Design & Stress analysis

This section of the report is dedicated to analyzing optimal and critical operating conditions of our chassis design for the EleCycle. The following analysis was carried out for an assumed worst-case scenario of 130 Kg loading condition – 65 kg per person. It was assumed that 80% of the loading condition was distributed across the seat and the rest distributed as axial load, at the handle. In addition, for simplicity all beams are assumed to be solid with equivalent cross-section area of a standard hollow tube, with a known inner and outer diameter. The final chassis design was obtained after several stress analysis and design optimizations.

Preliminary Design

The preliminary chassis design is given in figure 11. The initial design was developed to withstand the worst-case loading condition excluding motor and battery weight. In addition, the material used for the preliminary chassis frame was Aluminum 6061-O (SS). Figures 12, 13, and 14 are the results of FEA, carried out on the preliminary StreamLiner. They represent the Stress distribution, Strain, and Deformation of the frame, respectively.

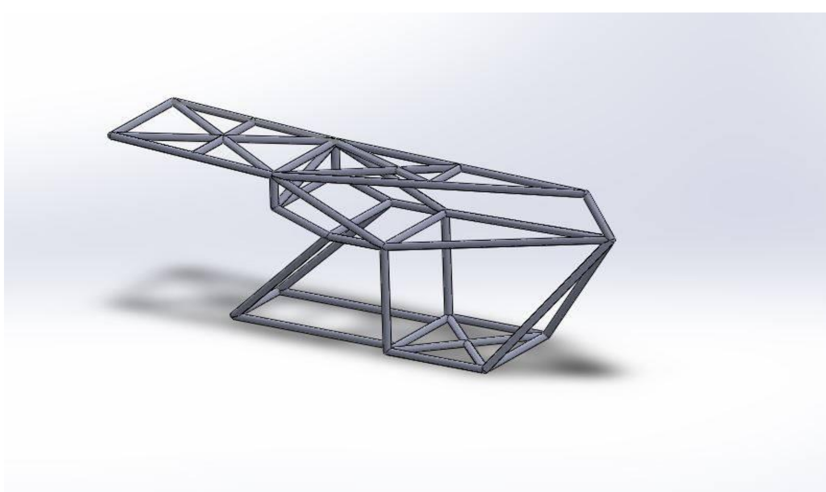

Figure 11: Preliminary Chassis Design

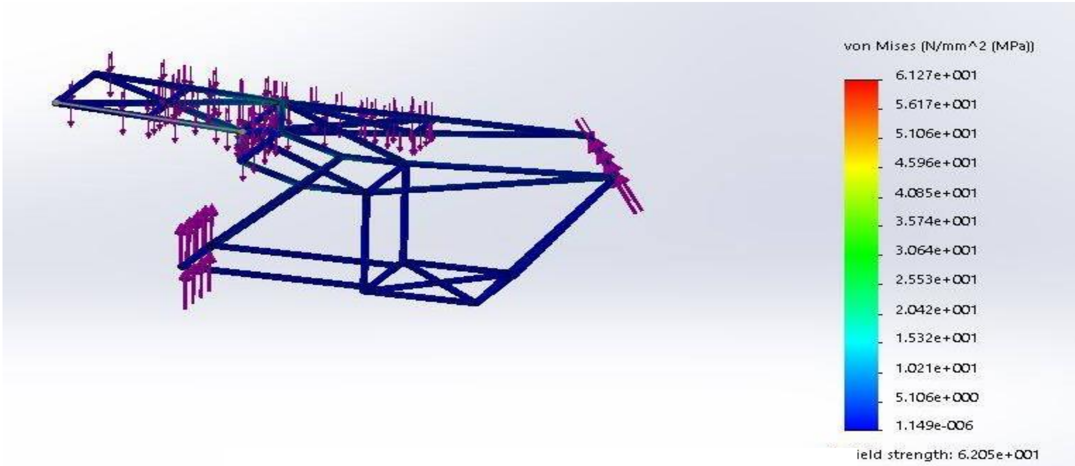

Figure 12: Preliminary Design Stress Analysis

The results of the stress analysis shown above depict that the preliminary design was able to evenly distribute the worst-case loading condition of the chassis frame. The max stress on the preliminary design was 61 MPa, experienced by the beam supporting the suspended backseat. The max stress experienced by the preliminary design was very close to the yield stress of the material chosen, Aluminum 6061-OS. The yield strength of Aluminum 6061-OS is given as 6.205 MPa, as shown by the figure 12. For the preliminary design we assumed that each element in the design had a cross-section area based on a cross-section given by a diameter of 20.1 mm, which is equivalent to a pipe with 1.5′′ outer diameter and 1.25′′ inner diameter.

