Off-Road Bumper Team

Final Report

Thomas Allen
Matthew Baker
Deja Hubbard
Yuwsef Alabdulhi

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Project Sponsor: Cesar Blancarte, Carson Pete
Faculty Advisor: Carson Pete
Sponsor Mentor: Austin Braatz
Instructor: Carson Pete

DISCLAIMER

EXECUTIVE SUMMARY

Bumpers are one of the major components of any vehicle, and if it is an off-road vehicle then its bumpers are the main point of impact. The clients have expressed a need to upgrade their factory bumpers to new off-road bumpers that are more durable and have new functionalities. The team has been tasked with designing three new aftermarket bumpers for two different vehicles. Our customers are looking for a bumper that is not just durable, but have aftermarket upgrades including: light pods, engravements, back up sensors, and winch support.

The team initially had two clients, David Bui and Carson Pete. Over the summer, David Bui sadly passed away and the team received a new client named Cesar Blancarte. Cesar and David are both employed at Evan's Alloys. The team was given these parameters at the start of the project:

1. Bumpers start at a budget of $1500 for the three bumpers ($500 each).
2. Understand customer requirements and engineering requirements and implement designs using the CAD (Computer Aided Design).
3. Work on the Blackbox model and functional model of the bumpers.
4. Perform FMEA analysis to make sure the designs are safe and meet the quality and security standards.

The team will implement the final design for the bumper by creating a schedule, a bill of materials, a testing procedure, a CAD model, and a physical model to be used for fitment. The team modeled the prototype in SolidWorks and 3D printed it at the end of the first semester. The team then worked to create a rear bumper for the new client at the beginning of the second semester. The team the created a manufacturing plan to achieve 100% build by the due date. Once the team finalized the designs with the client in SolidWorks, the team created a DFX file to have the parts cut to create the bumper. The team had to overcome the challenge of making one solid bumper out of individual plates that could be cut in 2D on sheet metal. Once the "cut" files were created, the team then began using a water jet at Evan's Alloys to cut the metal. Once all the parts were cut, the team began to shape the metal using a press brake. Once the bumper's shape was formed, the team tack welded the pieces together and a fitment test was performed to ensure the proper shape and angles were made. The team then structurally welded the bumper and then filled in all the gaps to make the bumpers look proficient and suitable for the vehicle. The team then installed all the components on the bumper and installed the bumpers to their respective vehicles. A testing plan was then made to ensure all engineering requirements were met. These tests measured the material strength and the durability of the design. The bumpers were then handed off to the Powder Coating Oven capstone team to be powder coated to add rust and scratch resistance to our bumpers. The team installed the bumpers onto the vehicles and made sure all factory lighting and sensors work. The team made sure that all requirements were met to install the aftermarket components like light pods and winches. Overall, both clients and all team members are extremely happy with the outcome of the product the team provided.

ACKNOWLEDGEMENTS

Elemental Motors- Provided testing equipment, providing storage and working environment for the team, providing technical assistance on challenging aspects of the testing plan, CAD and resources to complete the manufacturing of the bumpers.

Evan's Alloys- Providing storage and working environment for the team, providing resources and manufacturing equipment, supplying materials, providing welding equipment and cutting materials.

Austin Braatz – Provided welding expertise, provided welding equipment and welded parts of the front bumper.

Cesar Blancarte- Providing storage and working environment for the team, sacrificing a large amount of time to help the team, supplying welding equipment, providing expertise and supporting the team.

Charlie Commanda – Provided knowledge of converting Solidworks parts to DFX files and helped with CAD assemblies.

John Nargassans – Provided expertise on welding process on the bumpers and troubleshooted issues during assembly.

Seth Perkins – Provided expertise on electrical components used to test the bumpers, sacrificed time to teach the team about strain gauges, provided a circuit board and resistors to test and provided software to record data.

Carson Pete – Providing resources, providing expertise, sacrificing large amounts of time to help the team, organizing meetings, supplied tools and provided financial support.

Powder Coating Oven Capstone Team – Powder coating the bumpers and working alongside the team.

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1 BACKGROUND

1.1 Introduction

The off-road bumper project is a complex venture, aiming to create three top-notch aftermarket bumpers tailored for two different vehicles. Carson Pete, our primary client, needs both front and rear bumpers for his 2008 Chevy Silverado 3500HD. Cesar Blancarte is the secondary client and is the owner of a 2018 Dodge Ram 3500HD which the team will create a rear bumper for. David Bui was the owner of a 2011 Jeep Liberty which will be mentioned in the first semester designs. This project will allow the team to understand the real-world challenges of engineering by constructing three custom bumpers.

This project is a dynamic learning experience, mirroring the complexities and demands of professional engineering practices. This comprehensive report will cover the various tasks the team performed to complete this project. Beginning with the project's background, it then delves into defining the necessary requirements, conducting research within the design space, generating multiple conceptual ideas, and selecting the most fitting design. Progressing further, it outlines effective project management methodologies, detailing the development of the final hardware, testing procedures, comprehensive risk analysis, and strategies for mitigation. Additionally, it offers insights into the team's future developments before culminating in a summary encapsulating the entire project. Our aim isn't just to deliver functional bumpers; we're striving for a product that goes beyond the bumpers offered by current manufacturers.

The project tackles the need for enhanced vehicle safety through durable bumper solutions and the growing demand for aftermarket modifications that enhance vehicle utility. Our clients, Carson Pete and Cesar Blancarte, stand to gain peace of mind that if the get into a minor collision they will be protected. However, it's not just about ensuring vehicular safety but integrating aftermarket lighting and winches. This adds to both the utility and aesthetics of the vehicles.

In essence, this project is a blend of hands-on engineering experience and the tangible delivery of safer, more versatile vehicles for our clients. It's a collaborative journey where the team's learning curve aligns with the clients' desire for vehicular upgrades, highlighting the practical application of engineering principles in addressing contemporary automotive challenges.

1.2 Project Description

This project requires the students to do an extensive CAD design to create three bumpers for two different vehicles. These CAD files were converted into DFX format and transposed into a 2-D surface to be cut and then fabricated. These files were utilized to cut precision parts using a water jet at a local aerospace company. One vehicle is a 2008 Chevy Silverado 3500HD. This portion of the project required students to make both front and rear bumpers that match factory lines, are color matched by either powder coating or bed-lining with paintable bed-liner. The bumpers have increased strength and durability over the factory bumper, maintain factory lines, maintain higher functionally (will incorporate a 12 Ton winch into bumper, have additional off-road lighting capabilities, mount to existing factory bumper locations and maintain factory back-up sensors and inputs from existing lighting such as fog lights, license plates, etc.). The second bumper is for a 2011 Jeep liberty KK front bumper only, this bumper will have similar requirements to that of the previous listed vehicle. The bumper should maintain factory lines, be extremely durable, and incorporate a 6-10 Ton winch. Students will need to have fabrication skills, welding, and 3d modeling skillsets.

The requirements were then updated to include Cesar’s bumper which follows the same requirements of the rear bumper of the Chevy Silverado. The client additionally wanted to use the factory license plate light instead of purchasing an aftermarket one.

1.3 Original System

The original bumpers for both vehicles are made to limit impact from a collision to prevent damage to the frame. Both vehicles' bumpers are not very strong and will often need replacing after making small impacts when off-roading. The Chevy Silverado has bumpers made from 304 stainless steel and mostly plastic. These materials have minimal resistance for impacts when considering the weight of the truck [1]. The bumper on the Jeep Liberty is made entirely of plastic and has very little impact resistance.

The factory bumpers were made for casual driving and not for off-roading. The mounting locations for the original equipment manufacturer(OEM) bumper were maintained in the design to ensure easy installation of the new bumper. The team reused the factory back up sensors and airbag collision sensors. The factory wiring for towing was maintained and the plug location kept the same. No other parts of the factory bumper were used, or they were replaced with stronger materials.

2 REQUIREMENTS

The Off-road Bumper team was tasked with creating and designing three bumpers. To ensure optimal results, the team-initiated meetings with customers to define the essential functions each bumper must fulfill. This collaborative approach enables the team to comprehend customer expectations for each bumper and kick-start the creative process for their development. Once customer requirements are gathered, the team leverages its technical expertise to transform these into quantifiable engineering requirements, facilitating analysis for each specific customer need. Employing a tool known as the House of Quality (HOQ), the team systematically ranks engineering requirements in alignment with customer expectations, providing valuable insights into the most critical aspects of the design.

2.1 Customer Requirements (CRs)

To meet customers' expectations effectively, the team meticulously analyzed their specific needs for each bumper. The customers emphasized the need for enhanced durability compared to factory bumpers, aiming to improve vehicle protection in minor accidents. Preserving the current functionality, factory fit, and mounting were crucial aspects highlighted by customers; they expressed a clear desire not to compromise any existing bumper features. Additionally, customers sought the capability to install a winch of their choice along with extra aftermarket lighting. Dr. Carson Pete specified a unique requirement for an engraving during the cutting process. Given these requirements and a budget settlement of $1,500 distributed across the three bumpers, the team embarked on a comprehensive design process.

Table 1: **Customer Requirement and their importance to the customer**

Customer Requirements	Importance
EGR Engravement	3
Light Pods	3
License Pod	3
Factory Line Design	9
Sensor outlet	3
Tow Winch	9
Maintain Existing Hook Points	3
Functionality	9
Resistances	1
Durability	9
Reliability	3
Inexpensive	3

The customers prioritized durability, functionality, and maintaining factory design lines as the utmost crucial aspects, assigning them a significance rating of nine. This rating serves as a scalar during the House of Quality (HOQ) evaluation, guiding the importance placed on engineering requirements. Other customer needs, while still essential for inclusion in the design and final product, were rated at three or lower. This implies that, while necessary, these aspects won't significantly impact the design in a major way.

2.2 *Engineering Requirements (ERs)*

Given the customer requirements above the team went through and applied their technical knowledge to relate all the customer requirements to quantifiable engineering-based terms that are known as engineering requirements. These requirements allow them to be able to solve for and analyze specific aspects of the customers' requirements in a numerical way that can be used to determine how to design the bumpers and what the dimensions and type of material will be required. The engineering requirements that were used for this project primarily related to material properties as shown in the table below.

Table 2: Engineering Requirements and their importance raw score in comparison to the customer needs

Engineering Requiremetns	Impotance raw score	Target
Yeild strength (MPa)	70	200 ± 25
Hardness (N)	34	130 ± 10
Modulus of thougness (MPa)	69	400 ± 25
Weight (kg)	33	50 ± 10
Moment of Inertia (m^4)	39	
Limit of Elasticity (GPa)	68	200 ± 25
cost ($)	52	≤ 1,500

The highest importance being placed on yield strength, meaning the point at which a material will no longer deform elasticity and starts to deform plastically resulting in permanent damage. This was proven to be most significant as expected for it is the transition point between modules of toughness and the limit of elasticity. Modulus of toughness which is a materials ability to absorb energy during plastic deformation. This property was the second highest in importance for if the bumper was to get plastically deformed the ideal outcome would be to keep the damage solely to the bumper and absorb as much of the damage as possible. This is adding protection to the vehicle as well as the passenger there is an upper limit to this.

Since we don't want the bumper to be so strong that it then inflicts damage to the frame of the vehicle. But we want it to be strong enough to retain enough of its shape so that it doesn't damage the front of the vehicle. The limit of elasticity proved to be the last major factor in our engineering requirements. This is the regain in which a material deforms elastically meaning that it has retained no permanent damage from the force applied to it. The Elastic limit is important for when it meets another object the bumpers will retain their original shape and have no plastic deformation. This spec is dependent on the yield strength for a material as mentioned above. This is why it was proven significant but less significant than yield strength and modulus of toughness.

The team will try to set yield strength as high as possible to ensure the strength of the bumper within reason of cost. Cost was one of our requirements as it restricts the possible choices of material. It was shown to have important significance but not more than the desired material properties. There is another limiting factor to this which is weight. Weight plays a role due to the relationship a higher the yield stress is the result of a higher density for the most part. This is important because the customer asked that their bumpers not weigh more than required to help ensure the vehicles retain their gas mileage. Because of this weight appeared on the requirement but was the least important of the requirements chosen.

The remaining material properties that were chosen were Moment of Inertia and Hardness. Moment of inertia is a materials ability to resist angular momentum and Hardness is the resistance to localized plastic deformation. Both material properties prove to be important but not compared to the ones listed above. Thus, these requirements are only optimized if it is beneficial to the other requirements. Plus, they will both inherently go up as the materials yield strength goes up.

2.3 Functional Decomposition

To gain a comprehensive understanding of the bumper's functionality, our team engaged in a meticulous analysis, employing both a black box model and a functional model. The black box model served as a strategic overview, allowing us to simplify the complex system into inputs and outputs, highlighting the essential elements for each action without delving into intricate details. This approach offered a holistic perspective, emphasizing the "what" without being bogged down by the "how."

Complementing this, the functional model provided a detailed examination, delving into the intricate workings of each action. It meticulously broke down the processes into individual steps, elucidating how inputs transform into outputs throughout each action. This granular exploration was instrumental in deciphering the nuanced mechanics of the bumper, particularly in its ability to absorb and deflect energy. By seamlessly integrating both models, our team gained valuable insights into the synergies among subsystems and how they collectively contribute to the bumper's functionality. This analytical approach ensures a comprehensive grasp of the processes at play, paving the way for informed design decisions and a robust final product.

2.3.1 Black Box Model

This black box model intricately examines the core function of the bumper – to withstand and redirect potential damage away from the vehicle. Acting as a representation of inputs and outputs, the black box model serves as a valuable tool for anticipating results based on the necessary inputs for the system to operate effectively.

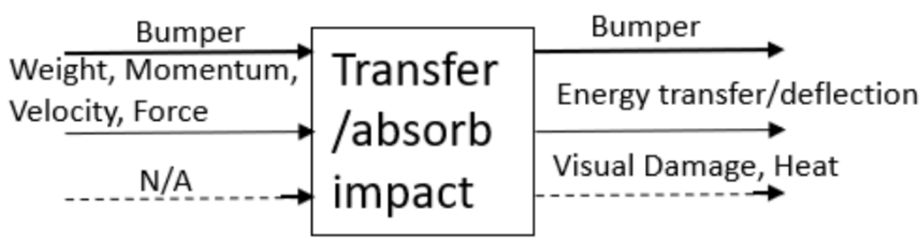

Figure 1: Black Box Model

Inputs and outputs are categorized into three sections: materials, energies, and signals. Materials encompass the solid objects involved in the action, including those entering and leaving the system. Energy signifies the requisite energy for the action, both for its execution and departure from the system. Lastly, signals represent the anticipated result or observation resulting from the action. The selected inputs, such as materials and energies, are fundamental for the bumper's role in resisting and absorbing energy. Following the law of physics, energy cannot be created or destroyed, necessitating the provision of energy to the system for effective energy transfer.

The outputs primarily revolve around the bumper as the material under consideration. The energy output is crucial, emphasizing the goal of energy transfer or deflection. Unlike the input signals, the output signals have an anticipated response, manifesting as physical damage to the bumper or the generation of heat. Failure to absorb all the energy may lead to its transfer to the vehicle or deformation of the bumper, signaling that the incoming force exceeded the bumper's capacity for effective transfer or deflection without damage.

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

To delve deeper into the intricacies of the black box, the team developed a functional model that meticulously explores how inputs and outputs collectively contribute to achieving the black box model's objectives. Like the black box model, the functional model categorizes inputs and outputs into materials, energies, and signals but takes it a step further by breaking them down into individual actions and subsections. This approach sheds light on how distinct systems interact, providing insights into the complex interplay within the black box.

