Off-Road Bumper Team

Final Proposal

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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 lifeguards. The customer survey says that there is a need for a new off-road bumper that is more durable and has new functionalities. To best serve the customers and fill the market gap, we are designing three new aftermarket bumpers for two different vehicles. Our customers are looking for a bumper that is not just durable, but has the latest functionalities, including sensor mounts, light pods, engravements, reliability and resistance.

Our proposed solution is for 2008 Chevy Silverado 3500HD (front and rear) and 2011 Jeep Liberty (front bumper only). The team is working on the following for this project:

1. Bumpers start at a budget of $1500 for the three bumpers ($500 each).
2. Understand customer requirements and engineering requirements and implement the design following the CAD (Computer Aided Design) Designs.
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 has modeled the prototype in SolidWorks and plans to 3D print it. The team will use the physical model to ensure proper fitment and then adjust CAD. After finalizing the design, the team plans to use Evans Alloy to water jet cut the metal required for the bumper. With these new bumpers, meeting the customer's needs will not just be affordable, but also a good addition to the available bumper options in the market. We have also performed several prototype tests on the design including fitment and bumper deformation tests and analyzed the results. Ten potential and critical failures are discussed and studied for the bumper designs and steps are taken to mitigate these failures that include multiple design changes.

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1 BACKGROUND

1.1 Introduction

The off-road bumper team has been tasked to build three aftermarket bumpers for two different vehicles. The first client for this project is the instructor, Carson Pete: 2008 Chevy Silverado 3500HD. Carson will need both the front and rear bumpers for his vehicle. The second client is David Bui, who owns a 2011 Jeep Liberty, requested only a front bumper produced by the capstone team. These bumpers are being designed to be more durable and have the capability of withstanding large impacts. This report will cover the requirements for the design, research on existing designs, a literature review, functional decomposition, concept generation, and the selected final design. This project is important to the team because it builds a strong understanding of the engineering design and manufacturing processes that they will experience in the real world. This project is important to the clients because it will allow them to have a safer vehicle and allow them to use aftermarket lighting and a winch.

1.2 Project Description

The following is the original product description provided by the sponsor:

"This project requires the students to do an extensive CAD design to create three bumpers for two different vehicles. These CAD files will be converted into DFX format and transposed into a 2-D surface to be cut and then fabricated. These files will be 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 will require 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 bumper should 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."

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 vehicle's 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 will be maintained in the design to ensure easy installation of the new bumper. The team will reuse the factory back up sensors and airbag collision sensors. The factory wiring for towing will be maintained and the plug location will be kept the same. No other parts of the factory bumper will be used and will be replaced with durable materials.

2 REQUIREMENTS

The requirements for the off-road bumper team are to create and design three bumpers. To achieve the best bumpers, the Off-road Bumper team met with the customers to establish the necessary function that each bumper will need to meet. This allows the team to gain the knowledge to understand what our customers are looking for in each bumper and start the process of how to create these bumpers. Once the customer requirements are obtained the team can begin to apply their technical knowledge and beginning the process of transferring the customer requirements into engineering requirements that can be quantified to allow for analysis on any individual customer need. With both the customer and engineering requirements the team used a tool called the House of Quality (HOQ) to rank the engineering requirements against the customer requirements. The HOQ is a useful tool to understand what the most significant Engineering requirements are.

2.1 Customer Requirements (CRs)

To successfully meet the customers' expectations, the team went through the process of understanding the customers' need for each bumper. The customers' requirements for these bumpers state that they are more durable than the factory bumpers and they will improve the protection their vehicles will have from a minor accident. The customers also stressed that they wanted to keep the current functionality of the factory bumper as well as maintain the factory fit and mounting. It was important that they didn't want to lose any of the current functionality that their bumper currently has. In addition to maintaining the base, the customers wanted to have the ability to have a winch of their choosing attached with additional parts of aftermarket lighting. The final requirement was that Dr. Carson Pete wanted to add an engraving to the bumper during the cutting process. With these requirements given and the customer budget settlement of $1,500 dollars which is to be distributed throughout the three bumpers.

