Modelling Parts and Assembly

Figure 47: Modelling individual parts

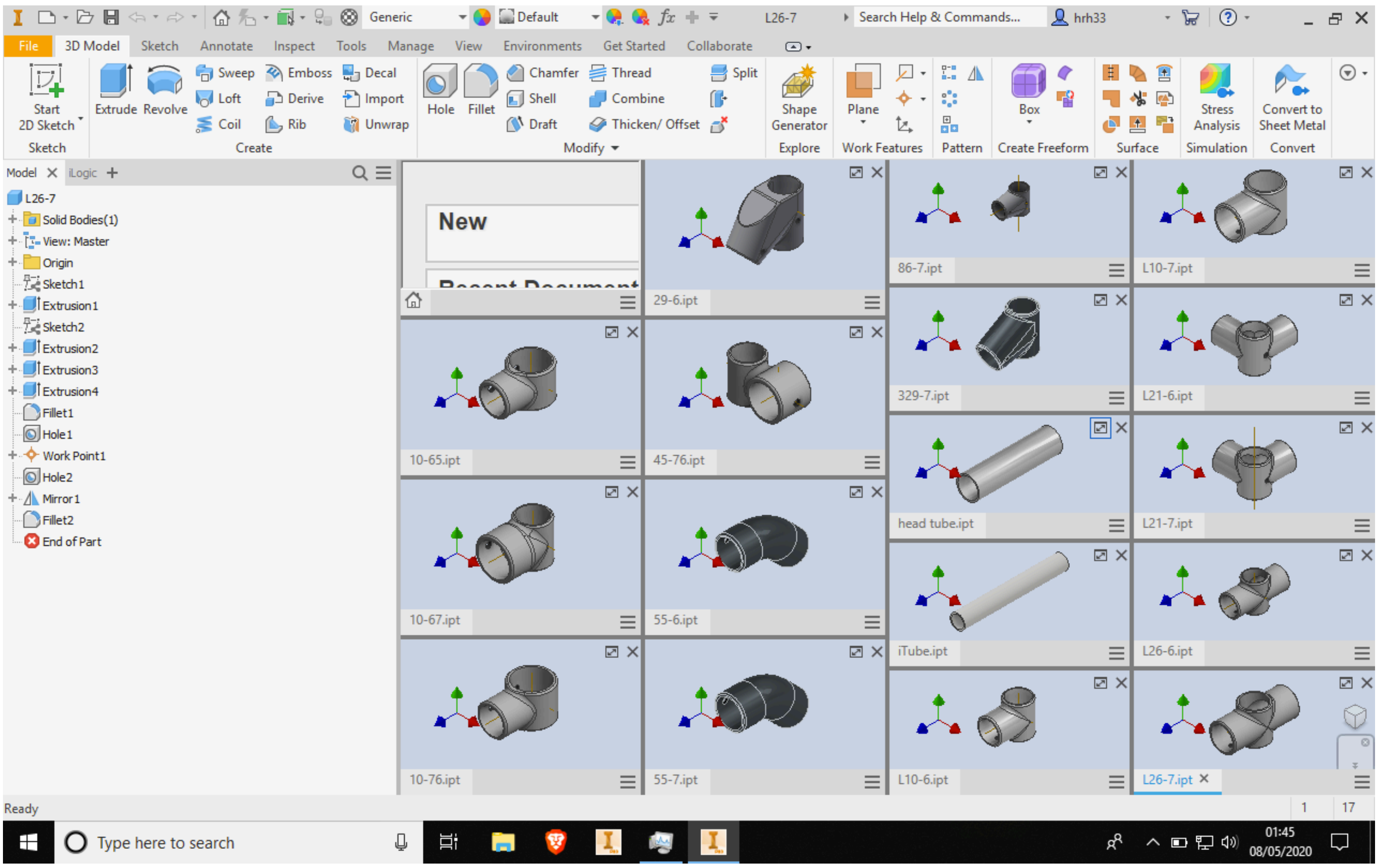


Figure 48: Some open part files

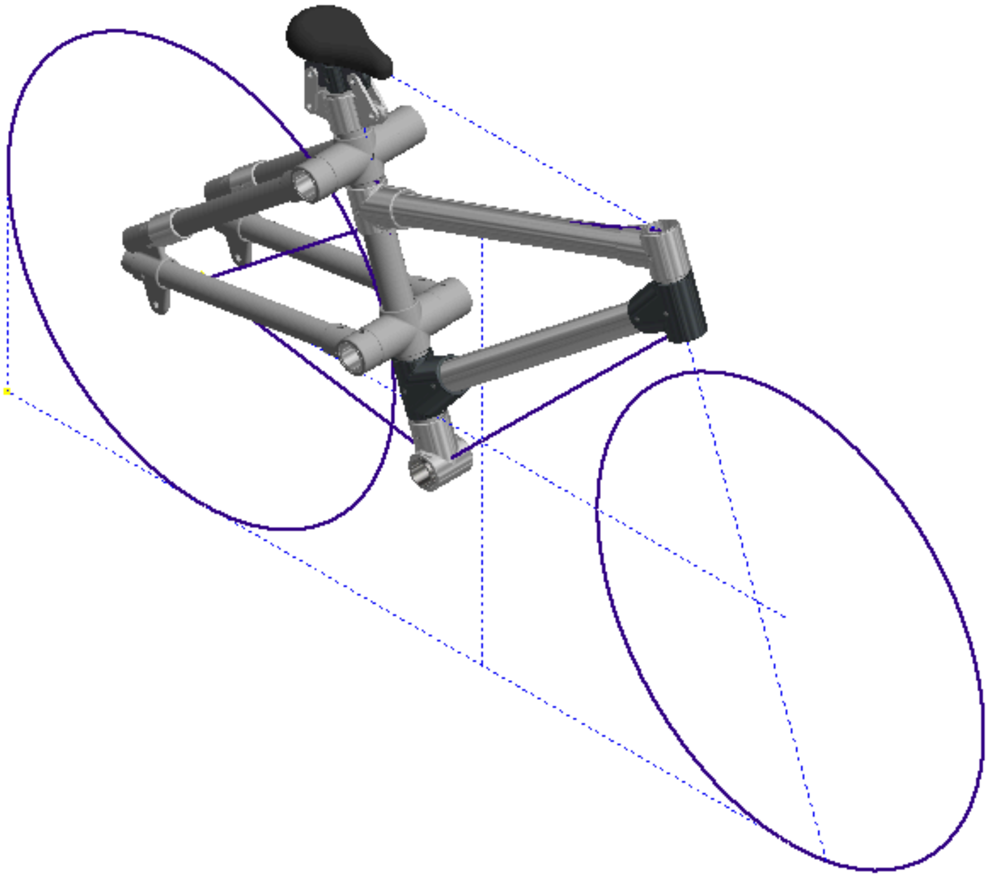


Figure 49: modelling assembly

Detail Design

Geometry Adjustment Tuning

When the design was initially modelled up, it became clear that the chainstay spacers and seatstay spacers would get in the way of the user's legs and make pedalling impossible. The bike was redesigned to be more ergonomic.