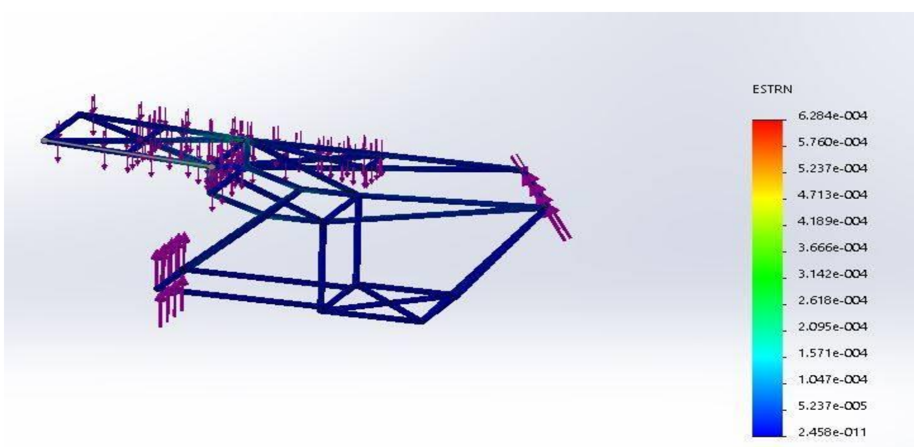

Figure 13: Preliminary Design Strain Analysis

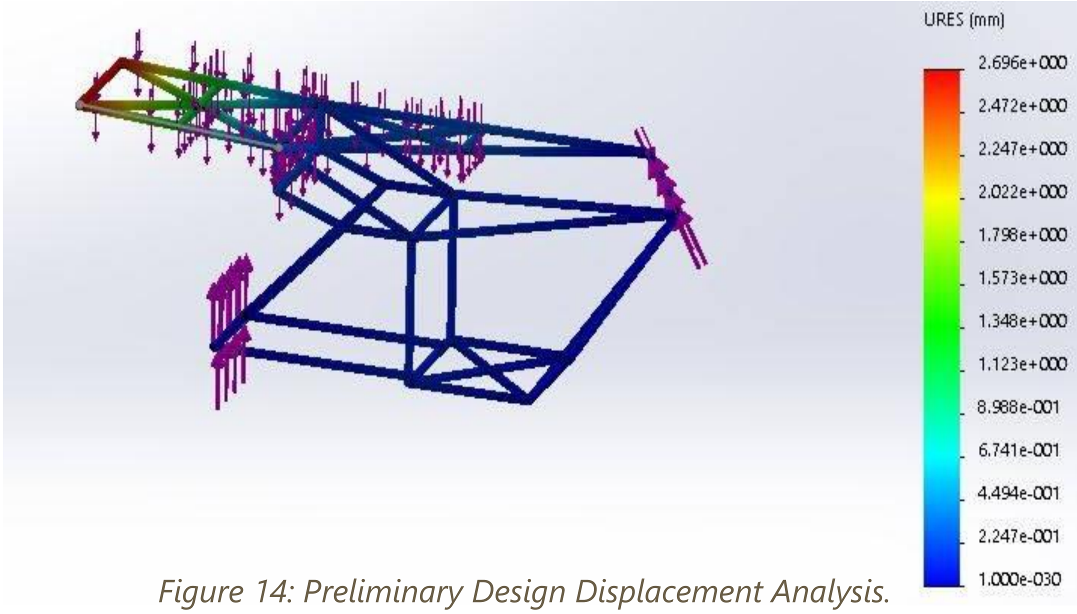

Figure 14: Preliminary Design Displacement Analysis.

Based on the FEA carried out on the preliminary design and the results depicted by figures 12, 13 and 14 we conclude our preliminary design is not safe. We reached this conclusion looking at the factor of safety of our design. Factor of safety of preliminary design is just over 1, which is not a preferred factor of safety in any mechanical structure. There was no restriction on the factor of safety in this project, but to ensure our product had a reasonable life span, a greater factor of safety was our personal requirement. Having a larger factor of safety, allows us to guarantee our investors that their investment will produce a reasonable rate of return on their investment. Moreover, analyzing figure 13 and 14, it can be noted that the maximum strain and deflection in our design is experienced by the backseat. The result is reasonable as our backseat was only support at one end. Therefore, based on the reasons mentioned, the preliminary design required modifications. The following section analyzes version 2 of our design, which improves upon the factor of safety.