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 most important aspect of the customers' needs was that the bumper be durable, functional, and keep the factory design lines. Which is why they all given an importance of nine that will be used as a scaler during the evaluation within the HOQ when establishing the importance to the engineer requirements. All the remaining customer needs were ranked at a three or lower. Meaning that they need to be present in the design and the final product, but they will not influence the design in any 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 of the material will be and what material will be used. 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 plasticly 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 cause 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 better understand the process and the goal of the bumper the team set out to think critically about how the primary function of the bumper will be met and how the sub-systems interact with it. To do this the team created a black box model to make a simple diagram with inputs and outputs to show the necessary inputs to complete an action and the given outputs of the action being completed. This is a useful tool because it takes a larger picture of what is happening and ignores the detail of how the action is completed, just what is needed. For the other part of this analysis the team used a functional model to fill in the void left by the black box model. For the Functional model goes into detail about how the actual action is being completed by breaking it down into individual steps showing the inputs and output as they change per action. With this knowledge the team was able to understand how the bumper is able to do the steps required for the bumper to be able to absorb and deflect energy and how the subsystem will work together.

2.3.1 Black Box Model

This black box model focuses on the primary function of the bumper which is to resist and deflect damage away from the vehicle that would have otherwise damaged it. A black box model is a representation of the inputs and the outputs of a particular action. It's a helpful tool to understand what the expected result will be depending on the inputs necessary for the system to work. The input and outputs are divided into three sections materials, energies, and signals. Theses each outline a specific action to complete the task at hand. Material refers to the necessary solid objects that are involved in the action as well as leaving the system. The energy is the required energy to perform the action as well as leaving the system. Lastly, the signal is the expected result, or the observation made due to the action.

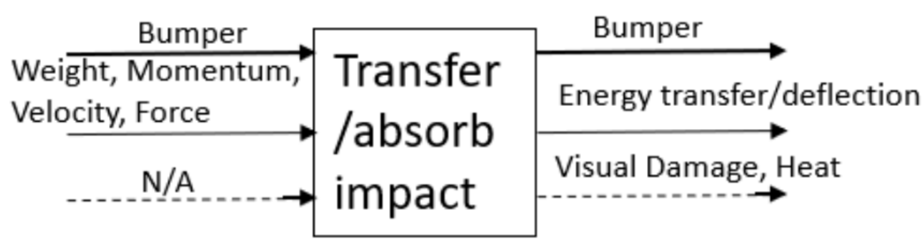

Figure 1: Black Box Model

These Inputs were chosen because they are all required to resist/absorb energy. According to the law of physis energy can't be created or destroyed thus energy must be proved to the system to transfer the energy. The bumper is the constant in this system and the material to be absorbing/ transferring the energy provided to the system. As mentioned above there is no signal since there isn't an expected response, only an observational response.

The outputs are in a similar vain. This is due to the bumper is still the material being acted upon. The energy output is where there starts to be a difference in the black box model. This is due to the action item, since the goal to transfer/absorb energy the energy output will be to transfer/deflection of energy.

The final output is the signal output. Unlike the signal input there is an expected response. Which appears as physical damage to the bumper and or heat. If the bumper fails to absorb all the energy the energy will either be transferred to the vehicle or will start to deform the bumper meaning that the incoming force was too great to transfer/deflect without damaging the bumper.

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

To better understand the black box, the team created a functional model which goes into detail about how the inputs and outputs complete the goal of the black box model. It does this with the same descriptions of inputs and outputs by categorizing them into materials, energies, and signals. The primary difference being that it's broken down into individual actions as well as subsections. Showing how separate systems interact with each other. In this functional model it considers the source of energy in the system that begins the vehicle. This is still a study showing how the bumper transfers and deflects energy. As mentioned before the functional model allows for the study of the sub-system being the lights, sensors, winch, and the object being hit to create the transfer of energy. This allows the team to truly understand how the system interacts with each other to be able to better design the bumpers to understand the function of each component.