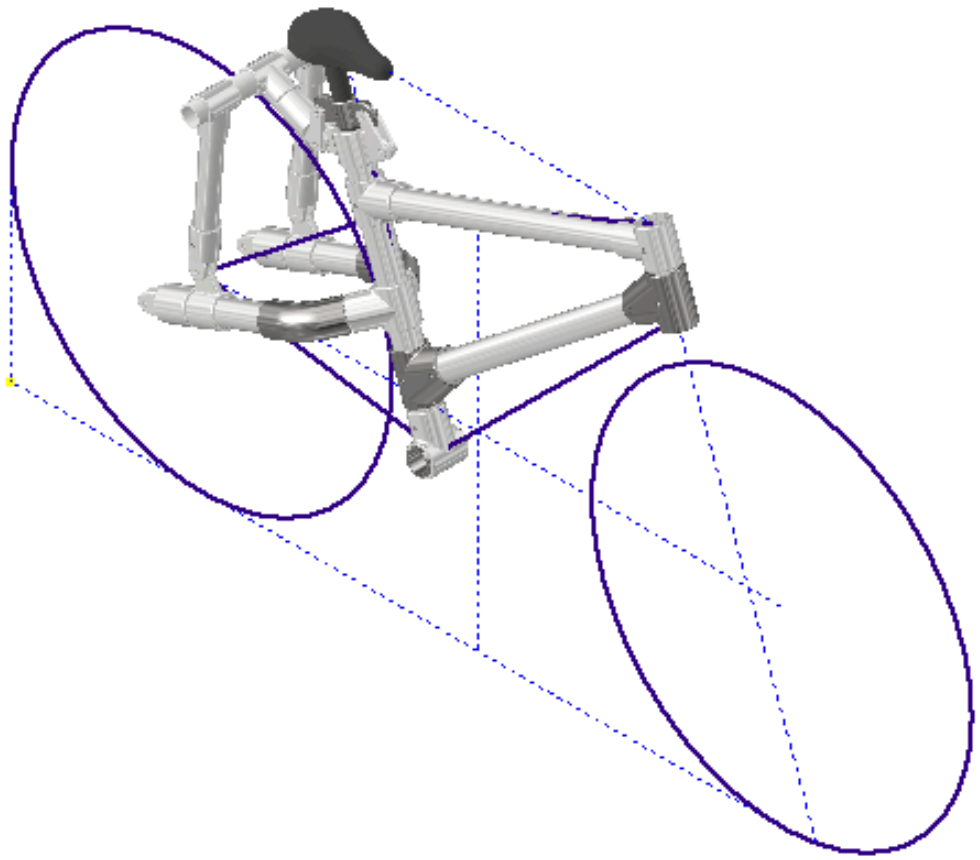


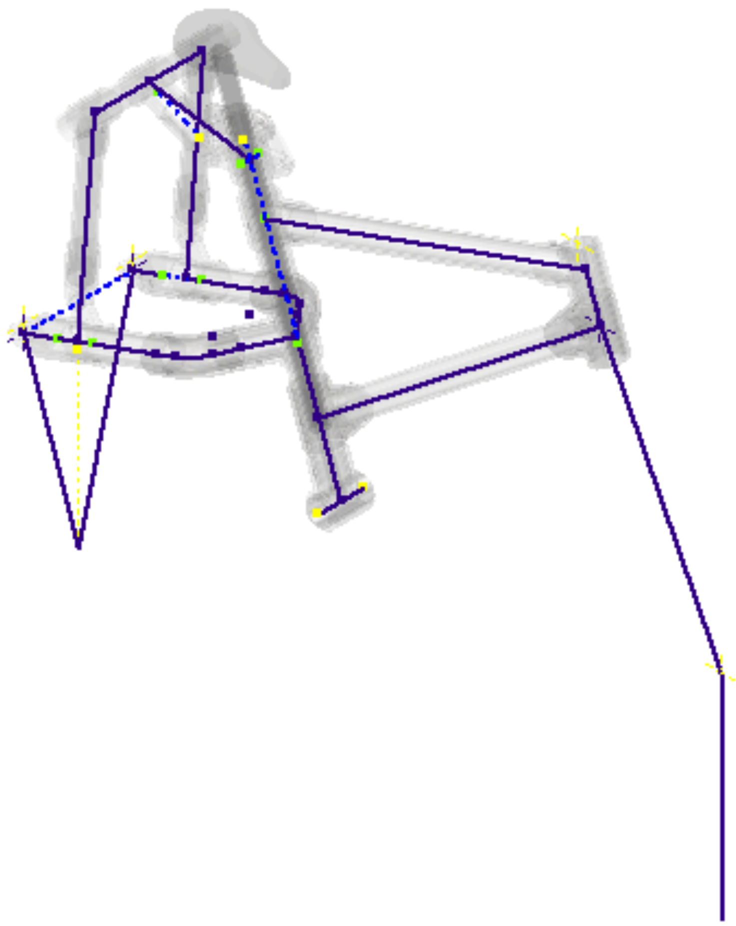
Figure 50: New, more ergonomic rear triangle design

iLogic was also used to automate the tubes to adjust their length according to a stack and reach value that was entered as a parameter. This was used to create a table with sample geometries and tube lengths for different riders on the assembly drawing (see Appendix VI: Drawings and BOMS).

Finite Element Analysis

FEA analysis was used to analyse, validate, and optimise the design. This is an entire field of study but I am short on time so I will try to illustrate the process I took as quickly as possible. Please note I am running out of time to write up all the analysis I did!

simplifying geometry:



geometry was represented with sketch lines. bike was modelled as if welded, neglecting the clamps, as this was the 'worst case scenario' since the clamps have a higher bending moment resistance than the tubes. The forces and bending moments were calculated as well as the stresses and compared with clamp test data from the manufacturer.

Defining Parameters:

- mesh
    - element types and cross sections
        - beam elements were used exclusively.
        - ideally these would only be used when the cross section is less that 1/10 of the length. This condition was true for most of the tubes, but not the bottom bracket
        - this idealisation should still be accurate enough to give a good idea
        - a topic of further work could be analysing the product in more detail
        - initially different cross sections were used according to the different tube cross sections, but it didn't mesh correctly when using the end release function. So, the cross section was first set as the size 6 tube, and the results for the rear triangle were evaluated. Then the cross section was set to that of size 7 tube and the rest of the results were evaluated.
    - element size
        - a mesh convergence study was performed and 5mm elements were found to be the best balance between speed and accuracy
    - end-release

- end release was used at the rear frame ends and the swivels in the rear triangle to simulate realistic constraints without over complicating the mesh

- constraints
  - the wheels were modelled as lines to allow the bike to tilt with the bending moment on the handlebars to a certain extent, to reduce unrealistic stresses
  - other than this, the bike was simply supported
- loads
  - loads were taken from the 1986 paper (7) from the 'starting tilted' load case
  - as the handlebars and pedals were not modelled, unsymmetrical loads were modelled with distributed moments on the BB and head tube.

