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From: Offroad Bumper Team

Engineering Calculations Summary

9/8/2023

ME486C - Engineering Calculations Summary Deliverable

Updated Fall 2023

For this assignment the bumper team has collected and formulated a summary of the calculations done for the project. The focus of the off-road bumper (ORB) capstone is to build a front bumper and two rear bumpers for our two clients, Carson Pete and Cesar Blancarte. The bumpers are meant to increase strength, durability, and resistance for off road driving. Before the start of fall semester, the team had already done calculations that would go towards our final design and will be discussed below. This paper will include basic codes/standards of the materials that will be used to create the bumper as well as the necessary data to provide more context for the equations and the ORB capstone project.

Top Level Design Summary (10pts)

The factory front and rear bumper on the Chevy Silverado and Dodge Ram are not strong enough to withstand impact forces that often occur when off roading. The team plans to design front and rear bumpers that: match factory lines, are powder coated, have increased strength and durability, maintain factory lines, increase utility (winch), include off-road lighting, mount to factory bumper locations ,and maintain factory sensors. The subsystems we will have in this will be the material we use, the bolts selected, the winch, and the additional lighting. These subsystems will help meet all the customer requirements and ensure the team will produce the best product for the clients. The customer requirements can be found in Table 1: Customer Requirements, and show a number value ranking their importance to the project. The engineering requirements for the project can be found in Table 2: Engineering Requirements and show their importance in comparison to the customer needs. This table shows the highest importance being placed on yield strength followed by the modulus of toughness. These factors are the most important for the team to increase the durability and strength of the bumper.

Table 1: Customer Requirements

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

Table 2: Engineering Requirements

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 current state of the CAD is currently minimal. This is because we had to change the design from last semester. The top-level CAD is shown in figures 1 and 2 of the front and rear bumper respectively. The CAD shows at least one of each part that will need to be cut out on the water jet. The bumper still needs to be assembled and adjustments need to be made. This gives a general picture of what resources will be required to finish the bumper on time. The rear bumper for the Dodge Ram is still waiting for measurements before the design process can begin.