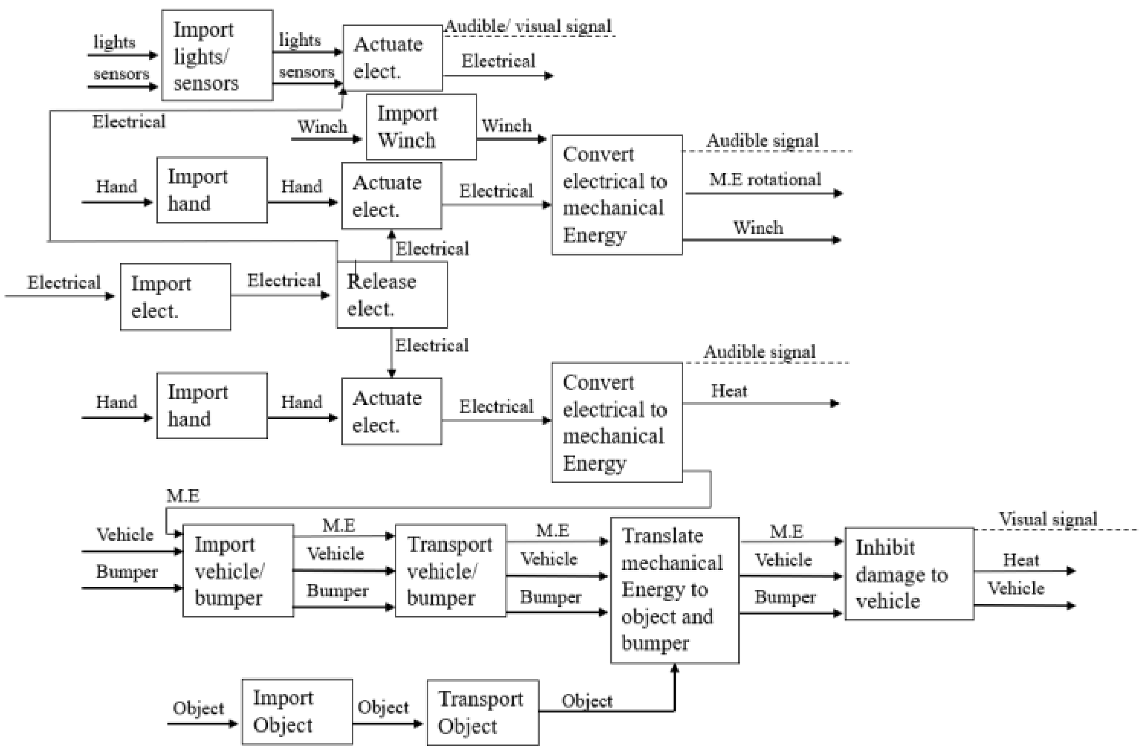

Figure 2:Functional Model

The functional model places particular emphasis on the energy source in the system, originating from the vehicle. This study delves into the intricate processes by which the bumper transfers and deflects energy, considering subsystems like lights, sensors, winches, and the object being impacted. This comprehensive analysis enables the team to gain a profound understanding of how the system components interact, facilitating informed design decisions for the bumpers.

Upon careful examination of the functional model, a crucial revelation emerges—the primary relationship among the subsystems lies in the electrical signal permeating the system and their coexistence within the bumper. This is a pivotal insight, underscoring the importance of ensuring seamless functionalities for all lights, sensors, and the winch. During the design phase, the team took proactive measures to safeguard the subsystems, ensuring their protection and preserving the bumper's fundamental functionality of shielding the vehicle from damage during minor accidents.

2.4 House of Quality (HoQ)

The House of Quality (HOQ) stands as a pivotal engineering tool employed to juxtapose customer requirements with engineering specifications. Beyond this, the HOQ offers a unique perspective by illustrating the interrelationships among various engineering requirements. The initial step involves gathering customer requirements directly from the source, assigning importance to each based on their significance in the design process, differentiating between critical aspects and desirable features. To quantify these relationships, engineering requirements are integrated into the HOQ, establishing a connection with customer demands. This is achieved through a systematic ranking process, assigning numerical values that signify the degree of correlation between customer and engineering requirements. The resultant data forms the central component of the HOQ, indicating the strength of these connections. The upper section of the HOQ delves into the interdependence among engineering requirements, providing insights into how modifications in one aspect might impact others. On the right side, a comparative analysis juxtaposes existing market offerings against customer requirements, offering a benchmark for evaluation.

The bottom section of the HOQ unfolds the results, presenting raw importance scores derived from multiplying customer requirement importance by the respective engineering requirement relationship scores. The percentage score, a straightforward ratio of raw score to total points, provides a normalized view of importance. Finally, the Competitive Design Assessment compares existing market options based on engineering requirements, offering a comprehensive snapshot of the current industry landscape. For a detailed visual representation, refer to the HOQ in the appendix.

2.5 Standards, Codes, and Regulations

In the intricate process of crafting an off-road bumper tailored for everyday use, strict adherence to established standards, codes, and regulations becomes paramount. These guidelines, emanating from various reputable organizations, serve as a cornerstone in guaranteeing the safety and durability of the designed bumpers. Compliance with these standards not only upholds the safety of our clients but also sets stringent regulations for the fabrication of automotive components.

Prominent among these regulatory bodies are the Society of Automotive Engineers (SAE) and federal government entities, each contributing comprehensive regulations aimed at ensuring the safety of both pedestrians and vehicle occupants. The following standards and codes have been identified as particularly relevant to the off-road bumper project:

Table 2: **Standards, Codes, and Regulations**

Standard Number or	**Title of Standard**	**How it applies to Project**

Code		
SAE J2976	Speedometer and Odometer Systems for On-Highway Vehicles	Helps the team know how durable the bumper needs to be and how safe in an off-road environment.
SAE J3115	Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices	Installation of aftermarket bumpers and other vehicle accessories like the winch and light bars
CFR 581	Bumper Standard for Impact Resistance	Helps the team determine if the bumper has enough resistance to impact. Also gives testing procedures.
SAE J2807	Performance Requirements for Determining Tow-Vehicle Gross Combination Weight Rating and Trailer Weight Rating	Tells the team how to design for failure at high forces. Also outlines the safety regulations of airbag sensors and seatbelts.
SAE J2340	Categorization and Properties of Dent Resistant, High Strength, and Ultra High Strength Automotive Sheet Steel	Helps the team select the correct materials for the bumper.
FMVSS 208	Occupant Protection	Covers the guidelines to keep the occupants safe during a collision.
FMVSS 215	Exterior Protection	Ensures the bumpers are the correct size and not placed two high or low.

By conscientiously adhering to these regulations, the team instills confidence in the safety and legal compliance of the bumpers produced. These standards serve as a robust framework, affirming that the designed bumpers are not only safe and durable but also capable of withstanding the demanding conditions of off-road driving.

3 DESIGN SPACE RESEARCH

The off-road bumper design project aimed to create three aftermarket bumpers for two different vehicles in response to the specific needs of customers Carson Pete and David Bui. We focus on improving durability and impact resistance to withstand off-road environments. This study deals with various aspects of the design process including CAD design, material selection and fabrication techniques.

3.1 Literature Review

The team did a project to design aftermarket bumpers for the 2008 Chevrolet Silverado 3500HD and the 2011 Jeep Liberty KK. The main goals were to improve durability, put accessories like winches and off-road lighting, and maintain factory lines and performance. The literature review included a review of available designs and materials for aftermarket shields. The original systems of both cars had limited impact resistance, the Chevrolet Silverado using 304 stainless steel and plastic parts and the Jeep Liberty using plastic bumpers. The project aims to improve these aspects and reuse some factory elements such as backup sensors and airbag crash sensors in the new design. The team conducted benchmarks, web searches, and a comprehensive literature review to decide on a design that considered factors such as material strength, impact resistance, and integration with existing vehicle features.

3.2 Benchmarking

1. Introduction:

The off-road bumper design project aimed to develop three aftermarket bumpers for two different vehicles: the 2008 Chevrolet Silverado 3500HD and the 2011 Jeep Liberty. This section focused on a benchmarking process that included site visits, observations, interviews, and online surveys to identify existing approaches and similar design challenges.

2. Identified Areas for Benchmarking:

a. Material Selection and Durability:

- Research the materials used in aftermarket bumpers for off-road vehicles.
- Evaluate impact resistance and durability of existing designs.

b. Integration of Winch and Lighting:

- Check out how other designs seamlessly integrate heavy duty winches.
- Analyze the inclusion of additional off-road lighting features.

c. Maintaining Factory Features:

- Check how existing designs maintain factory lines and functionality.
- Evaluate factory backup sensor retention and wiring integration.

3. Findings from Benchmarking:

a. Material Selection:

- Heavy alloy steel is usually used to increase durability.
- Some designs use innovative composite materials to reduce weight.

b. Winch and Lighting Integration:

- Various approaches to the integration of large winches were observed.
- LED light bars and spotlights are often integrated seamlessly into the bumper design.

c. Maintaining Factory Features:

- Succeeded in maintaining factory lines through accurate 3D modeling.
- Integrating sensors and maintaining wiring is a common practice in advanced designs.

4. Application to Project:

- Consider heavy alloy steel for added durability.
- Exploring innovative materials that reduce weight without sacrificing strength.
- It has an insight into seamless integration of winches and additional lighting.
- Prioritize 3D modeling accuracy to maintain factory lines and functionality.

3.2.1 System Level Benchmarking

These designs were selected based on reputation, performance, and alignment with specific requirements outlined in the project description.

3.2.1.1 ARB 4x4 Accessories Bumper for Chevy Silverado 3500HD

Source: ARB is a well-known manufacturer of off-road accessories known for its durable fenders.

Design Features:

- Uses high tensile steel sheet for increased durability.
- Built-in winch base compatible with 12-ton winch.
- Designed to match factory lines for a seamless look.
- Maintains compatibility with OEM sensors and light.
- Powder coating for corrosion resistance.

Rationale: ARB bumpers are widely recognized for their rugged design and off-road performance. This design was chosen as a benchmark due to its compatibility with larger winches and maintaining OEM performance.

3.2.1.2 Smittybilt XRC Gen2 Front Bumper for Jeep Liberty KK

Source: Smittybilt is known for rugged off-road accessories like fenders.

Design Features:

- Made of sturdy steel for durability.
- With a winch base suitable for 6–10-ton winches.
- Maintain the factory line and achieve a uniform appearance.
- Provides additional lighting options for off-road use.

Rationale: The Smittybilt XRC Gen2 bumper was chosen for its strength, winch compatibility, and off-road lighting integration. This meets the requirements of the Jeep Liberty project.

3.2.1.3 1.1.1.1 Addictive Desert Designs Honey Badger Front Bumper

Source: Addictive Desert Designs is known for its aggressive off-road designs.

Design Features:

- Made of high strength material for durability.
- Uses a winch base suitable for heavy winches.
- Provides additional lighting options.
- Unique and aggressive design for an aftermarket look.

Rationale: HoneyBadger fenders were chosen for their aggressive design and compatibility with heavy duty winches. It delivers a unique aesthetic while meeting your off-road performance needs.

Rationale for Selection:

- ARB fenders are chosen for the Chevrolet Silverado because of their reputation for durability and compatibility with heavy duty winches.
- The Smittybilt XRC Gen2 was chosen for the Jeep Liberty project because of its strong construction and alignment with the specified specifications.
- The HoneyBadger bumper adds a unique design option, catering to off-road enthusiasts looking for both performance and aesthetics.

3.2.2 Subsystem Level Benchmarking

3.2.2.1 Winch Mount Subsystem

This subsystem focuses on integrating a rugged winch mount to ensure secure placement and compatibility with rugged winch systems, enhancing off-road recovery.

3.2.2.1.1 Warn Zeon 10S Winch Mount

Source: Warn is a famous brand of winches and accessories.

Design Features:

- Designed for harsh applications.
- Winch compatible with 10,000 lb towing capacity.
- Durable steel structure
- Integrated fairlead for cable management.

Rationale: The Warn Zeon 10S winch base was chosen to meet the project's needs due to its robust construction and compatibility with heavy winches.

3.2.2.1.2 Smittybilt Winch Plate

Source: Smittybilt is known for its off-road accessories.

Design Features:

- Strong steel structure
- Universal design to fit different winches.
- Powder coating for corrosion resistance.
- Easily attaches to most bumpers.

Rationale: Smittybilt winch plates are versatile and durable, making them suitable for integration into a variety of bumper designs.

3.2.2.1.3 1.1.1.1.1 Factor 55 ProLink Winch Shackle Mount

Source: Factor 55 is a specialist in rescue and equipment accessories.

Design Features:

- Machined from light and strong 6000 series aluminum.
- Provides a place to install shackles.
- Designed to optimize the use of synthetic ropes.
- Easy installation of ring hook.

Rationale: The Factor 55 ProLink was chosen for its innovative design, lightweight materials, and secure attachment to the shackle, an alternative to traditional winch mounts.

3.2.2.1.4 Lighting Integration Subsystem

The lighting integration subsystem is designed to seamlessly integrate high-performance LED lighting solutions into aftermarket bumpers to optimize visibility when driving off-road.

3.2.21.5 *Rigid Industries E-Series LED Light Bar*

Source: Rigid Industries is a leader in high performance LED lighting.

Design Features:

- High power LED technology
- Durable construction for off-road use
- Available in different lengths
- Designed for easy integration into your bumper.

Rationale: Rigid Industries LED light bars are chosen for their consistent durability and high-performance lighting suitable for off-road conditions.

3.2.2.1.5 KC HiLiTES Gravity LED G4 Fog Lights

Source: KC HiLiTES is known for off-road lighting solutions.

Design Features:

- Compact and versatile LED fog light.
- Gravitational reflection diode (GRD) technology to improve efficiency.
- Durable construction with IP68 waterproof rating.
- Easy integration into your shield design.

Rationale: KC HiLiTES Gravity LED G4 fog lights were chosen for their compact design, performance and compatibility with aftermarket bumpers.

3.2.2.1.6 Baja Designs Squadron Pro Auxiliary Lights

Source: Baja Designs specializes in high-performance off-road lighting.

Design Features:

- High brightness LED light with long visibility.
- Durable housing to increase durability
- Can be used for spot or flood beam patterns.
- Versatile installation options for custom designs.

Rationale: Baja Designs Squadron Pro lights were chosen for their long-range visibility and versatility to improve off-road lighting subsystems

3.2.2.2 Sensor and Wiring Subsystem

Due to the integration of factory sensors and wiring, this subsystem ensures the preservation of OEM functionality such as backup sensors and electrical components when transferred to an aftermarket bumper.

3.2.2.1.7 EAG Backup Sensor Relocation Kit

Source: EAG is known for its off-road accessories.

Design Features:

- Relocation kit to integrate OEM backup sensors into aftermarket bumpers.
- Durable bracket for secure sensor placement.
- Compatible with different shield designs.
- Maintain sensor performance.

Rationale: EAG relocation kits were selected for their specific design to allow integration of factory backup sensors.

3.2.2.1.8 Bumper Plug Trailer Hitch Plug

Source: Bumper plugs provide a solution to maintain the beauty of your car.

Design Features:

- Custom plug to fill the gap left when removing the OEM bumper.
- Maintains factory appearance when replacing OEM bumper.
- Easy installation without modification
- Durable materials for long-term use.

Rationale: Trailer shock plugs were chosen for their simplicity and effectiveness in maintaining factory appearance after bumper replacement.

3.2.2.1.9 Tekonsha Brake Control Wiring Adapter

Source: Tekonsha is a leading brand in trailer brake control solutions.

Design Features:

- Wiring adapter for brake control system integration.
- Car specific design for easy installation.
- Suitable connector for plug and playing.
- Guaranteed compatibility with OEM wiring.

Rationale: Tekonsha wiring adapters are chosen for a custom approach, ensuring seamless integration of the brake control system into the modified bumper.

4 CONCEPT GENERATION

To brainstorm potential ideas the team took benchmarking and started to create designs to be able to start to create the bumper. Each design will take certain aspects of benchmarking and combine them to create a full design. The team in addition will create several sub-system designs to best describe each function of the system to allow for the best bumper possible. The primary changes being made to the bumper are overall strength, geometry, and location of the sub-systems.

