# Individual Analytical Analysis

## Capstone Team
## Off-Road Bumper

NORTHERN ARIZONA UNIVERSITY


**Deja Hubbard**


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**Introduction**

The purpose of this analysis is to determine which carbon steel would be the leading material that the off-road bumper team will use for the final production. The carbon steels will be tested on their maximum stress, factor of safety,  in two different positions. Situation one will be where all four edges are fixed and force will be applied on one face of the part. Situation two will be the same thing as the first scenario but only be fixed on two edges. Each testing will then be converted into the correct carbon steel type that the team agreed upon: Low, medium, and high carbon steel. Results from this analysis will either confirm or deny the steel type the team selected the best to meet the requirements of yield strength, modulus of toughness, and limit of elasticity.

**Experimental Method**

To start the individual analysis there needs to be a type of benchmark to properly evaluate the different types of carbon steel that would best be suitable for the final production of the bumper. The plan is to create a small but probable layout of the clients driving off-road and hit a simple object and then do another run of hitting a more resistant object. After creating the distance of the accident, finding the average speed of off-roads, and average weight of each car the force acting upon the bumper is achieved. Once the force is found, creating a simulation of how the metal will react depending on the location could give a rough analysis of the stress and deformation that each material might experience. SimulationXpress should provide the results of the maximum shear the part can take until failure is reached. We can also make a shear and moment graph based on the reactions the metal part is experiencing during the simulation. The main focus is to find the possible force the material might encounter as a bumper and how will that after effect look like with each carbon steel type.

**Collision Force Analysis**

There are three types of collisions: vehicle collision, human collision, and internal collision. In order to find the crash force a bumper will undergo the vehicle collision is our primarily focus when finding the force. The equation that will be used to find the force acting for both cars is Newton's Second Law by finding the mass of each car and the total acceleration. To the correct acceleration the average speed of driving off-road, 15 MPH, was used to find the first velocity of the cars. After getting the reaction of the car slowing down after hitting the object the second velocity was calculated. Multiping the found acceleration with the mass of the car the forces per car was found. A summary of the calculations executed is detailed below.

$V_1$ = 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

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

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

$a_1 = \frac{V2-V1}{t} = \ - 1.5m/s2$ [Eqn. 3]

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

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

With Dr. Carson car weighting being 6,694lb [2] and Mr. David's car weighting is 1,950lb [3], neglecting the difference in time recovery, the force of contact for each car is found. Reference Appendix A for a detailed summary calculation of both scenarios.

**Simulation Analysis**

All simulation that were performed was done on SolidWorks 2022, by using the tool SimulationXpress the user is able to test designs on the computer instead spending money and time to get field tests. The program simulates the wanted test by allowing the user to put restraints and select a specific location to apply the force on the CAD design. Once all the required inputs are filled and the design has the respective material make-up the simulations show the safety levels and critical areas at various regions. With the saved time and money this simulation offers, it will allow the team to re-evaluation the design and make the bumper more well balanced if required.

For the individual analysis the simulation was used to confirm the tester's expectations on the metals behavior between two situations that the bumper might experience. With the focus of the carbon steel types being tested for their durability and maximum strength, the actual model of the bumper will not be used during the testing. The testing shown below is a part that was created based on the agreed thickness for both clients' bumper and average length of what the center portion of the bumper would be. The first situation is having all four edges of the part being restrained or fixed in the designated coordinates. Either face of the part will experience the approximate force the client would have if the bumper would slam into a wild animal or rock. The program ran the scenario and reconstructed the part if the force was constantly applied until failure was achieved. The final result of the part came out to be similar to a dent that a piece of metal would form if something was thrown right in the middle, which was the aimed damage type. To get a visualible image of run one reference to figure 1 and figure 2.