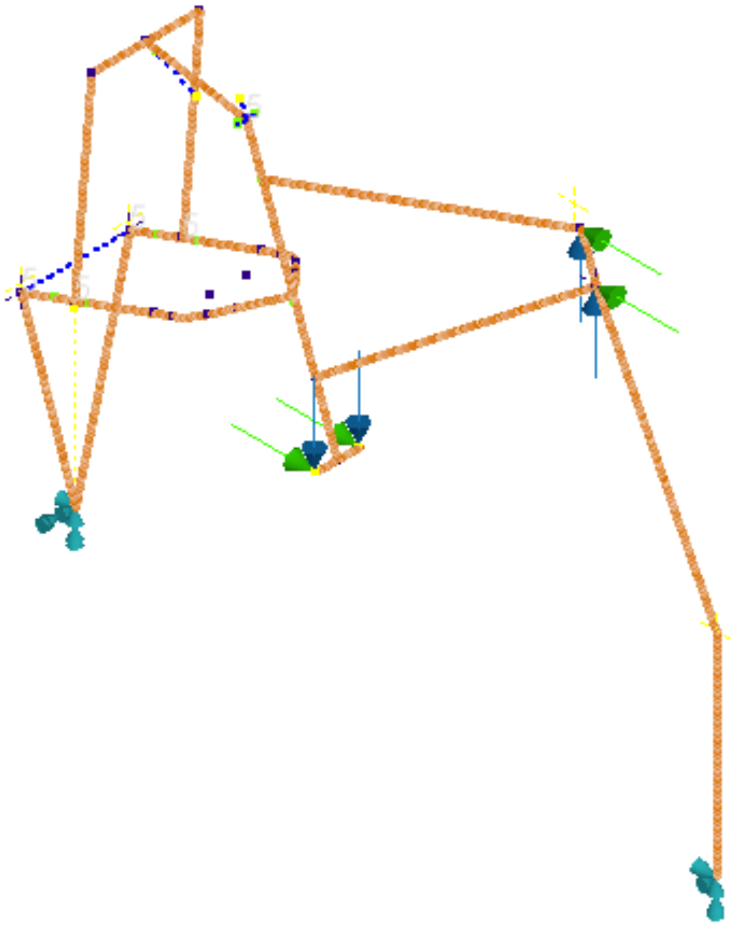


Figure 51: showing the mesh, constraints, and loads

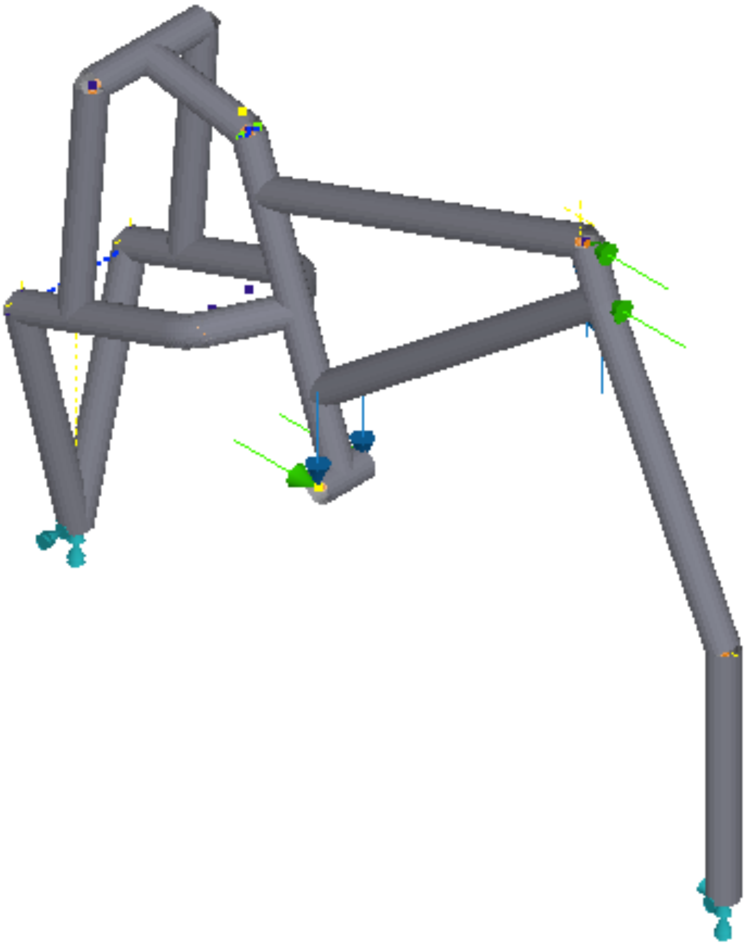


Figure 52: showing cross sections