StreamLiner – Final Design

The results obtained from FEA carried out on the preliminary design were used to finalize the chassis design for EleCycle's StreamLiner. The preliminary design was modified to increase the factor of safety of our design under the worse-case loading condition. Figure 15 is the CAD drawing of EleCycle's final chassis design.

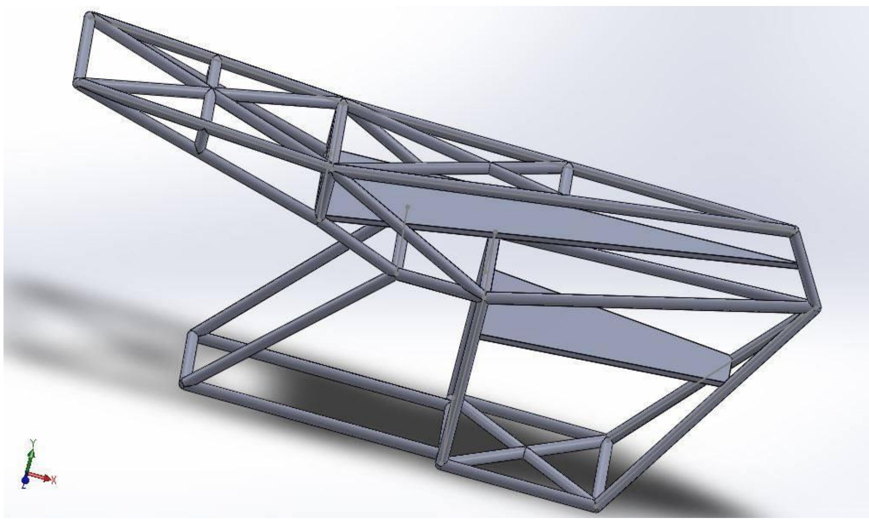

Figure 15: Streamliner –Final Design Chassis

The improvements made to the preliminary design are shown by figure 15. The main goal of modification was to increase the factor of safety. This objective was achieved by changing the material of the chassis and adding elements to support the backseat. Moreover, the improved design also considers the weight of the battery and motor, in addition to the worst-case loading condition. The battery used in the StreamLiner weighs 50 Kg. Each cell has a diameter of 18 mm diameter and a height of 65 mm. The battery has 1100 cells, the weight of battery is distributed over two planks, with majority of the load supported by the lower plank. The motor weighs 10 Kg and its weight is distributed over the lower diagonal beams – region below the lower plank. The material of the chassis frame was changed to Aluminum 6061-T6, which had a higher yield strength. The yield strength of Aluminum 6061-T6 is 275 MPa, an increase in yield stress by 213 MPa.