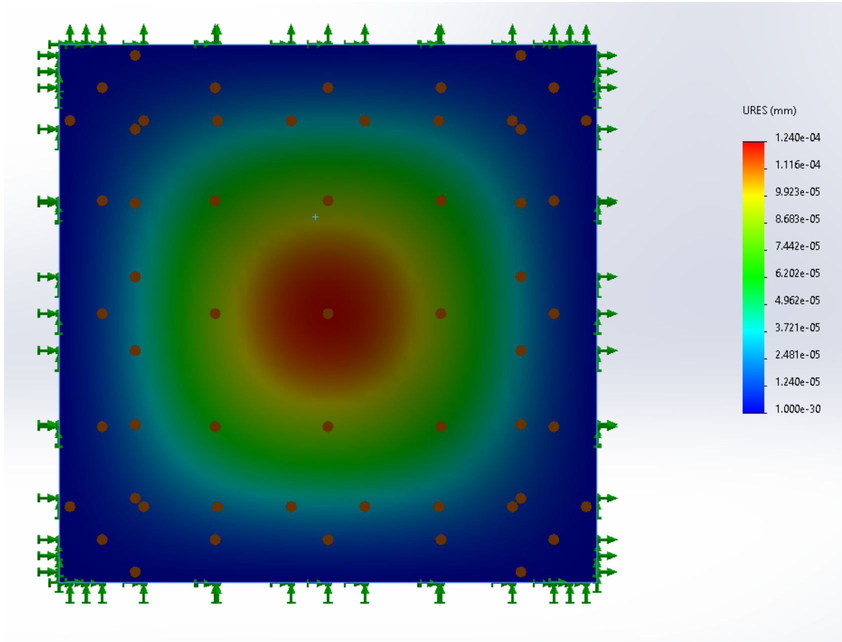



Figure 1: Front view of displacement with four restraints.

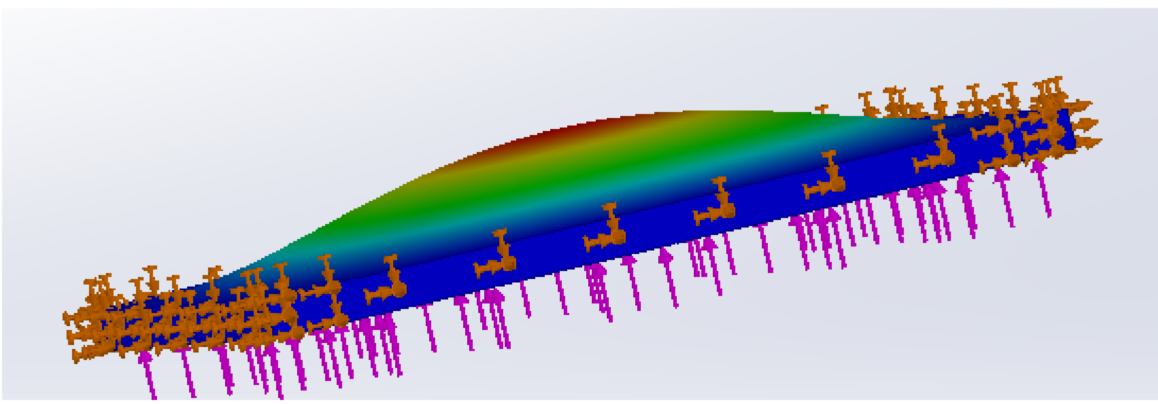


Figure 2: Side view of displacement with four restraints.

Situation two used the same design and set-up as situation one with the exception that instead of four fixed edges the part only had two fixed edges that were parallel to each other. The same amount of force was applied to either side of the faces. The goal for this test run was to simulate what the long portions of the bumper would experience when there is a force acting on it. Similar to if the car suddenly hits a pit hole, caught on an object that elevated the car, or bumping into an immovable object. After the reconstruction of the part, the displacement that showed in figure 3 and 4 is the expected outcome.