validation – mesh convergence study:

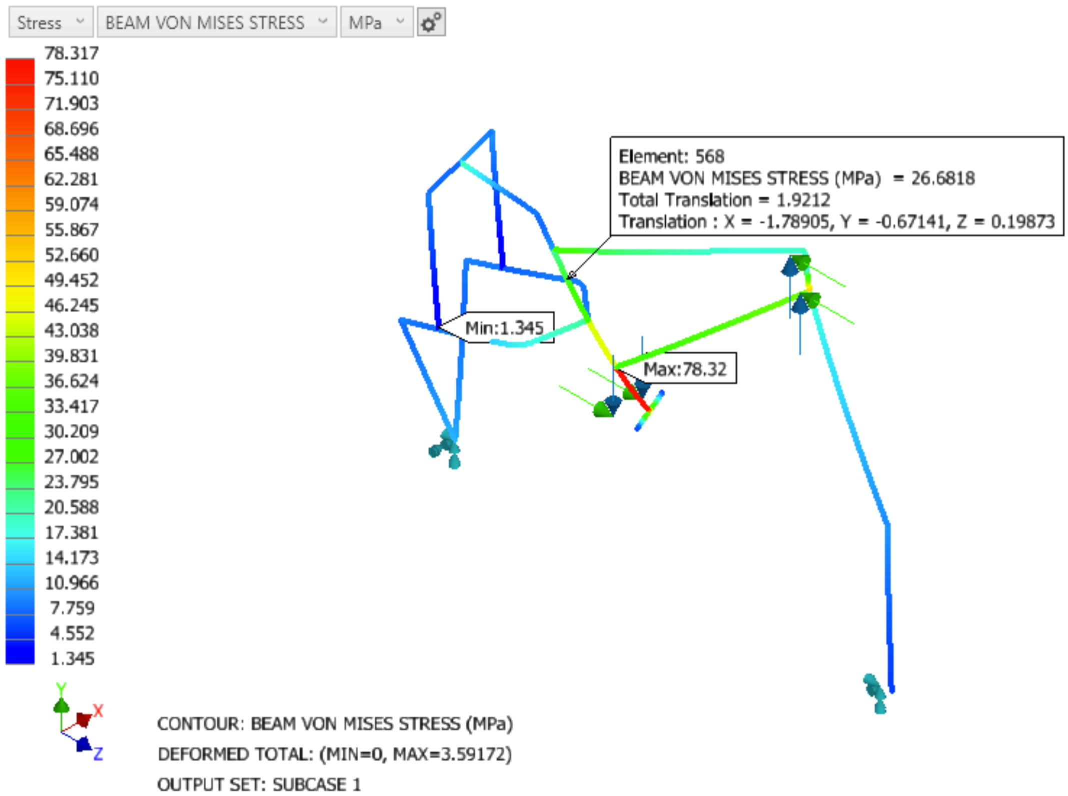


Figure 53: Von Mises stress results with probe showing point where mesh convergence study was carried out