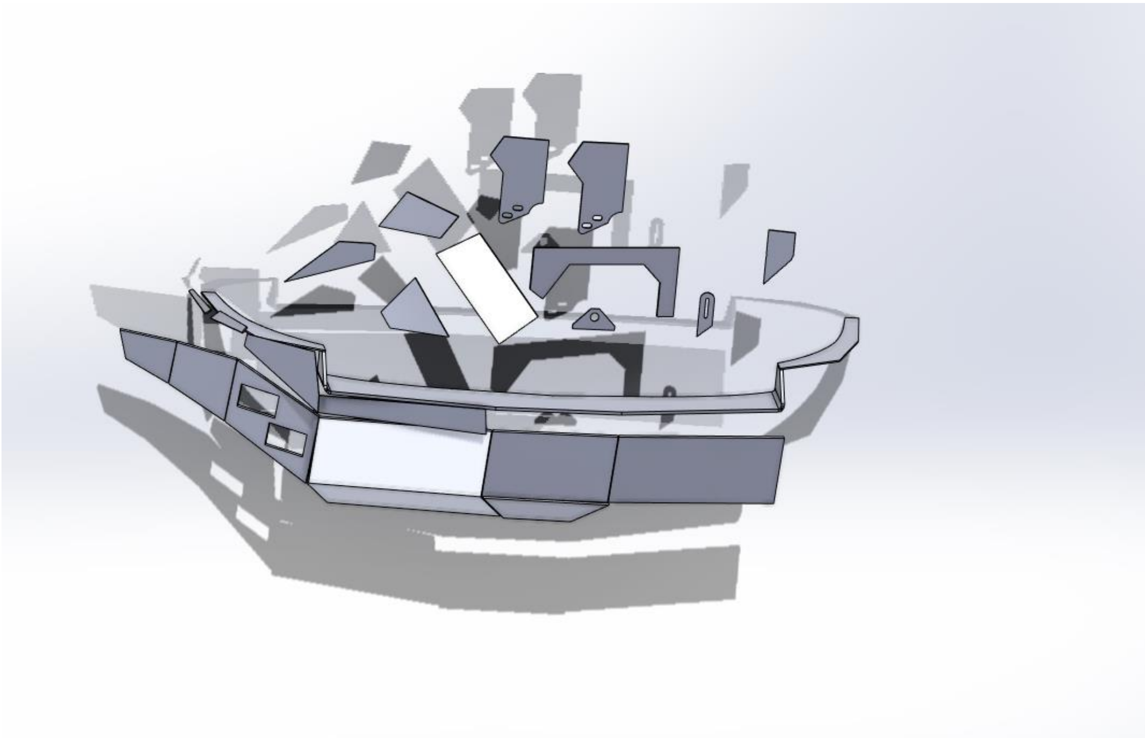

Figure 1: Chevy Silverado Front Bumper

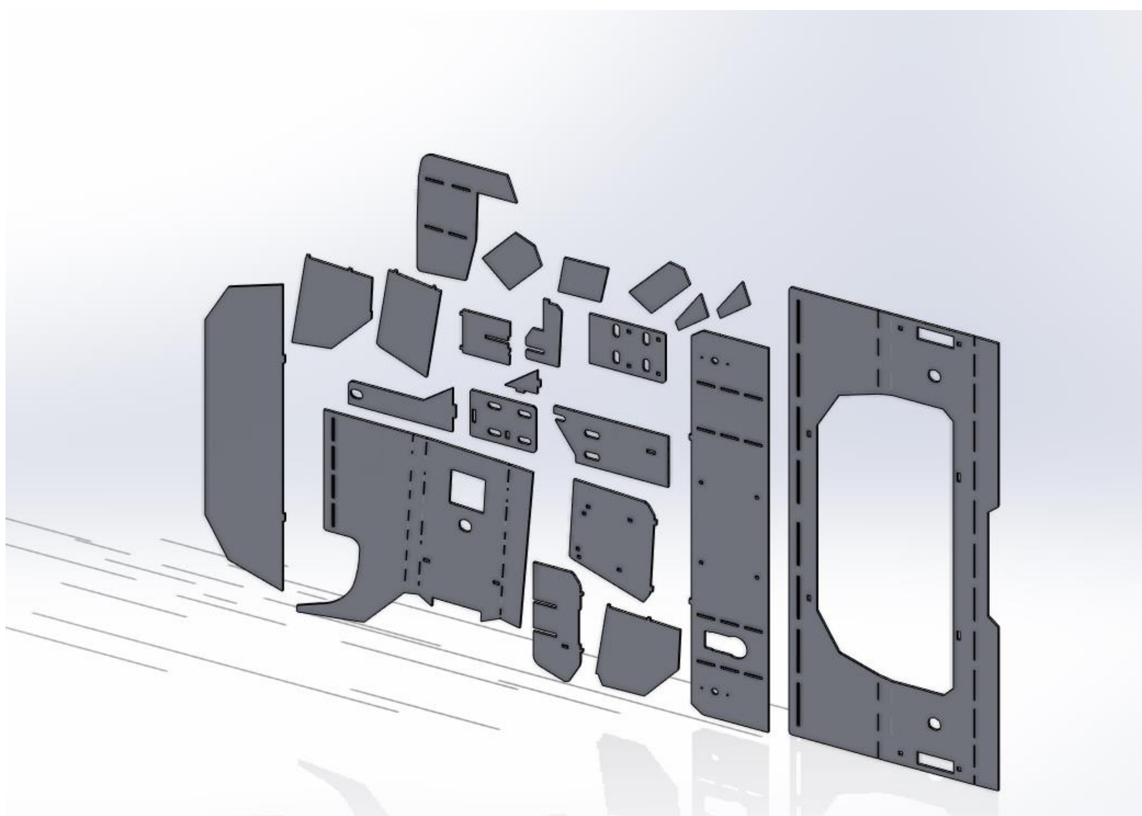

Figure 2: Chevy Silverado Rear Bumper

Summary of Standards, Codes, and Regulations (20pts) TJ

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. Keeping pedestrians safe

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.

Summary of Equations and Solutions (35pts total)

When assessing the worst-case scenario for the bumper the team applied a force of 45mph collision with an object to test the strength and durability of the bumper. The team noticed that the bumper itself would withstand most blows or impacts it could experience in regards the thickness of the material chosen. Since the bumper plating wasn’t our primary concern, we looked at the supports/winch plate which the bumper plating will weld to as well as attaching the bumper to the vehicle. Through this our first possible failure was identified. The bolts that attach the support/winch plate to the vehicle could be sheared off due to fatigue cycle or meeting a greater force that the bolts can't withstand. Another failure that was identified was that the winch bolts could shear off due to the pulling forced applied from the winch. The final failure that was identified during the calculations that were run was that the winch plate could be damaged from the force being applied from the winch bending the bumper.