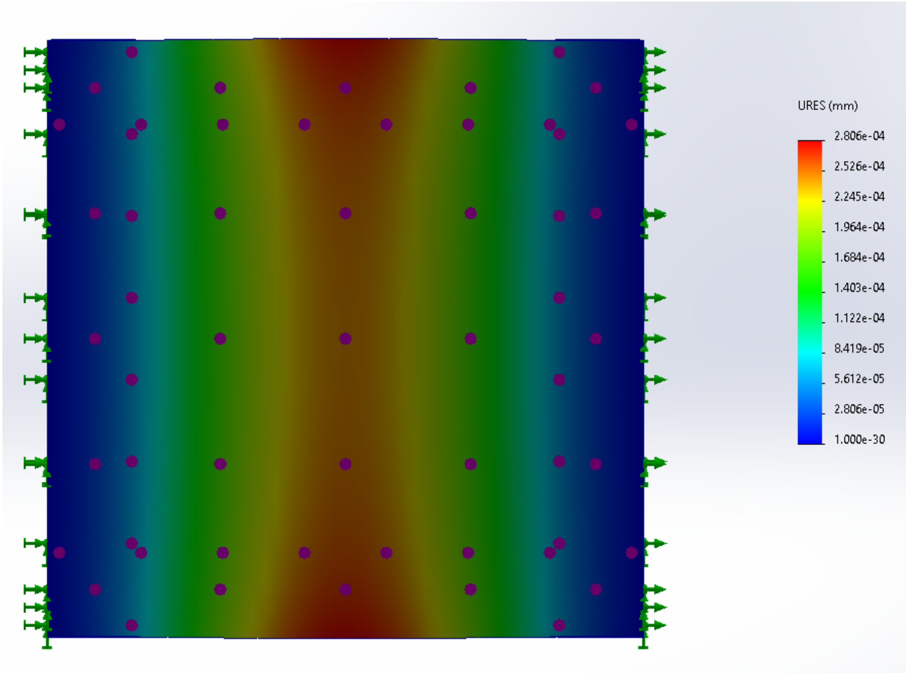



Figure 3: Front view of displacement acting with two restraints.

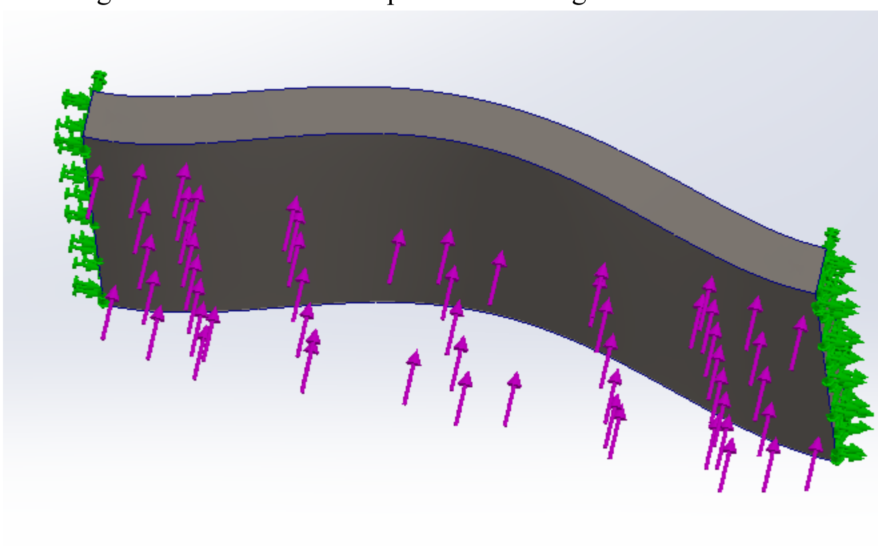


Figure 4: Top view of displacement with two restraints.

