the chosen designs to life, including a lot of designing on Solid Works, 3D printing, and testing, which was all accompanied with several visits to the ERC.

Further testing proved the initially proposed truss design to be faulty, and hence a new final design involving pulleys was designed, which ultimately resulted in a 24% reduction in the pulling force required. In addition to this, and as mentioned previously, the final design was put together with the potential of meeting all the target objectives listed at the very start. Finally, a cost estimate was put together for this project, and came out to a grand total of nearly nine thousand dollars, primarily consisting of materials purchased and machinist work.

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APPENDIX A

David Pizzi Customer Requirements:

<table>
<tr><td colspan="2">Customer Requirements</td></tr>
<tr><td>Design Organization: David Pizzi on behalf of FISP TC</td><td>Date: 1/3/22</td></tr>
<tr><td colspan="2">Product: Bedload Sampler Operable Mechanism</td></tr>
<tr><td colspan="2">
1. Who are the primary users of the product? Engineers, scientists, and technicians using pressure-difference samplers to measure bedload transport in rivers.

2. What skills or education will the primary users have? There will be a range of educational experience from Ph.D.s to technicians that may have limited if any post-secondary education. Nearly all users are expected to be mechanically inclined and creative in solving problems with limited resources (such as when a sampler breaks hours from an office and only materials and equipment in the back of the truck are available for a fix).

3. Describe any primary user physical conditions that affect the design of the product. The operable mechanism will need to be set up quickly in the field, durable enough to be transported in a truck (perhaps in a Pelican-type case for protection), and resistant to the muddy, wet conditions in which it will typically be operated.

4. Who will purchase the product? Federal agencies that implement sediment monitoring programs, and contractors that work for these federal agencies.

5. Who else is a stakeholder in the design of the product? The FISP TC because they work to unify research and development activities of Federal agencies involved in fluvial-sediment monitoring and investigations. The continuing mission of the FISP is to provide leadership in the development of standardized, calibrated equipment and methods to allow consistent and accurate quantification of sediment characteristics and transport in surface waters.

6. Describe any cultural practices or customs related to the product. None known.

7. How much is the purchaser willing to pay for the product? I speculate up to about $750.

8. How much is the user willing to pay to operate the product? I do not envision an operating cost.
</td></tr>
</table>

9. How much is the user willing to pay to maintain the product? *I speculate up to a few hundred dollars on a periodic (every other year?) basis.*

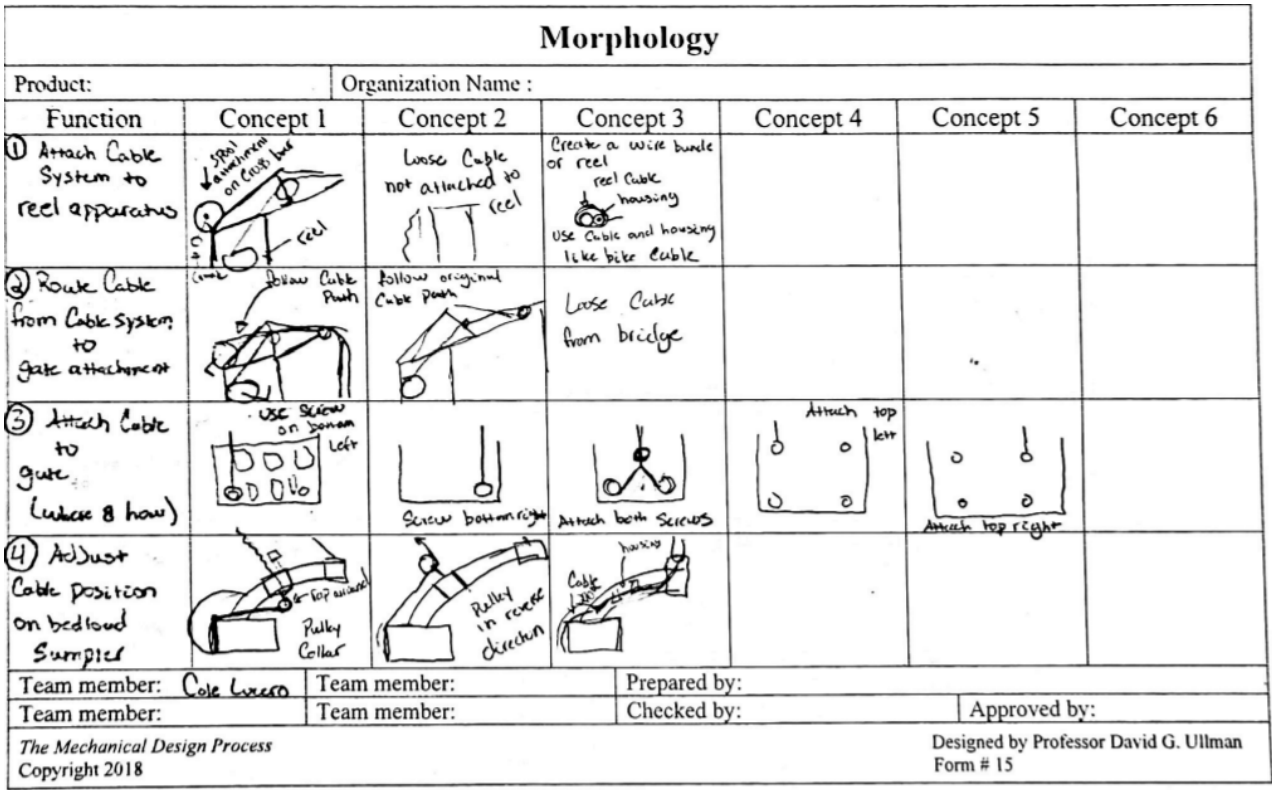
How:

1. For what specific purposes will the product be used? *Accurately measuring bedload transport when scooping bias is a potential concern.*
2. What is the current process used? *Operators of the sampling equipment rely on experience and judgment to infer when scooping is likely to have biased a sample.*
3. How often will it be used? *I expect all the time in gravel bed streams/rivers, and perhaps all the time in sand bed rivers.*
4. How long will it be used each time? *A sample typically lasts under 2 minutes, but up to 40 samples may be required for a single site.*
5. Describe the quality expected by the user. *Reliably repeatable measurements of bedload transport.*
6. How far, how often and in what way will product be transported? *The equipment may travel by automobile or plane across the county, and for an agency such as the USGS, the equipment may be used multiple times per day for many days when flows are capable of mobilizing and transporting bedload.*

Where:

1. Describe the surroundings for normal use. *Near rivers and streams, sometimes in fair weather and sometimes in foul weather (but usually at least above freezing).*
2. Describe the noise, weather, temperature, or other environmental factors that may affect the design of the product. *See previous.*
3. Describe any size or weight limitations. *Lighter and easier to transport onto and off of boats is advantageous.*
4. Describe the aesthetics of the use surroundings. *No aesthetic concerns.*
5. Describe the energy available when the product is in use. *If power is needed, it will need to be provided by batteries accompanying the equipment.*

Morphology Charts:



Morphology

Product:	Organization Name :					
Function	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**
① Attach Cable System to reel apparatus	Spool attachment on cross bar; reel	Loose Cable not attached to reel	Create a wire bundle or reel; reel Cable housing; Use Cable and housing like bike cable			
② Route Cable from Cable System to gate attachment	Follow Cable Path	Follow original Cable Path	Loose Cable from bridge			
③ Attach Cable to gate (where & how)	Use Screw on bottom left	Screw bottom right	Attach both Screws	Attach top left	Attach top right	
④ Adjust Cable position on bedload Sampler	top around; Pulley Collar	Pulley in reverse direction	housing; Cable			

Team member: Cole Lucero	Team member:	Prepared by:	
Team member:	Team member:	Checked by:	Approved by:

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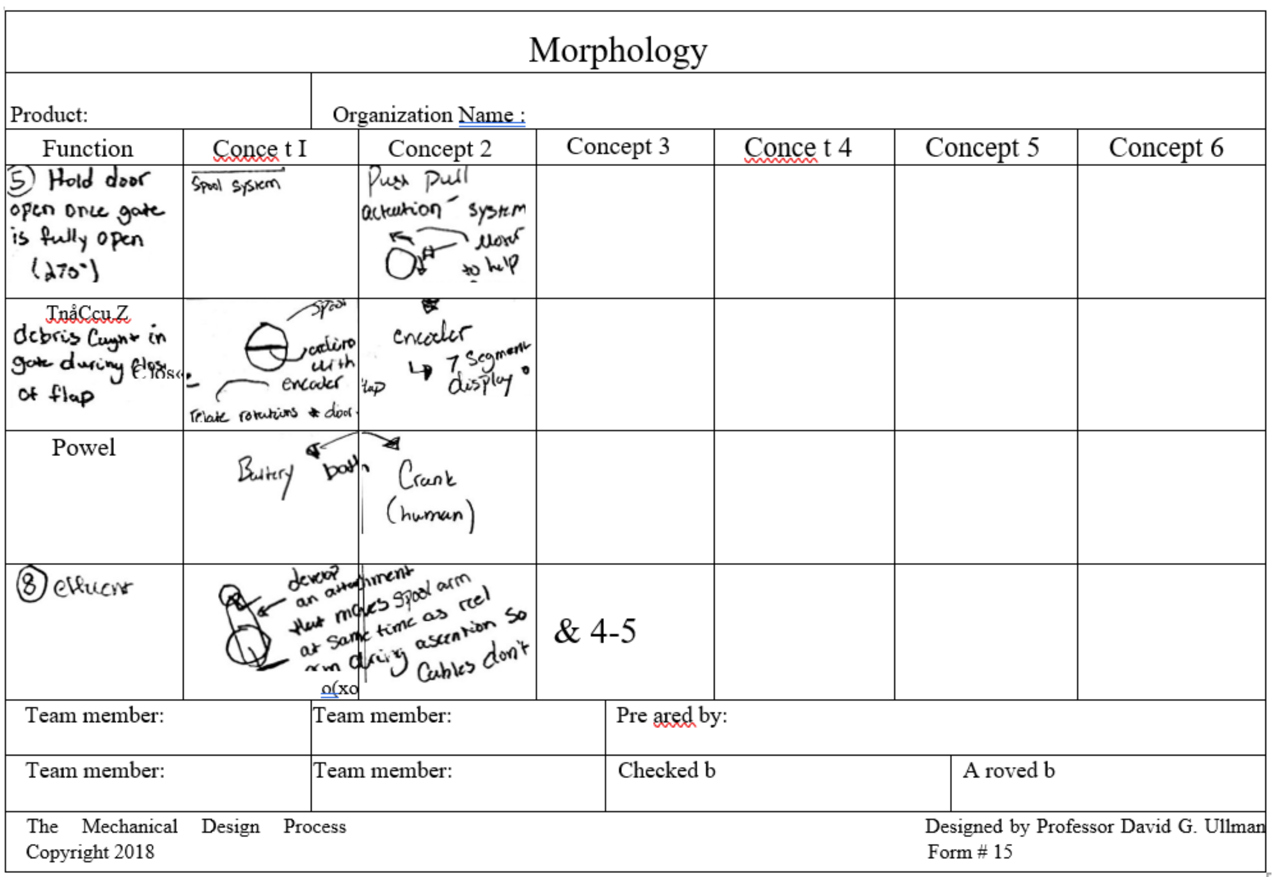
Form # 15



Morphology

Product:	Organization Name :					
Function	Conce t I	Concept 2	Concept 3	Conce t 4	Concept 5	Concept 6
⑤ Hold door open once gate is fully open (270°)	Spool system	Push pull actuation system; motor to help				
TnåCcu Z debris Caught in gate during close of flap	Spool; encoder with encoder; relate rotations ↔ door flap	encoder ↳ 7 segment display				
Powel	Battery; both	Crank (human)				
⑧ efficient	device? an attachment that moves spool arm at same time as reel arm during ascension so cables don't; o(xo		& 4-5			