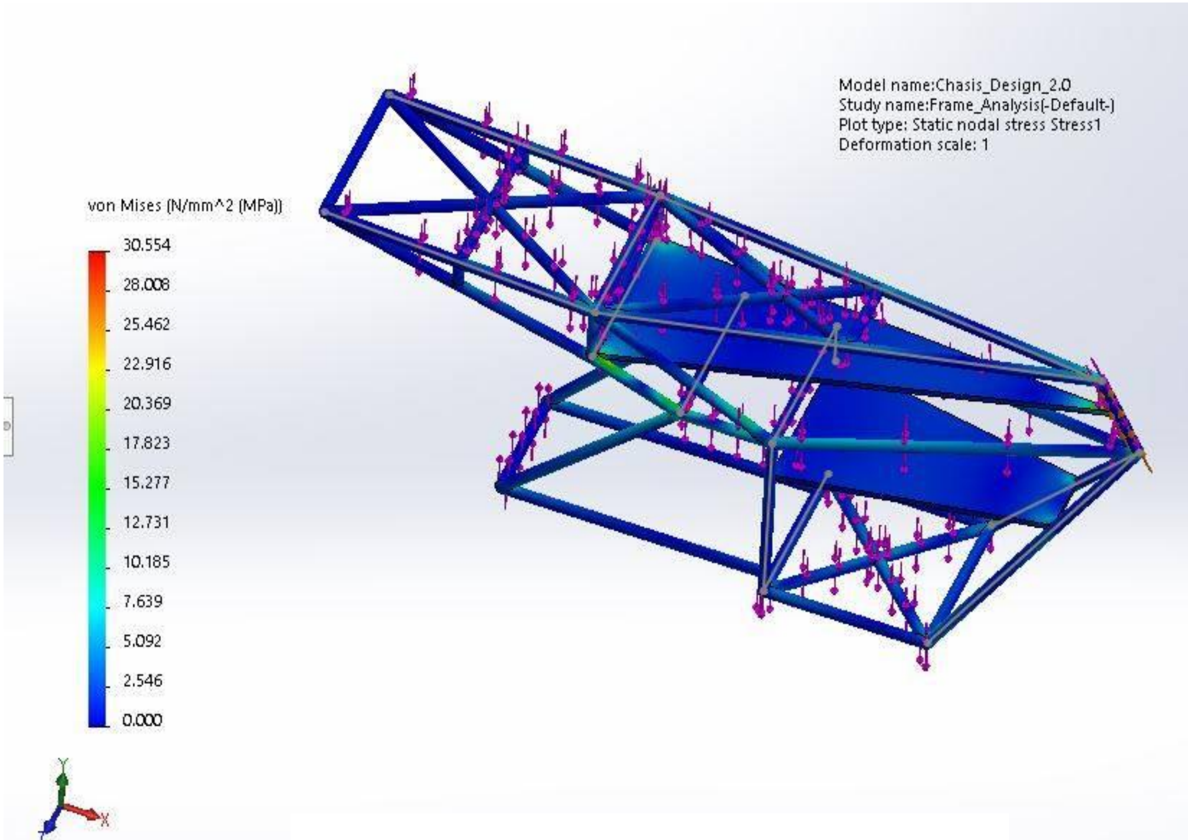

Figure 16: Streamliner -Final Design Stress Analysis

The results of the stress analysis shown above depict that the improved design was able to evenly distribute the new worst-case loading condition of the chassis frame. The new worst-case loading condition includes 2 riders, motor and battery weight. The max stress on the improved design was 30.6 MPa, experienced by the beam supporting the top battery plank. The max stress experienced by the improved chassis design is far from the yield stress of the material chosen, Aluminum 6061-T6. For the improved design we assumed that each element in the design had a cross-section area based on a cross-section given by a diameter of 20.1 mm, which is equivalent to a pipe with 1.5'' outer diameter and 1.25'' inner diameter.