**Stress Analysis**

Using the acting forces found in the collision force analysis allows the next step 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 carbon steel we would like to go further 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.

$$\sigma = \frac{\Delta Force}{\Delta Area}$$

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.

$$\Delta L = \varepsilon\% * \text{Width}$$

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 1: 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 |

**Carbon Metal Life Analysis**

Knowing the low, medium, and high carbon steel factor of safety is important because the team wanted to make sure that the material could take a high impact force and still be usable afterwards. Since the main focus of this analysis section is figuring out the materials maximum force it can withstand and the factor safety, FS, the tables shown below are only reflecting Dr. Carson's analysis. For more information on both clients' analysis view appendix A. From figure 6-4 the ultimate tensile strength, $TS_{ult,}$ is given for each carbon steel type. The ultimate tensile strength formula, as shown below, allows for the calculation of the maximum force that each part made of carbon steel can withstand.

$$\mathbf{TS_{ult}} = \frac{Fmax}{Original\ Cross{-}Section\ Area}$$

Multiplying the given tensile strength with the area of the test piece the values of how each steel type is reflected in table 2. The values that table 2 provides commonly reflects the science behind the carbon steel types. The low carbon steel contains less than .30% of carbon, medium contains an average between .30 to .60% carbon, and high carbon steel has more than .60% carbon steel. The level contents of carbon in steel provides a strengthening and hardness to the materials final production.

Table 2: Dr. Carson's Calculated Max Force

| Type | Max Force (N) |
|---|---|
| Low | 4,630.50 |
| Medium | 5,159.70 |
| High | 6,048 |

When evaluating the strength of each carbon steel it is important to consider the potential for failure under different types of loads. By calculating the factor of safety it allows the team to measure the material's ability to withstand a certain amount of stress being applied without it facturing. The collected values that are associated with table 3-6 present valuable information of all three carbon steel types.

Table 3: Calculated FS

| Type | Factor of Safety |
|---|---|
| Low | 1.01 |
| Medium | 1.1 |
| High | 1.3 |

**Conclusion**

The result of this individual analysis will assist the team by layout which of the carbon steel would best fit the final material of the design. The high carbon steel is most desirable out of the three carbon steel because of the strength the material has and a higher factor of safety. Additionally, if the team wants a bumper that has a good strength to provide the car but also flexibility of absorbing the force the car will experience then medium carbon steel is the choice. After stating the top choices the best decision for the material of the bumper would depend on which client it is being made for. The High carbon steel will be best applied for Carson's bumper because the car has a well support beam built in the car. For Mr. David bumper the medium carbon steel would be the best choice because the amount of force it can take before failing and the car isn't as friendly to modifications. Attaching a full metal bumper could damage the car itself instead of absorbing the collision force. Overall, this analysis could be used as a guideline to find a new type of material if the team chooses not to go through with the carbon steel as the final material.

## Appendix:

Table 4: High Carbon Steel Properties

| Physical Properties | Metric | English |
|---|---|---|
| Density | 0.451 - 8.26 g/cc | 0.0163 - 0.298 lb/in$^3$ |
| Particle Size | 6.70 - 12.0 µm | 6.70 - 12.0 µm |
| **Mechanical Properties** | **Metric** | **English** |
| Hardness, Brinell | 163 - 600 | 163 - 600 |
| Hardness, Knoop | 195 - 769 | 195 - 769 |
| Hardness, Rockwell B | 43.0 - 100 | 43.0 - 100 |
| Hardness, Rockwell C | 10.0 - 70.0 | 10.0 - 70.0 |
| Hardness, Vickers | 182 - 748 | 182 - 748 |
| Tensile Strength, Ultimate | 161 - 3200 MPa | 23300 - 464000 psi |
| Tensile Strength, Yield | 275 - 3340 MPa | 39900 - 484000 psi |
| Elongation at Break | 0.500 - 30.0 % | 0.500 - 30.0 % |
| Reduction of Area | 13.4 - 73.0 % | 13.4 - 73.0 % |
| Modulus of Elasticity | 13.8 - 235 GPa | 2000 - 34100 ksi |
| Flexural Yield Strength | 159 - 5130 MPa | 23000 - 744000 psi |
| Compressive Yield Strength | 1320 - 3100 MPa | 191000 - 450000 psi |
| Bulk Modulus | 160 GPa | 23200 ksi |
| Poissons Ratio | 0.280 - 0.313 | 0.280 - 0.313 |
| Fracture Toughness | 13.2 - 165 MPa-m½ | 12.0 - 150 ksi-in½ |
| Machinability | 10.0 - 125 % | 10.0 - 125 % |