4.1 Full System Concepts

This section includes the design for the entire bumper. This section will include consideration of all the subsystems to compile it into one design. There will be three separate concepts the team wants to aim for. These are: a heavy-duty design, a medium duty design, and a lightweight design. The team discussed which designs they would like to see the most and included individual concepts of the designs. The three designs below are the final designs the team will move forward with after the analysis has been completed.

4.1.1 Full System Design #1: Heavy Duty Bumper Design

This final design is a heavy-duty design and will be the strongest of the three designs. This design includes diamond plating for impact resistance. The winch will be a winch plate to limit the weight on the bumper. This bumper has both pods and lightbars for maximum illumination. This design will be the most expensive and weigh the most. However, it will be the most durable and have the highest impact resistance of all the designs.

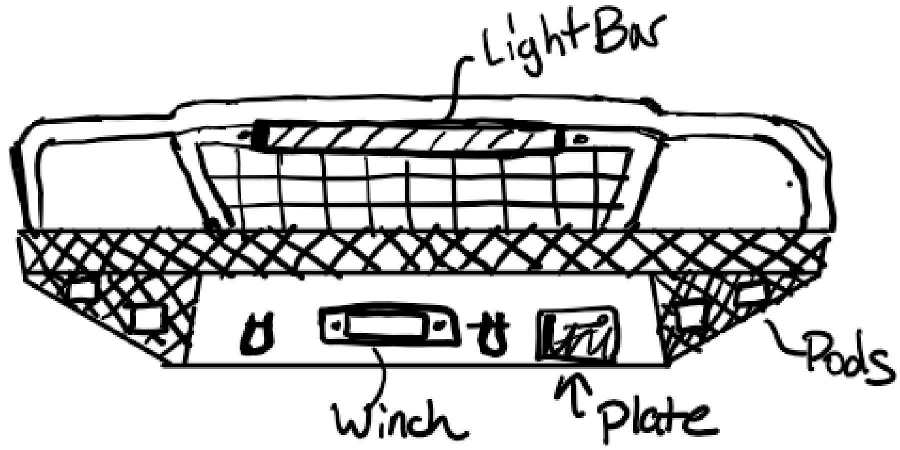

Figure 3: Heavy Duty Bumper

4.1.2 Full System Design #2: Off-Road Medium Duty Bumper

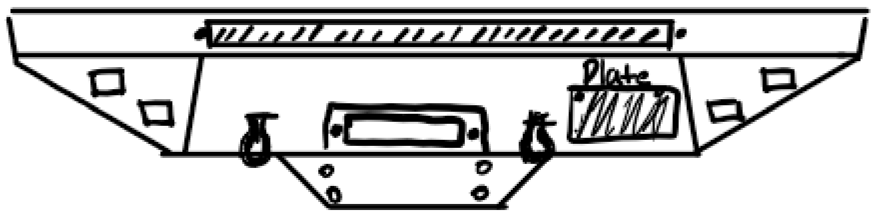

Figure 4: Medium Duty Bumper

This design is meant to look aggressive while maintaining the factory lines of the OEM bumper. This bumper is strong and should be able to support a 12-ton winch. This design includes a light bar and pods. The main benefit of this design is that the bumper will meet all the customer requirements and be lower cost than the heavy-duty bumper. The cons are this bumper does not include a bull bar in order to keep the cost low. This bumper will be moderately heavy but durable enough to meet the engineering requirements.

4.1.3 Full System Design #3: Lightweight Bumper Design

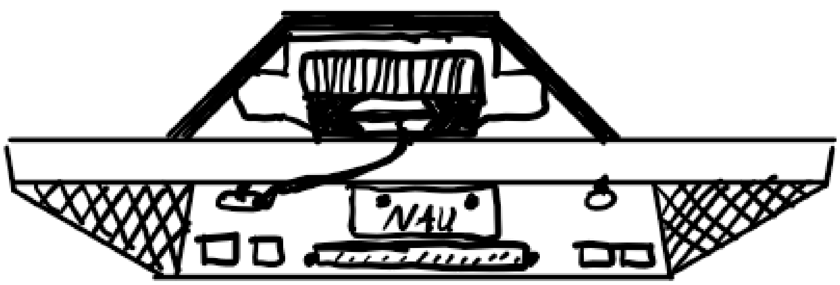

Figure 5: Lightweight bumper

This bumper design is aimed at the 2011 Jeep Liberty more than the Chevy Silverado. This design includes a plate on top of the bumper for the winch to be mounted to. The bumper is made to be light weight with a minimalistic design. This bumper would be made from aluminum and reinforced with diamond plate along the edges. This is to increase the surface toughness with the plate since aluminum is not as impact resistant. This winch will be displayed on top to save money for the lighter, more expensive, material.

4.2 Subsystem Concepts

Sub-systems are critical to any system, this is no different. Within this system the following elements were studied to better understand their interaction with the system and what design will be used moving for in order to produce a good product were the sub system function as intended.

4.2.1 Subsystem #1: Winch Locations

The winch location is dependent on the design of the bumper and how it is built into the bumper. For our designs, we came up with three unique designs that utilize benchmarked traits. These designs utilize the winch plate, the hidden winch plate, and the visible winch. Each has a benefit over the other depending on what the desired outcome is.

4.2.1.1 Design #1: Winch Plate

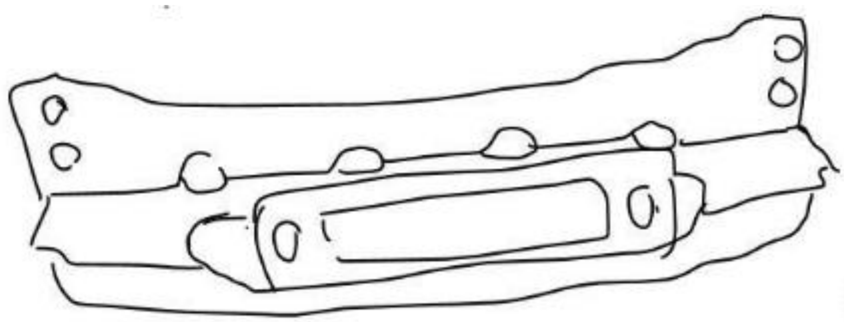

Figure 6: Winch Plate

The winch plate is critical to the overall system for there needs to be supported so that it doesn't damage the bumper or the vehicle. The winch plate lives behind the bumper and mounts to the factory mounts allowing to save space keep the current bumper if desired. The pros to this are that it conserves space and gains strength since it mounts to the frame. The cons are that the winch plate and the bumper are two separate entities.

4.2.1.2 Design #2: Hidden Winch

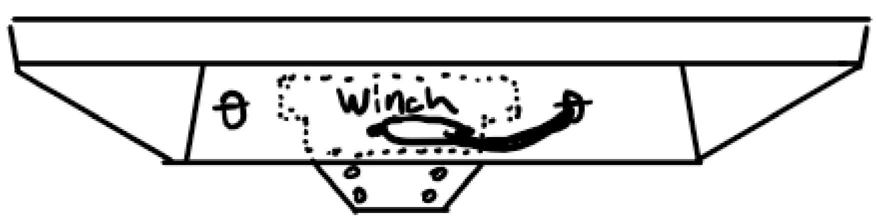

Figure 7: Hidden Winch

The hidden winch design is like the winch plate that lives within the bumper itself. This design then adds to the protection of the winch and the bumper by covering majority or the space which the bumper lives in and leaving a small space to allow for the hook and cable to travel freely. This Pros to this design are that it combined both the winch and the bumper into the same system allowing for increased strength. The con to this design is that it will weigh the most out of all the possible choices since there it the most material present to protect the winch and the bumper.

4.2.1.3 Design #3: Visible Winch

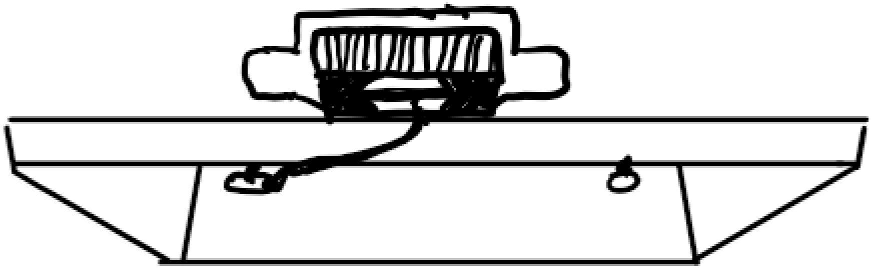

Figure 8: Exposed Winch

This design is the simplest of the three where the winch bolts to the top of the bumper, like the last design it connects both the winch and the bumper in one system. This allows easy access to the winch in the case of repair and or use. The cons to this system are that the winch is exposed to the environment as well as any collision that the bumper may endure.

4.2.2 Subsystem #2: Lighting and sensors

This subsystem is where most of the customization and designer choice come into play. This is because the functionality of the lights will still be improved equally as long as there is symmetrical lighting across the design. Therefor customer input is critical to choosing the correct in lighting the following sub system where model light bar, pod lights, and lighting rear bumper sensor.

4.2.2.1 Design #1: Light Bar front bumper.

Figure 9: Light bar concept

The light bar design allows for a large light to be placed in the center of the bumper to optimize the usage of space available on the bumper. The cons to this design are that the light bar is rather large and requires a lot of space to be placed on the bumper. The pros are since this is a large light source, it produces a large amount of light.

4.2.2.2 Design #2: Pod Lights front bumper.

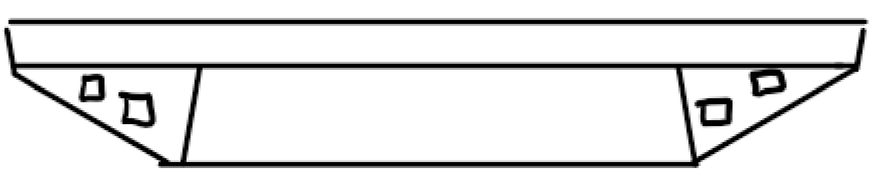

Figure 10: Light pod concept

The Pod light design is small and easy to add to the bumper and allow for the use of unused space. This design, even though it takes advantage of unused space, also takes away from the overall protection that the bumper provides for the vehicle.

4.2.2.3 Design #3: Lighting and sensors rear bumper.

These will be the rear sensors and the pod light locations for the rear bumper of the Chevy Silverado.

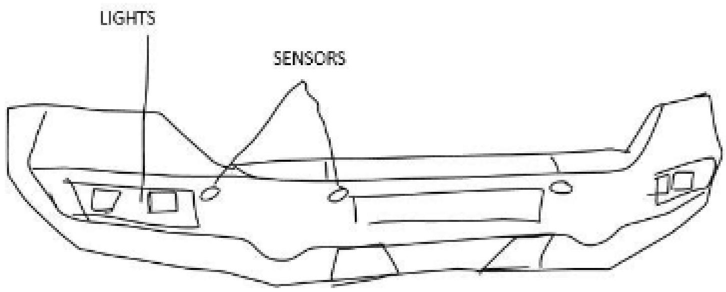

Figure 11: Sensor design

Subsystem #3: Impact resistance

Impact resistance is necessary in any vehicle bumpers, this resistance saves the bumper from accidental cracking, and it absorbs the impact to its fullest. This impact resistance will be attached to the rear bumper, and it will be to protect our bumper from any damage.

4.2.2.4 Design #1: Diamond Plated bumper.

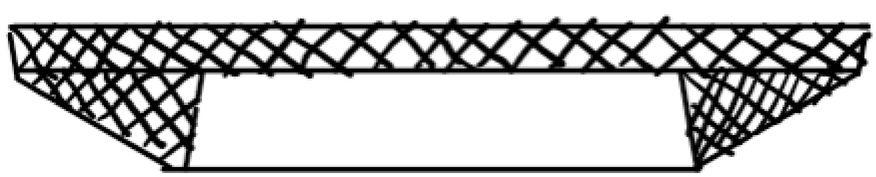

Figure 12: Diamond plate design

This design takes full use of the diamond plate that covers the bumper to allow for an additional layer of protection to the bumper. This design will inherently add weight to the design since you are adding the weight of the base material as well as the diamond plating. The benefits are that it will be much stronger having two layers. The other added benefit is that it is highly customizable.

4.2.2.5 *Design #2: Steel thickness*

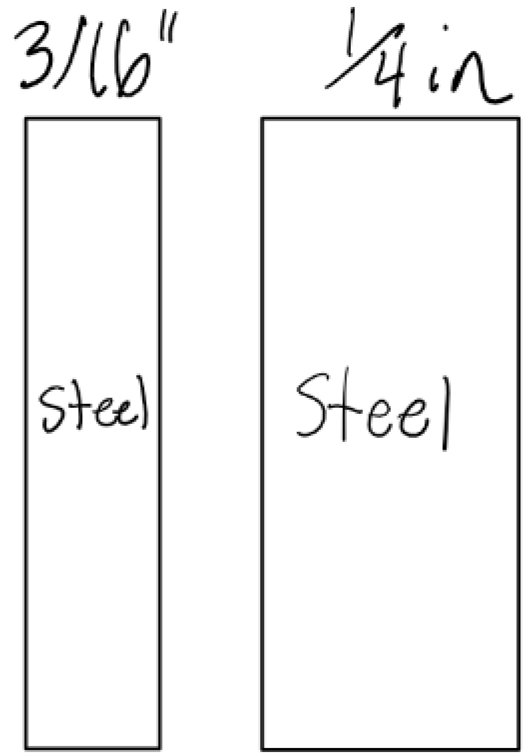

Figure 13: Steel thickness

This design incorporates a thicker base material. With a thick material the bumper will be significantly stronger, but that strength comes at the cost of weight as well as how much it will cost to buy.

4.2.2.6 *Design #3: Bumper angle*

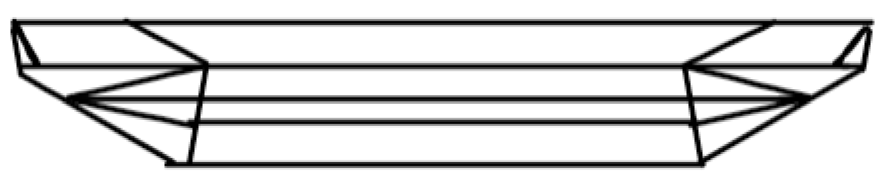

Figure 14: Bumper angles

This design incorporates the use of angles to help deflect any incoming damage to the system. The added benefit to this design is it will increase the strength of the bumper without changing the weight of the bumper. The primary downside to this style of bumper is that is more difficult to produce.

5 DESIGNS SELECTED – First Semester

The chapter is based on the key points which were considered to select and develop the required designs of the model as per the requirements of the customer. Product idea generation, evaluation, and selection have two main objectives. The first step is to come up with design ideas that meet the needs of the product's design. It depends on the design team whether all the design requirements have been determined. The second is to pick a product idea that has a good chance of succeeding. Selecting a concept that can be turned into a product that meets all the product requirements, adheres to the design schedule, and can be introduced with few manufacturing issues is what this means from the viewpoint of design. As a result, when choosing a concept design, the risks associated with its manufacturing, technological, financial, and schedule aspects must be considered.

A design team may opt to keep working on several concept designs with various success rates. The goal is to ascertain whether it is feasible to lower the risk associated with designs that are thought to provide a greater competitive advantage than other concepts with lower risks. The design team can then reassess the dangers of the various designs at a later stage in the development process and choose one design for further development. There are two objectives from the viewpoint of materials engineering. Finding possible raw materials and manufacturing methods for the product concepts is the first step. The second step is to identify the risks connected to the various materials and production methods that can be used for the various ideas. This evaluation aids the design team in removing overly risky ideas before expending excessive effort on them. Additionally, the knowledge aids the team in choosing which designs to advance.

