

Senior Design Project: Galaxy Clamp Bike Rack

Honors Thesis

Presented in Partial Fulfillment of the Requirements for the
University Honors Program
Colorado State University

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Spring 2026

Abstract

Cycling is popular worldwide for recreation and transportation. Bike racks, especially those mounted on personal vehicles, allow people to take their bikes farther for recreation. However, the bike racks currently on the market skimp on securing the rear tire, relying only on a flexible plastic ratcheting strap, which is vulnerable to theft targeting the rear wheel. A survey conducted by our team confirms that many cyclists are uncomfortable leaving their bikes unattended on these vehicle-mounted bike racks. Our senior design team's goal is to improve durability and integrate a locking mechanism into the rear part of a bike rack. Our project sponsor, a patent attorney based in Colorado, intends to patent our design and then approach established bike rack manufacturers such as Thule, Yakima, and Küat. He plans to offer licenses for the patented design, enabling manufacturers to legally incorporate our innovation into their future products. Using the engineering design process, our four-person team clarified sponsor requirements, researched the market, and established design objectives. We adapted our design to an up-to-date hitch-mounted bike rack from Thule. After brainstorming alternatives to the flexible strap, the team decided on a handcuff-inspired design and iterated through CAD models and low-cost rapid prototyping. To create a more production-ready prototype, our team decided to laser-cut steel parts and outsource the plastic parts to be manufactured via SLS 3D printing. Finally, we tested our design by fitting multiple bike types that the team owned and applying a vertical pulling force on the mechanism. Our bike rack with the redesigned rear mechanism met most of our design requirements. The final prototype was able to withstand a vertical pulling force of 150 pounds, exceeding our target of 100 pounds. The bike rack continues to accommodate road and mountain bikes. An improved vehicle-mounted bike rack encourages

more people to use their bikes for commuting or recreational purposes. Studies have shown that bicycles have health and environmental benefits. Cycling produces zero tailpipe emissions, which reduces pollution in cities and lowers greenhouse gases in the atmosphere that contribute to climate change.

Becoming the Project Coordinator

Once the team was formed, we were told to form a team contract and reach out to the project sponsor, faculty advisor, and graduate teaching assistant assigned to our project. While our team equally contributed to the team contract, I decided to be the one to reach out to the three people we meet every two weeks. This action was enough for the team to suggest that I should be the project coordinator for the team, and I accepted the role. After getting responses from all three people, I attempted to get the team's availability by sending them a When2Meet.com form; however, not all team members filled that out in a reasonable time. I then messaged the group chat directly, confirming if everyone is available at the proposed meeting times. As suggested by the professor, Dr. Mitchell Stansloski, I sent an agenda for each sponsor and faculty advisor meeting and a short summary of what was discussed in each meeting. All meeting notes were saved in a folder in the team's shared Google Drive folder, so that all meeting notes can be referenced at a later point. This proved to be helpful when drafting the patent write-up. One problem I encountered at the start was licensing problems for Microsoft Project, the software we were suggested to use to schedule tasks and milestones in Gantt chart form. Until I was able to get access to Microsoft Project by working with the lab coordinator and CSU's IT department, I settled on a Gantt chart template someone created on Microsoft Excel. I was also in charge of the progress reports that go out to the sponsor and faculty advisor every other week. These reports consisted of schedule and budget updates, upcoming events, and work logs from the past two

weeks. I was the main writer for these reports and made sure all team members uploaded their worklogs.

Clarifying Sponsor Requirements

My main goal for the first sponsor meeting was to figure out what his requirements were for our team and his budget. As I facilitated the meeting, the team learned that our sponsor, Joe Kovarik, is a patent attorney based in Denver. He was very flexible when it came to what the design looked like, and he plans to patent our design and sell licenses to established bike rack manufacturers such as Thule and Yakima for use in future products. The sponsor was also flexible when it came to how much he wanted us to modify an existing bike rack. Soon after, our team worked on the Specification and Plan presentation, which focused on our customer requirements, project plan, and budget. I was tasked with creating slides for the schedule, workspaces, and budget. I made a rough draft of the Gantt chart showing what we want to accomplish by the end of the semester. While the team has access to the Magellan computer lab, the Engineering Research Center, and the Engineering Manufacturing Education Center (EMEC), the team met in the library most often due to private study rooms. The sponsor was willing to give us a \$7500 budget; however, due to the smaller scope of our project, we estimated a \$4500 budget. I also contributed to the house of quality matrix, which compares performance specifications, customer requirements, and relative importance. The house of quality matrix was able to give us a better understanding of what functions our design needed to have and what requirements it needed to satisfy.