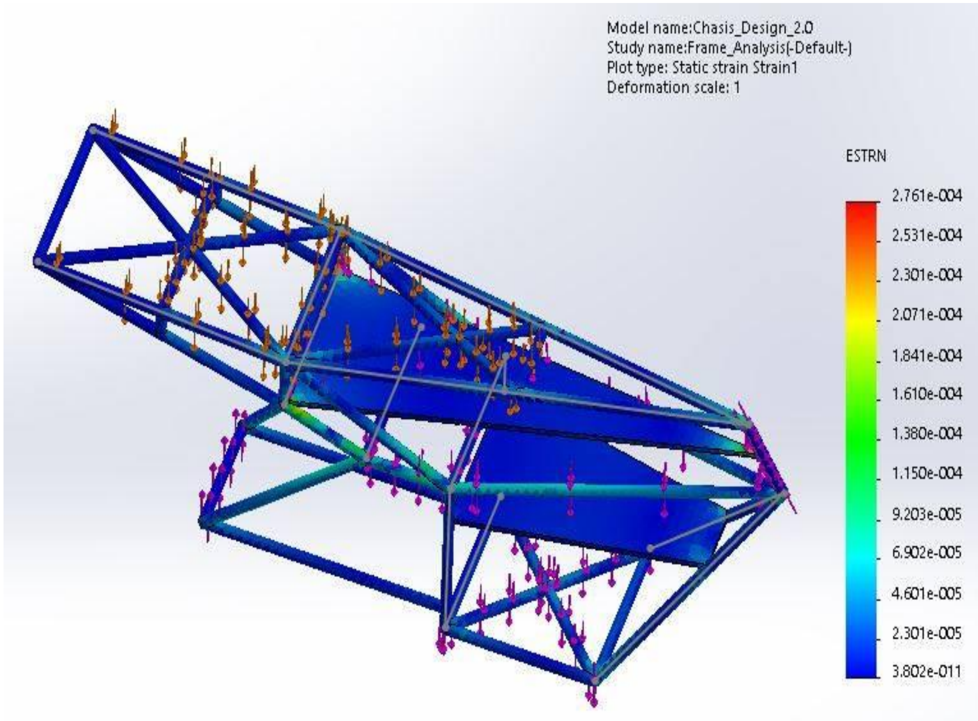

Figure 17: Streamliner -Final Design Strain Analysis

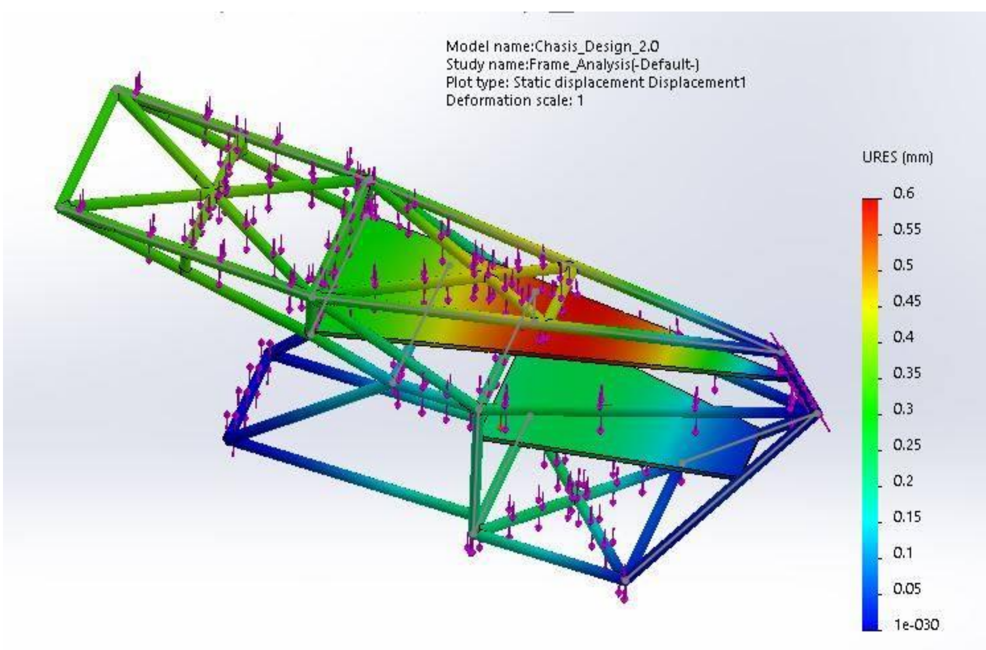

Figure 18: Streamliner -Final Design Deformation Analysis

Based on the FEA carried out on the improved design and the results depicted by figures 16, 17 and 18 we conclude our improved design has achieved structural safety. We reached this conclusion by looking at the factor of safety of our design. Factor of safety of improved design is 10. Recalling that there is no restriction on the factor of safety in this project, but our personal design goal was to obtain a factor of safety greater than 2, to ensure our product had a reasonable life span. Moreover, analyzing figure 17 and 18, it can be noted that the maximum strain and deflection in our design is no longer at the backseat – the preliminary chassis design issue. The maximum strain and deflection now occur at the top battery shelf due to our chosen shelf width of 10 mm. However, the maximum strain in the design is lower than the strain at the elastic limit of Aluminum 6061-T6. Therefore, based on the results and rational mentioned, the improved design has achieved over the desired factor of safety 3.

The finalized chassis frame in figure 15 experiences fluctuating cyclic loading. Therefore, it's customary to carry out a fatigue failure analysis to determine the safety of our frame. The fatigue failure analysis could easily be carried out by SolidWorks Simulation tool. However, due to the max stress in our frame being less than minimal stress considered by SolidWorks Fatigue Stress simulation tool, SolidWorks Simulation cannot be utilized to determine the safety of our design by considering cyclic loading. Therefore, hand calculations were carried out to carry out fatigue failure analysis. Namely, we employed the Goodman Method to determine the safety of our StreamLiner chassis frame by considering the average stress and actual stress amplitude of our frame design. The results of the hand calculations carried out are discussed in the following text, the hand calculations can be found in the Appendix A.

Fatigue Failure Analysis - StreamLiner

The Goodman method was utilized to determine the safety of our chassis design in this project. The Goodman method and the Stress analysis figure of the final chassis frame using FEA were used to determine the cross-section area of our pipes.

The hand calculations for our design safety and stress concentrations are included in Appendix A. Based off the results from the Goodman method, our chassis design is safe as the maximum stress experienced by the frame was less than the actual endurance limit of Aluminum 6061-T6, and the average stress experienced by the frame was less than the ultimate tensile strength of the material. The Goodman method plot for our design safety is shown below.