Table 5: Medium Carbon Steel Properties

| Physical Properties | Metric | English |
|---|---|---|
| Density | 7.75 - 7.89 g/cc | 0.280 - 0.285 lb/in$^3$ |
| Particle Size | 6.70 - 12.0 µm | 6.70 - 12.0 µm |
| **Mechanical Properties** | **Metric** | **English** |
| Hardness, Brinell | 126 - 578 | 126 - 578 |
| Hardness, Knoop | 145 - 616 | 145 - 616 |
| Hardness, Rockwell B | 71.0 - 112 | 71.0 - 112 |
| Hardness, Rockwell C | 9.00 - 71.0 | 9.00 - 71.0 |
| Hardness, Vickers | 131 - 614 | 131 - 614 |
| Tensile Strength, Ultimate | 450 - 2730 MPa | 65300 - 396000 psi |
| Tensile Strength, Yield | 245 - 1740 MPa | 35500 - 252000 psi |
| Elongation at Break | 5.00 - 34.2 % | 5.00 - 34.2 % |
| Reduction of Area | 20.0 - 71.4 % | 20.0 - 71.4 % |
| Modulus of Elasticity | 187 - 213 GPa | 27100 - 30900 ksi |
| Bulk Modulus | 152 - 163 GPa | 22000 - 23600 ksi |
| Poissons Ratio | 0.280 - 0.300 | 0.280 - 0.300 |
| Fatigue Strength | 138 - 614 MPa | 20000 - 89100 psi |
| Fracture Toughness | 80.9 - 143 MPa-m½ | 73.7 - 130 ksi-in½ |
| Machinability | 40.0 - 80.0 % | 40.0 - 80.0 % |
| Shear Modulus | 72.0 - 82.0 GPa | 10400 - 11900 ksi |

Table 6: Low Carbon Steel Properties

| Physical Properties | Metric | English |
|---|---|---|
| Density | 2.85 - 8.08 g/cc | 0.103 - 0.292 lb/in$^3$ |
| **Mechanical Properties** | **Metric** | **English** |
| Hardness, Brinell | 86.0 - 550 | 86.0 - 550 |
| Hardness, Knoop | 103 - 682 | 103 - 682 |
| Hardness, Rockwell B | 30.0 - 105 | 30.0 - 105 |
| Hardness, Rockwell C | 10.0 - 64.0 | 10.0 - 64.0 |
| Hardness, Vickers | 22.0 - 661 | 22.0 - 661 |
| Tensile Strength, Ultimate | 241 - 2450 MPa | 35000 - 355000 psi |
| Tensile Strength, Yield | 140 - 2400 MPa | 20300 - 347000 psi |
| Elongation at Break | 3.00 - 48.0 % | 3.00 - 48.0 % |
| Reduction of Area | 15.4 - 75.0 % | 15.4 - 75.0 % |
| Modulus of Elasticity | 183 - 213 GPa | 26500 - 30900 ksi |
| Compressive Yield Strength | 152 - 1800 MPa | 22000 - 260000 psi |
| Bulk Modulus | 148 - 163 GPa | 21500 - 23600 ksi |
| Poissons Ratio | 0.250 - 0.300 | 0.250 - 0.300 |
| Fatigue Strength | 758 - 772 MPa | 110000 - 112000 psi |
| Fracture Toughness | 33.0 - 115 MPa-m½ | 30.0 - 105 ksi-in½ |
| Machinability | 50.0 - 160 % | 50.0 - 160 % |
| Shear Modulus | 70.0 - 80.0 GPa | 10200 - 11600 ksi |

**Appendix A: Stress analysis**

C = Carson    D = David

$M_C = 6694 lb \cdot \frac{1kg}{2.2lb} = 3{,}042.7 kg$

$M_D = 4290 lb \cdot \frac{1kg}{2.2lb} = 1{,}950 kg$

S1 (t = .3): $V_1 = 15 MPH \rightarrow 6.7056 m/s$, $V_2 = 14 MPH \rightarrow 6.26 m/s$