Preliminary Design

One of our team members, Christopher Rivera, was very knowledgeable about bike racks going into this project, and he mentioned four competitive bike racks on the market: The Thule T2 Pro XTR, Thule Proride XT, Yakima HighRoad, and Thule Passage. I did some research into each of those bike racks by looking at the product page, non-sponsored demonstration videos, and reviews from popular YouTube channels. I used those sources to list the pros and cons of each bike rack. I noticed that all of the bike racks were either mounted to the frame only or used a flexible plastic strap on the rear tire. Since I did not know much about bike racks before this project, this research allowed me to better justify my proposed design improvements and create a plan to implement our final design. I met up with most of the team, and we formulated seven new design ideas to replace the rear tire strap. These included a double clamp, single cuff, small ratcheting arm, and even a semi-circle case that hugs around half of the rear wheel. We were able to find out what the sponsor prioritizes in the bike rack, so I met with the team another time to rank our design requirements. Theft security, durability, and ease of use were our top priorities. To prepare for the Preliminary Design Review presentation, which focuses on the design requirements and concept generation, I drafted a CAD model of a design idea involving a hoop that went around the rear wheel. I helped the team make decision matrices to decide our four best designs, which included the original galaxy clamp design and the single cuff mechanism that ended up scoring the best. After I realized that we needed to make decision matrices for each performance specification, I worked with my teammate, Gerard Garcia, to create the six decision matrices and score each idea based on customer requirements. As a result, Gerard and I helped show the decision matrices in our presentation, and the belief maps we used to justify the scoring for each design option. Expanding the decision matrices for each performance specification

likely resulted in a better grade for that aspect, and it also allowed us to focus on each function. These matrices also made the design goals clearer since the requirements were no longer generalized for the entire design. We were able to get one rehearsal before our actual presentation.

Comprehensive Design Review

The professor of this class wanted us to rehearse more before the presentation. So, when I met with the team to update the schedule for the rest of the fall semester, I wanted to make sure we had some time to rehearse more than once. I also finally got the license to use Microsoft Project, and I was able to transfer the Gantt chart to that program and learned the basics of how to organize tasks and show progress. As suggested by Dr. Bonnie Roberts, our faculty advisor, I went back to our House of Quality matrix and attempted to follow the correct procedure when filling out the different sections. Some performance specifications and customer requirements were either missing from the matrix or were in the wrong place. Since the upcoming presentation focused on probabilities of success for each performance specification, it was important that our performance specifications are clear and accurate. Our team wanted to show off a physical prototype for our Comprehensive Design Review presentation, so I coordinated with the team to decide on a bike rack to purchase and modify. We decided to purchase the most up-to-date hitch-mounted and roof-mounted bike racks from Thule, which are known respectively as the Thule Verse and the Thule ProRide XT. I worked with the GTA to clarify the requirements for the Comprehensive Design presentation. Once the hitch-mounted bike rack arrived, I met with the full team to measure the geometry of the rail using the calipers I owned. After a couple of 3D-printed tests, we found the correct dimensions to base our 3D model on. Finding the dimensions of the rail allowed each team member to try out a different design without worrying about it not

fitting on the existing bike rack. I attempted to design a mechanism where the ratcheting system is on the same side as the joint used to rotate the cuff over the bike tire and through the spokes. While this would make for safer handling and using purchased components, the weight would be balanced too much on one side of the design. I also considered a way to integrate a separate padlock into our design. Our team eventually settled on a design Gerard made that combined a handcuff-like system into the already existing mechanism for the rear tire. The lock would be integrated into that mechanism later. For the presentation, I coordinated with the team to divide the sections. I was tasked with predicting the performance and probabilities of success of the rear mechanism's ability to slide along the rail to adjust for different bike wheelbases. I was also in charge of showing the schedule for the second semester and the slide discussing how we designed for manufacturing, assembly, and safety. We were able to rehearse our slides once before our presentation, where the only adjustment the professor suggested was to make all prototyping done by the end of spring break instead of early April.

Design Modifications and Prototyping

Once the second semester started, I went ahead and reconnected with our sponsor and faculty advisor. I reached out to our new graduate teaching assistant, Madelynn Schwartz. We also have a new senior design professor, Dr. Brian Johns. I coordinated with the team to make sure our schedule and team contract are still agreeable. The biggest shortcoming of our current design was the lack of a sophisticated and integrated locking mechanism, so I coordinated meetings with the team to figure out the best approach. I also worked with our team purchaser, Gavin Howsden, to purchase premade locks as well as metal stock and tests of Nylon parts. One of the design improvements we wanted to make was to integrate metal brackets into the base holder to improve the part's strength. So, I took some time to 3D model brackets while

considering material and ease of bending. After showing and discussing this design with the group, we decided to go along with this change after slight modifications by Gerard. I also worked on trying to integrate a spring into our design to keep the pawl latched onto the cuff. We wanted to replace the existing plastic spring with a metal one; however, we had difficulty finding a metal spring that could work. I researched a 45° torsion spring; however, those are not very common, and a peg would have to be added to keep the torsion spring in place. After discussions with my group and faculty advisor, we settled on bending a sheet of spring steel into a V-shape to fit our design. This was most like the plastic v-spring that already existed. After all of these part modifications, some of the parts had very complex model trees in SolidWorks that made it difficult to make adjustments. I therefore re-did some of the parts by taking measurements in the current CAD model and recreating it with fewer features required. I ultimately used these re-done parts to reduce the weight and number of parts required for our design. The revised models also made adjusting any dimensions easier since people are better able to find the feature they want to adjust.