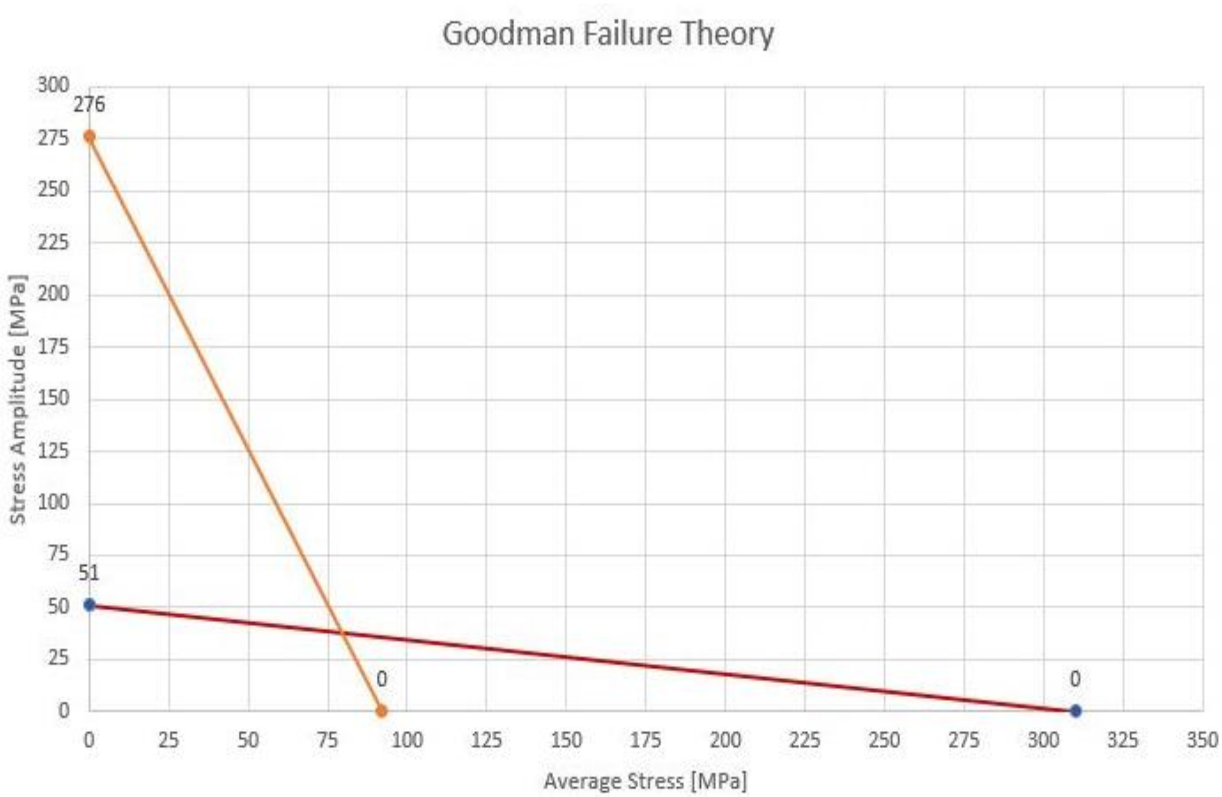

Figure 19: Goodman Failure Theory

The region enclosed by the two curves is the safest design. Hence, our design is safe as our stress amplitude and average stresses are as follows.

Stress amplitude = σ_a= 15.3 MPa < 51 MPa

Average Stress =σ_m = 15.3 MPa < 92 MPa

Where,

51 MPa = $S_n{}'$= Actual Endurance Limit of our Frame.

$$92\text{MPa} = \frac{S_y}{K_t} = \frac{Yield\ Strength\ of\ Frame}{Stress\ Concentration\ of\ Frame}$$

In addition, the Goodman failure theory was also employed to determine the stress concentration of our chassis pipes. According to the Goodman method, the stress concentration in our frame design was less than 3.16. This suggested that using the stress concentration plots for different round shafts, the dimensions of our frame pipes can be selected provided the stress concentration was less than 3.16. The calculations for these conclusions are included in the Appendix A.

The actual endurance strength of the chassis frame was calculated as shown in the Appendix A. Due to lack of information about the properties of Aluminum 6061-T6 in the textbook, the parameters for endurance strength calculation were determined by using the textbook and some online resources. The sources are cited in the references and some of the justifications are as follows. For our material the material factor C_m was approximated using the given C_m table in the textbook for steel due to lack of sources. S_n was obtained from and online source, the website is cited in the references.