Team member:	Team member:	Pre ared by:	
Team member:	Team member:	Checked b	A roved b

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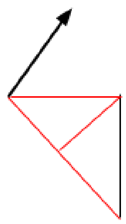
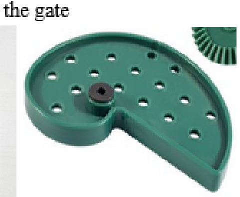
Form # 15

Morphology

Product: | Organization Name :

Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Attach cable system to reel apparatus	Parallel reel (with identical circumference / relative to cable width)	Use a larger single spool with a divider				
Route Cable from Cable System to gate attachment	Parallel pulley system to main cable	Offset pulley - would require a pulley to be mounted in front of the main pulley	An offset pulley could provide an advantageous angle of force application			
Attach cable to gate (where and how)	Build a truss on the gate and attach cable to center bar 		Cable is attached to a gear on a center mounted axle with dual nautilus shaped cams welded to the gate  		Weld to gate	Create an eyelet with the cable and bolt it down or weld a loop to the gate
Adjust Cable position on bedload sampler					Motors spinning the system on the left	

Team member: Michael Mar | Team member: | Prepared by:

Team member: | Team member: | Checked by: | Approved by:

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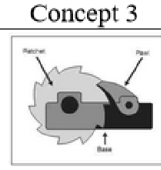
Morphology

Product: | Organization Name :

Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Hold door open once gate is fully open	Spool lock	Ratchet and Pawl system		Manual clamp		
Indicate debris caught in gate during closure of flap	Electronic rotation measurer of gate opening cable spool.	Visible indication on cable of fully closed and open. Height variation should be considered	<- This could be a manual process of marking it on the cable each time			
Power source	Manual crank	Battery	Manual cable pull			

Team member: Michael Mar | Team member: | Prepared by:

Team member: | Team member: | Checked by: | Approved by:

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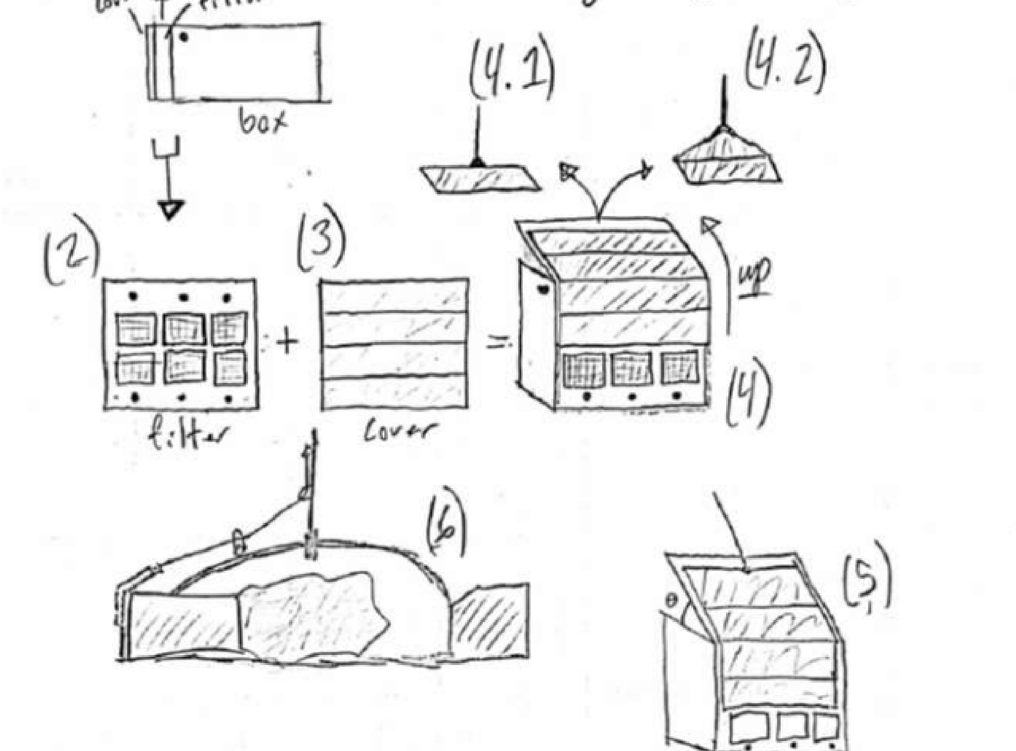
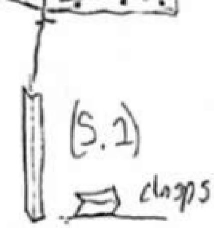
Form # 15

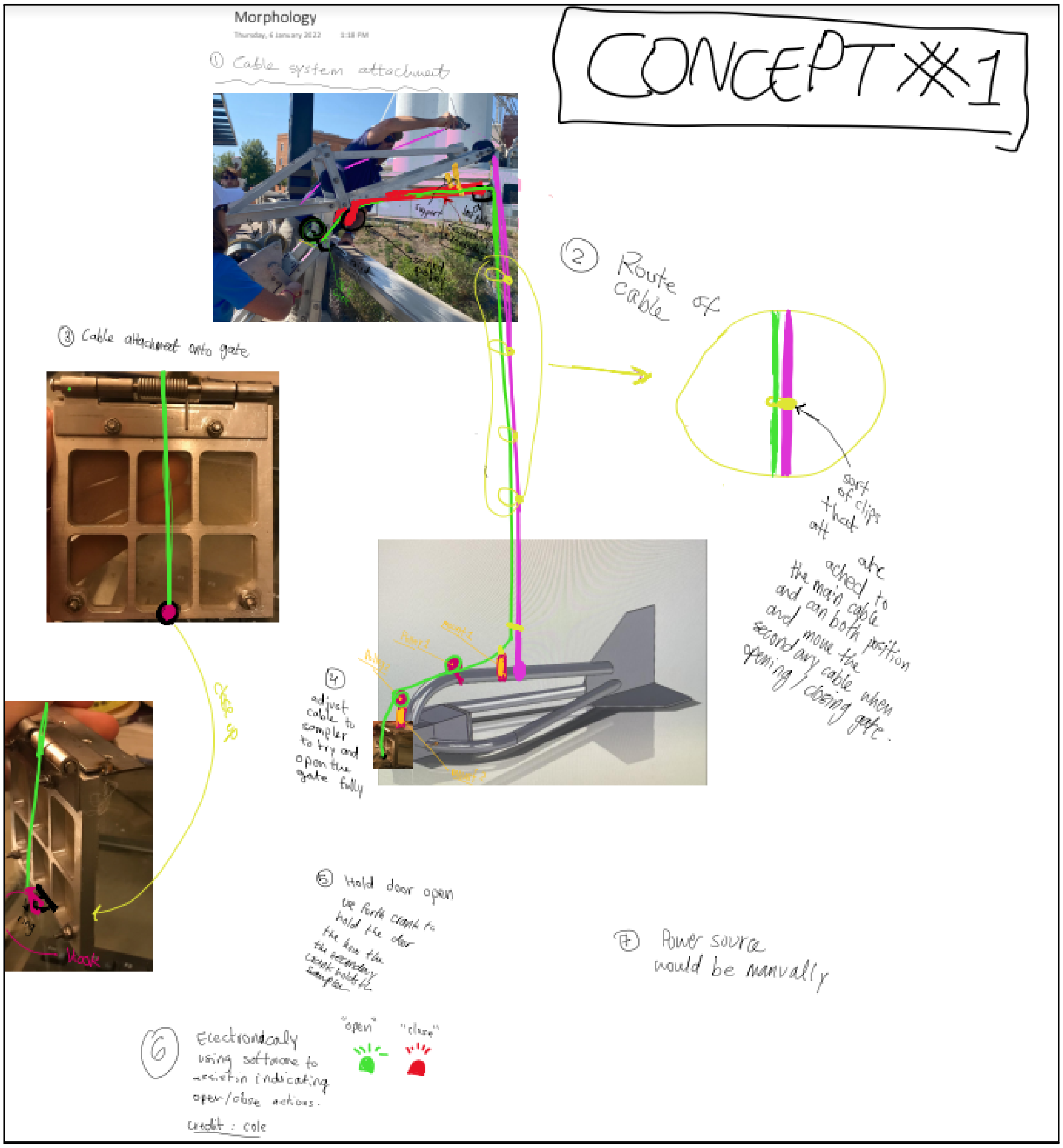
Jackson Oye | CIVE 403 01/17/22 | Design Alternative

Sliding Garage Pulley System





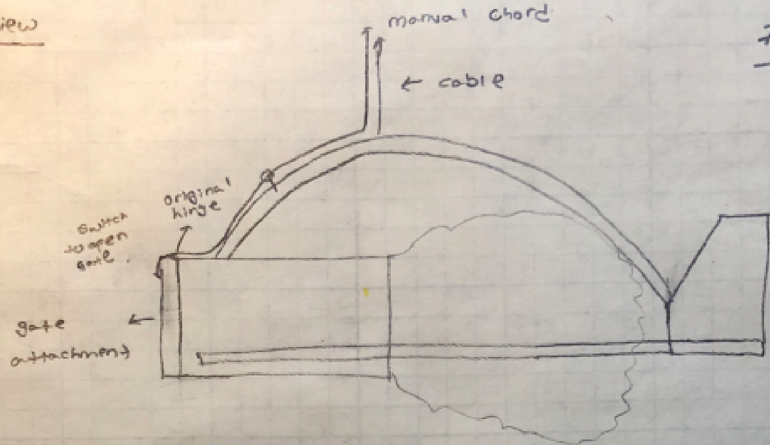
The sliding pulley system utilizes a release the door, a garage door type cover over the filter (1).
The filter will be an add-on but will not open as it did before (2).
The cover will act like a garage door and be pulled upward by the pulley attached (3).
The door will slide up the ramp to reveal the filter (4).
One option is to weld a thick wire to the middle of the garage to pull upward (4.1).
The second is to weld a bunch of wires or a triangular shape attach by wire to optimize and spread the force of the pull (4.2).
For less friction there will be a metal late above the gate welded at a specific angle to allow the door to open and close (5).
The garage door will be held down by a set of clasps throughout the box to facilitate movement and hold in place (5.1).
The final system will attach the wire through loops allowing for less friction when pulling the garage upward (6).