The following equation used to study the applied forces to the materials are as followed for the bolt analysis that was performed by Thomas Allen. These equations are useful to find the maximum expected force each bumper should encounter. The maximum expected force can then be used to find the factor of safety for the bolts used. The shear force was tested and calculated against known values found through the engineering toolbox website. The bolts need to be tested because the team wants to design the bolts to be the failure point of the bumpers. This will ensure permanent damage doesn't happen to the vehicle in the event of a crash. The results show that 10mm grade 10.9 bolts will be best to mount the bumper to the frame. The 12mm bolts will be the best selection for the winch because they will experience more force over the life of the bumper.

$$Shear\ Force = \frac{F}{A_x}$$

$$F_{max} = m\ x\ \frac{\Delta V}{t}$$

$$Factor\ of\ Safety = \frac{Ultimate\ Stress}{Allowable\ Stress}$$

Table 4: Factors of safety for selected bolts

Bolt size (mm)	Grade	Ultimate Stress	Allowable stress	Factor of safety (Chevy)	Factor of safety (Jeep)	Factor of safety (Jeep)
6	8.8	3619	4375	0.8	1.8	0.6
6	10.9	4699	2000	1.1	2.3	0.8
8	8.8	6564	6000	1.5	3.3	1.1
8	10.9	8565		2.0	4.3	1.4
10	8.8	10431		2.4	5.2	1.7
10	10.9	13556		3.1	6.8	2.3
12	8.8	15152		3.5	7.6	2.5
12	10.9	19716		4.5	9.9	3.3
14	8.8	20682		4.7	10.3	3.4
14	10.9	26977		6.2	13.5	4.5

The following equations are used to study the material properties with both Matthew Baker, and Deja Hubbard through their Material Thickness Analysis and the Material Choice Analysis. These equations are all based on the material property thus there was overlap in the equations used by both analyses. The major difference was the output that they were searching for changed based on the desired outcome of the analysis.

An evaluation of different types of steel was performed to determine the appropriate option to consider based on cost vs durability. This was done by studying the Yield Strength, Ultimate strength, and modulus of elasticity. These properties were chosen because they outline a material ability to deform without being damaged and then as it starts to deform plasticly tell failure.

Variables

- Yield strength = σ_y
- Ultimate strength = UTS
- Modulus of elasticity = λ

The following variables are defined through a materials ability to withstand stress and strain. Thus, the following variables are specific points and regions on a stress strain curve. Each Variable can be defined by an equation to find where on that curve you are for a given material based on the stress and strain involved in the system at work. Yield stress can be calculated from the following equation.

$$\sigma_y = \frac{Force\ at\ Yield}{Orignal\ area{-}sectional\ area}$$

$$UTS = \frac{Ultimate\ Force}{Orignal\ area{-}sectional\ area}$$

$$\lambda = \frac{Stress}{strain}$$

These variables have an agreed upon value for a given material. Thus, for this part of the analysis going over the yield strength and ultimate strength and then determine the best material that fits the need for strength.

The defined force for this analysis is ~100kPa. Based on the force generated by Dr. Pete's truck moving at approximately 35mph. Based on this the team chose to use steel. However, there are several different types of steel which all should have the necessary strength. The following choices are as follows that will have the strength needs to fulfil our customer requirements.

Table 5:Material Properties

Material	λ	UTS	σy	cost
	Gpa	Mpa		
Steel, Structural ASTM-A36	200	400	250	cheapest
Steel, High Strength Alloy ASTM A-514		760	690	mid
Steel, stainless AISI 302	180	860	502	most

From strictly a material property standpoint, the high strength steel would withstand the most damage and allow the customer the most protection. However, once cost and the expected force are accounted for, the cheaper structural steel is more than appropriate for this application.