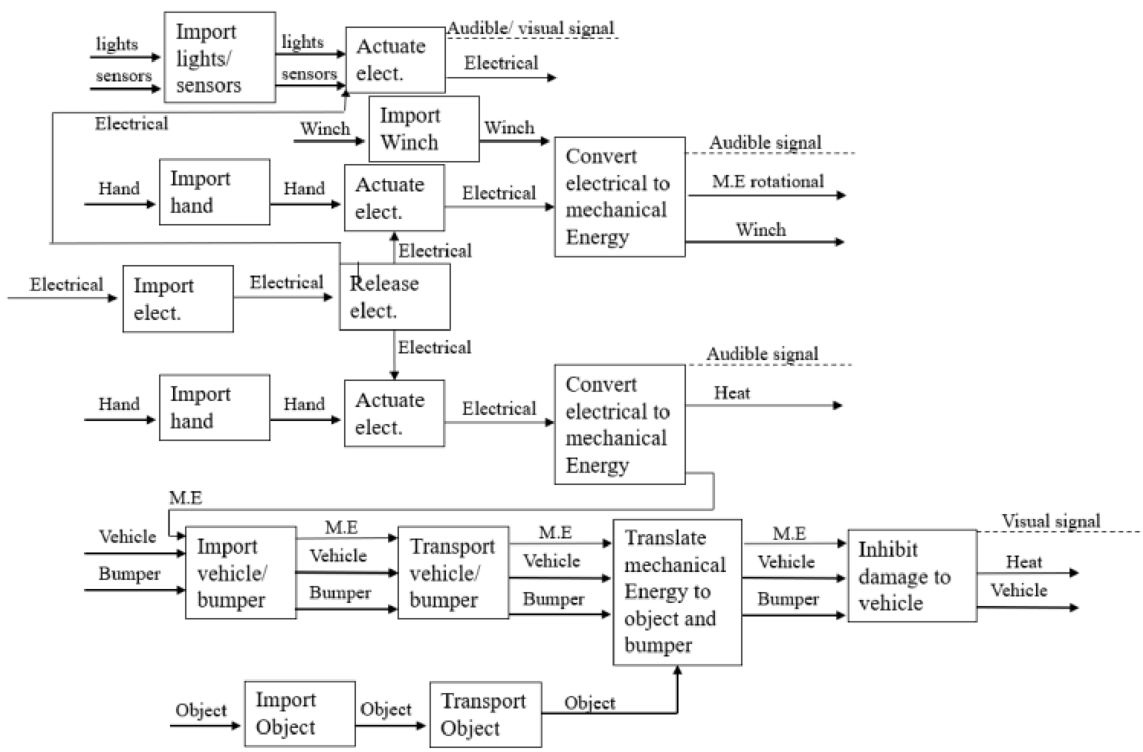

Figure 2: Functional Model

Upon review of the Functional model, it shows that their primary relationship to each other is the electrical signal distributed throughout the system and their link that they all live within the bumper. This is important due to the understanding that it's important for all the lights, sensors, and the lights to work and that during a minor accident they do not damage or trip the sensor unintentionally. Because of this the team accounted for this during the design process to best protect the sub-systems as well as keep the functionality of the bumper being to protect the vehicle from damage.

2.4 House of Quality (HOQ)

The House of Quality (HOQ) is an engineering tool that is used to compare the customer requirements and engineering requirements. Another aspect of the HOQ is that it allows the team to see how the engineering requirements relate to one another. The team used the Customer requirements gathered from the customer and assigned importance to the customer requirements to establish what has a high importance in the design as opposed to what would be a nice to have. This information is used as a scaler during the calculation of the raw score for the importance of the engineering requirements. Thus, the engineering requirements are placed in the HOQ to understand the importance of the engineering requirements. This is done through a calculation made by ranking each customer requirement to how it relates to that engineering requirement. The higher the number the more that engineering requirements relate to that customer requirement. This data makes up the middle of the HOQ. The top of the HOQ is the relationship that the engineering requirement have with one another showing if you increase one what will happen to the other. The right of the HOQ is what is currently on the market ranked against the customer requirements to see how they compare against each other. The bottom of the HOQ is the results. The results are split into raw importance, percentage, and competitive design assessment. The raw importance score is the customer requirement importance score multiplied by the relationship to that engineering requirement. The percentage score is simply the raw score over the total points. The last part of the results section is the Competitive design assessment which is a comparison of the current market to see how the best was based on the engineering requirements. See appendix for HOQ.

2.5 Standards, Codes, and Regulations

When designing and building an off-road bumper for everyday use, it is crucial to adhere to several standards codes and regulations to ensure the bumper's safety and durability. Standards and codes help ensure the safety of our clients by setting strict regulations on parts manufactured for automotive use. Standards and codes come from many organizations and help engineers by determining the minimum design requirements. The Society of Automotive Engineers (SAE) as well as the federal government has set regulations designed to keep pedestrians and vehicle occupants safe. The standards and codes that are most relevant to the bumper project are listed below.