Morphology
CONCEPT #1
① Cable system attachment
② Route of cable
③ Cable attachment onto gate
④ adjust cable to sampler to try and open the gate fully
⑤ Hold door open
⑥ Electronically using software to ... indicating open/close actions.
⑦ Power source would be manually
"open"
"close"
credit : cole

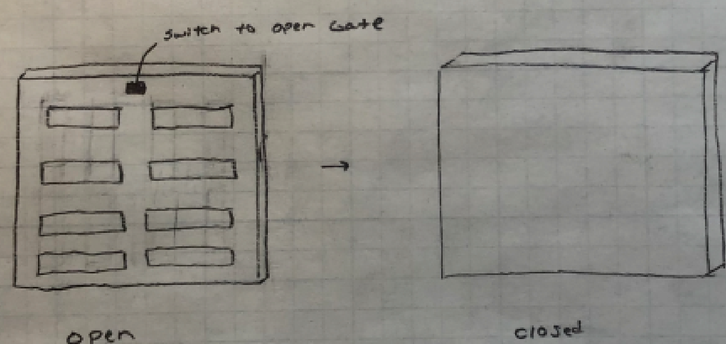
1/10/22 | Design Alternative | Alex Bauchat

#1

Side view



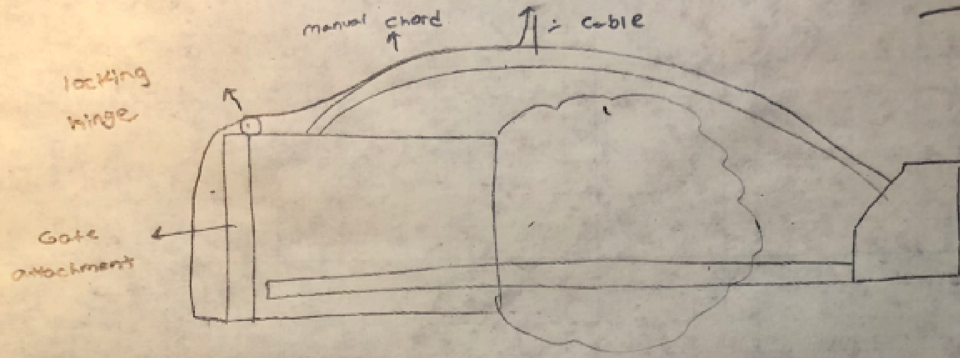
new gate attachment



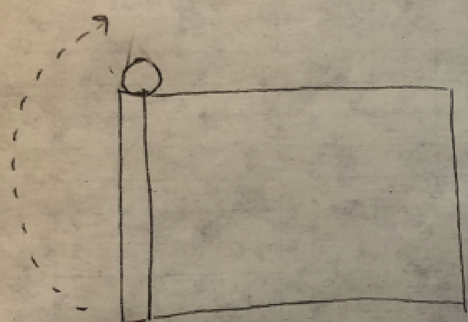
Essentially, this acts like a home vent system. It changes the gate to be fully closed going into the river and having it manually open via a chord when the user wants to start collecting data. It eliminates having to lift the entire flap under the hydraulic conditions and also improved the chord management.

Locking Hinge - Gate Attachment

#2



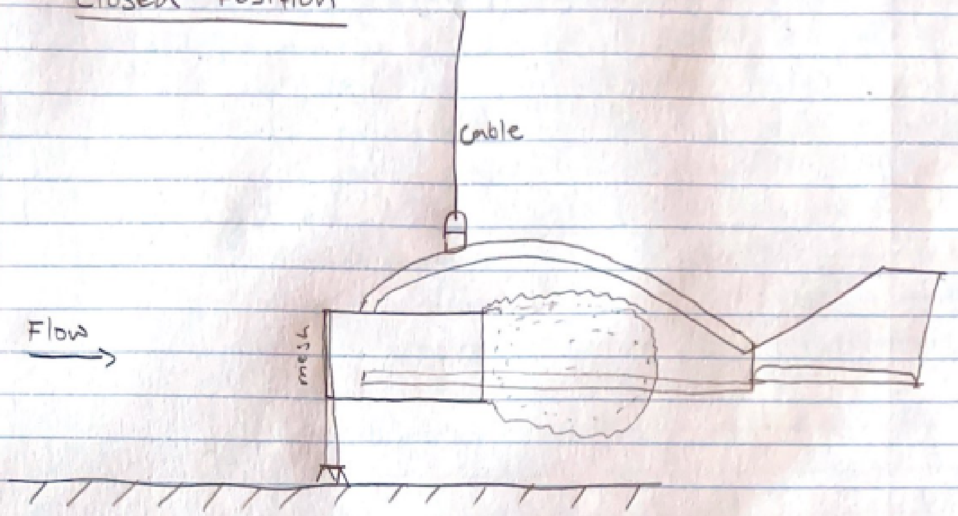
Locking hinge



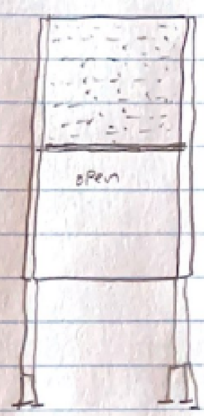
The locking hinge will work the same as an arm-rest in a car. The hinge will lock the higher it gets until it reachs the apex and will go all the way back to the bottom. It would have to either have a noticible clicking system or sensor to ensure the user doesnt keep dropping the gate attachment. This deign also has a improved chord system.

Design Draft Madison Maroney 01/10/2022

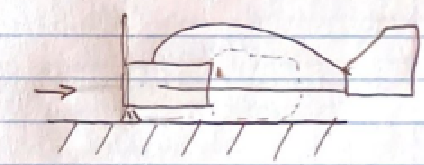
Closed position



Front view of sliding door



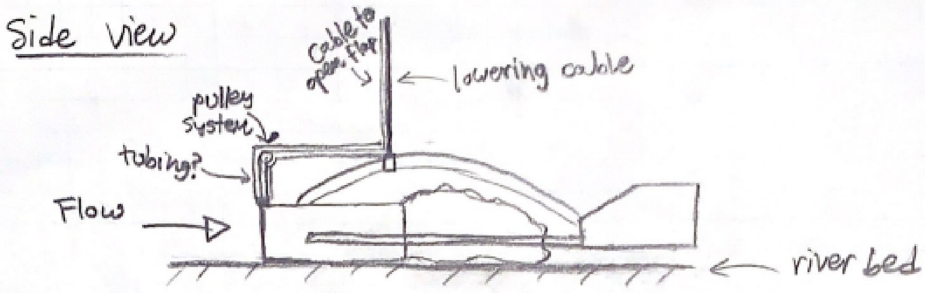
open diagram



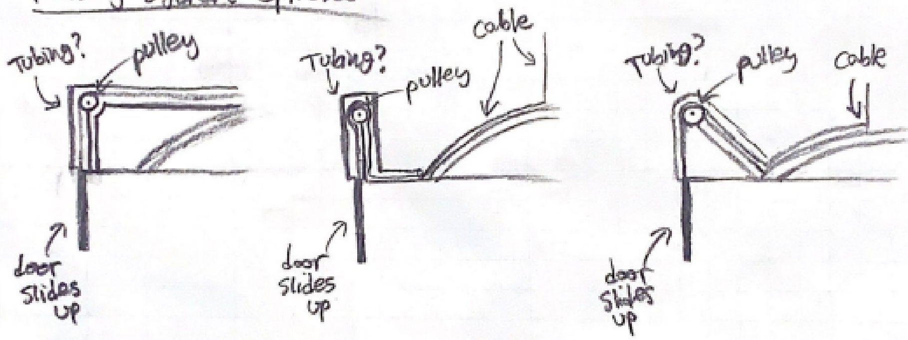
Slide door is initially in the closed mess position. As sampler is lowered to the river bed it makes contact and the weight of the sampler pushes the door up guided by steel track (tube) to the open position. when raised the door slides back down to closed position.

Design Concept | Mathieu Viola | 01/14/22 | 1

Side view



Pulley System Options

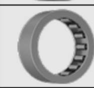
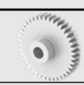
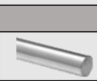


This design concept uses a separate cable and pulley system to raise the door, allowing it to slide upward. The pulley is situated directly above the door to facilitate the sliding, and is connected to the body of the bedload sampler device in all three scenarios/alternatives shown. This cable system runs up the length of the primary cable used to lower the device (alongside it), and can be operated manually, or by means of a battery/motor. Tubing or some sort of protective equipment is added around the pulley system to protect it from water flow and debris.

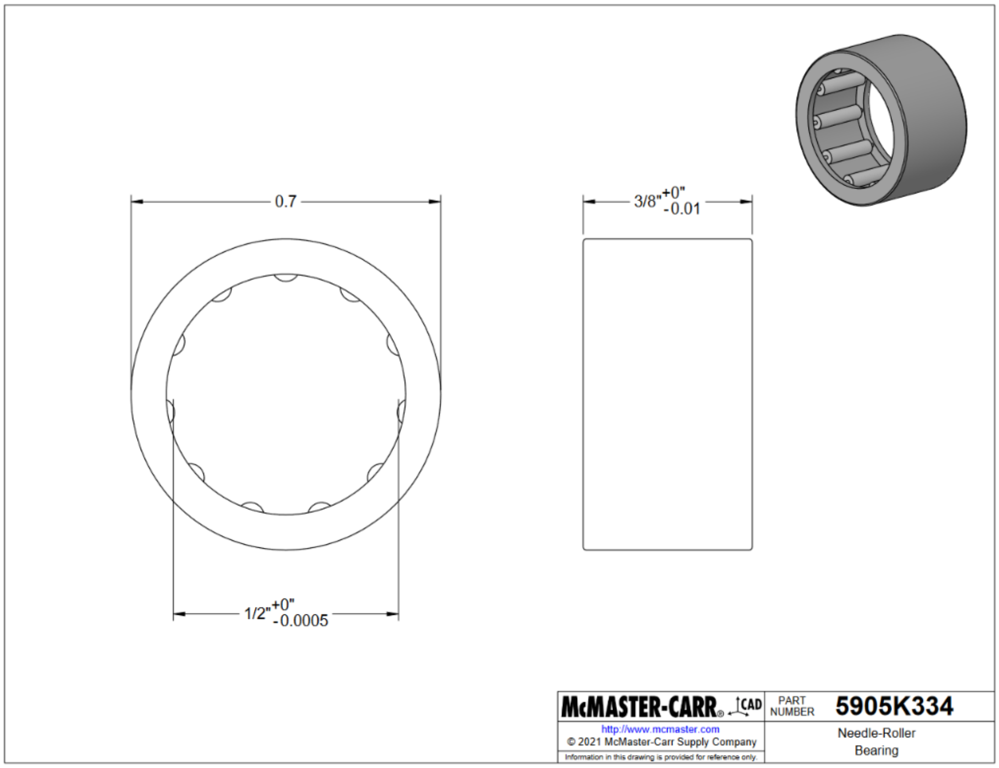
APPENDIX B

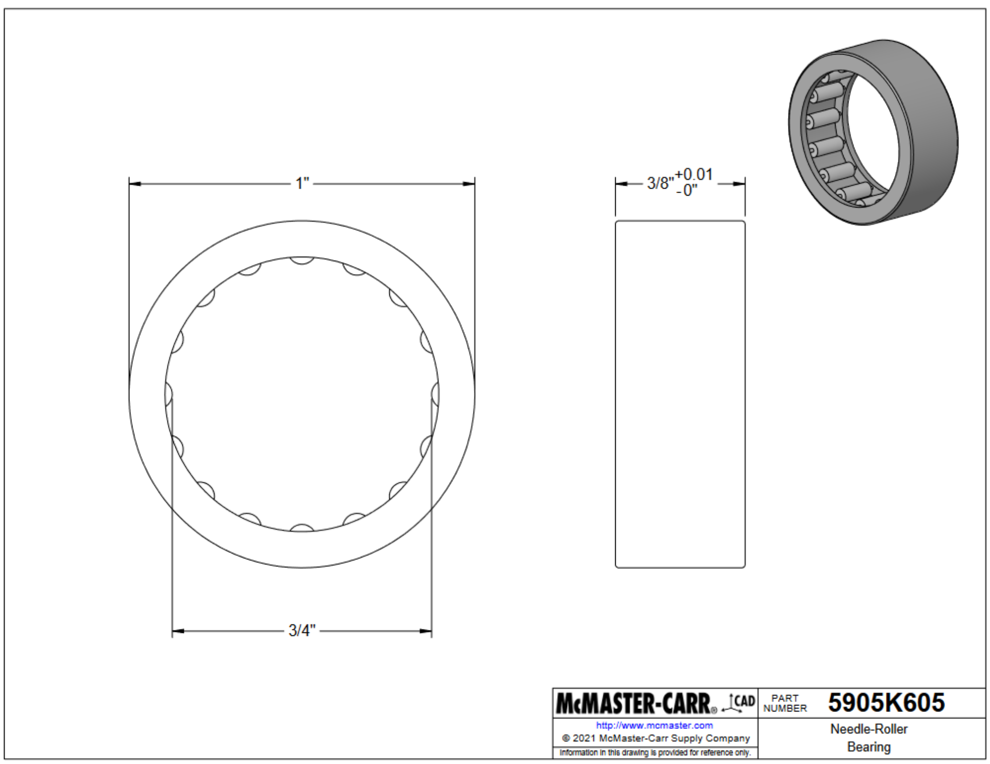
Bill of Materials:

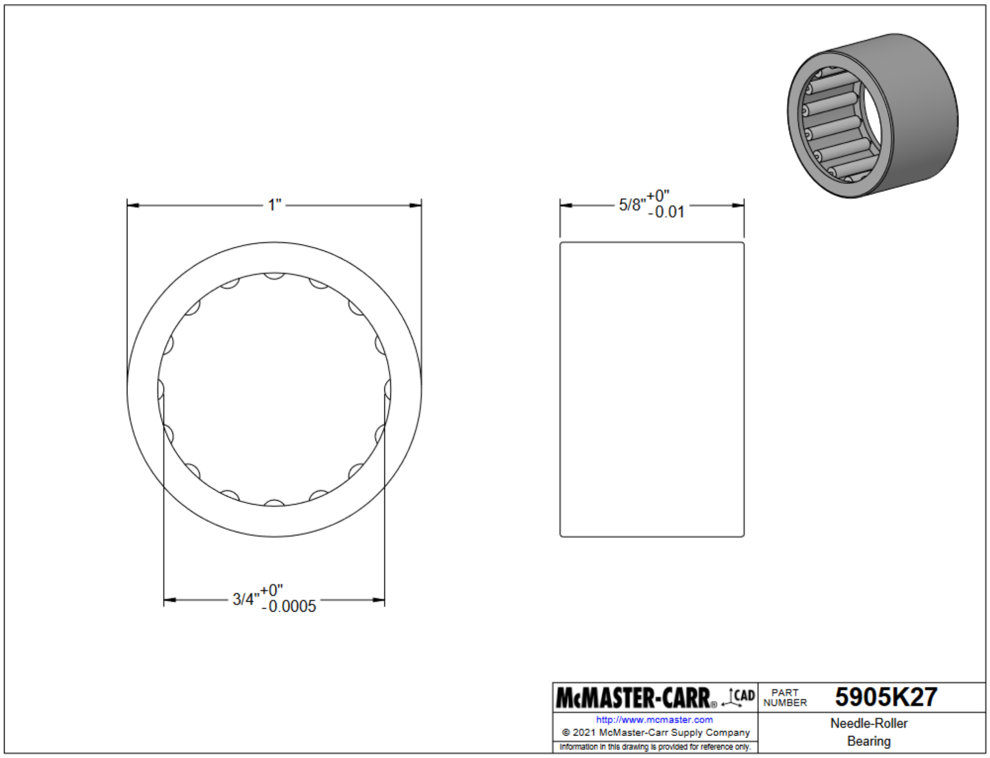
Part Count	25
Total Costs	$ 464.82

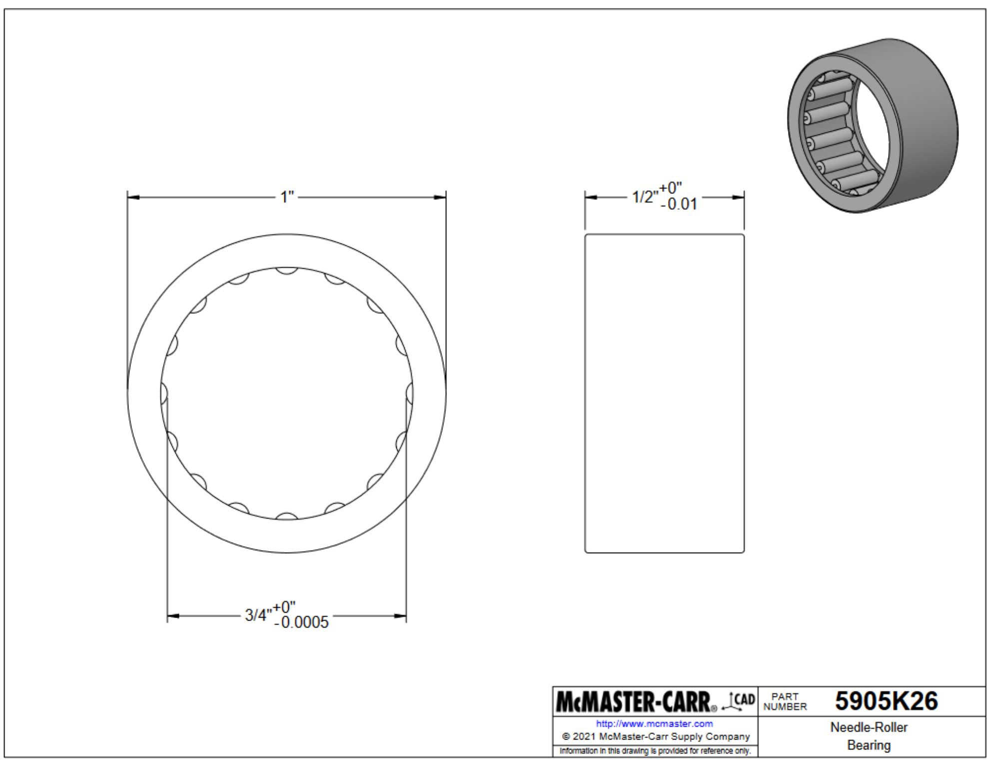
Number	Part Number	Part Name	Discription	Quantity	Unit Costs	Image	Amount	Batch Order	Shipping	Sales Tax
Bearings										
1	5905K334	Needle-Roller Bearing	1/2"shaft dia, 11/16" housing id, 3/8" wide	2	$ 6.69		$ 13.38	1	$ 9.94	$ 9.55
2	5905K605	Needle-Roller Bearing	3/4"shaft dia, 3/8" wide	2	$ 7.96		$ 15.92			
3	5905K27	Needle-Roller Bearing	3/4"shaft dia, 1" housing id, 5/8" wide	2	$ 6.34		$ 12.68			
4	5905K26	Needle-Roller Bearing-1/2"shaft dia, 11/16" housing id, 3/8" wide	3/4"shaft dia, 1" housing id, 1/2" wide	2	$ 6.64		$ 13.28			
5	57155K371	stainless steel ball bearing, shielded		6	$ 7.25		$ 43.50			
Gears										
6	2515N11	Metal Bevel Gear	0.190" face width	1	$64.76		$ 64.76	2	$ 10.50	$ 25.21
7	25115N12	Metal Vebel Pinion	0.190" face width	1	$64.76		$ 64.76			
8	57655K14	18 tooth Plastic Gear	14-1/2 pressure angle,round bore, 48 pitch	1	$ 9.58		$ 9.58	3	$ 9.32	$ 3.04
9	57655K19	36 Tooth Platic Gear	14-1/2 pressure angle, round bore, 48 pitch	1	$10.55		$ 10.55			
10	2662N5	40 Tooth Plastic Gear	20 pressure angle, round bore, 20 pitch	1	$ 7.80		$ 7.80	4	$ 9.32	$ 1.68
11	2662N1	12 Tooth Plastic Gear	21 pressure angle, round bore, 20 pitch	1	$ 3.31		$ 3.31			
Shafts										
12	1346K511	Rotary shaft 3/8" dia.	1556 carbon steel, 18" long	1	$11.55		$ 11.55	5	$ 9.32	$ 0.87
13	98957A159	1/2"-20 threaded rod	Grade B7 medium strength rod, 1 1/2' long	1	$12.66		$ 12.66	6	$ 9.45	0.96
Misalanious										
14	94751A778	Side-Mount Retaining Ring	Wide-grip	2	$ 3.16		$ 6.32	7	$ 9.45	$ 0.48
15		Lexan Ploycarbonate Sheet	.1" thick	1	$ 5.48		$ 5.48			
16		3D Printing Fillament		2	$30.10		$ 60.20			

Bearing Drawings:






1"
5/8" +0" -0.01
3/4" +0" -0.0005
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
5905K27
Needle-Roller Bearing