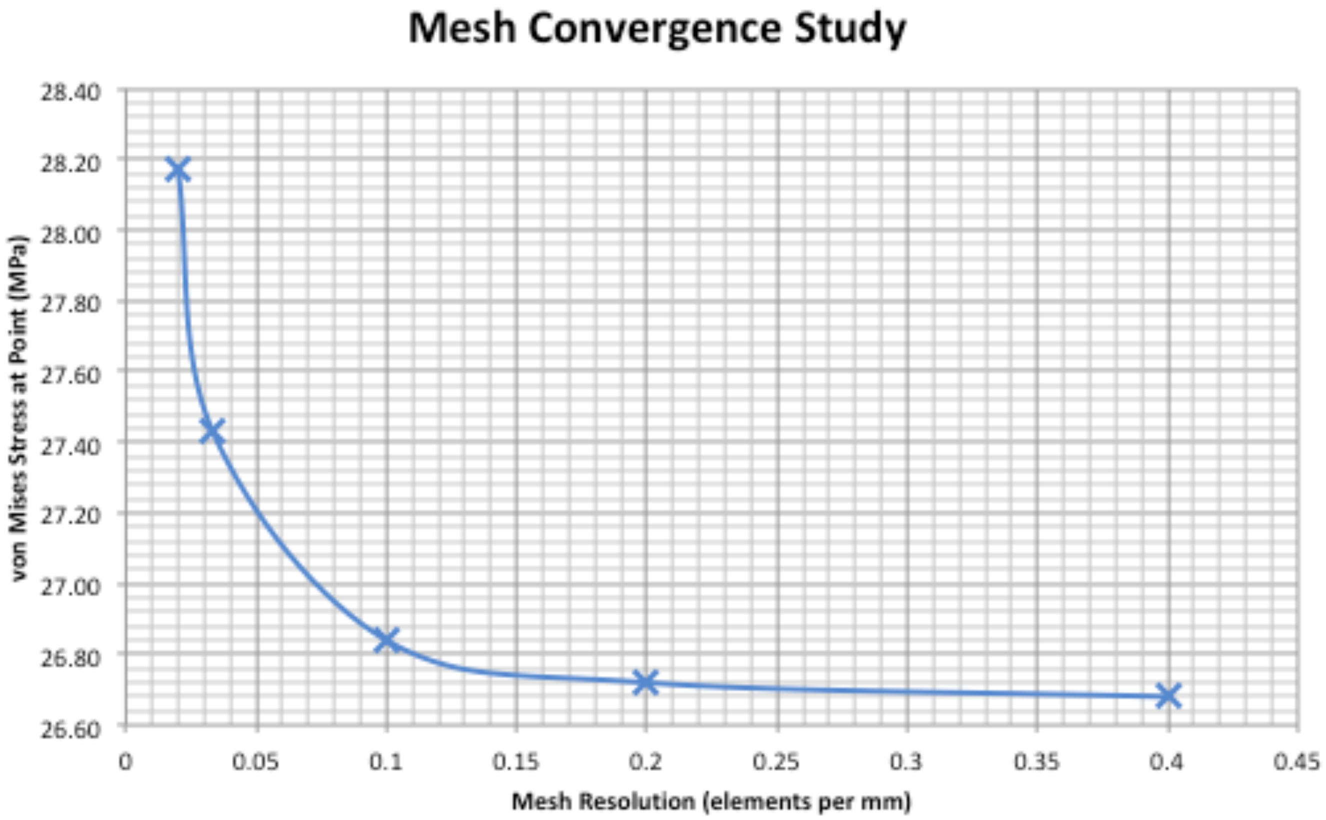


Figure 54: Mesh convergence study

Results

The results of the analysis were encouraging. The maximum von mises stress was well within the safe limit of the tubes. The minimum safety factor was 4.71, and that may have been caused by a singularity (see Figure 57: closeup safety factor results plot screenshot). The axial forces and bending moments were also well within the safe limit for the clamps (see Figure 59, Figure 60, Figure 62, and Appendix IV: Kee Systems Testing Data; note that units in screenshots are in Nmm and units in testing data are in kNm; also note safety factor included in testing data). In view of this, the design was optimised to be lighter and cheaper (see Optimising Design and Appendix VI: Drawings and BOMS) and the FEA analysis was carried out again. The results again confirmed that the loads and stresses were within safe limits (see Figure 63 through Figure 67). The minimum safety factor was the 2.6, which is not ideal, but a) it was near a likely singularity and b) it would be reinforced by the clamp anyway.

Confidence in the Results

I have a reasonable degree of confidence in the results considering the time limits, enough to say that this is feasible and safe to build a prototype. However, it is definitely not a polished, foolproof consumer product. It needs more testing. This model made strategic simplifications due to time constraints and lack of data on clamp geometries, but it would be good to model and analyse the clamps. It would also be good to do some fatigue testing, especially for the bottom bracket clamp. It can withstand a static force but further testing is required for dynamic, cyclic loads, and fatigue analysis, and perhaps some modal analysis for vibration. It would also be good to validate the analysis with experimental data. If the BB needs to be reinforced, R&K have a clamp that might work, but it is heavy – 1.5kg.