S2 (t = 1.2): $V_1 = 6.7 m/s$, $V_2 = 7 MPH \rightarrow 3.13 m/s$

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

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

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

$F = m \cdot a$

$F_{C_1} = 3042.7(-1.5) = 4{,}564.05 N$    $F_{C_2} = 9{,}067.246 N$

$F_{D_1} = 1950(-1.5) = 2{,}925 N$    $F_{D_2} = 5811 N$

Normal stress

$C_w = .1875''$  $D_w = .25''$

$\sigma = \frac{\Delta F}{\Delta A}$    $A = 2(wl + hl + hw)$

$\sigma_{C_1} = \frac{4564.05N}{1.89m} = 2414.84 MPa$    $A_C = 2(.1875(7) + 5(7) + (5).1875) = 74.5 in \rightarrow 1.89 m$

$\sigma_{C_2} = \frac{9067.25N}{1.89m} = 4797.48 MPa$

$\sigma_{D_1} = \frac{2925N}{1.93m} = 1{,}515.54 MPa$    $A_D = 2(.25(7) + 5(7) + 5(.25)) = 76 in \rightarrow 1.93 m$

$\sigma_{D_2} = \frac{5811N}{1.93} = 3{,}010.88 MPa$

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

Carson:
$\varepsilon_H = .3(.1875) = .0565 in$
$\varepsilon_M = .342(.1875) = .0641 in$
$\varepsilon_L = .48(.1875) = .09 in$

David:
$\varepsilon_H = .3(.25) = .075 in$
$\varepsilon_M = .0855 in$
$\varepsilon_L = .12 in$

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

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: $F_{max} = 4630.5 N$    $F_{max} = 4{,}728.5 N$

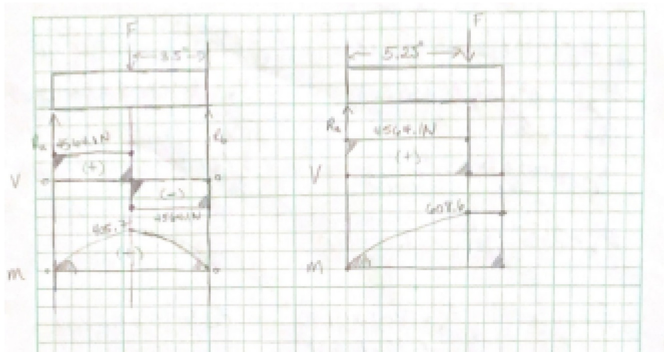
**Appendix B: Factor of Safety Analysis**

$FS = \frac{\sigma_{max}}{\sigma} = \frac{3200}{2414.84} = 1.3$ – High

$= \frac{2730}{2414.84} = 1.1$ – med

$= \frac{2450}{2414.84} = 1.01$ – Low

**Appendix C: Shear and Moment diagrams**



## References


[1] Department of Transportation, "Three Collisions" MDT. [Online]. Available: https://www.mdt.mt.gov/visionzero/people/buckleup/docs/three-collisions-in-crash.pdf

[2] Edmunds Experts "2008 Chevrolet Silverado 3500HD / Curb weight" Edmunds. [Online]. Available: https://www.edmunds.com/chevrolet/silverado-3500hd/2008/review/

[3] Edmunds Experts "2011 Jeep Liberty / Curb weight" Edmunds. [Online]. Available: https://www.edmunds.com/jeep/liberty/2011/features-specs/

[4] Material Property Data, "Material Group Search" *MatWeb*. [Online]. Available: https://www.matweb.com/Search/MaterialGroupSearch.aspx?GroupID=225

[5] SOLIDWORKS Help, "Overview of SOLIDWORKS SimulationXpress" *Dassault Systemes*. [Online]. Available: https://help.solidworks.com/2022/English/SolidWorks/cosmosxpresshelp/c_Overview_of_SOLIDWORKS_SimulationXpress.htm?id=b1bce643af53438aa96939dbf2f24a82#:~:text=SimulationXpress%20simulates%20the%20design%20cycle,Deformed%20shape