Table 3: Standards, Codes, and Regulations.

Standard Number or Code	**Title of Standard**	**How it applies to Project**
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 offroad 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.

These regulations ensure that the team is meeting all standards set by these associations. By following all these regulations, the team is confident that our clients will be safe and not have legal issues while driving with their bumpers. These standards ensure that the bumper is safe, durable, and able to withstand the rigors of off-road driving.

3 Testing Procedures (TPs)

The purpose of testing procedures is to ensure that the component or material the group will be using is meeting the required specifications and standards the team has set. Our intention is to make sure that the used materials can be used, and are safe, reliable, and effective. These testing procedures can help identify and address any design weaknesses and provide valuable feedback for improving production quality and performance. The first testing procedure is understanding the correct thickness of the front frame of the bumper to withstand a reasonable amount of force.

3.1 Testing Procedure 1: Bumper deformation test

The test procedure of bumper deformation was created to test the most important engineering requirements of yield strength. This test is composed of creating a smaller bumper based on are DFX file and create that bumper to perform destructive test to understand how it will deform and confirm the work done by the team to ensure that the material will be able to withstand the forces that will be applied to it. In addition to our destructive testing the team will be performing test procedures for [1] the code of federal regulations title 49 subtitle B chapter V part 581 section 7. This will allow the team to ensure their bumper with holds to the standers. This test will require the team to create a smaller scale version of the bumper and apply forces to it understand how the bumper will react as well as provide a scale that can be applied to understand the forces that the full-size bumper will see during an impact.

3.1.1 Testing Procedure 1: Objective

The objective of this test is to ensure that our bumpers can withstand the damage expected from them by our customer as well as the standard set by federal regulations. This test will allow the team to visually see how the bumper will deform as well as understand what aspects of they might need to be improved prior to creating the bumper. This test will ensure that the assumptions and the decisions made by the team for the material and thickness are correct.

3.1.2 Testing Procedure 1: Resources Required

The required resources to run this test is the material of the proper thickness determined by the team's analysis. The water jet provided by Mr. Bui to cut the scaled down version of our bumper. Once all the pieces are cut the team will need to fully weld the model together in order to truly be able to scale the force and have a comparable data point. The last component needed for this test is a hydraulic press of some sort to apply the needed for on the bumper to study it failure.

3.1.3 Testing Procedure 1: Schedule

This test will be performed over the summer prior to the fall semester. This test will take approximately two weeks to complete. For the expected time frame is a week to construct the scaled down version of are bumper per the DFX file and then another week to complete all the required testing from both the team standard the federal regulation standards. At the most this testing will be completed within a month to ensure that that the material chosen, and thickness are correct for application.

3.2 Testing Procedure 2: Fitment test

To ensure that the team is keeping the proper factory fit lines the team created a test procedure to ensure the fit is correct. This test is to ensure that are measurements from both Dr. Pete's and Mr. Bui vehicle and that the DFX file measurement are correct. This test is to be completed to ensure that the team is fulfilling the customer requirements of fitment are meet. This test also tests the tolerance that we will assign to the measurements to ensure that upon the cuts will be correct when we need to cut the steel plates.

3.2.1 Testing Procedure 2: Objective

The objective of this experiment is to ensure that we don't waste material and ensure that the measurements within the DFX file are correct. To complete this experiment the team will use either cardboard or a cheap metal and cut it to the DFX file. Once all the pieces are cut the team will construct the bumper that was cut out. Ones the bumper is constructed, remove our customers' current bumper, and place the test bumper on it and take measurements to see how well the bumper fits and adjust based on what the team observes. As well as get are customers opinion on any changes that they would like to make to it.

Figure 3: Cardboard Bumper Fitment test comparison

3.2.2 Testing Procedure 2: Resources Required

The required resources to complete this test are cardboard or a cheap metal to construct the bumper from. If cardboard is chosen the team will need a knife to cut the cardboard to the DFX file to the given measurements. If a metal is used, we will need to use the resources of our customer Mr. Bui to use his water jet to cut the material to the DFX file. Once the materials are cut, they will either need to be glued/taped or welded together. One the bumper is constructed we will need the customers vehicle see how well it fits on their vehicle.