The following processes flow chart describes the steps for the selection criteria of engineering material.

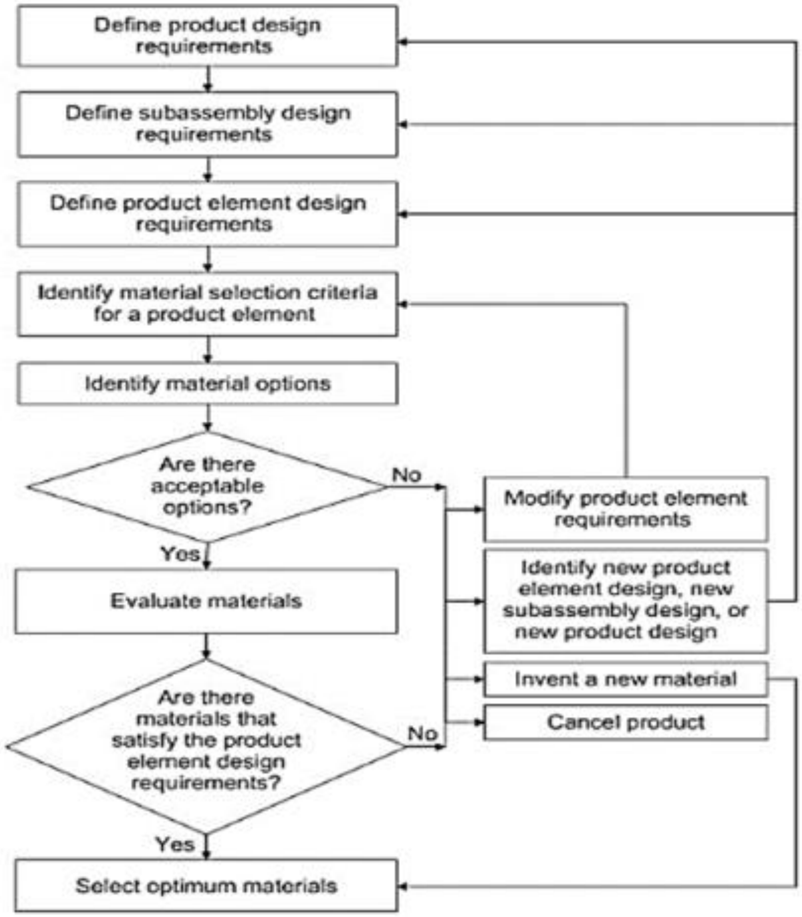

Figure 15: Process flow design chart

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It is an important aspect of engineering that whenever a design is to be created, there occurs a lot of background research and criteria for the selection and the production of the most suitable engineering design. Same is the case in this project of making different designs of the off-road bumpers of automobiles including both rear and front bumpers. The chapter describes the main criteria for the selection of the off-road bumpers for the vehicle which are technical criteria and the rationale for design selection. Before proceeding to the specific criteria of the design selection, it is helpful to go through some of the key points on which many of the design's selection criteria rely.

6 DESIGN SELECTED – Second Semester

This season, we'll use our extensive research, functional analysis, and concept production to create the final designs for the front bumpers for both cars. The next section describes the design, including the prototype developed by the team. The Design Description section provides an overview of the final design selected by the team and includes calculations that support the concepts the team generated. The implementation section discusses the team's future, bill of materials, and final CAD design. The final design was influenced by the team's technical analysis, which led to the selection of materials and hardware.

6.1 1.1 Design Description

The design for Dr. Carson's front bumper follows the factory line layout of a 2008 Chevrolet Silverado 3500HD. Since the client's main demand for the creation of the off-road bumper was to increase its durability and strength the current design is simple. The bumper features have some additional designs to make the bumper more custom made for the selected car. As well as adding angling features towards the bottom of the bumper to allow easy connection with foreign objects the client might encounter. The difference of the front bumper design in the preliminary report to our current CAD design is the placement of each item on the car. The winch that is going to be attached to the bumper is still hidden but raised higher to the top. With the winch now closer to the top of the bumper the light bar is at risk of becoming damaged if any mishaps were to occur. The team agreed that the bar light will be removed to eliminate the possibility of becoming damaged by the winch hook recoiling into it.

For Mr. David Bui the team didn't have a sketch or CAD model of the support beam for the car. When the team was collecting measurements of the 2011 Jeep Liberty in person, they notice that the car doesn't have any proper support to attach the custom bumper. The team then focused on creating some sort of support system that could be attached to the frame of the vehicle. The key to building this support system is having the part attached to the jeeps framework that was visible in the front and bottom of the car. After finding a good connection point between the car and future bumper the team need to develop a good model that could hold the winch and complete bumper up without damaging the frame. By benchmarking other car owners', the team was able to create the current support system to the jeep liberty.

The designed CAD model of the off-road bumper design is based on a thorough analysis of various types of accidents, including vehicle accidents, personnel accidents, and domestic accidents. To properly report bumper design performance, the primary focus is on finding the forces that the bumper experiences during a vehicle crash. Newton's second law is an equation used to determine the forces acting on both cars. The team used an average off-road speed of 15 mph to determine the vehicle's initial speed. The second speed is calculated by the car's reaction to deceleration after hitting an object at 14 mph. To find the acceleration, the team subtracted the second speed from the first speed and divided it by the time (0.3 seconds). The force is determined by multiplying the determined acceleration by the mass of the selected car. The comprehensive calculations performed provide a solid foundation for off-road bumper design to effectively resist the forces during vehicle collisions. See Appendix A for a more accurate calculation of the stresses applied to the shield.

V_1 = 6.7m/s - Initial Velocity

V_2 = 6.26m/s - Final Velocity

t = .3s - Time

m_C = Mass of Dr. Carson's car

m_D = Mass of Mr. David's car

a = Acceleration

F = Force

$m_C = = 3,042.7kg$ [Eqn. 1]

$m_D = = 1,950kg$ [Eqn. 2]

$a1 = = -1.5m/s2$ [Eqn. 3]

$F_C = ma = 4,564.05N$ [Eqn. 4]

$FD = ma = 2,925N$ [Eqn. 5]

The above values are the possible force the bumper will experience while the client drives on a dirt road. Using the front part of the bumper to estimate the ultimate stress force that the bumper can withstand a maximum of 400 MPa. Converting the applied force acting on a section of bumper into normal force the bumper should withstand approximately 150kPa of force being applied to it before yielding and failure will start to accrue.

The prototype the team is designing is the winch mounting plate for David's Jeep. The team plans to mount the bumper to the frame using existing holes and new holes. The prototype considered all calculations and has mitigated the risk of failure from the bumper.

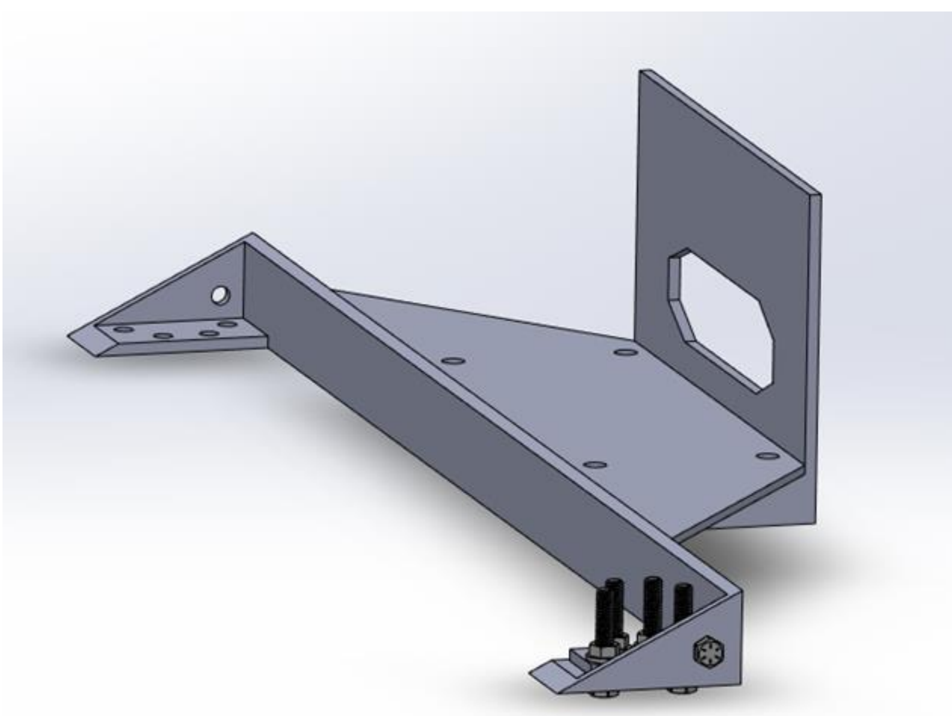

Figure 16: Prototype Plate for the Jeep

The prototype the team is designing is the winch mounting plate for David's Jeep. The team plans to mount the bumper to the frame using existing holes and new holes. The team's prototype design can be seen in Figure 4. The prototype considered all calculations and has mitigated the risk of failure from the bumper.

The prototype will use a minimum of 4 bolts to mount the bumper to the Jeep. This piece is made from mostly ¼ inch steel to ensure it is the strongest part of the bumper. The winch will be mounted to the holes on the top. This plate is reinforced by the design the team currently is using to support the winch. The mounting points will potentially be the strongest part of this bumper.

6.2 1.1 Implementation Plan

The team will implement the final design for the bumper by creating a schedule, a bill of materials, a testing procedure, a CAD model, and a physical model to be used for fitment. The team has modeled the prototype in SolidWorks and 3D printed it. The team will use the physical model to ensure proper fitment and then adjust in CAD. After finalizing the design, the team used Evans Alloys to water jet cut the metal required for the bumper. The clients David Bui and Cesar Blancarte work at Evans Alloys and will be supplying the materials that the team will pay for. After the materials have been cut out the team will weld together the bumper based off the CAD design. The team will be assembling the bumper with the vehicles present to ensure the bumper is assembled at the proper angles and dimensions. After the welds are complete, the team will grind down the bumper to ensure there are no sharp angles or potential safety hazards. The team will then clean the bumper and prepare it for powder coating. After the bumper is painted the team can install all the lights and sensors onto the vehicle and verify that the accessories work. The final touches can be made to the bumper and the bumper can be confidently delivered to the clients.

Current Budget:	$470.78	Under/Over:			31.39%	Current percent on hand:	100.00%		Total Spent by Team:	$1,029.22		
Item		Units	$/Units	Total Cost	Team Cost	Part Statues	Part Statues	Material	Description	Primary vender	Back Up	Part #
Carbon Steel Sheet		3	166.62	$499.86	$499.86	Purchased	On Hand	A36	.1875" thickness (4x8 ft) A36	Evan's Alloy	Reliance Metal	P1316
Carbon Steel Sheet		1	222.16	$222.16	$222.16	Purchased	On Hand	A36	.25" thickness (4x8 ft)	Evan's Alloy	Reliance Metal	9610
Powdercoat		3	10.99	$32.97	$0.00	Purchased	On Hand		Paint Matched Powder Coat	PCO team	PHX supplier	P114
Winch		1	399.99	$399.99	$0.00	Purchased	On Hand		Carson Winch	HarborFreight	N/A	N/A
Light Pods		1	59.99	$59.99	$0.00	Purchased	On Hand		Total of eight pods per purchase	Amazon	N/A	N/A
Tow Shackles		2	22.99	$45.98	$0.00	Purchased	On Hand		Total of two hooks per purchase	Amazon	N/A	N/A
License Plate light		2	7.99	$15.98	$0.00	Purchased	On Hand		For both rear bumpers	Amazon	N/A	N/A
Winch Guide		1	17.69	$17.69	$0.00	Purchased	On Hand		For front bumper winch	Amazon	N/A	N/A
Bolts		50	2.49	$124.50	$0.00	Purchased	On Hand		All bolts for the bumper	NAPA	Copper State	N/A
Filler Rod		4	34.3	$137.20	$137.20	Purchased	On Hand	SAE 4130	SAE 4130 rod: 1lb pack	Arc-Zone	N/A	SAE4130-332-36-1
Tank of Argon		2	85	$170.00	$170.00	Purchased	On Hand	Argon (Ar)	Size 60 High Pressure Cylinder	Air Gas and Linde	N/A	N/A

Figure 1616: Bill of materials

A bill of materials has been included as well as the team schedule. The bill of materials is shown in figure 16 above and shows the itemized cost and total cost of the project. The bill of materials breaks down each item that the team will purchase and displays the total cost to build all three bumpers. The team estimates they will spend $1029.22 on steel, winches, and accessories. The team started with a budget of $1500 which leaves a remainder of $470.78 for the team to spend on unexpected expenses.

Figures 17 and 18 show the schedule for each semester.

Summer				
Finalize Cad and convert to DFX	Team	0%	5/21/23	6/4/23
Materials cut out	Team	0%	6/4/23	6/18/23
Assembly/Welding	Team	0%	6/11/23	7/9/23
Test fitment	Team	0%	7/16/23	7/30/23
Modifications to original design	Team	0%	7/30/23	8/27/23
Final Fitment check for both front bumper	Team	0%	8/13/23	8/27/23
ME486C Self learning	Team	0%	8/13/23	9/4/23
Project management	Team	0%	8/20/23	9/11/23

Figure 17: Summer schedule

Tasks leading up to 33% build				
Self Learning Activity	Individual	0%	8/27/23	9/13/23
Project Management	Team	0%	9/13/23	9/21/23
Website Check 1	Individual	0%	9/21/23	9/27/23
Completely done with one bumper	Team	0%	2/24/23	9/27/23
Start Testing	Team	0%	9/27/23	10/13/23
Tasks leading up to 67% build				
Finalized Testing	Team	0%	10/12/23	10/23/23
Ugrads Registration	Team	0%	10/23/23	10/30/23
CAD adjustments of second bumper	Team	0%	10/23/23	11/6/23
Finalize second bumper	Team	0%	11/6/23	11/13/23
Draft of Poster	Team	0%	11/6/23	11/20/23
Tasks leading up to 100% build				
Cad adjustments of third bumper	Team	0%	11/16/23	11/22/23
Finalize Third Bumper	Team	0%	11/23/23	11/30/23
Final Poster	Team	0%	11/23/23	11/29/23
Final Presentation	Team	0%	11/26/23	12/2/23

Figure 18: Predicted fall schedule

The team plans to complete at least one bumper by the end of the summer. At minimum, the team will have all the materials cut out and ready to be welded. This will put the team on track to achieve the deadline for the 33% build in the fall. The team currently has a prototype of the mounting plate for David's Jeep as well as a CAD model of Carson's front bumper. The team will

use the summer to get ahead of where they should be going into the final semester.
The original CAD model for the Chevy Silverado's front bumper is pictured below. This CAD model implements a light bar, light pods, and an area to mount the winch to.

Figure 19: Initial front bumper design

7 Project Management – Second Semester

7.1 Gantt Chart

The Gantt chart for the second semester is more extensive and detailed compared to our initially theorized expectations. Based on the information presented in the first semester, which introduced the team members and outlined the team capstone, as well as the extensive research conducted, we underestimated the amount of work required. The team faced unexpected tasks such as updating presentations and performing additional calculations, which posed challenges in staying on track, especially given the capstone's heavy focus on CAD design. Another challenge arose when the professor encouraged the team to expand further and provide exciting, unconventional information. Despite these challenges, the team managed to finish on time and establish a sturdy foundation for the capstone project.