1"
1/2" +0" -0.01
3/4" +0" -0.0005
McMASTER-CARR
CAD
http://www.mcmaster.com
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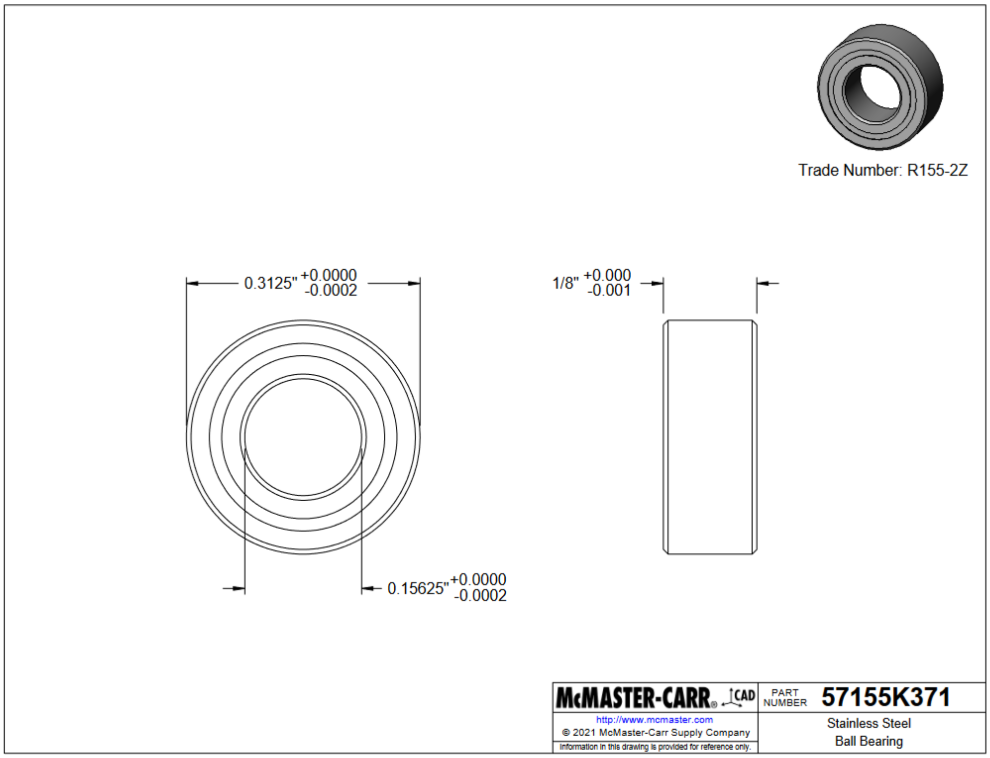
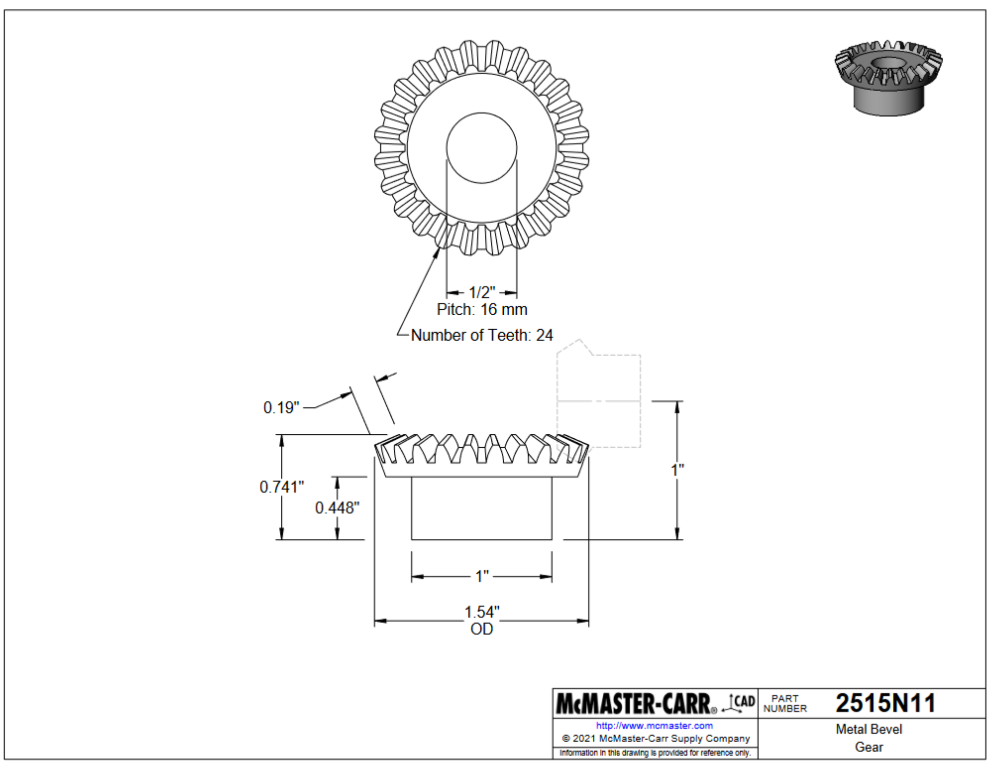
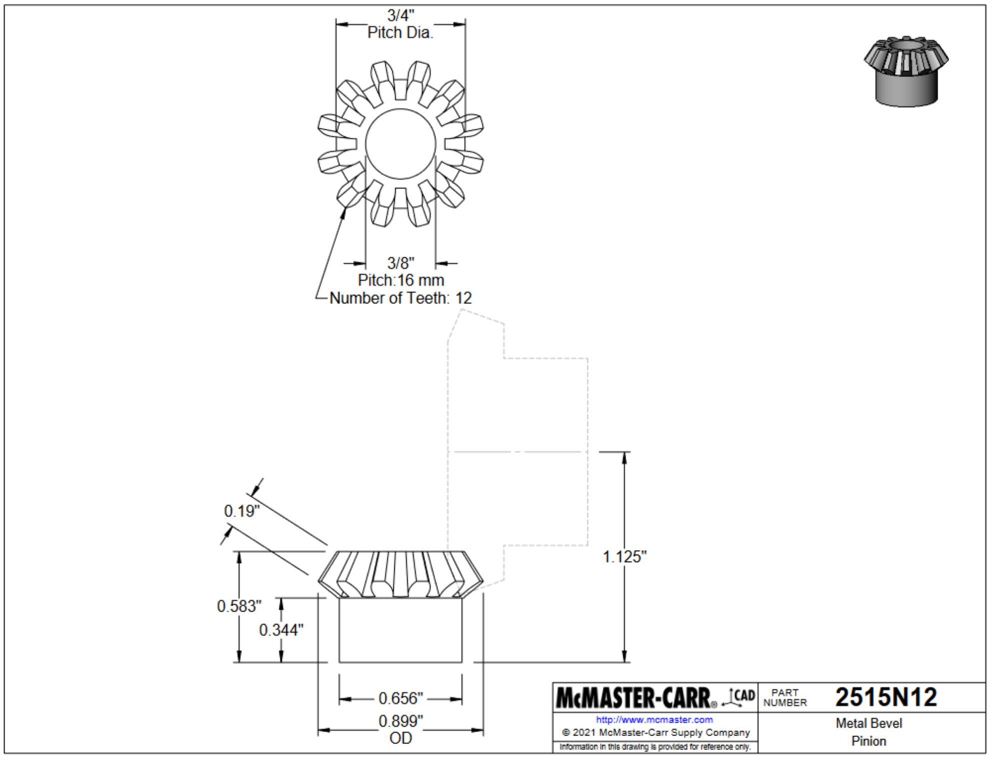
Information in this drawing is provided for reference only.
PART NUMBER
5905K26
Needle-Roller Bearing



Gear Drawings:




3/4"
Pitch Dia.
3/8"
Pitch:16 mm
Number of Teeth: 12
0.19"
0.583"
0.344"
1.125"
0.656"
0.899"
OD
McMASTER-CARR
PART NUMBER
2515N12
http://www.mcmaster.com
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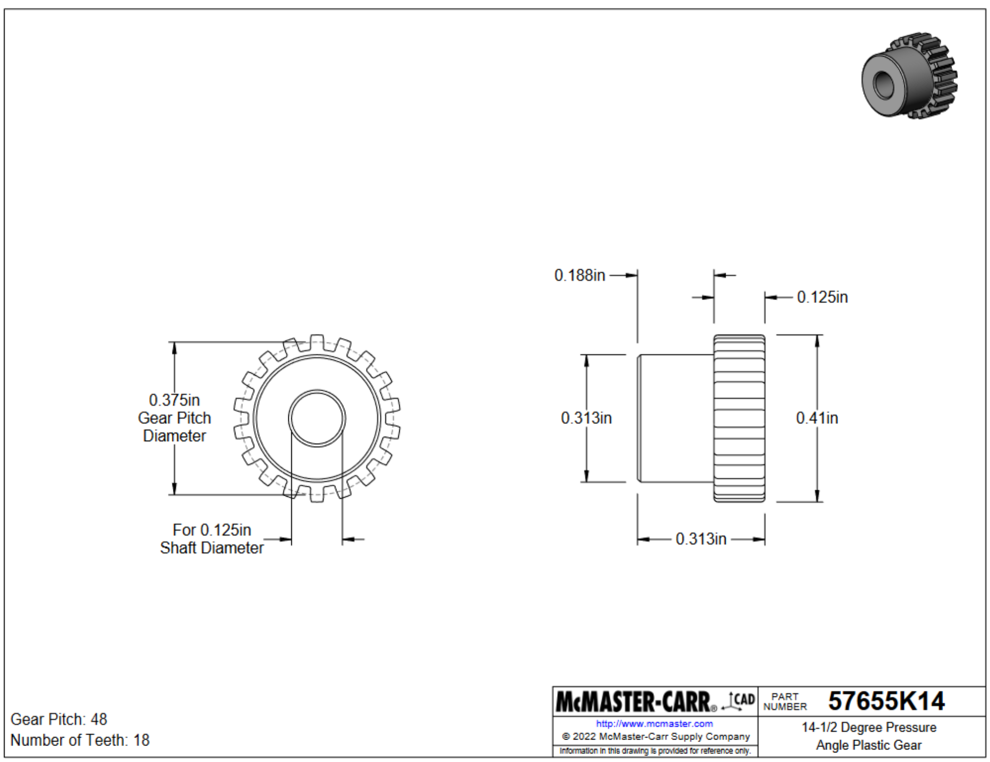
Information in this drawing is provided for reference only.
Metal Bevel
Pinion


0.375in
Gear Pitch
Diameter
For 0.125in
Shaft Diameter
0.188in
0.125in
0.313in
0.41in
0.313in
Gear Pitch: 48
Number of Teeth: 18
McMASTER-CARR
PART NUMBER
57655K14
http://www.mcmaster.com
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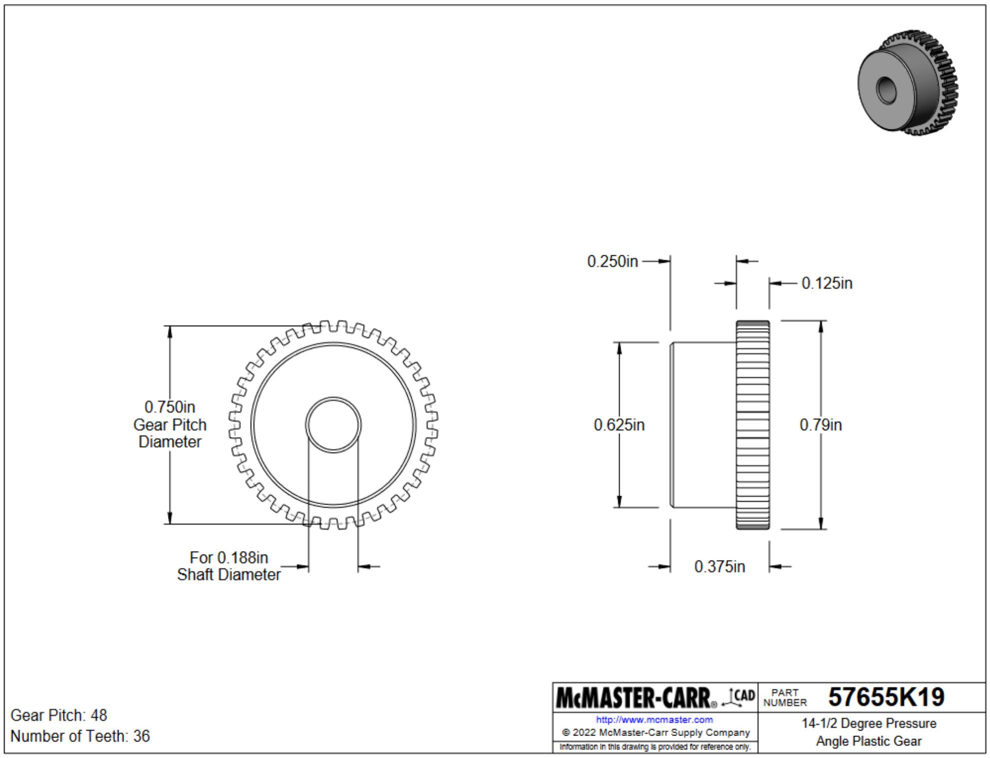
Information in this drawing is provided for reference only.
14-1/2 Degree Pressure
Angle Plastic Gear


0.250in
0.125in
0.750in
Gear Pitch
Diameter
0.625in
0.79in
For 0.188in
Shaft Diameter
0.375in
Gear Pitch: 48
Number of Teeth: 36
McMASTER-CARR
CAD
PART NUMBER
57655K19
http://www.mcmaster.com
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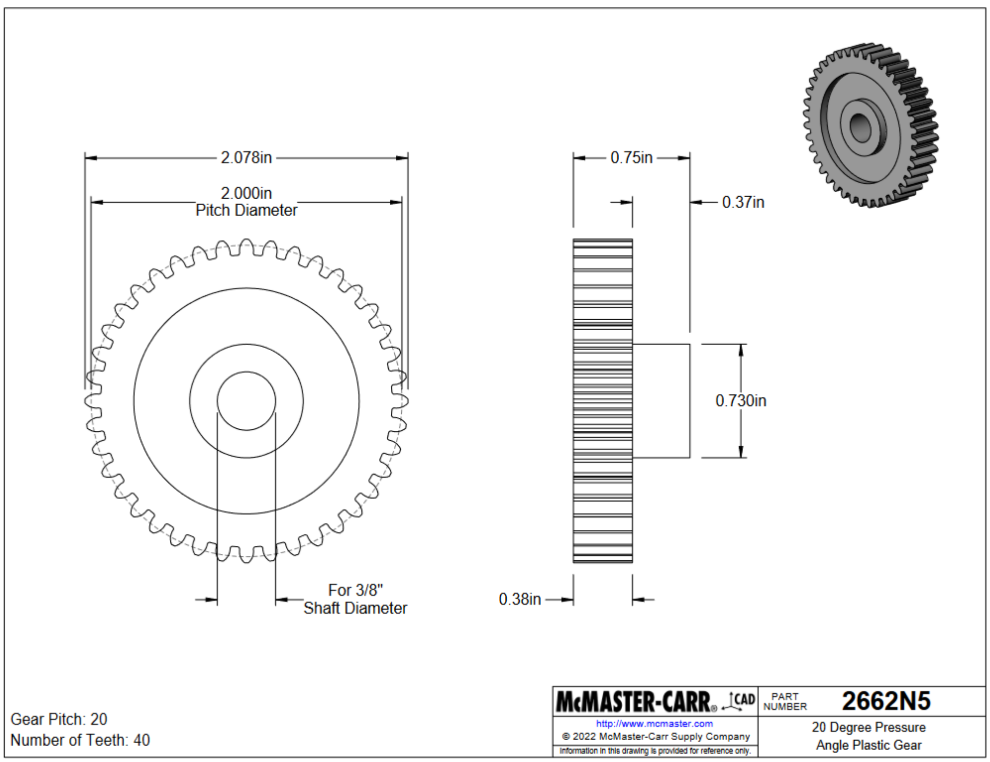
Information in this drawing is provided for reference only.
14-1/2 Degree Pressure
Angle Plastic Gear