3.2.3 Testing Procedure 2: Schedule

This test is to be conducted over the summer prior to the fall semester. This test will approximately take an upwards of two weeks. A week for each bumper. It will take approximately a day to get all the material cut. Then constructing the bumper will take about a day as well depending on whether cardboard or metal is used. If metal is used the build time goes up depending on how much welding is required to hold the bumper together during testing. The remainder of the time is scheduled out to best fit are customers time to remove their bumper and install our test bumper and take the needed measurements then reinstall their current stock bumper. In a perfect world only one test bumper will need to be created on the off chance that multiple test bumpers are required that timeline will go up linearly.

4 Risk Analysis and Mitigation

For our project "Off-Road Bumper", there are several tests we conducted to discuss potential failures and a plan to mitigate the failures. The FMEA (Failure Modes and Effects Analysis) performed gives an idea of all potential failures and effects. This analysis was conducted before the final design as we proposed new solutions based on the potential risks identified. The testing procedure for this involved performing the Bumper Deformation Test procedure outlined above. This helps the team determine where the potential failures will be as well as determine the appropriate level of risk associated with each failure mode and determine if any further action is required to mitigate the risk the to an appropriate level for the given failure.

4.1 Critical Failures

A critical failure is a failure in the design that has catastrophic effects on the system integrity causing a failure of the system or a major failure causing the system a significant reduction in effectiveness in achieving the goal. In this application a critical failure will significantly reduce the overall strength of the system compromising the overall strength of the system. Which can result in unintentional damage to the bumper or our client's vehicle. To provide the best product possible, the team went through the possible failure points to ensure that the risk level was appropriate and adjusted if necessary.

4.1.1 Potential Critical Failure 1: Bumper plate frame failure

A failure in the bumper plate frame could cause a significant weak point in the bumper causing it to fail well before the expected range. This could be caused by a crack in the material or an unintentional cut causing an increase in force at the point of damage significantly affecting the overall strength of the bumper. This kind of failure is high risk failure and due to the importance of mitigating this kind this risk this component is composed of $\frac{1}{4}$" steel to significantly increase the strength of this component to ensure that the failure point is at a different location.

4.1.2 Potential Critical Failure 2: Failure at the welds

This failure mode depends on which weld fails and if it is possible to be repaired. For a weld failure at the frame can be a critical failure causing the bumper to be forced into the vehicle or ripped of the frame depending upon the direction of the force. A welding failure within the external frame of the bumper is an ideal failure allowing the transfer of energy out of the system while having an easy repair. The risk of a failure of the weld at of around the frame has a high risk and to mitigate that risk the team will ensure during the creation of their bumper that the welds are correct and up to standard. As for a weld failure of the external shell of the bumper is a moderate to low risk for it's easy to repair and the risk to the vehicle and or low. Therefore, no mitigation activities will be performed for welds of the external shell.

4.1.3 Potential Critical Failure 3: Mounting plate bolt shears

A failure of the mounting plate bolt will cause the bumper to fall or be significantly weaker when it comes into with an object. However, this is one of the failures points assigned by the team. The bolts are significantly easier to replace and have a set value associated with when they will shear. Thus, making them a great control to set when failure will occur. Thus, the risk mitigation will come from the assessment of the factor of safety for the bolts used for the mounting plate.

4.1.4 Potential Critical Failure 4: Mounting plate failure

A mounting plate failure is a failure is a failure of the plate in which the mounting bolts attach the bumper to the frame. This failure has the potential to cause critical failure where the bumper will no longer be attached to frame and or significantly weaken the bumper's ability to withstand the impact force being applied to the bumper. To mitigate this failure the mounting plates will be constructed of $\frac{1}{4}$" thick steel as opposed to $\frac{3}{16}$".

4.1.5 Potential Critical Failure 5: Winch bolts shear

This failure mode consists of the bolts shearing during operation of the winch causing the winch to no longer be attached to the mounting plate as well as increasing the strain on the remaining bolts that are holding the bumper together. This failure has potential to damage the external frame of the bumper and the winch. To mitigate efforts will be addressed in the factor of safety for the winch bolts to ensure that they will not shear unit the yielding strength of the winch mounting plate is hit then have a shear point to ensure that the bumper isn't damaged.