Tasks leading up to 33% build				
Self Learning Activity	Individual	100%	8/27/23	9/13/23
Finish CAD Package	Team	100%	8/27/23	9/26/23
Project Management	Team	100%	8/27/23	9/6/23
Engineering Calculations	Team	100%	9/4/23	9/8/23
Website Check 1	DEJA/Team	100%	9/2/23	10/9/23
Finalize Designs with Client	Team	100%	9/26/23	9/18/23
Finish Ordering Process	Team	100%	9/24/23	9/28/23
33% Build Update	Team	100%	9/18/23	9/25/23
Receive Parts	Team	100%	9/27/23	10/2/23
Tasks leading up to 67% build				
Finish CAD for 3rd bumper	Team	100%	9/4/23	10/1/23
EFEST Registration	Team	100%	10/21/23	10/23/23
Welding Rear Bumpers	Team	100%	10/13/23	10/31/23
Testing rear Bumpers	Team	100%	10/31/23	11/6/23
Finalize last rear bumper design	Team	100%	10/31/23	11/7/23
Finish Ordering Process final bumper	Team	100%	11/7/23	11/10/23
Receive parts	Team	100%	11/10/23	11/24/23
67% build Update	Team	100%	10/11/23	10/16/23
Draft of Poster	Team	100%	10/21/23	10/30/23

Figure 20: Gantt chart 67% build

Tasks leading up to 100% build				
Welding Final Bumper	Team	100%	10/26/23	11/9/23
Test Last Bumper	Team	100%	11/9/23	11/16/23
Finalize Testing Plan	Team	100%	11/16/23	11/30/23
Final Poster	Team	100%	11/3/23	11/13/23
Final Presentation	Team	100%	11/4/23	11/14/23
Testing Video	Team	100%	11/10/23	11/20/23
Final Report	Team	100%	11/14/23	11/27/23
Product Demo/Testing	Team	100%	11/16/23	11/27/23
Final Website Check	Team	100%	11/9/23	11/27/23
Final Project Deliverables				
Final Cad Package	Team	100%	12/1/23	12/10/23
Presentations	Team	100%	12/2/23	12/8/23
Practice Presentations	Team	100%	12/1/23	12/4/23
Final Report	Team	100%	12/1/23	12/10/23

Figure 21: Gantt chart 100% build

7.2 Purchasing Plan

Carson Pete and Cesar Blancarte set the budget of $1500 for the group to produce three sturdy bumpers. Formerly the cost for manufacturing all three bumpers were estimated to use the whole budget and a couple hundred over for insurance of human error from the group. The reason of the budget going over throughout the manufacturing process was caused by the material, A36. Each steel sheet was ranging from $1,000 to $350. As the team progressed in CAD modeling the design for the bumpers, there was recommendations to where we should purchase the 3/16ths and 1/4th metal sheets which lowered purchasing cost.

Current Budget:	$179.24	Under/Over:		11.95%	Total Spent by Team: $1320.76
Item	**Units**	**$/Units**	**Total Cost**	**Team Cost**	**Description**
Carbon Steel Sheet	2	352.96	$705.92	$705.92	.1875" thickness (4x8 ft) A36
Carbon Steel Sheet	1	560.1	$560.10	$560.10	.25" thickness (4x4 ft)
Winch	1	322.99	$322.99	$0.00	David Winch
Winch	1	499.99	$499.99	$0.00	Carson Winch
Light Pods	8	59.99	$479.92	$0.00	Total of eight pods
Steel Pipe	1	54.74	$54.74	$54.74	2.5" OD with length being 5 feet
Tow Shackles	4	22.99	$91.96	$0.00	Total of two hooks
Light Bar	1	32.39	$32.39	$0.00	Length of light bar is 22"

Figure 22: Initial budget

All types of purchases for the project have been documented in an excel sheet that shows what the team paid, what the client paid personally, the quantity, the cost, and the description of the item. The purpose of this type of documentation is to keep track how much the team has spent constructing the bumpers, this provides accurate information when presenting invoices to our clients. Everything would be categized to what the item is, why the group bought the item, where the item was purchased, and the link of the page. The excel sheet also had two columns that showed the team if the items were purchased and if it was in route or received. This helped ensure that there isn't any repurchasing of items or wasting time on waiting for an item that was already in house. To help identify the item, images of what the item looks like, which is attached in the column located on the left of the label name (reference *Figure 16*).

The first purchase that the team made was ordering the carbon steel sheets since the product itself was a steel bumper. The 3/16th inch hot-rolled steel sheet was primarily used for both rear bumpers, with an extra sheet in case cuts don't come out right or human errors during the manufacturing processes. The 1/4th inch hot-rolled steel sheet was used for the front section of Carson Pete's front bumper, with some 3/16th inch pieces that would be later welded on the side. The filler rod, a 3/32" SAE 4130 compatible with the carbon steel sheets, needed to be purchased from the group since Cesar Blancarte was allowing the members to come and use his personal TIG and MIG machine to weld all individual pieces to structurally assemble the bumpers. The size 60 tank of argon is listed in our budget because TIG welding requires argon gas to maintain a good welding process, and with the size of each bumper, the group used a ton of gas and needed to refill the tank to continue welding.

$1,029.22 is the amount the group spent manufacturing all three bumpers. These expenses include the sheet metals, welding equipment, and testing materials. There was zero cost for production cuts and bending since Cesar, our client, handled the cutting process. For the bends on certain material pieces the team had access to a press brake, leaving the labor cost of production staying at $0. Also, the welding labor costed zero dollars since one of the members knew and is certified to weld, only dealing with the filler rod and tank refill going towards the total welding process being $307.2. The other items are accessories that the clients personally purchased themselves for more customization that the team later attached onto the bumpers, this was the client's decision. All three hot rolled carbon steel sheet cost $722.02 leading to our finalized total; this shows that the material was purchased at a lower price leading to each bumper being roughly $343.07 each per production.

7.3 Manufacturing Plan

Three bumpers are expected from the group, one rear bumper for a 2018 Dodge Ram 3500 Laramie and two bumpers, a rear and front, for a 2008 Chevy Silverado 3500HD. To start, a CAD design needs to be constructed, analyzed, and approved by the clients to proceed. First semester, the group had created two SolidWorks models. One was a support beam to attach the front bumper once manufactured for our past client, David Bui, and the other model was the front bumper for Carson Pete. At the beginning of the second semester there was a client change, leading to new customer requirements and the manufacturing process. Below is the finalized CAD design for all three models, now the group can proceed with the manufacturing of the bumpers.

With the completion of the CAD model of the bumpers, the team needs to convert the design into a DFX file. The CAD model is constructed as a fully assembled 3D model that needs to be converted and taken apart into a 2D layout for the waterjet. Building the bumpers by cutting individual pieces from the steel of metal provides flexibility when assembling the bumper. The customization that these methods allowed became handy when a client did not like the design or forgot to mention custom upgrades on the vehicle. If the group does not have access to any machines to press a single metal sheet, the team had to build three different models, and there is little room for flexibility or changes to the design.

Once each file has been properly transformed into a 2D layout of each individual piece on the DFX file it is later turned into a G-code. The G-code is for the water jet to understand what we want the machine to cut out on carbon sheet metal. How the water jet cuts into the metal sheet are by using high pressurized water, ranging from 30,000 to 90,000 psi, and an abrasive garnet sand, which is combined with the water to enhance the cutting capabilities of the machine. The nozzle, that narrows the stream and directs the pressurized mixture, follows the program path for cutting all the bumper parts. The path program is created by analyzing the G-code that the team created and provides an estimate of how long the cut will take, how the machine will cut the metal sheet, speed change, feed change, and if there are any incomplete shapes. There was a total of four different speed settings that the water jet provided that changed the cut time and how clean the abrasive mixture cuts the material. Cut speed three was set on the water jet, which was agreed upon with all team members, because even though the cut was not completely a clean finish each individual part was getting welded. After reviewing the path program, the sheet of metal is clamped down then submerged under water to keep the metal from overheating and warping.

Each piece cut from the water jet was dried off to decrease the material's erosion process. Mentioned before that, some metal parts must be bent to properly assemble the bumper together. The workshop had an old WWII sheet metal bending brake that no one in the group knew how to operate and taught how to operate the machine. Since the machine is old, the measurements of how much the metal will be bent is non-existent and the group had to adjust to bending each necessary part little by little until we hit the correct angle. With this machine being so old, once the press had entered a cycle and contacted with the part, there was no way of reversing the bender to get it off the part until it completed its whole cycle. If the part were over bent, we would turn the part upside down, lift the bender, and lightly press it down to the correct angle. Operations on this machine was difficult because controlling the speed was all based on the amount of pressure the user was putting on the press pad.

After all the required parts that needed to be bent were aligning correctly, the group continued onto the next part of the manufacturing process. Before each bumper could be fully welded the team needed to ensure that the bumpers would look right on the vehicle and see if there is any modification that needs to happen. A metal inert gas (MIG) was used in the welding process to help spot weld and structural weld the whole bumper. The MIG is a welding machine that uses constant voltage power to heat up a selective area with electric current leading the melting of the metal and filler that is being constantly fed into metal puddle and fused. Fast and efficient is the focus of a MIG machine, to ensure proper functionality the team made sure that the part was grounded and used argon gas to help keep impurities out of the weld. By spot welding all three bumpers together, everyone can envision what the final production of the bumpers would look like and spot issues. Luckily, the spot-welded bumpers looked great, and both clients approved to move further with the process. The next step involved structurally welding the bumpers. The focus was using a MIG machine on the inside of the bumper since the welding causes more splatters from the impurities. This saved time and money during the manufacturing process.

Next, the team needed to weld the front of the bumper to conceal the assembly process of the build. This was achieved by using tungsten inert gas (TIG), which provides great precision and control, allowing for clean welding. Similar to MIG, but instead of having an automatic feed, TIG uses a non-consumable tungsten rod to deliver the electrode arc onto the metal and is hand-fed with a filler rod. The process of fully welding each bumper took over 12 hours of work since it is a delicate process, and the welder aimed to reduce the grinding time. Despite TIG welding being cleaner than MIG because the area is more controlled, decreasing the number of impurities entering the weld puddle, the final look and feel are not aesthetically pleasing. The team needed to grind down all the uneven metal on the bumper until there was a fully flush feel. The outside of the bumper was ground down using a grinder, and when grinding the corners of the bumper, an angle grinder was used. The production of the bumper was fully complete and could be handed over to our sister team so they could powder coat the bumpers and then attach them to the vehicle.

8 Final Hardware

8.1 Final Hardware Images and Descriptions

8.1.1 1.1.1 Rear Chevy Bumper CAD Packet

This image shows a comprehensive diagram of the Chevrolet rear bumper CAD package, showing the detailed design and functional features included in the aftermarket bumper.

Structural Precision:

- CAD renderings highlight design precision and ensure a seamless fit with the Chevrolet Silverado 3500HD frame.
- Precise lines match factory lines for aesthetic continuity.

Material Composition:

- Visual representation of high strength steel compounds of critical structural components.
- Clear integration of high impact plastics in areas where flexibility is required.

Winch Mount and Lighting Integration:

- The installation part of the winch compatible with the 12-ton winch is clearly stated.
- Groove and mounted visual cues for additional off-road lighting improve visibility.

Sensor and Wiring Integration:

- Highlights OEM sensor locations and shows retention of factory backup sensors.
- Visible wiring routes and connection locations ensure a user-friendly installation process.

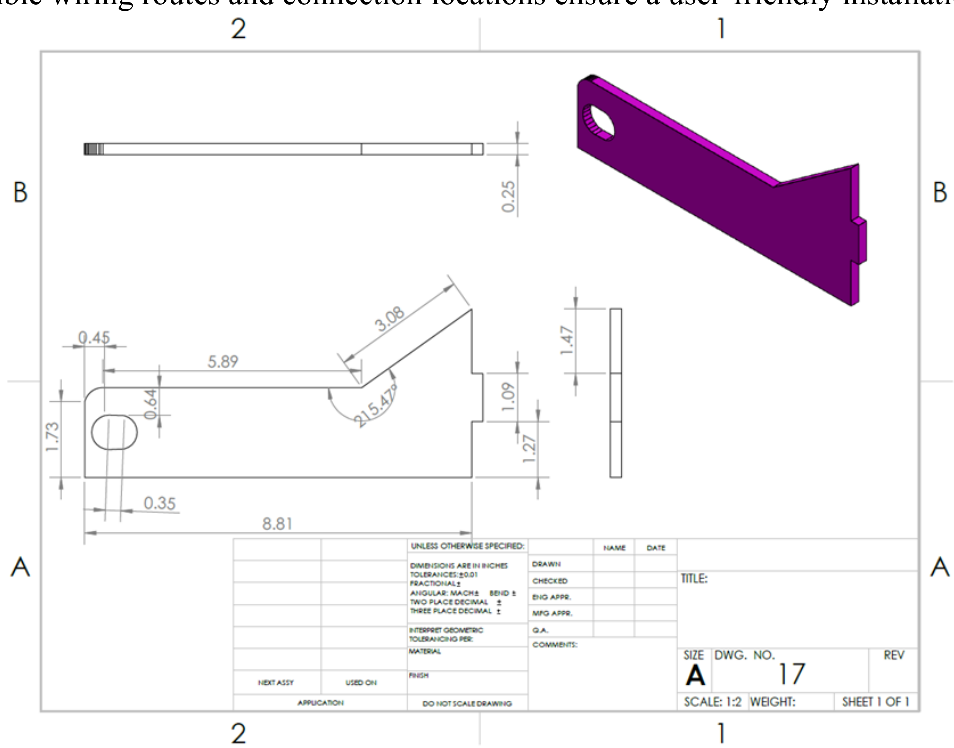

Figure 23*:* Size: A; Scale: 1:2; DWG. NO. 17

Finish and Coating Options:

- Expression of color matching options with bed lining with powder coating or paintable bedspread.

– Close-up showing anti-corrosion coating for long-lasting durability.

Installation Guidance:

– CAD annotation showing OEM mounting points for easy installation.

– Clear instructions are provided in the CAD package to guide the user.

Customization Choices:

– Rendered images showing the different color options available for powder coating.

– CAD images for additional features. Users can customize the bumper based on their preferences.

Safety and Compliance:

– CAD elements highlight compatibility with airbag crash sensors.

– Image showing the load bearing tests performed to ensure compliance with safety standards.

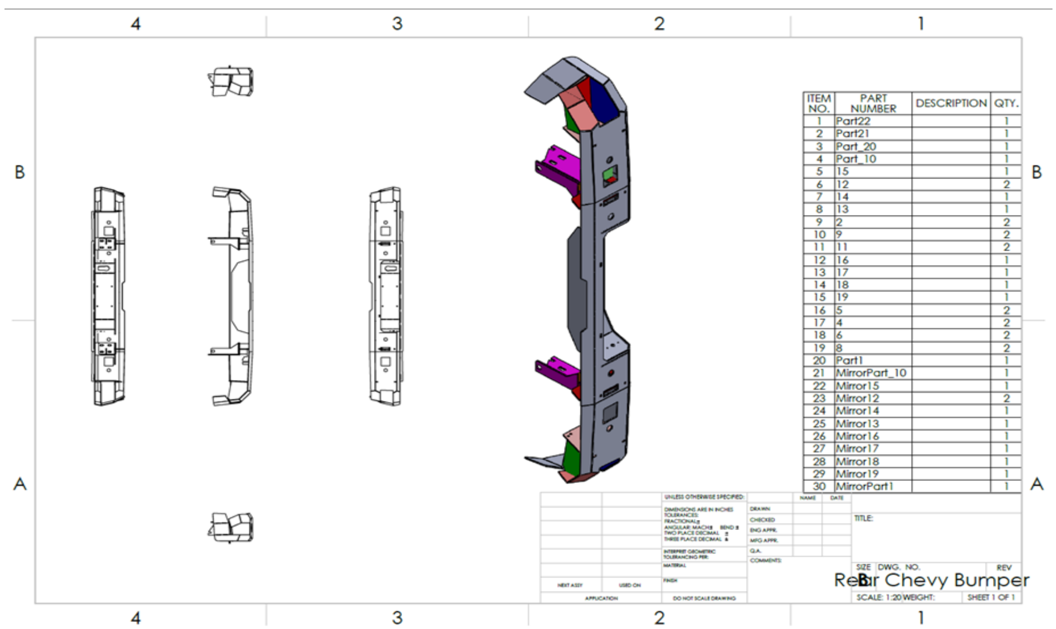

Figure 24*:* Rear Chevy Bumper CAD Packet

8.1.2 1.1.1 Front Chevy Bumper CAD Packet

The Chevrolet Front Bumper CAD Package features detailed design and engineering to ensure seamless integration with your 2008 Chevrolet Silverado 3500HD. Here is a summary of the features captured in the CAD package image:

Structural Precision:

– All lines and details of the shield are accurately recorded in the CAD model.