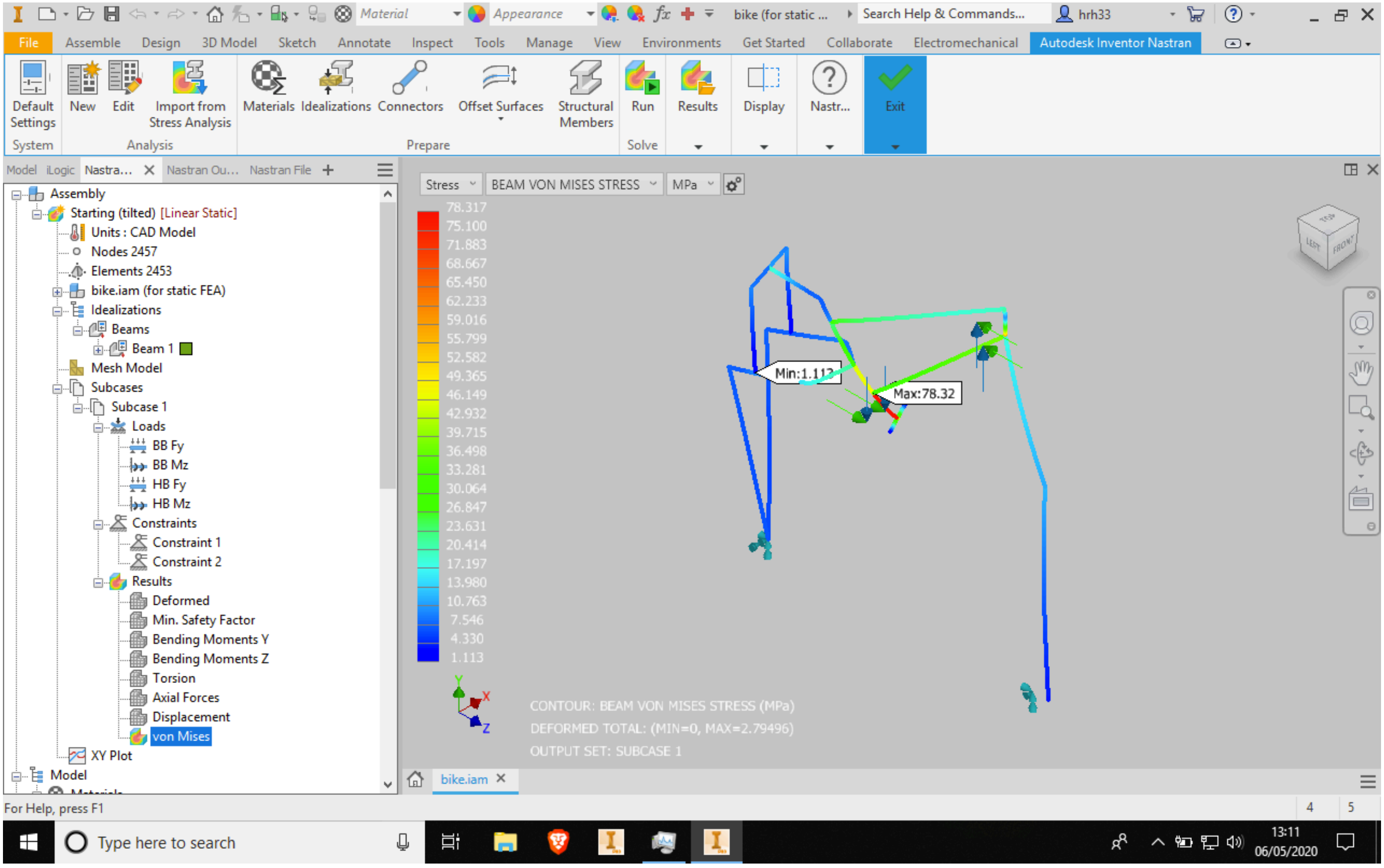


Figure 55: Von Mises Stress results plot screenshot