4.1.6 Potential Critical Failure 6: Winch mounting plate failure.

This failure mode consists of the winch mounting plate deforming from the force being applied from the winch and the bolts reaming in place. This failure mode causes the mounting plate to start having a displacement of the metal where forms its original position deforming plasticly where the material will not return to its original position. The risk mitigation efforts will be making the mounting plate out of $\frac{1}{4}$" thick steel to ensure that the failure point is at the intended location.

4.1.7 Potential Critical Failure 7: Material imperfection

This failure mode of materials imperfections the focus of the material the team receives from the manufacturing company and the material itself has imperfections. When talking about imperfections in the material the team is referring to the flaws in the product condition. Having an imperfected material can cause the piece that is being cut to be damaged by chatter, unnecessary jamming, or damage the cutter instead. Another issue that the team might come across if the material has imperfections would be vacant holes through the metal sheet.

Potential Critical Failure 8: Incorrect Manufacturing

4.1.8 Potential Critical Failure 8: Incorrect manufacturing

4.1.9 Potential Critical Failure 9: DFX file measurements incorrect causing collisions

The failure mode of this material consists of an error in the drawing measurement causing the need to have a large weld creating a natural weak point for the material to fail. This failure is dependent on where the error in the drawing occurs for if a failure at or around the bumper frame or the winch will have significantly higher risk than that of the exterior bumper plates. For the overall force will be lower. The risk mitigation involved with this critical error is the fitment test procedure to ensure that the bumper fit is correct prior to creating the final model.

4.1.10 Potential Critical Failure 10: Overbuilding causing damage to the frame.

This failure mode consists of the bumper being able to withstand a higher force than that of the frame of the vehicle. This failure mode is a problem because it has the potential to total the vehicle because the bumper was over engineered for the intended uses or didn't have a point of failure to ensure that the frame of the vehicle is undamaged. This mitigation effort is to ensure that there are failure points within the system that are less the yielding strength of the frame of the vehicle.

4.2 Risks and Trade-offs Analysis

The risk mitigation effort for this analysis came down to where do we need the bumper to deform and where must we drive the strength of that component to ensure the failure was at the intended location. In order to achieve this the team had to think critically about what each potential failure could mean to the integrity of the system as outlined above. Once the critical failures have been outlined the risk mitigation efforts can start to be considered. For Example, the frame, mounting plate, and the winch plate were modified to be constructed of $\frac{1}{4}$" thick steel to ensure that failure point would be the bolts. However, this increases the risk associated with the bolts for it the bolts fail prematurely the whole system fails. Thus, the bolt technical analysis that was performed will be essential to assure the correct factor of safety is assigned to the bolt. The final risk mitigation task that will be performed is based on the fitment test procedure to ensure that our welds aren't bigger than required and the material is the proper size. Ensuring that the material has a little room for manufacturing error or at least limit the potential error. Risk a part of creating any part or object the best effort we can make is to ensure that as a team we think through as many failures as possible and ensure that the remaining risk is at an appropriate level to where a result of those decision doesn't result in a critical failure.

5 DESIGN SELECTED – First Semester

This chapter takes all the previous extensive research, functional decomposition, concept generation to create a final design of the front bumpers for both vehicles. The following section will go over the design description including the prototype the team has developed. The design description section will outline the final design the team selected and include calculations that back up the concepts the team has generated. The implementation section will go over the future plans the team has as well as the bill of materials and final CAD designs. The final design was influenced by the team's technical analyses that led to the selection of the materials and hardware.

5.1 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 moved to rest on top of the bumper, allowing movement for the light and decreases the possibility of becoming damaged by the winch hook jumping back wrong.

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. Since then, the team has been focused on creating some sort of support system that could be attached or modified too. 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 which could be found in figure 4.

The designed CAD model of the off-road bumper design is based on the thorough analysis of different types of collisions: vehicle collisions, human collisions, and internal collisions. To properly report about the efficiency of the bumper design, the focus is primarily on finding the force that the bumper will undergo during a vehicle collision. Newton's Second Law is the equation used to determine the force acting on both cars. The team used the average speed of driving off-road, 15 MPH, to determine the first velocity of the car. The second velocity is calculated by the reaction of the car slowing down after hitting the object 14 MPH. To find the acceleration the team subtracted the second velocity to the first velocity and then divided it by time, .3 seconds. By multiplying the found acceleration with the mass of the selected car, the forces are found. The comprehensive calculations executed provide a solid foundation for the off-road bumper design to effectively withstand forces in a vehicle collision. For more extensive calculation for applied stress acting upon the bumper reference appendix A.