– Structural elements are clearly defined, which shows the strength and durability of the design.

Winch Mounting Platform:

– Dedicated space for 6–10-ton winch is evident in the CAD model.

– Attachment points are strategically placed to ensure optimal weight distribution.

Lighting Integration:

– Displays specified slots and mounts for additional off-road lighting.

– CAD package documents the thoughtful integration of LED lights for increased visibility.

Sensor and Wiring Maintenance:

– CAD model highlights retention of factory backup sensors as indicated by specific sensor locations.
– Wiring routes are carefully maintained, and wiring routes are visible for easy installation.

Material Selection:

– The distinctive shade and texture highlight the use of high strength steel in the structural components.
– The impact-resistant plastics are clear and highlight the comprehensive material selection.

Color Options and Finish:

– CAD models may include variations that show different color options for powder coatings.

Surface coatings are shown for visual representation, either powder coating or substrate lining.

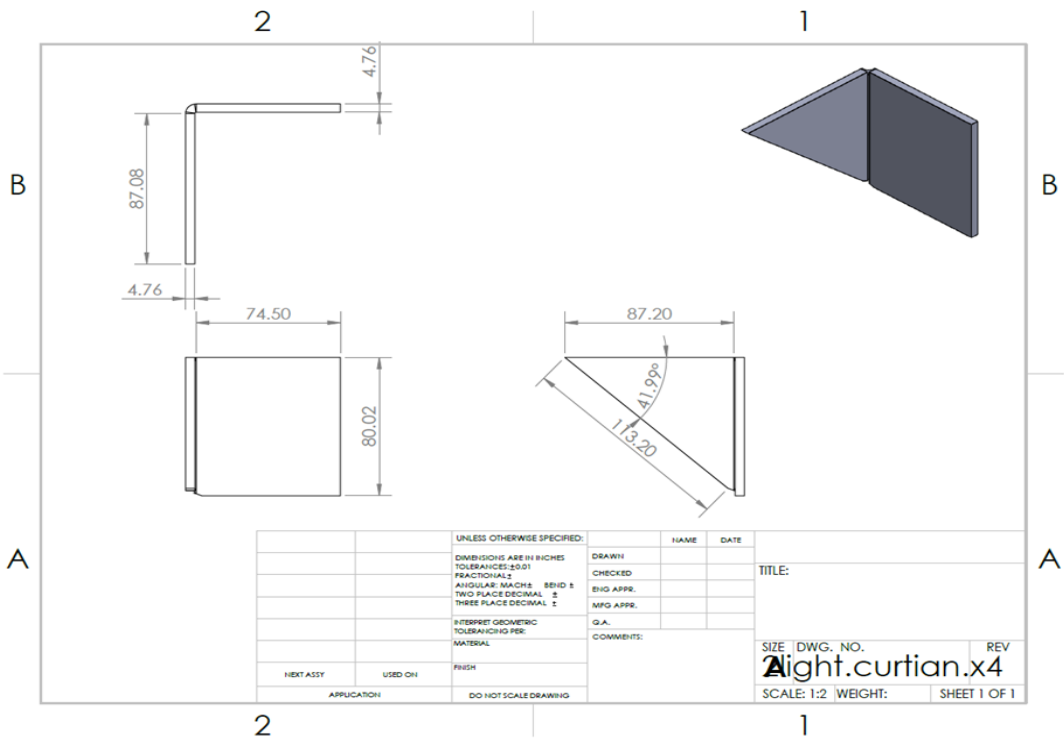

Figure 25*:* Size: A; Scale: 1:2; DWG. NO. 2light.curtian.x4

OEM Mounting Points:

– Clearly marked mounting points match OEM locations and easily replace your factory bumper.
– CAD package registers alignment with existing frame structure.

Customization Features:

– CAD models may contain customizable elements, such as changes to design elements or integration of accessories.
– If customization options are available, they are shown for user review.

CAD Packet Legibility:

- The pictures should clearly show the dimensions of the shield, the transfer of materials and the overall design.
- Annotations may explain specific design options and features.

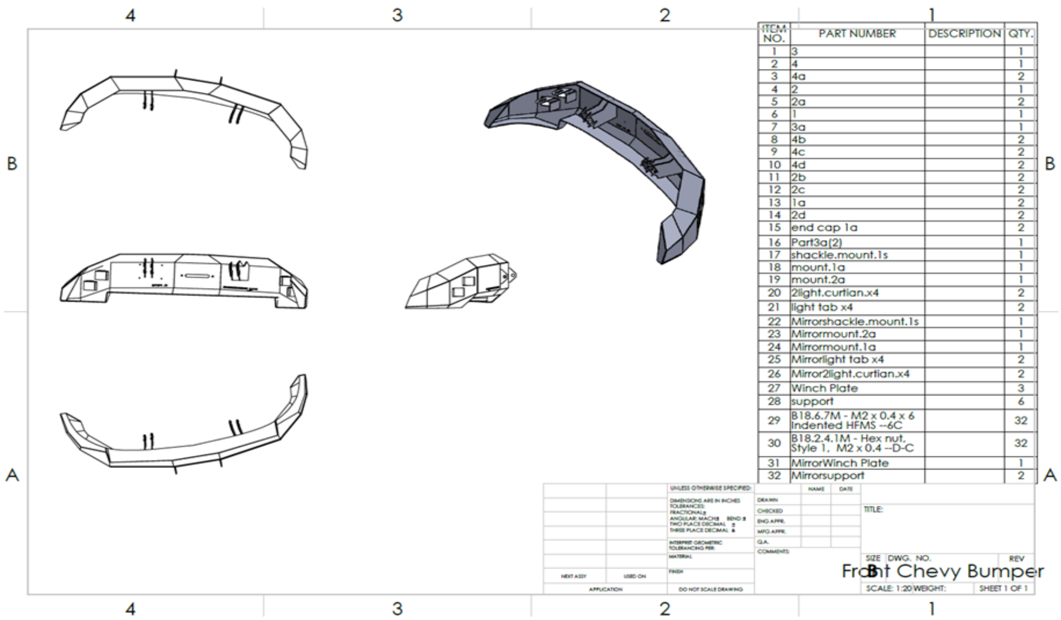

Figure 26*:* Front Chevy Bumper CAD Packet

8.1.3 1.1.1 Rear Dodge Bumper CAD Packet

The Rear Dodge Bumper Packet CAD showcases an innovative design carefully crafted using advanced CAD software. This design balances beauty and function and blends seamlessly with the lines of Dodge vehicles.

Structural Components:

- CAD images show a solid frame structure that highlights the use of high-strength materials.
- Precision engineering ensures a perfect fit for your Dodge vehicle and enhances its overall appearance.

Winch Mount Integration:

- Shows the designated space for winch integration and enables the installation of powerful winch systems.
- CAD designed for durability and optimal support of your winch during off-road adventures.

Lighting Features:

- Clearly visible internal slit for additional off-road lighting for increased visibility.
- Designed to accommodate a variety of lighting options, from LED bars to spotlights.

Sensor and Wiring Integration:

- Well-defined space to store OEM sensors and maintain vehicle safety features.
- CAD images show organized and hidden wiring channels to ensure a clean and professional installation.

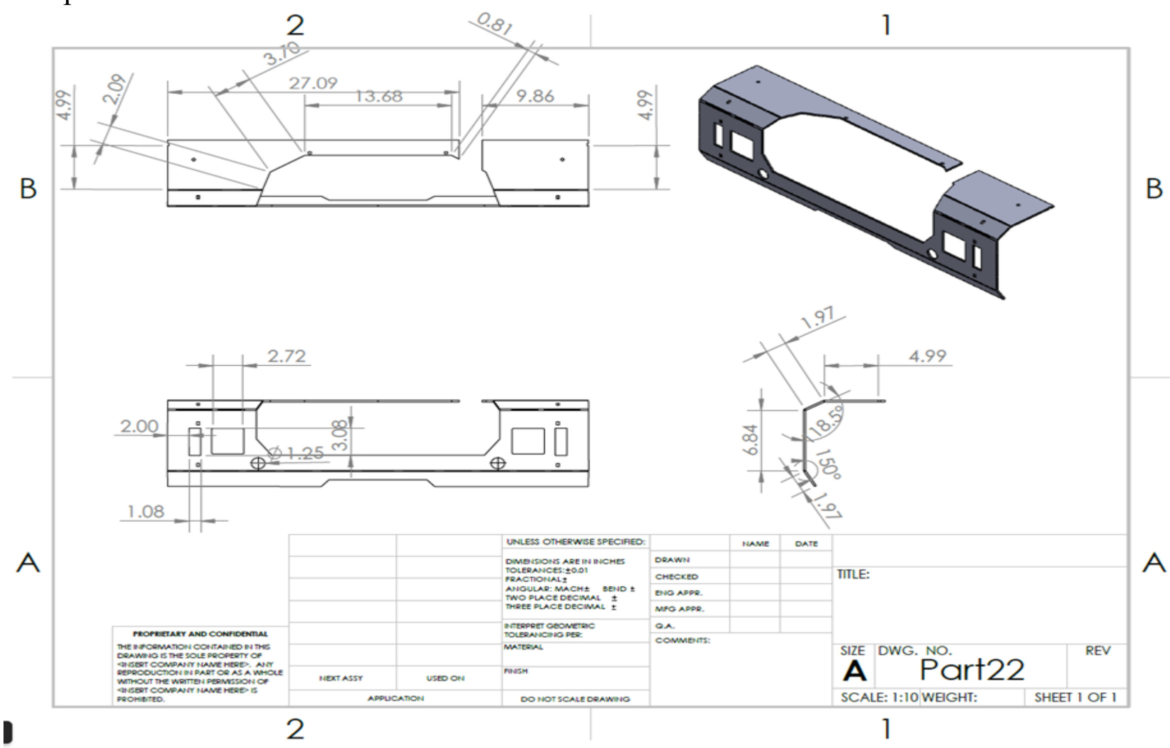

Figure 27: Size: A; Scale: 1:2; DWG. NO. Part22

Finish and Coating:

- A variety of finish options, including powder coating and flat lining, help you customize your look.
- Features a durable coating design that highlights its resistance to corrosion and environmental elements.

Installation Guide:

- Marked locations for easy alignment with vehicle mounting points.
- CAD packages may include step-by-step assembly instructions for user-friendly installation.

Tow Hitch Integration:

- The towing display adds versatility to the bumper for towing purposes.
- CAD drawing shows a reinforced section to support the tow clip.

Material and Durability:

- The possibility of annotation about the use of high-quality steel or other durable materials.
- Design elements with a focus on impact resistance for increased off-road durability.

Customization Options:

- Possibility of cutting changes for user customization, including style patterns.
- Space for additional accessories allows users to customize the shield.

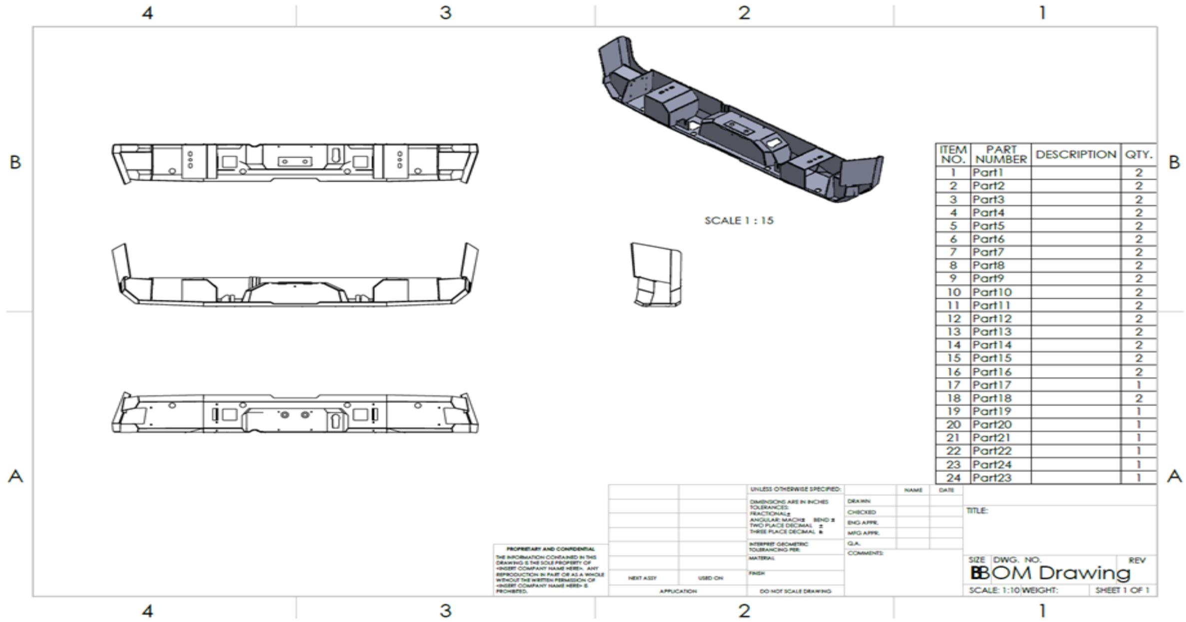

Figure 28: Rear Dodge Bumper CAD Packet

8.2 1.1 *Design Changes in Second Semester*

During the second semester, significant design improvements were implemented in various subsystems to improve performance and address specific requirements, ensuring overall system improvement and increased efficiency.

8.2.1 1.1.1 Design Iteration 1: Change in Winch Mount Subsystem discussion

During the first design iteration of the winch mounting subsystem, we identified opportunities to improve both the functional and aesthetic aspects of the shield. The main changes were the integration of a dedicated compartment for the winch and optimization of its placement in the subsystem, resulting in improved performance and a simpler appearance. The purpose of this modification was to create a stronger and more attractive winch installation subsystem.

Original Design:

Early designs of winch mounting subsystems had standard attachment points without a dedicated winch housing.

Change Description:

For the first time, we realized that we needed to optimize the integration of the winch into the bumper to improve performance and aesthetics. The main change was a redesign of the winch mounting subsystem to include a special winch compartment strategically placed to improve weight distribution and accessibility.