2.078in
2.000in
Pitch Diameter
0.75in
0.37in
0.730in
For 3/8"
Shaft Diameter
0.38in
Gear Pitch: 20
Number of Teeth: 40
McMASTER-CARR
CAD
PART NUMBER
2662N5
http://www.mcmaster.com
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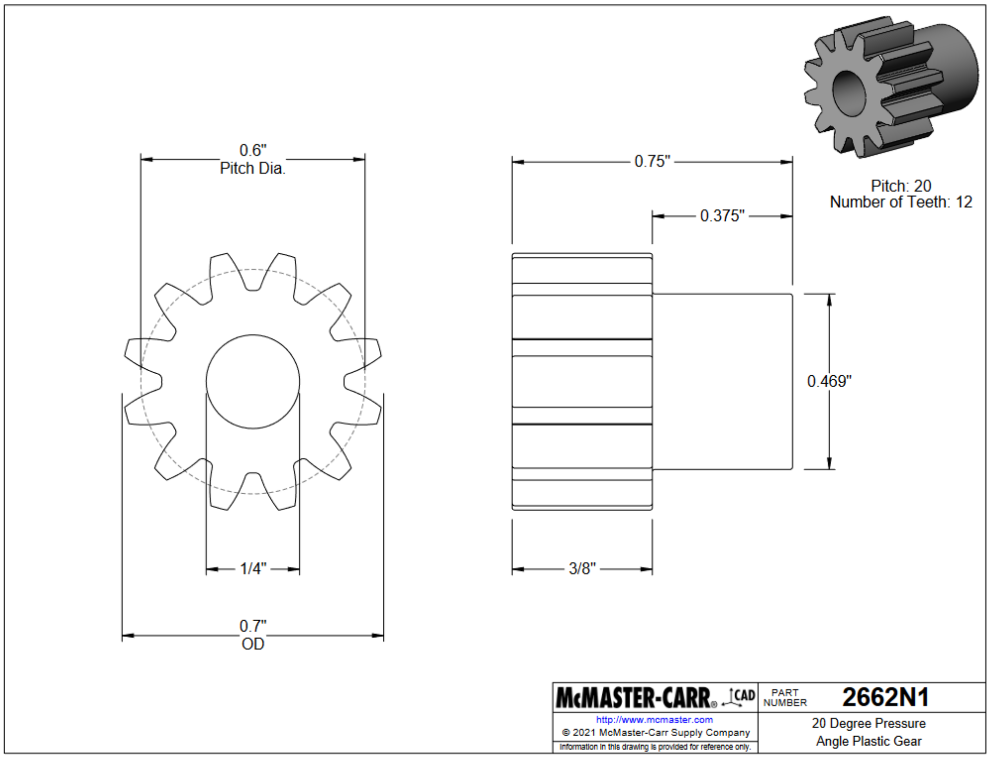
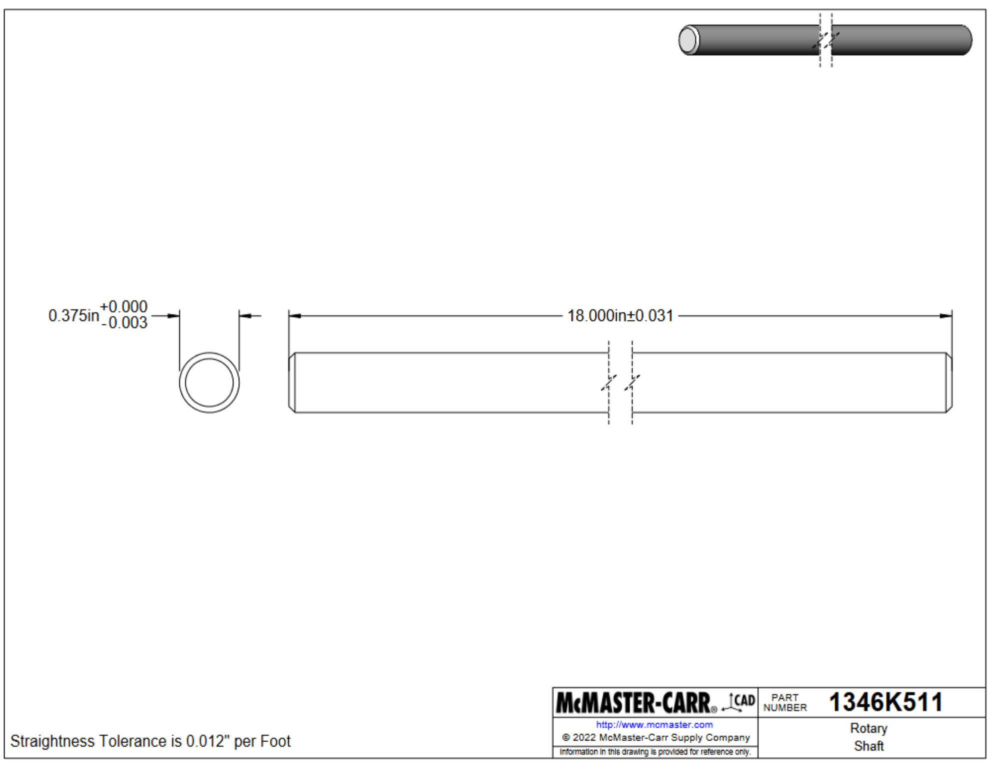
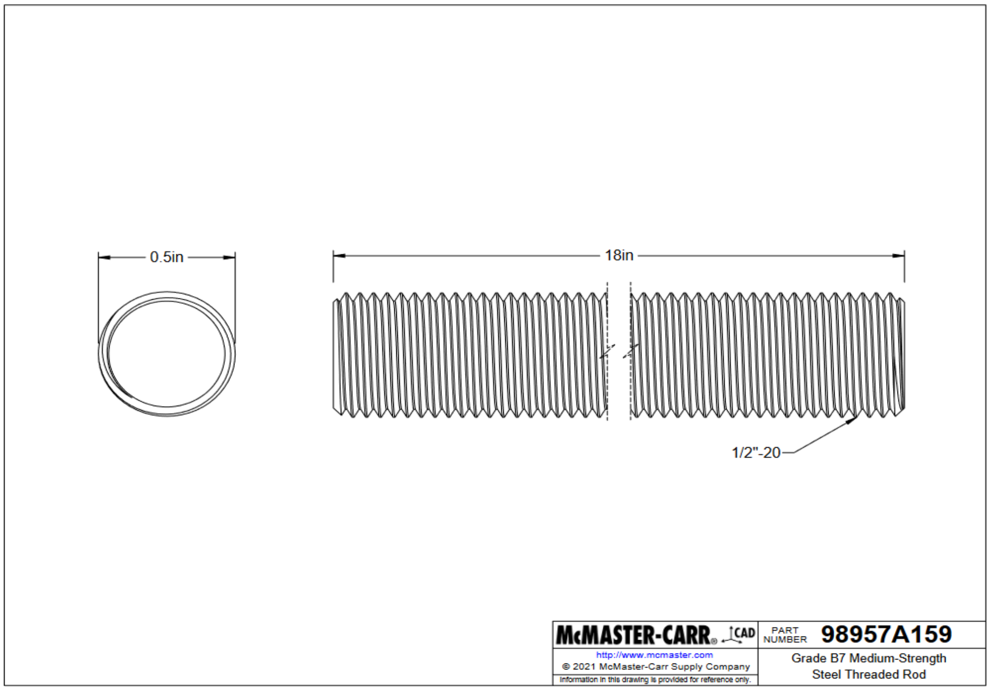
Information in this drawing is provided for reference only.
20 Degree Pressure
Angle Plastic Gear



Shaft Drawings:





0.5in
18in
1/2"-20
McMASTER-CARR
CAD
PART NUMBER
98957A159
http://www.mcmaster.com
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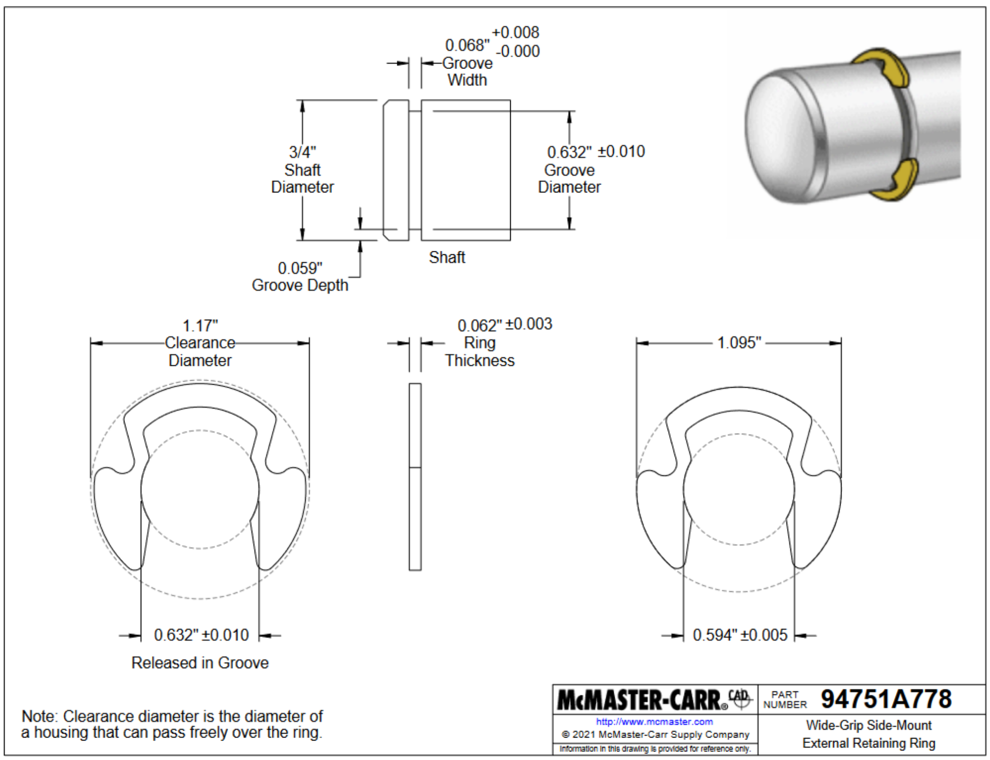
Information in this drawing is provided for reference only.
Grade B7 Medium-Strength Steel Threaded Rod