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

$m_C = 6694lb\left(\frac{1kg}{2.2lb}\right) = 3,042.7kg$ [Eqn. 1]

$m_D = 4290lb\left(\frac{1kg}{2.2lb}\right) = 1,950kg$ [Eqn. 2]

$a1 = \frac{(V_2 - V_1)}{t} = -1.5m/s2$ [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 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.

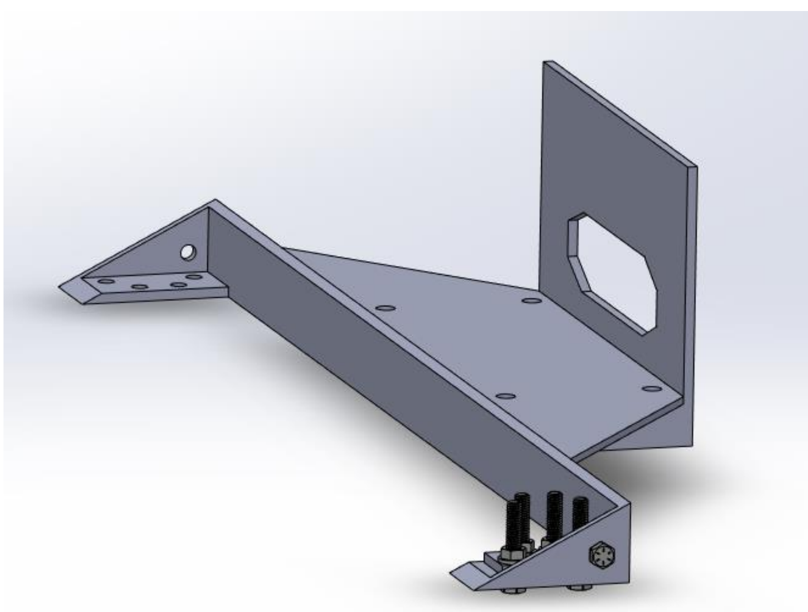

Figure 4: Prototype Plate for the Jeep

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.

5.2 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 plans to 3D print it. The team will use the physical model to ensure proper fitment and then make adjustments in CAD. After finalizing the design, the team plans to use Evans Alloy to water jet cut the metal required for the bumper. The client David Bui works at Evans Alloy 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.

A bill of materials has been included as well as the team schedule. The bill of materials is shown in figure 5 and shows the itemized cost and total cost of the project.

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		1	59.99	$59.99	$0.00	Total of eight pods per purchase
Steel Pipe		1	54.74	$54.74	$54.74	2.5" OD with length being 5 feet
Tow Shackles		2	22.99	$45.98	$0.00	Total of two hooks per purchase
Light Bar		1	32.39	$32.39	$0.00	Length of light bar is 22"

Figure 5: Bill of Materials for all three bumpers

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 $1320.76 on steel, winches, and accessories. The team started with a budget of $1500 which leaves a remainder of $179.24 for the team to spend on unexpected expenses.

Figures 6 and 7 show the schedule for each semester. Figure 6 shows the team schedule for the summer, while figure 7 shows the next semester schedule.

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 6: Team 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 7: Fall semester detailed schedule.

Looking at figure 6, you can see 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. Figure 7 shows the estimated schedule for the fall semester and if the team can complete one bumper over the summer, they will be ahead of schedule going into the final semester. 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 CAD model for the Chevy Silverado's front bumper is pictured below in figure 8. This CAD model implements a light bar, light pods, and an area to mount the winch to. The team's focus moving forward will be to finish the CAD design for the Jeep's front bumper. The team currently only has the mounting plate for the winch designed in CAD for the Jeep. By the start of the next semester the team will have finished the CAD for the Jeep and hopefully be in the final stages of producing the bumper. The CAD for the Jeep can be seen in Figure 4. The team will expand on this plate to finalize the CAD on the Jeep by the end of the summer.