Pictorial Evidence:

Original Design:

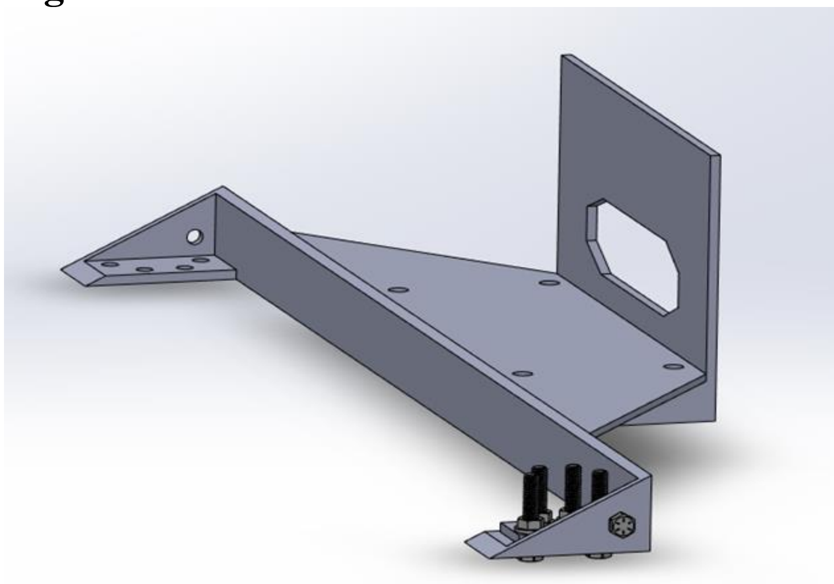

Figure 29: Original winch design for the Jeep

Figure 30: Original front bumper design

New Design:

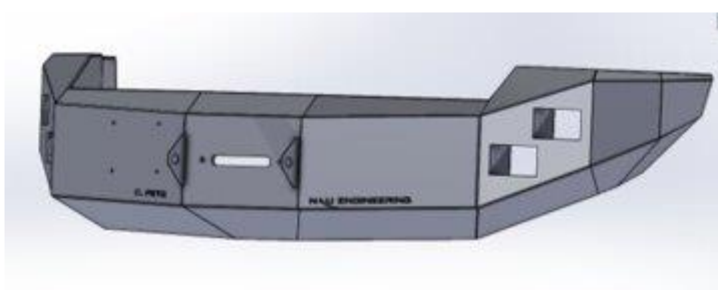

Figure 31: Final front bumper design

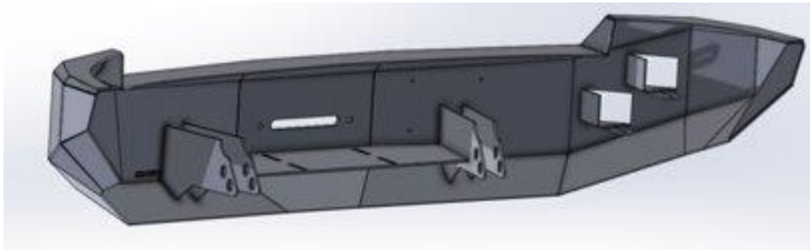

Figure 32: Final winch plate design

Justification:

The decision to change the winch mounting subsystem was based on the desire to provide a seamless and user-friendly experience for users. The updated design provides better winch support, ensures stability during use, and improves the overall appearance of the bumper.

8.3 1.1 Challenges Bested

Our team faced several challenges to achieve 100% hardware completion within the specified time frame. One of the main challenges was the complexity of the CAD design process, particularly in ensuring the precise integration of the winch and other subsystems. This complexity made the design phase longer than expected. To overcome this challenge, we implemented a collaborative and iterative design approach. Regular team meetings and feedback sessions were organized to allow each member to provide insight and quickly address potential design issues. This collaboration significantly accelerated the design process and improved the overall quality of the CAD model.

In addition, sourcing and obtaining quality materials within the budget and project schedule presented logistical challenges. We addressed this by creating strategic partnerships with local suppliers and leveraging existing relationships to streamline the procurement process. This approach allowed us to secure materials on time and within budget constraints. In addition, unexpected technical problems in the water jet cutting process caused unexpected delays in the production phase. Our team responded by working closely with Evan’s Alloys to proactively troubleshoot issues and adjust production schedules. This adaptability and quick problem-solving approach played a key role in minimizing the impact of delays.

9 Testing

9.1 Testing Plan

Based on the QFD below in figure 27 the team composed of three test methods to test fully test the bumper to meet the engineering/ customer requirements. The test is designed to isolate a specific variable and determine if the bumper will meet the needs of the customer requirements by being within tolerance of the engineering requirement. The test are as follow in table

Table 3: Test methods and Customer/Engineering Requirements

Experiment/Test	Relevant Design Requirements
EX1- Fitment Test	CR1,CR2,CR4,CR5,CR7,CR8,CR9,ER3
EX2- Material Strength Test	CR2,CR6,CR7,ER1,,ER4,ER5
EX3- Bumper Pull Test	CR2,CR6,ER1,ER2,ER4,ER5

Yield Strength (MPa)		1	1	0	1
Pulling Strength(kN)	1		1	0	1
Ultimate Strength(Mpa)	1	1		0	-1
Weight (lb)	0	0	0		0
Material Deflection(mm)	1	1	1	0	

Engineering Requirements / Customer Requirements	Importance	Yield Strength (psi)	Pulling Strength (lbs)	Ultimate Strength (Mpa)	Weight (lbs)	Material Deflection(mm)	Rough Country	Paramount	Icon
Engravement	2	1	1	1	1	1	1	1	1
Winch Support	9	8	8	8	6	6	1	1	1
Inexpensive	6	6	6	6	7	6	7	7	8
Offroad Lighting support	3	3	3	3	3	3	5	6	7
Back up sensors	3	1	1	1	1	1	2	2	1
Strength and Durability	9	9	9	9	9	8	7	9	7
Maintain legality	4	4	4	4	1	3	9	9	9
Functionality	5	2	2	2	4	1	9	7	5
Factory Lines	6	6	6	6	8	5	9	9	9
Rust resistance	1	9	7	9	9	9	9	9	9
Importance Raw score		63	66	63	63	54			
Relative Percentage Importance		20	21	20.5	20.3	17.3			
Competive Design Assessment	#4					X			
	#5	X	X						
	#6			X	X				

Figure 33: QFD

Fitment Test

This test aims to ensure the bumpers will have proper fitment on the vehicles and that the bumpers pass the design requirements from the customers. To complete this test all the original functionalities of the bumper need to be restored. This includes the rear backup sensors, the license plate lights, and the original mounting points to work as expected. The test will verify that the bumpers follow the factory lines and are safe for other motorists and the client. The design requirements that will be tested are as follows: CR1- Engravement of the front bumper, CR2- Winch support, CR4- Offroad lighting support, CR5- Factory back up sensors, CR7- Maintains legality and functionality, CR8- Match factory lines, CR9- Powder coated, and ER3- Weight. This test will be based purely on visual data and measurements.

• Procedure

1. Install all the bumpers
2. Check fitment
3. Adjust as needed
    a. Verify fitment
4. Tighten all bolts to specified torque.
5. Ensure lights and sensors work properly.
    a. If applicable
6. Verify with clients that all parts fit properly, bumpers look level, and have good clearance

Material Deformation test:

This test is designed to verify that the material will deform as expected per the analysis preformed earlier in the year. This will demonstrate that the following material will increase the strength of the bumper as intended and have minimal deformation. Primarily testing the engineering requirements of the ER1- Yield strength, ER4- Modulus of toughness, and ER5- material deformation. The following design requirements will be tested as well CR2- Winch support, CR6- Increased strength and durability, and CR7- Maintains legality and functionality.

This function will be tested with the use of a strain gage and a arbor press. The press applies force to a piece of scrap material of the same material and thickness of the bumpers. Force will be applied until the material starts to plasticly deform and the results will be compared to the material thickness and mounting plate technical analysis. The variable that will be isolated will be strain (mm) of the material.

Procedure

1. Configure wheat stone bridge to be able to gather data using a strain gage and calibrate the gauge.
2. Place strain gage on the opposite side of the material being pressed approximately 2 inches away from the point of contact of the press.
3. Clean the surface of the area where the strain gauge will be placed.
4. Place tape on the top of the strain gauge.
5. Apply glue to the cleaned surface and place strain gauge and tape over the glued area.
6. Connect the strain gauge to a data collection device and set up the program. In order to collect data.
7. Begin to apply force to the strain gauge through the press until plastic deformation is achieved.
8. Repeat the test 2 additional times to achieve a statistical comparison.

Bumper Pull Test:

The test will also prove that the welds and mounting points are able to sustain a continuous force. The Bumper pull test will help to validate the following design requirements: CR2- winch support, CR6- increased strength, and durability, ER1- Yield strength, ER2- Towing/ pulling strength, ER4- Modulus of toughness, and ER5- Material deflection (mm). This test is meant to simulate our client getting stuck and being pulled out by the shackles. This test was performed using a tow rope, strain gauge, and Ford F350. This test had both vehicles tied to each other while the Ford backed up. To increase the force, the client sat in the car and applied the brakes. The strain on the bumper was then measured and the deformation was found to be minimal if any. This shows that the bumpers are strong enough to withstand the forces it was designed for.

Procedure

1. Mount strain gauge to bumper in appropriate location
2. Install shackles and secure tow rope between vehicles.
3. Calibrate strain gauge and run initial test.
4. Eliminate slack in the tow rope.
5. Start to record data on strain gauge
6. Back up secondary vehicle to apply force.
7. Continue to apply force until satisfied.
8. Check data to see if reasonable.

9.2 Testing Results

The Fitment Test was successful and proved that the team produced three bumpers that were able to be attached and fit within the tolerance set by the team and the customer. As well as being able to be installed this test proved that the functionality of all bumpers was maintained and well as added functions that the team added. The team proved that the biggest gap discrimination was a ¼” which is within tolerance. This test was proven to pass all requirement that it was testing set in table 3.

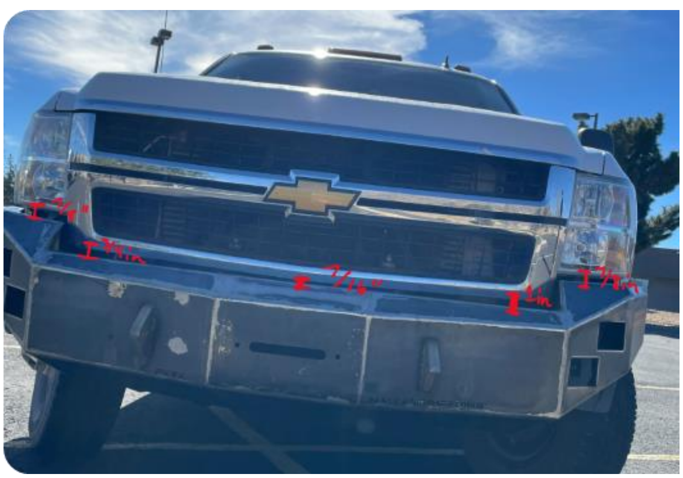

Figure 34: Fitment Test Data

The material deformation test showed that the material proved to have a similar module of elasticity to the expected value of 250MPa for the calculated result was 241MPa. Along with that are strain data provided the Ultimate strength of the vehicle to be 412MPA and the expected value was around 400MPa. With both of these data points proven to be near the expected value and within the tolerance set by the team. The team concluded that the material would act as expected when force was applied to the system. The max force applied to the system to achieve these results was 501711.824psi giving a max deflection of .004” and max strain of .0145.

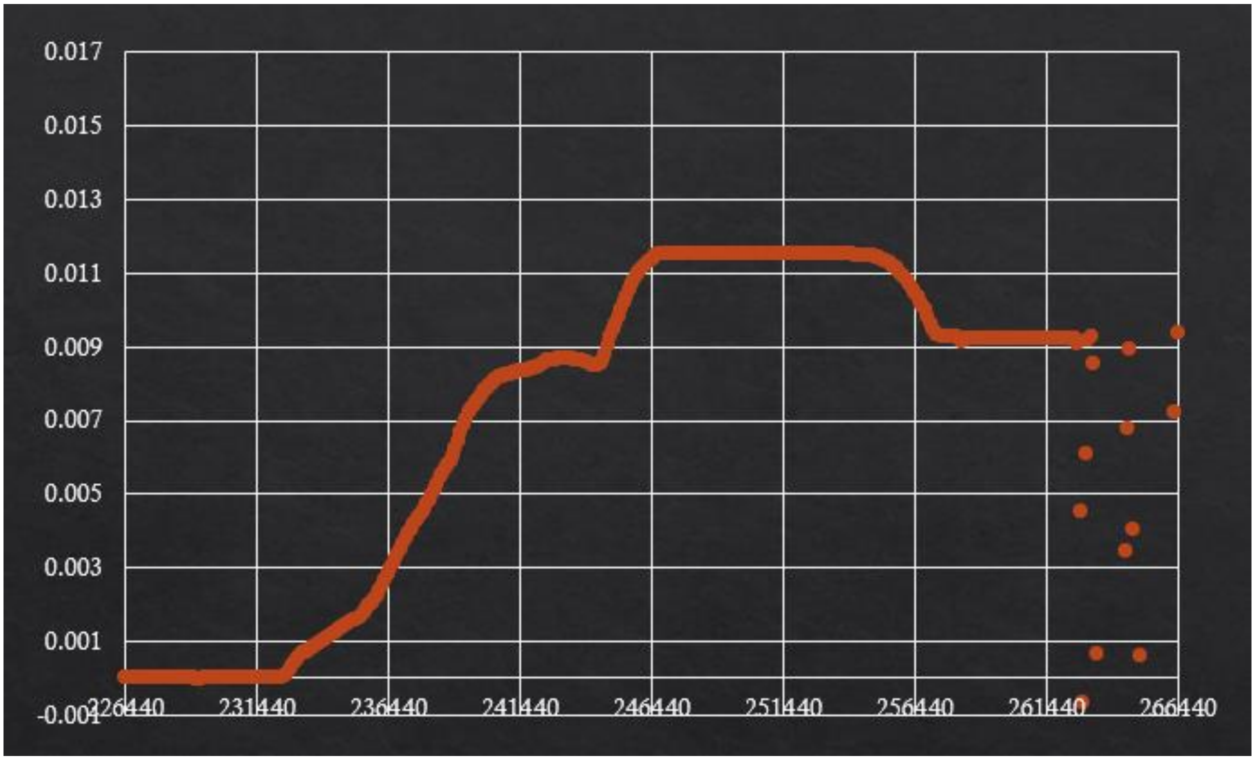

Figure 35: Stress vs Strain(mm) for material deformation test

Lastly the Bumper pull test showed that the bumper will be able to withstand the force that would be applied to it if the vehicle was stuck and needed to be pulled out. In doing so proved that welds would hold and that there was no structural problem with the bumper and how they were creating and that they should be able to withstand any force applied to them. While performing this test strain data was collected to see if the bumper would have significant strain on the mount that the force was being applied to. The data showed little to no deformation would accrue for the max deformation was 0.000054 of an inch at a force 6663.70lbf showing very little deformation.

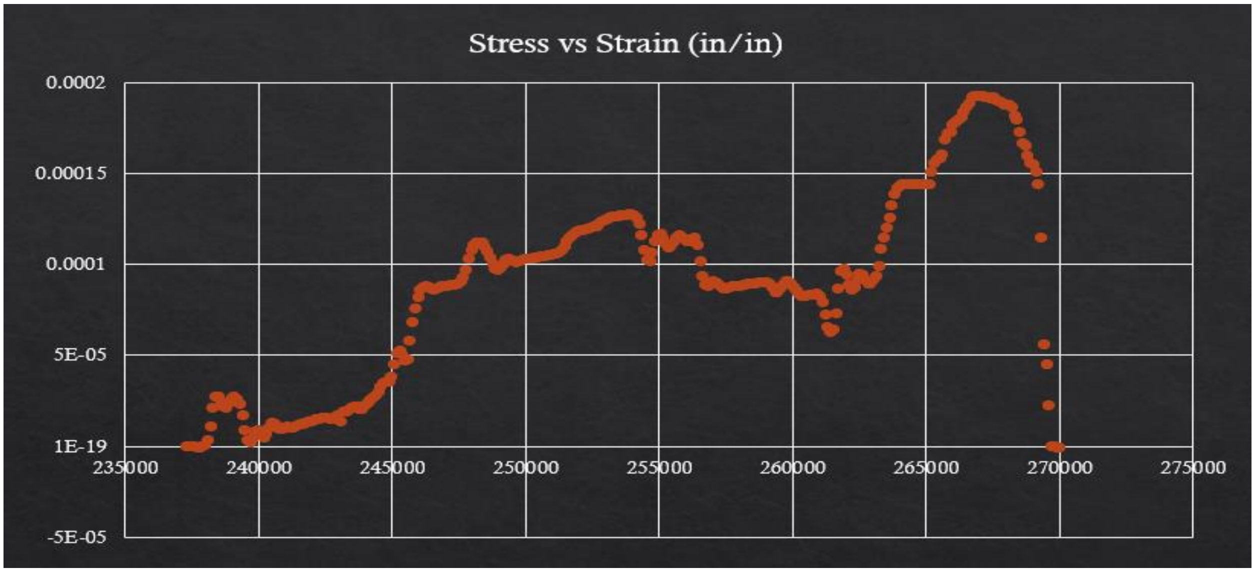

Figure 36: Stress vs Strain curve for Bumper pull test.