0.068" +0.008 -0.000
Groove Width
3/4" Shaft Diameter
0.632" ±0.010 Groove Diameter
Shaft
0.059" Groove Depth
1.17" Clearance Diameter
0.062" ±0.003 Ring Thickness
1.095"
0.632" ±0.010
Released in Groove
0.594" ±0.005
Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.
McMASTER-CARR
CAD
PART NUMBER
94751A778
http://www.mcmaster.com
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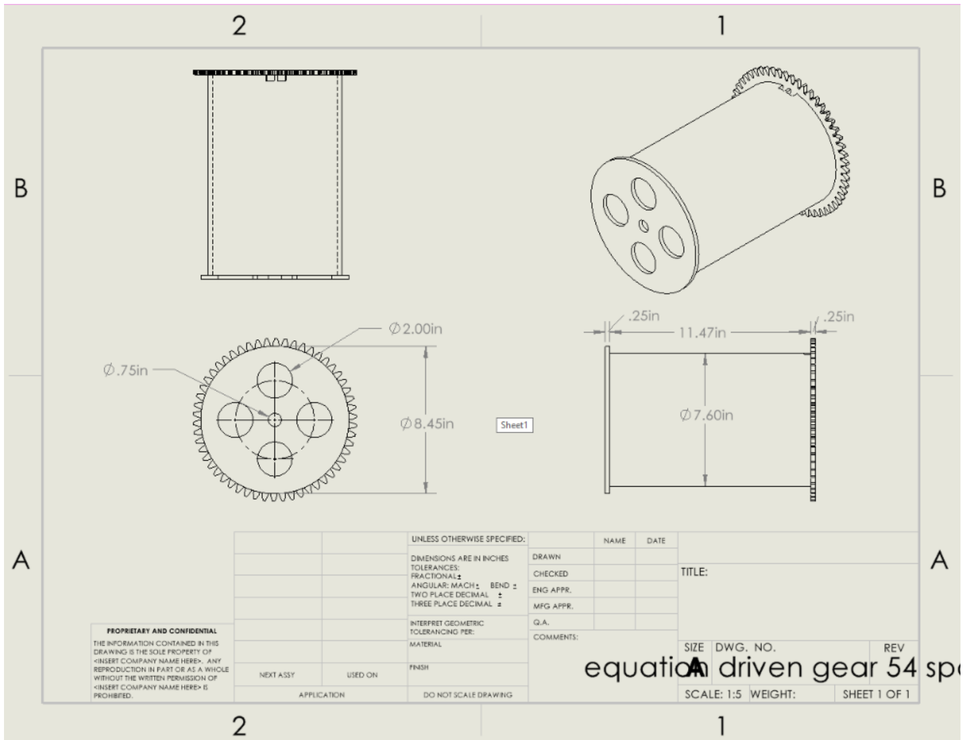
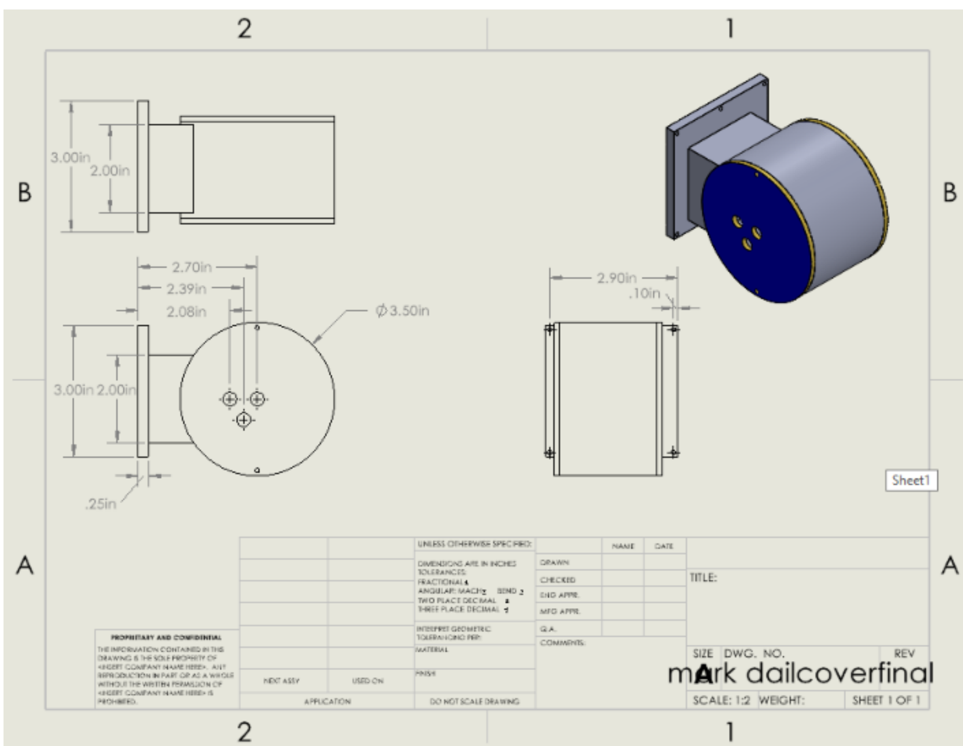
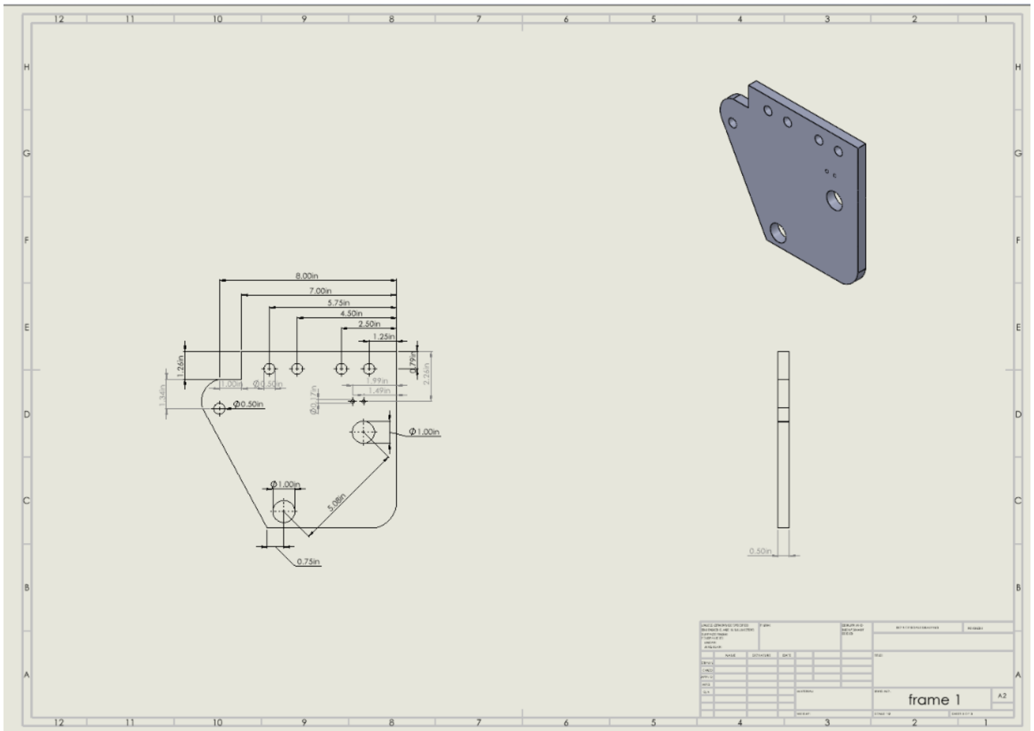
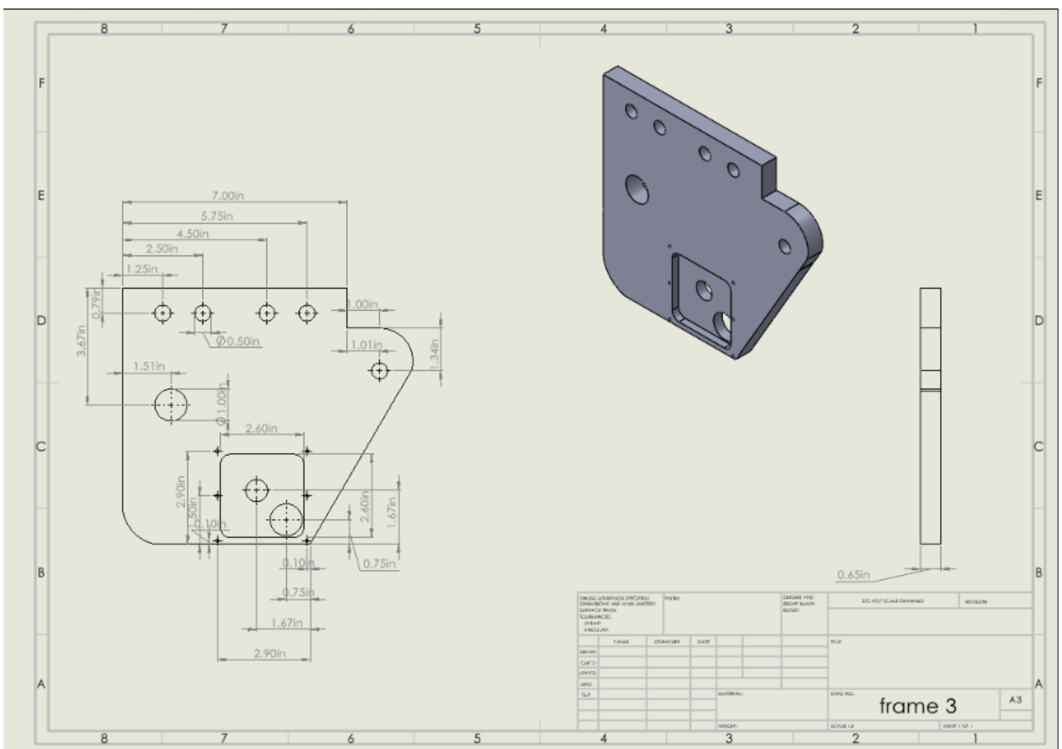
Information in this drawing is provided for reference only.
Wide-Grip Side-Mount External Retaining Ring