Using the acting forces allows the next steps in finding the normal stress acting on the metal. With the way of the above analysis the normal force will be a form of tensile force acting in the center of the test part. By analyzing the normal stress distribution in each material type the team can identify which steel we would like to use that can experience excessive force but still be cost effective. Shown below is the normal force equation that was used to gather each situation's stress that would be experienced on the bumper.

$$\sigma = \frac{\Delta Forces}{\Delta Areas}$$

Since the simulation couldn't properly generate the three different types of carbon steel, researching the metals properties was required. Using MatWeb to collect the appropriate data that was needed to calculate the maximum force each metal could withstand and found each type's elastic modulus. The data chat that MatWeb showed gave a percentage of when how long the material could withstand until fracture, shown in table 4-6. All three types were properly converted based on the testing size; the formula that was used is provided below.

$$\Delta L = \varepsilon\% * Width$$

Using the provided elongation percentage and the width of the test part we were able to calculate each carbon steel type's possible lengthening. Table 1 lays out both clients' change in length when the test piece is experiencing force until failure point to meet.

Table 6: Elongation calculated values

Type	Elongation %	Carson's ΔL(in)	David'sΔL(in)
Low	48%	0.09	0.12
Medium	34.20%	0.0641	0.0855
High	30%	0.0563	0.075

Based on the information above table 4 was created to summarize the factor of safety and give a visual representation of the loading and the critical factors that were identified and studied.

Table 4: Factor of safety table

Sub-system	Part	Load Case Scenario	Material	Minimum FoS
Main system				
	Bumper Impact	Maximum allowable force that the bumper will be able to withstand	A36, Structural Steel	Need to find
Sub-system 1				
	Mounting bolts	Low-medium speed impact as a non-distributed load. Weight of bumper and vehicle	10mm Grade 10.9 Hardened bolts	3.1
	Winch bolts	Maximum load the winch is rated for mounted into ¼" steel.	12mm Grade 10.9 Hardened bolts	4.5
Sub-system 2	Material thickness	Collision at approximately 45mph for a 3500lbs vehicle	A36, Structural Steel	N/A bolts will fail prior to metal plating
	Material type	Collision at approximately 45mph for a 3500lbs vehicle	A36, Structural Steel	N/A bolts will fail prior to metal plating

The table above shows that the design has a failure point and the factor of safety of the failure points is high. This will allow for low impacts that would normally cause damage to the bumper and not the vehicle. These failure points ensure that if the load becomes too large the bumper can fail and prevent any permanent damage to the vehicle (bent frame).

Flow Charts and other Diagrams (20pts)

The following flow charts and diagram that are applicable to the ORB capstone are the Black box model and Function model. Both diagrams help explain the function of the bumper and how it will achieve its goal. These diagrams are applicable to all three bumpers that the ORB capstone is responsible for creating for their clients.

The black block model is a tool used to help understand the function what the bumper is trying to achieve on a high level. Thus, ignoring the detail in how it will be performing the task of transferring and absorbing. The important aspects of a black box model are the materials, energy, and the signals going into and out of the system. For the black box model the input is the bumper for materials. For the energy inputs weight, momentum, velocity, and force are all that are applicable. Lastly, there are no signal inputs for this black box model. As for the output, the material is still the bumper. There is a change in the energy output since the action has been applied. Therefore, the energy output is energy transfer/deflection. Finally, the signal output is any visual damage or heat coming off the bumper from the transfer of energy.

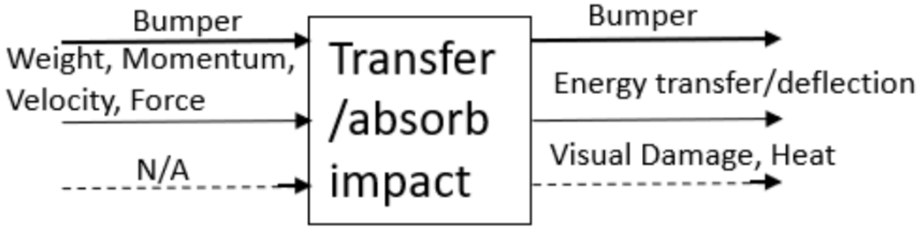

Figure 3: Black Box Model

The other diagram that is still applicable to our current state is the functional model. The functional model fills in the gaps that the black box model leaves blank making it a useful tool to understand the systems being connected to the bumper as well as how the bumper completes the task of transferring/ absorbing energy. This model includes the inputs provided by the person driving the vehicle as well as the sub-systems of the light pods, and winches. Which includes all the applicable to the ORB capstone project.