While our purchaser Gavin made most of the 3D-printed models, we wanted to make a higher-quality prototype for the E-days showcase. First, we needed to laser cut a thick slab of stainless steel to create the cuff that goes over the bike tire and through the spokes. After the metal parts were finalized, I filled out the form by stating the part material, thickness, model files, and my availability. Dawson Baucke, who works at the EMEC, scheduled a laser cut appointment, and I oversaw the process. One cuff was able to print successfully; however, the laser cutter encountered problems with our thick material. Therefore, I suggested we make a few cuffs using the same SLS process as the other plastic parts. That way, in case the metal cuff broke during testing, we would still have something to display at E-days. We also thought it

would be important to have two models for the showcase with one attached to the bike rack and one on a table. The pawl was also too small to be laser cut due to the material thickness. As with most laser cutters, cut quality decreases as a shape approaches the material thickness. Before I submitted the form, I attempted to redesign the pawl and the surrounding parts to be larger. However, I realized that it would take too much time to redesign these components. So, our team agreed to make the pawl out of SLS. With the help of Gavin, we were able to order the SLS parts from Xometry on time to test the final prototype and show off at E-days. I also made a second appointment to laser cut the remaining parts out of a thinner sheet of steel, which could be cut a lot faster. I attempted to schedule a time to get trained on how to use the CNC sheet metal bender in the EMEC. However, since the trained staff were busy, my team member, Christopher Rivera, offered to bend the brackets using tools at the university's bike workshop, which turned out to produce adequate parts. By being relatively proactive on laser cutting the metal parts, I was able to spot potential problems and fix them before it was too late.

E-Days and Final Design Review

The final steps left before the showcase were testing the prototype and creating the poster board. After multiple discussions with our advisor and team, we decided to do a tensile force test on the entire mechanism and compare the result to our target requirement of at least 100 pounds of force. I have a luggage scale I suggested we use for the force test; however, my team was able to figure out how to modify a Mark-10 motorized tensile tester in the materials lab. My team members were able to get the prototype fixed and have the motorized arm attached to the cuff, allowing us to read the force number. Unfortunately, we could not use the full functionality since all our student accounts were locked out of the LabVIEW programs made for the machine. Therefore, we decided to take a video recording of the reader to make sure the maximum force

was recorded. The full prototype was able to handle 150 pounds of pulling force without anything breaking, which is more than our target requirement. We were worried that the pawl would break since it is a small plastic part. While this component would have been stronger if it was made of metal, nylon proved to be strong enough for our purposes. As for the poster, I suggested that the team use Canva since we can collaborate in real time. This allowed each team member to contribute to the poster.

E-Days turned out to be a success for our team due to a generally positive reception by the public. For our Final Design Review presentation, I suggested our team should work on the same sections we focused on talking about at the E-days showcase. My sections were the problem statement, design requirements, and constraints, but I also worked on the slides, and speaker notes for the section talking about key design decisions. The final presentation had a pretty good reception despite a small timeframe to complete it. The sponsor was satisfied with the final design, and I am keeping in touch with him about the patent write-up that the team is currently drafting. This write-up is mostly headed by Gerard; however, I am currently implementing the feedback Mr. Kovarik gave to our first draft.

Reflection

Before my senior year of college, I interned at a construction company over the summer. There were many recurring meetings each week, and I observed how they were run and how meeting notes were taken. I was able to apply what I observed in my project coordinator role, where I had to run the meetings and record meeting minutes. As a result, this project allowed me to grow my skills as a coordinator, which I expect to use in future jobs. One thing I would have done differently was establish a recurring meeting time with just the team. There were some

points in the school year when the only time I could see the full team was during a sponsor, TA, or advisor meeting. People sometimes had to leave for other events, which prevented the full team from discussing after a meeting. Having a team meeting would reduce the number of times I have to reach out to the team about progress or meetups. A recurring team meeting would also serve as a natural deadline for smaller tasks and would help motivate people to get things done by a certain day. I once proposed a recurring team meeting to the team, and most of them did not think that was needed. I also learned the importance of designing for manufacturing. It is important that every engineer knows how the tools accessible to them work. Ignoring this approach may result in delays and parts with compromised performance. I also learned the importance of quality, function, and deployment analysis. The first few presentations would have run a lot smoother if this process was done correctly at the start. When it came to 3D modeling, the team typically agreed to make models on their own and decide later which model is the best. However, people who were not as skilled in modeling tended to procrastinate and ultimately not have a model in time. This issue also could have been mitigated if the team had a better understanding of each other's strengths and weaknesses. Finally, I should have taken testing more seriously when the team was coming up with design requirements. While we were able to test the overall strength, we could have done an actual vehicle test if we took more time to figure out logistics. There were ways we could work more effectively, but I am still satisfied with what we were able to get done this school year. This project was my first time going through the entire design process on a real problem, so the lessons I took from this project will carry with me throughout my entire engineering career.