All our test proved that all Customer and engineering requirements were meet by the team and the team had produced three successful bumpers by the specification sheet below. Each requirement was discussed and evaluated by the team and the customer to ensure that the need was meet and the product delivered to customer was as expected and desired as proven by tables 4 and 5.

Table 4:Customer Requirements Specification sheet

Customer Requirments	CR Met? Y/N	Client Acceptable Y/N
CR1- Engravement of the front bumper	Y	Y
CR2- Winch support	Y	Y
CR3- Low cost	Y	Y
CR4- Offroad lighting support	Y	Y
CR5- Factory back up sensors	Y	Y
CR6- Increased strength and durability	Y	Y
CR7- Maintains legality and functionality	Y	Y
CR8- Match factory lines	Y	Y
CR9- Powder coated	In Progress	In Progress

Table 5: Engineering requirements specification sheet

Engineering Requirement	Target	Tolerance	Measured/ Calcated value	ER Met? Y/N	Client Acceptable Y/N
ER1- Yield strength (MPa)	250MPa	±25MPa	241MPa	Y	Y
ER2- Pulling strength (lbs)	13,000lbs	±130lbs	1300lbs	Y	Y
ER3- Weight (kg)	150 lbs	±50lbs	178 lbs	Y	Y
Rear Bumper (Carson's)	100 lbs	±25lbs	113lbs	Y	Y
Rear Bumper (Cesar's)	100 lbs	±25lbs	108lbs	Y	Y
ER4- Ultimate Strength (MPa)	400MPa	±40MPa	412MPa	Y	Y
ER5- Material deflection (mm)	0in	0.0625±in	0.0001924	Y	Y

10 RISK ANALYSIS AND MITIGATION

Following the robust design of the off-road bumper, our team actively engaged in comprehensive risk analysis to identify potential vulnerabilities in the system. This section describes the various risks assessed and the strategic actions taken to mitigate these risks. Our goal is to increase the reliability and safety of the proposed off-road bumper solution by thoroughly reviewing design decisions and addressing potential failure points.

10.1 Potential Failures Identified First Semester

During the early stages of the off-road bumper project, the team performed a complete failure mode and effects analysis (FMEA) to predict potential vulnerabilities in the design. As we move into the second semester, it is essential to revisit the insights gained in the first semester and think about the changes implemented to address the identified risks. This section summarizes the FMEAs performed in the early stages and provides an overview of critical failures that require our attention and strategic adjustments.

10.2 Potential Failures Identified This Semester

As our off-road bumper project progressed into its second semester, further design improvements and iterations were made to refine subsystems and improve overall bumper performance. This section highlights the identification of new potential failures that arose during the semester, particularly those related to design changes and improvements made to specific subsystems.

Design Iteration 1: Change in Winch Mount Subsystem Discussion

In our constant pursuit of excellence, the first design iteration of the winch mounting subsystem showed room for improvement in both performance and aesthetics. The main changes focused on the inclusion of a dedicated compartment for the winch and the strategic optimization of its placement in the subsystem. These changes were made with the aim of improving performance and creating a more complex visual profile.

Original Design:

Early versions of the winch mounting subsystem had traditional mounting points without specific winch housing.

Change Description:

Recognizing the need for simpler winch integration, the subsystem was redesigned to include a dedicated winch compartment strategically placed to improve weight distribution and ease of access.

Challenges Bested:

Navigating the complex CAD design process presented a major challenge, particularly in ensuring accurate integration of the winch and other subsystems. To overcome this, an iterative and collaborative design approach was adopted, including regular team meetings and feedback sessions. This simple communication accelerated the design phase and improved the overall quality of the CAD model.

10.3 Risk Mitigation

Mitigating potential failures in our off-road bumper system was a careful process that involved careful review, iterative design adjustments, and a proactive approach to addressing identified risks. Below, we discuss how our team worked on a list of potential failures and an integrated design solution to reduce the likelihood of critical failures.

Design Evidence for Mitigated Failures

Winch and Light bar Integration:

Potential Failure: The original design would have placed the winch in a position where it could damage the light pole during operation.

Mitigation: With repeated design changes, the position of the winch was strategically adjusted to no longer pose a hazard to the light pole. The light strip has been moved to the top of the bumper to reduce the risk of collision.

Jeep Liberty Support System:

Possible Failure: Lack of proper support system for custom bumper installation on 2011 Jeep Liberty. Mitigation: After careful analysis and benchmarking, a robust support system was designed to address the support deficit and ensure a secure connection between the bumper and the Jeep frame.

FMEA Analysis:

Potential Failure: Unknown risks associated with off-road bumper design and response to various impacts.

Mitigation: A comprehensive FMEA analysis was performed to identify potential failures and their severity. The design was iteratively adjusted based on the FMEA results to minimize critical failures.

Trade-offs and New Risks

CAD Design Complexity:

Trade-off: Due to the risk of collision between the winch and the light pole, the complexity of the CAD design increased, resulting in a longer design phase.

Mitigation: Regular team meetings and feedback sessions helped manage CAD complexity but resulted in a longer design phase.

Logistical Challenges in Material Sourcing:

Trade-off: Strategic partnerships with local suppliers helped supply materials but introduced the risk of dependence on foreign organizations.

Mitigation: Active collaboration and use of existing relationships reduced risk but created dependence on external partners.

Technical Issues in Water Jet Cutting:

Trade-off: An unexpected problem occurred during the water jet cutting process, causing a delay.

Mitigation: Proactive troubleshooting and close collaboration with manufacturing facilities minimized the impact of delays but highlighted the risks inherent in the manufacturing phase.

11 LOOKING FORWARD

As the team wraps up the semester, the team still has a few obligations to complete with the client. The team will have to install the bumpers back onto the vehicles after they have been powder coated. The team will then need to install the factory components that are coupled with the bumpers. The team will install the backup sensors and the license plate lights. The license plates will need to be installed and the pod lights fitted and wired to the battery. The Chevy Silverado will need to have to winch installed and wired to the vehicle. After these procedures have been completed the team will ask the client if any additional work needs to be performed. If no additional work is required, the team will be completed with the project. The team will be offering a 30-day warranty period after the bumpers have been installed. This will includes replacing any components that fail on the bumper after installation for 30 days. This does not cover replacing the bumper because of impacts or user caused failure. The team will be responsible for completing any repairs included in the warranty process. After the 30 days have expired, the customer will be responsible for any issues or repairs.

11.1 Future Testing Procedures

Future tests will be conducted by the client while using the product this team created. As the client drives around and gets into minor impacts the bumper will be tested. The client intends to offroad the vehicle and the bumper will prove its strength over time. The team expects the bumper to have infinite life if no collisions or damage occurs to the bumper.

11.2 Future Iterations

If this project was to be handed off to another team, they would have to make modifications to the CAD model the team has created. If the clients want a new custom engravement, added features, or a new bumper; the team has created a more than excellent starting point. If future things like a winch cutout need to be made, then the future team can modify the existing bumper to meet the new client demands.

12 CONCLUSIONS

The team completed all three bumpers by the required deadline. These bumpers offer custom engravement, offroad lighting, and winch support. These bumpers are significantly more durable and look better than the factory bumpers. The team was able to meet and exceed all customer requirements and the clients are extremely happy with the final product the team achieved. The team tested and proved the bumpers to meet the engineering requirements and feel confident that the bumper will be a product that last the customer the lifetime of the vehicle. Over the two semesters the team performed multiple design changes and iterations of the bumpers. The team overcame challenges of client changes and specific design requirements. The bumper project involved more manufacturing than the team initially anticipated. This led to the team learning more about the manufacturing processes than any other previous project done by the team members. The final design met and exceeded the expectations and calculations the team previously had. This shows that the team made the correct changes to the initial design and properly used the engineering method to complete the project. Overall, the team is proud of the final products and the clients are happy with the final products the team manufactured.

12.1 Reflection

The team applied the engineering design principles that produced a solution that ensures the safety of our client and the people around the vehicle. The team did this by testing the strength and material properties of the bumpers to ensure that they can withstand minor impacts. The team ensures the health, safety, and welfare of the community by validating that there are no sharp edges or puncture points. While the focus was to protect the customer, the team still made steps to ensure that the public is not at risk being around the bumpers. If a low-speed impact was made with a pedestrian, then the team predicts that the person will not be injured more because of the use of the bumper. The team did this by grinding all exterior edges of the bumper and powder coating the metal to give it a nice surface finish. If someone was to walk up to the bumper and run their hand along it, they would be safe and sustain no injuries. Each face and surface on the bumper were checked and tested to be sure it was smooth and safe.

12.2 Resource Wishlist

If the team were to do this project again a welding machine that the team could use would have been helpful. Additionally, a consistent space where the team, clients, and mentors could use to work on the bumpers would have been helpful as the team had to move the bumpers around constantly to complete this project. A technical class should be required prior to this assignment to teach the students how to weld, manufacture, or prepare students to go beyond designing and start manufacturing. For many students this is the first time they had to build a full system as elaborate as many of the capstone projects. An additional member would have been helpful given the number of tasks needed to be completed over this course. A few team members had to do more than others to complete many of the projects assigned to the students.

12.3 Project Applicability

The Off-road Bumper project was useful to the students by helping them learn useful tools to manufacture a final product. This showed how things work on paper but don't work in real life. It allowed the team to use the knowledge they have gained over their education. The team has learned the complexities beyond the design stage and into the manufacturing stage. The team values the experience gained while building these bumpers and working closely with our clients. The project challenged the team with complexities that other capstones would not have experienced. Everyone involved in this project is satisfied with the bumpers and the team believes they have produced the best possible product they can.

13 REFERENCES

[1] "The Federal Register," *Federal Register :: Request Access*. [Online]. Available: https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-581. [Accessed: 30-Apr-2023].

[1] "Test procedures," *NHTSA*. [Online]. Available: https://www.nhtsa.gov/vehicle-manufacturers/test-procedures. [Accessed: 30-Apr-2023].

[2] "J2976_202205: Speedometer and odometer systems for on-highway vehicles," *SAE International*. [Online]. Available: https://www.sae.org/standards/content/j2976_202205/. [Accessed: 30-Apr-2023].

[3] "J3105_202001: Electric Vehicle Power Transfer System using conductive automated connection devices," *SAE International*. [Online]. Available: https://www.sae.org/standards/content/j3105_202001/. [Accessed: 30-Apr-2023].

[4] "J2807_201602: Performance requirements for determining tow-vehicle gross combination weight rating and trailer weight rating," *SAE International*. [Online]. Available: https://www.sae.org/standards/content/j2807_201602/. [Accessed: 30-Apr-2023].

[5] "J2340_201703: Categorization and properties of Dent resistant, high strength, and Ultra High Strength Automotive Sheet Steel," *SAE International*. [Online]. Available: https://www.sae.org/standards/content/j2340_201703/. [Accessed: 30-Apr-2023].

[6] "Review of four Federal Motor Vehicle Safety Standards: FMVSS 214, 215 ..." [Online]. Available: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/802343. [Accessed: 01-May-2023].

[7] "Silverado 1500 Bumpers Overview," *AmericanTrucks*. [Online]. Available: https://www.americantrucks.com/chevrolet-silverado-bumpers-overview.html. [Accessed: 02-Apr-2023].

[8] Donlon, D. (2016). Design for Manufacturability: Off-Road Toyota Bumper.

[9] Isaacson, A. C. (2016). The Design and Construction of a Rear Bumper with Incorporated Spare Tire Rack.

[10] Wrangler-NightCrawler, J. T. Modular Front Bumper-Skid Row Offroad.

[11] Vellequette, L. P. (2013). Modified Jeeps hit the trails. Automotive News, 87(6561).

[12] Mervin, J. J., Mariyappan, M., & Ramesh, B. (2020, September). Design and impact analysis of a jeep bumper made of composite material. In IOP Conference Series: Materials Science and Engineering (Vol. 923, No. 1, p. 012015). IOP Publishing.

[13] BumperOnly, "Why top manufacturers prefer steel for off-road truck bumpers," *BumperOnly*. [Online]. Available: https://www.bumperonly.com/blogs/learning-center/why-top-manufacturers-use-steel-for-off-road-truck-bumpers

[14] T. Xometry, "All about carbon steel as a manufacturing material," *Xometrys RSS*, 24-Oct-2022. [Online]. Available: https://www.xometry.com/resources/materials/carbon-steel/

[15] "Metric Nuts and bolts:" *Thomsonrail*, 07-Nov-2022. [Online]. Available: https://thomsonrail.com/metric-nuts-and-bolts/

[16] BumperOnly, "How thick should an off-road truck bumper be?" *BumperOnly*. [Online]. Available: https://www.bumperonly.com/blogs/learning-center/how-thick-should-an-off-road-truck-bumper-be

[17] "Tables of material properties," *MechaniCalc*. [Online]. Available: https://mechanicalc.com/reference/material-properties-tables

[18] D. Aylor, D. L. Ramirez, M. Brumbelow, and J. M. Nolan, “Limitations of current bumper designs and potential improvements,” in SAE Transactions, vol. 114, pp. 1591-1598, 2005.

[19] A. C. Isaacson, “The Design and Construction of a Rear Bumper with Incorporated Spare Tire Rack,” in Proceedings of the 2016 IEEE International Conference on Engineering Design (ICED), 2016, pp. 1-6.

[20] BumperOnly, “How to build your own custom steel bumpers?” *BumperOnly*. [Online]. Available: https://www.bumperonly.com/blogs/learning-center/diy-how-to-build-your-own-truck-bumper. [Accessed: 02-Apr-2023].

[21] Blowtorch-Betty and Instructables, “Custom Steel Bumper for off-road truck,” *Instructables*, 28-Oct-2017. [Online]. Available: https://www.instructables.com/Custom-steel-bumper-for-off-road-truck/. [Accessed: 02-Apr-2023].

[22] “DigitalCommons@CalPoly | California Polytechnic State University, San ...” [Online]. Available: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1216&context=imesp. [Accessed: 02-Apr-2023].

[23] B. Badel, “THE EVOLUTION OF BUMPERS: AN AUTO SAFETY APPARATUS” [Online]. Available: https://www.badellscollision.com/blog/evolution-of-bumpers/

[24] *Kanufautomotive.com*, “From metal to plastic bumpers: in search of the balance between aesthetics and safety” [Online]. Available: https://knaufautomotive.com/the-history-of-bumpers/

[25] N. Natarajan, P. Joshi, and K.R. Tyagi, “Design Improvements of vehicles bumper for low speed impact” in proceedings, 2021, Vol.38, p.456-465.

[26] M. Zou, J. Song, S. Xu, S. Liu, Z. Chang, J. Merodio, “Bionic Design of Bumper Beam Inspired by the Bending and Energy Absorption Characteristics of Bamboo” Applied bionics and biomechanics, 2018, Vol.2018, p.8062321-12

[27] Austin “Top 10 Best Off-Road Bumpers for your Truck” [Online]. Available: https://amanandhisgear.com/best-off-road-bumpers-for-your-truck

14 APPENDICES

14.1 Appendix A: Final Product Photos

Figure 37: Cesar Blancarte's rear bumper

Figure 38: Carson Pete's front bumper

Figure 39: Carson Pete's rear bumper

14.2 Appendix B: Photos of bumpers on vehicles

Figure 40: Bumper on Carson Pete's truck

Figure 41: Bumper on Carson Pete's Chevy.

Figure 42: Speed one of water jet

Figure 43: Speed two of water jet

Figure 44: Speed three of water jet

Figure 45: Speed four of water jet