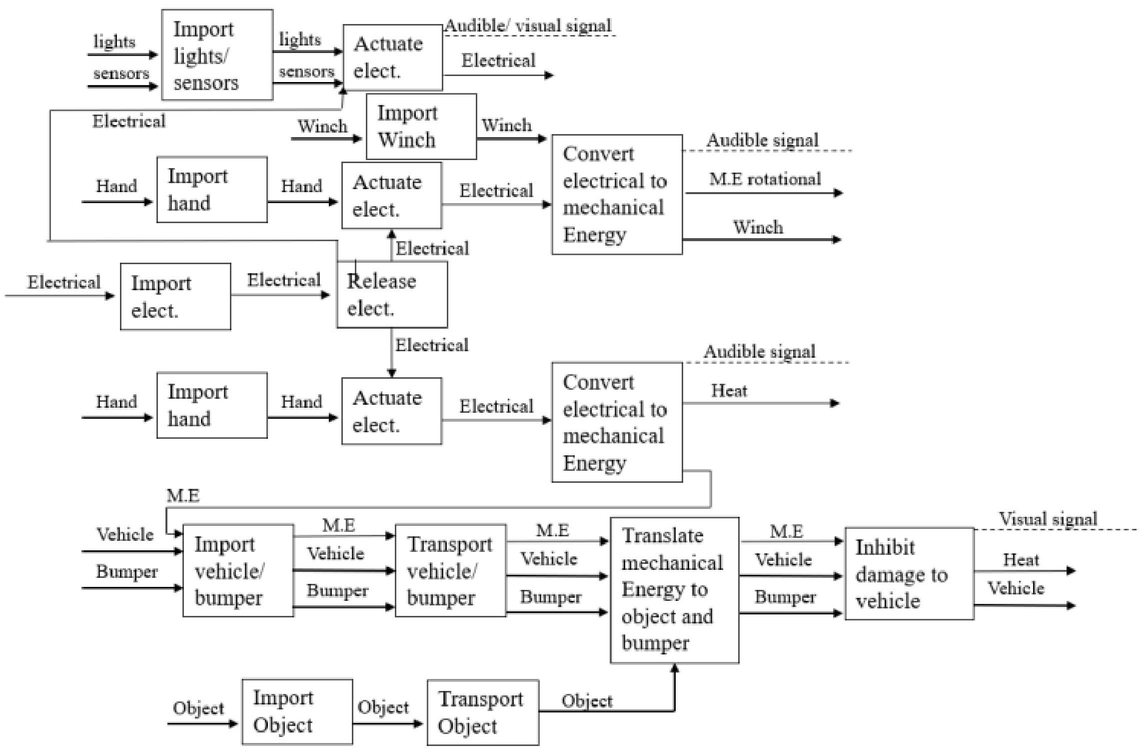

Figure 4: Functional Model

Moving Forward (15pts)

The team believe that they will need to reperform the FEA analysis done by Yuwsef because the CAD design has changed. These calculations will help the team determine the weak points of the design and adjust components prior to production. This is the main component calculation that the team will need to make any adjustment to the CAD. The analysis is not included because the team does not have access to it, and it is no longer relevant to the current design. The team needs to work extensively on updating the CAD design and starting the design of the Dodge rear bumper. The Silverado bumper designs will be done within the next week and the team will be able to start following the schedule set at the beginning of the project. The team will begin ordering parts and assembling the first bumper by the end of the month.

One of the other needs that was identified was that a wire diagram will need to be created to show how power will be supplied to the winch and the light pods. This will allow the team to better understand the needs of the system from a power perspective and how the system will be wired together to ensure that all components have the necessary power to function as well as the power needs from each component.

There would be added value in doing a further dive into the materials factor of safety to better identify at what point the material will start to fail. This data will be used with the FoS found for the bolts of both the winch and mounting. For the bumper, in a perfect world, it should deform and break long before any damage occurs to the frame of the vehicle or any of the other components of the vehicle to ensure that we have meet the customer requirement of increasing the durability of the vehicle during a collision.

To conclude, the team will soon be back on track to completing the three bumpers by the end of November. Once the team completes the CAD, they can start ordering and assembling the materials that make up the bumper.