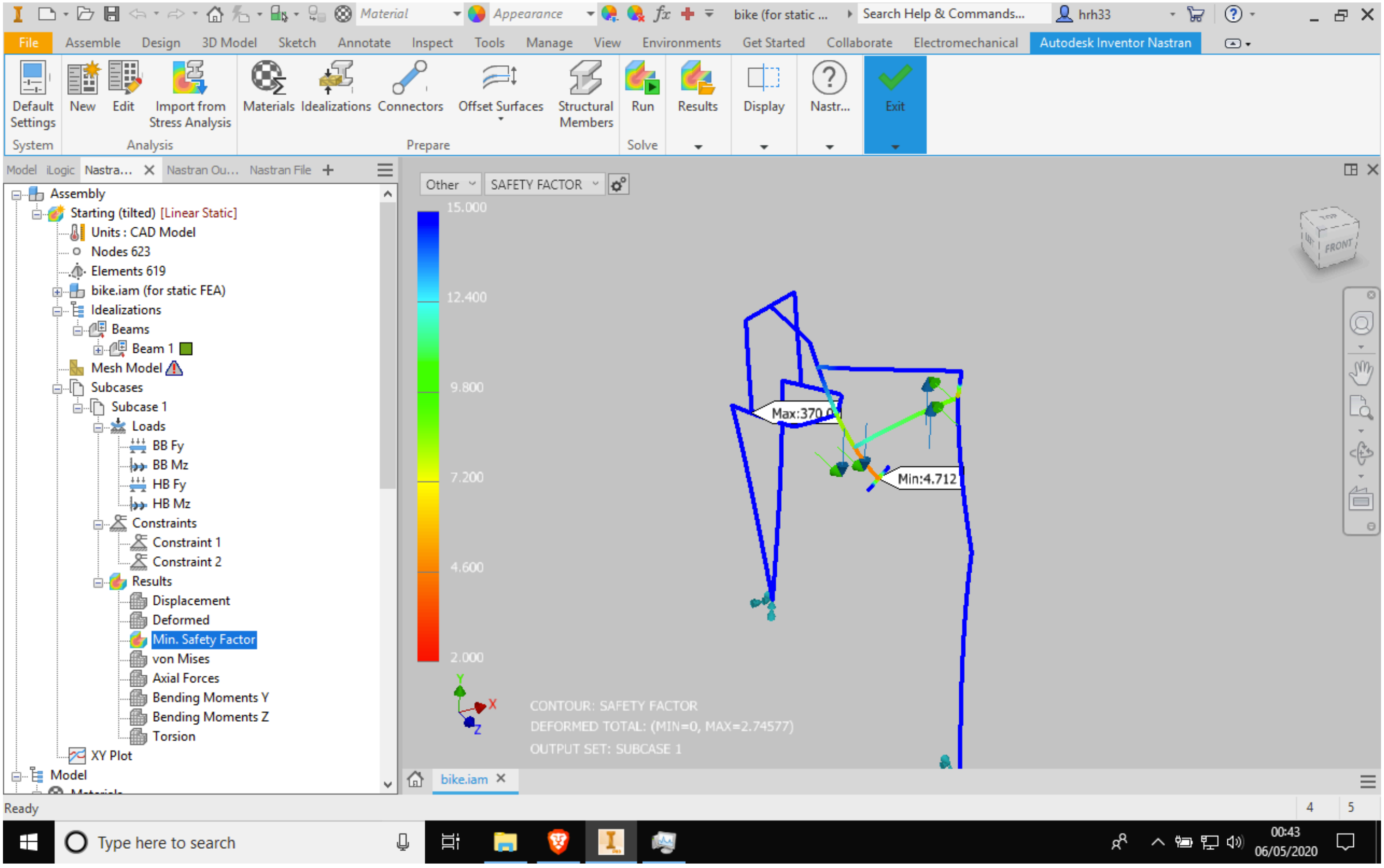


Figure 56: Safety factor results plot screenshot

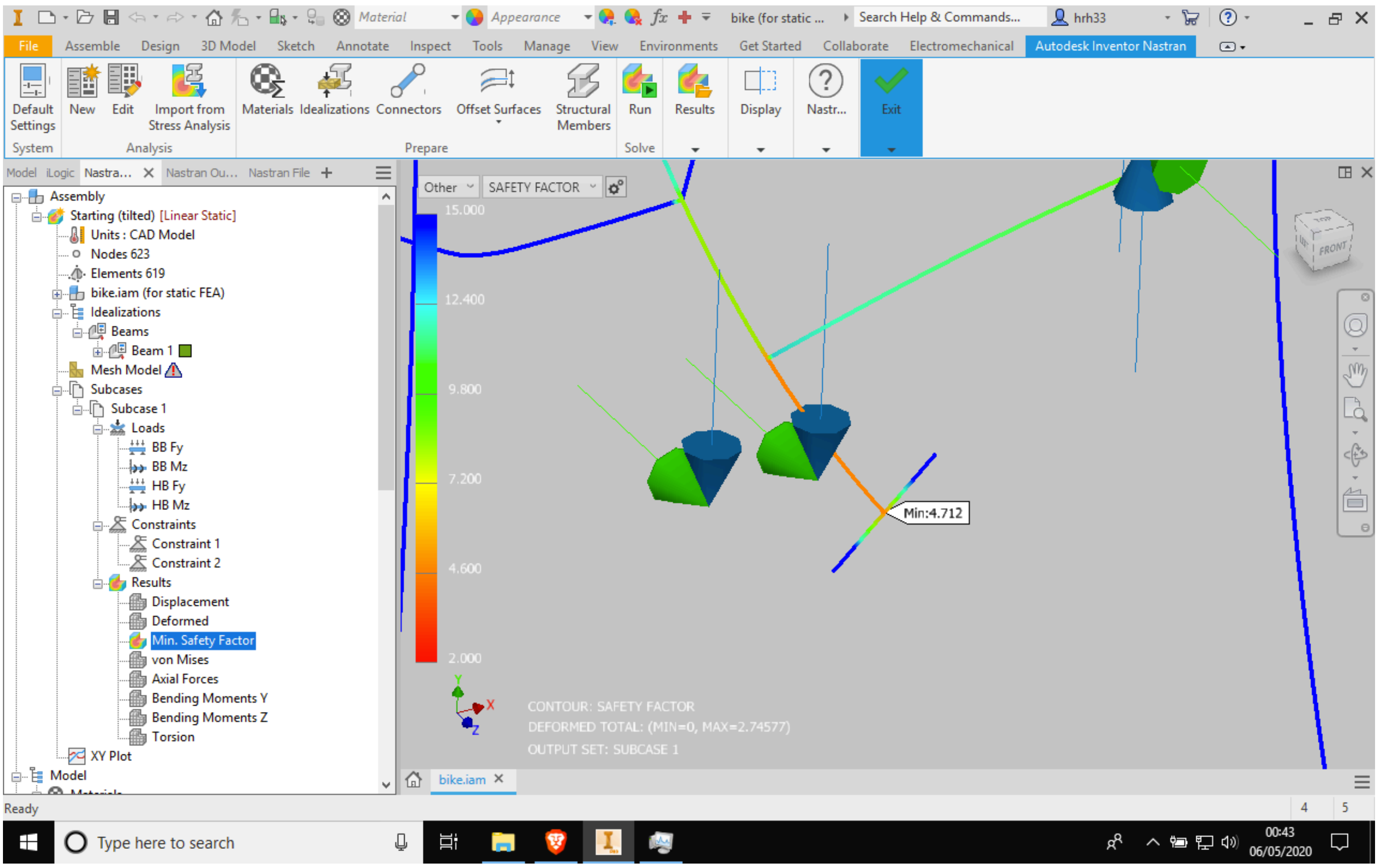