Figure 8: Chevy Silverado Front Bumper

6 CONCLUSIONS

The Off-Road Bumper team was tasked with designing and building three aftermarket bumpers for two different vehicles. The team was able to successfully design bumpers for both clients, Carson Pete and David Bui, that were more durable and able to withstand a large amount of impact. Through extensive research, functional decomposition, concept generation, and design selecting the team was able to finalize the design of the bumpers. The team's design maintains factory lines, incorporates a winch, additional off-road lighting capabilities, and mounts to existing factory bumper locations while maintaining factory back-up sensors, license plates, etc. The team also conducted a Failure Modes and Effects Analysis (FMEA) to identify potential critical failures and developed a plan to mitigate them. By using high-quality materials and ensuring correct welds and bolt shears, the team was able to mitigate the risks of critical failures, thus providing a safer product for their clients. The team plans to continue their work into the summer to be ahead of schedule when the fall semester begins. The next steps the team will take are developing the prototype and finalizing the CAD designs. Overall, this project allowed the team to gain a strong understanding of the engineering design and manufacturing processes that they will experience in the real world.

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8 APPENDICES

8.1 Appendix A: Analysis


C=Carson D=David

M_C = 6694 lb ... = 3,042.7 kg

M_D = 4290 lb ... = 1,950 kg

$a = \frac{V_2 - V_1}{t}$

$a_1 = \frac{6.26 - 6.71}{.3s} = -1.5 m/s^2$

$a_2 = \frac{3.13 - 6.71}{1.2s} = -2.98 m/s^2$

S1: V_1 = 15 MPH → 6.7056 m/s; V_2 = 14 MPH → 6.26 m/s

S2: V_1 = 6.7 m/s; V_2 = 7 MPH → 3.13 m/s

F = m·a

F_{C_1} = 3042.7(-1.5) = 4564.05 N

F_{C_2} = 9067.246 N

F_{D_1} = 1950(-1.5) = 2925 N

F_{D_2} = 5811 N

Normal stress

$\sigma = \frac{\Delta F}{\Delta A}$

A = 2(wl + hl + hw)

σ_{C_1} = 2414.74 MPa

σ_{C_2} = 4797.48 MPa

A_C = 74.5 in → 1.89 m

A_D = 76 in → 1.93 m

σ_{D_2} = 3,010.88 MPa

Elongation %: High = 30%, Med = 34.2%, Low = 48%

Carson / David

$TS_{ult} = \frac{F_{max}}{A}$

H: F_{max} = 1.89(3200) = 6,048 N; F_{max} = 6176 N

M: F_{max} = 5159.7 N; F_{max} = 5268.9 N

L: F_{max} = 4630.5 N; F_{max} = 4,728.5 N

Appendix B: House of Quality

Yield Strength (psi)	0	1	0	1	1	0	-1			
Hardness (N)	1	0	1	1	0	0	-1			
Modulus of Toughness (psi)	1	1	0	1	1	0	-1			
Weight (lb)	-1	1	1	0	1	1	-1			
Moment of Inertia (in^4)	1	0	1	1	0	-1	-1			
Limit of Elasticity (N/m^2)	1	-1	0	0	1	0	-1			
Cost ($)	-1	-1	-1	-1	-1	-1	0			

Engineering Requirements / Customer Requirements		Importance	Yield Strength (psi)	Hardness (N)	Modulus of Toughness (psi)	Weight (lb)	Moment of Inertia (in^4)	Limit of Elasticity (N/m^2)	Cost ($)	Rough Country	Paramount	Icon
EGR Engravement		3			3			1	3	#4	#5	#6
Light Pods		3	1	9	9		1	3	1	4	6	3
License Pod		3	1	9	9		1	3	1	8		
Factory Line Design		9	3	3	3	3	3	1	9	9	9	9
Sensor outlet		3	1	9	9			9	1	2	2	1
Tow Winch		9	9	3	9	9	3	9	3	7	9	7
Maintain Existing Hook Points		3	9	1	3	9	3	9	1	7	6	7
Functionality		9	9	3	9		3	9	9	9.0	7.0	5.0
Resistances		1	3	9	9				1	7.0	9.0	7.0
Durablitliy		9	9		3	1	9	9	3	7.0	7.0	8.0
Reliablilty		3	9		9		9	9	3	7.0	8.0	8.0
Inexpensive		3	3	1	3	9			9	3.0	1.0	2.0
Importance Raw score			70	34	69	33	39	68	52			
Relative Percentage Importance			19.1	9.3	18.9	9.0	10.7	18.6	14.4			
Competive Design Assessment	#4						X		X			
	#5		X	X				X				
	#6				X	X						