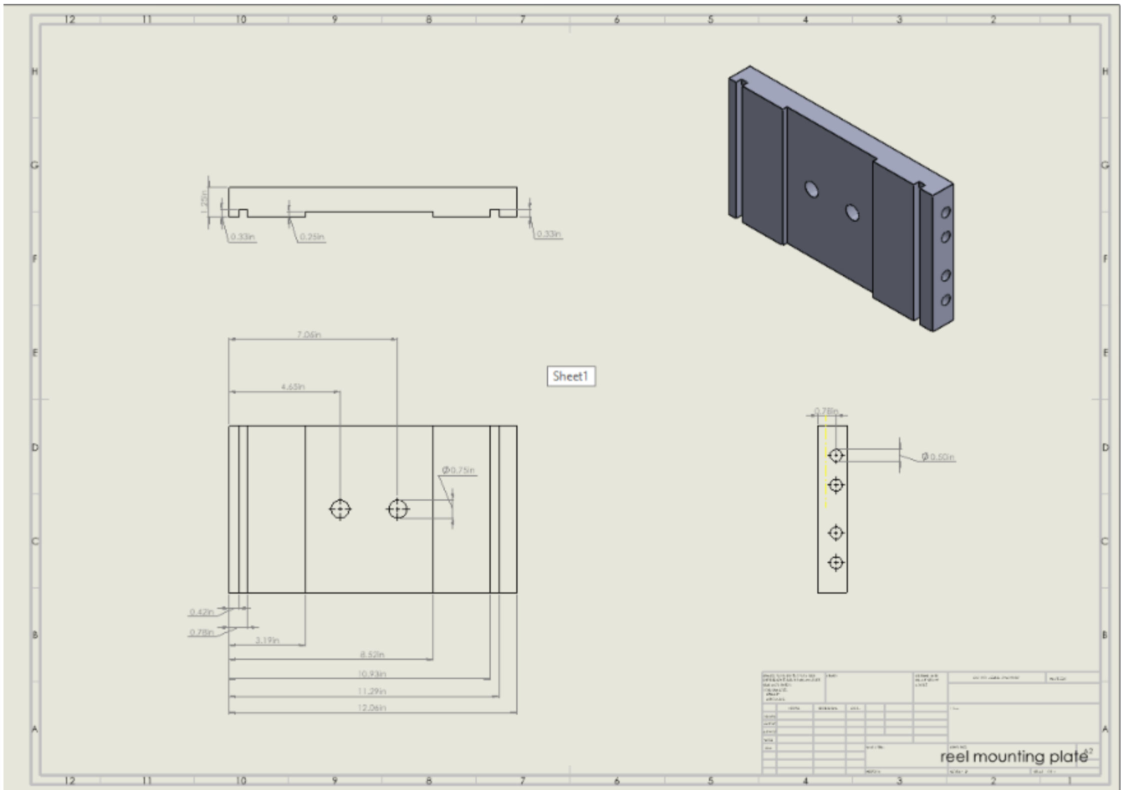
Secondary Push-Pull Reel Drawings:

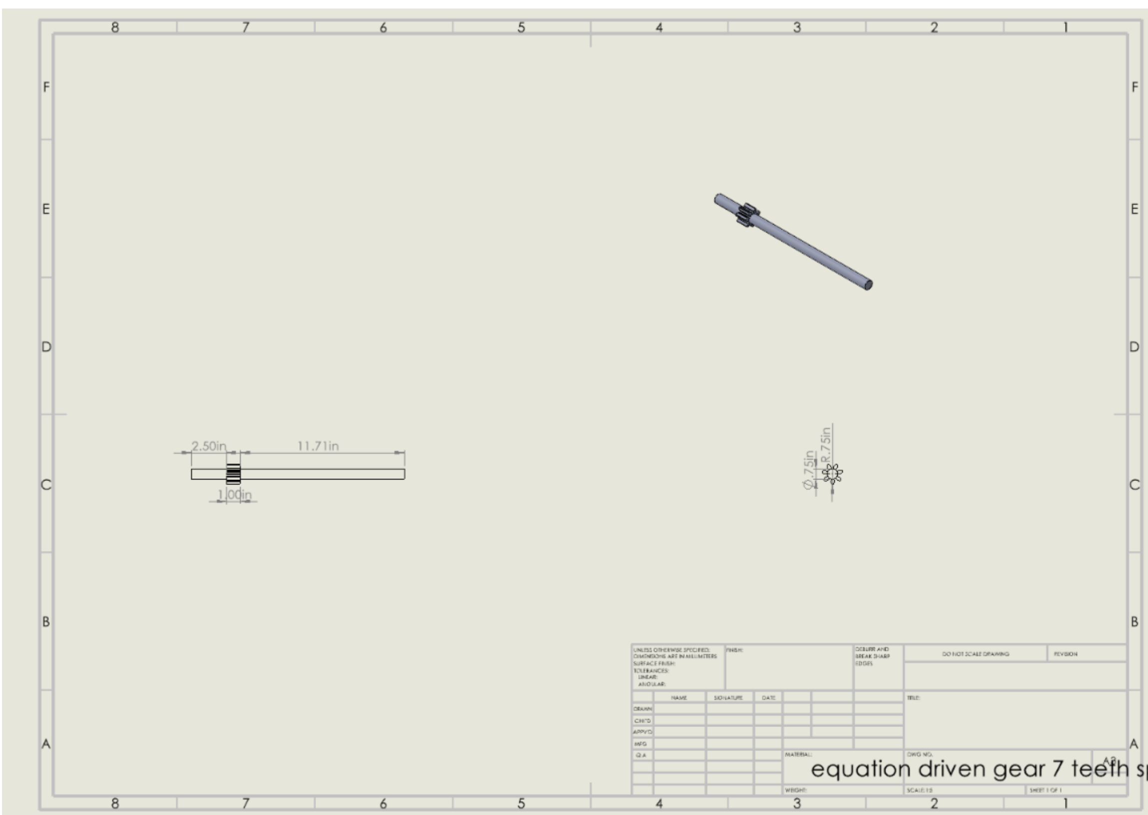





8.00in
7.00in
5.75in
4.50in
2.50in
1.25in
Ø0.50in
Ø0.50in
Ø1.00in
Ø1.00in
5.08in
0.75in
0.50in
frame 1
A2


7.00in
5.75in
4.50in
2.50in
1.25in
0.79in
3.67in
Ø0.50in
1.00in
1.01in
1.34in
1.51in
Ø1.00in
2.60in
2.90in
1.50in
1.10in
2.60in
1.67in
0.10in
0.75in
0.75in
1.67in
2.90in
0.65in
frame 3
A3


Sheet1
7.06in
4.65in
Ø0.75in
Ø0.50in
0.78in
0.42in
3.19in
8.52in
10.93in
11.29in
12.06in
0.33in
0.25in
reel mounting plate


2.50in
11.71in
1.00in
Ø.75in
R.75in
equation driven gear 7 teeth sp

APPENDIX C

Calculations:

Given:

(Full System Gear Train Teeth Number)

$T_1 = 7$, $T_2 = 54$, $T_3 = 12$, $T_4 = 40$, $T_5 = 24$, $T_6 = 12$, $T_7 = 36$, $T_8 = 18$, $T_9 = 36$, $T_{10} = 18$

1- Spool

$$\frac{T_2}{T_1} = \frac{54}{7} = 7.71 \ : 1$$

Where:

T_1: $Number\ of\ teeth\ in\ driving\ gear$

T_2: $Number\ of\ teeth\ in\ driven\ gear$

2- Distance Indicating Dial

$$\frac{T_4}{T_3} \times \frac{T_6}{T_5} \times \frac{T_8}{T_7} \times \frac{T_{10}}{T_9} = \frac{40}{12} \times \frac{12}{24} \times \frac{18}{36} \times \frac{18}{36} = 0.42 : 1$$

Selections for the dial gear train were based upon a derived equation to determine the number of teeth required to achieve a half revolution in the dial for every one and half revolution of the spool.

$$\frac{T_2}{T_1} = \frac{0.5}{N_2}$$

$$\frac{T_3}{T_2} = \frac{N_2}{N_3}$$

$N_2 = N_3$; Compound Gear #1

$$\frac{T_4}{T_3} = \frac{N_3}{N_4}$$

$$\frac{T_5}{T_4} = \frac{N_4}{N_5}$$

$N_4 = N_5$; Compound Gear #2

$$\frac{T_6}{T_5} = \frac{N_5}{N_6}$$

$$\frac{T_7}{T_6} = \frac{N_6}{N_7}$$

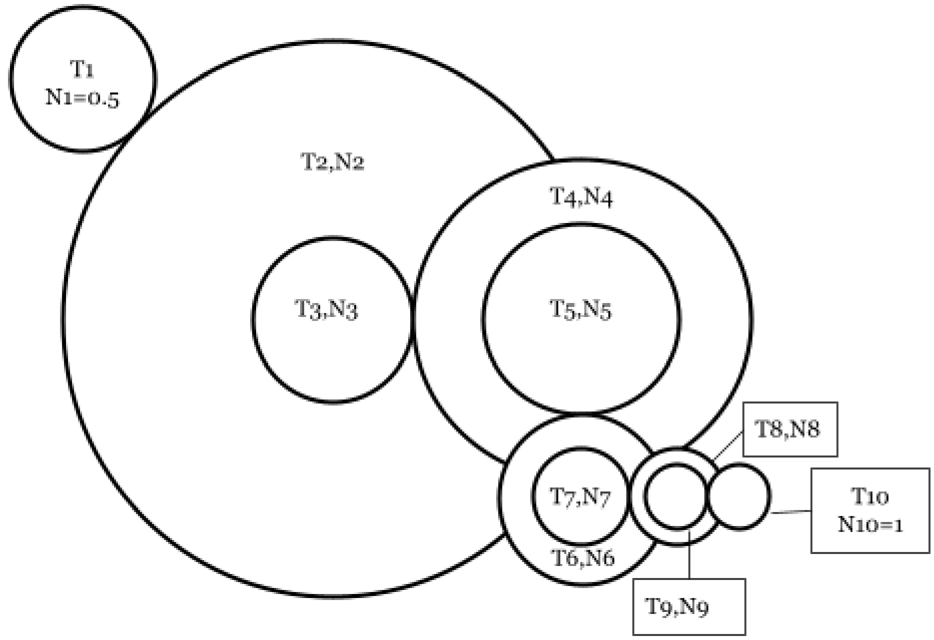
$N_6 = N_7$; Compound Gear #3

$$\frac{T_8}{T_7} = \frac{N_7}{N_8}$$

$$\frac{T_9}{T_8} = \frac{N_8}{N_9}$$

$N_6 = N_7$; Compound Gear #4

$$\frac{T_{10}}{T_9} = \frac{N_9}{1}$$



Secondary Push-Pull Reel System Gear Train Schematic

Finally, the equation was derived from the **third gear**, the output of the first compound gear, which leads into the dial gear train. Therefore the equation was found to be:

$$\frac{T_{10}}{T_1} = 0.5$$

APPENDIX D

Project Gantt Chart:

UPRIVER ENGINEERING

Project Start: Mon, 9/13/2021

TASK	Task Description	START	END
Phase 1: Research			
Task 1	Research Door Cams	9/13/21	9/26/21
Task 2	Material Research	9/26/21	10/5/21
Task 3	River Mechanics Research	10/5/21	10/16/21
Phase 2: Constraints			
Task 1	Determine Door Hinge System Constraints and Operations	10/16/21	11/1/21
Task 2	Bedload Sampler System Constraints	10/16/21	11/4/21
Task 3	Determine River Mechanics Constraints	11/1/21	11/19/21
Task 4	Cost Analysis	11/1/21	11/19/21
Phase 3: Design			
Task 1	Create SOLIDWORKS drawing of bedload sampler	11/19/21	11/23/21
Task 2	Develop Designs - Draw Four Alternatives	11/23/21	12/11/21
Task 3	Evaluate Alternatives	1/22/22	1/25/22
Task 4	Create SOLIDWORKS Model of Chosen Design	1/25/22	1/30/22
Task 5	3D Print Chosen Alternative Design	1/30/22	2/2/22
Task 6	Evaluate 3D Model Functionality on Bedload Sampler	2/2/22	2/16/22
Task 7	3D Print and Test Design Once Again	2/16/22	3/6/22
Phase 4: Manufacturing			
Task 1	Order Required Design Materials	3/6/22	3/9/22
Task 2	Manufacture Design at ERC	3/6/22	3/10/22
Phase 5: Data Collection & Analysis			
Task 1	Test BL-84 door control design in Flume	3/12/22	3/19/22
Task 2	Collect Bedload Sampler Data from Flume Test	3/19/22	3/22/22
Task 3	Analyze Design System Compared to Tetra Tech's Design	3/22/22	4/3/22
Phase 6: Final Deliverables			
Task 1	E-Days Poster	4/7/22	4/20/22
Task 2	E-Days Presentation	4/7/22	4/20/22
Task 3	Final Presentation to FISP	4/20/22	4/27/22
Task 4	Technical Report to FISP	4/20/22	5/2/22