Figure 57: closeup safety factor results plot screenshot

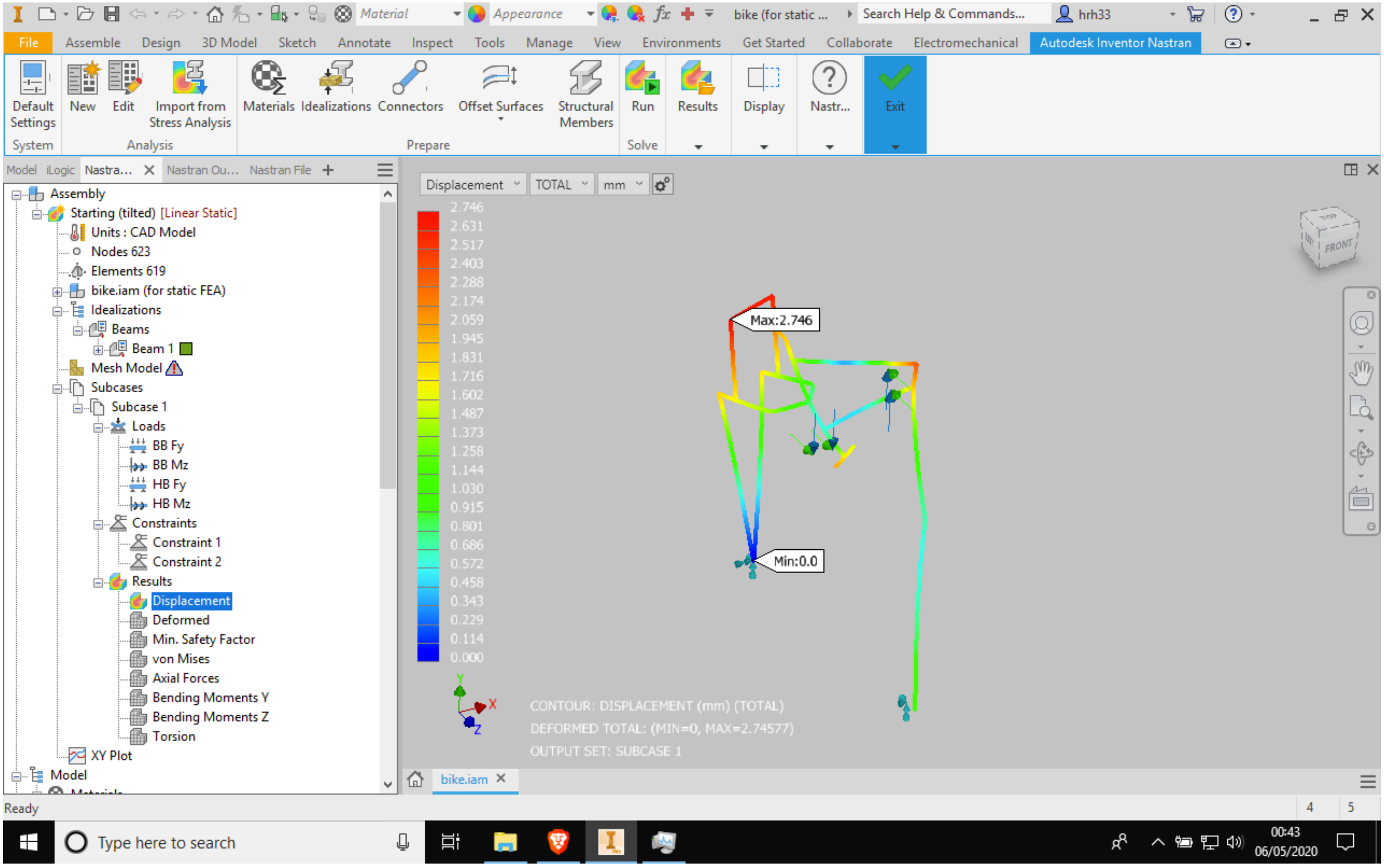


Figure 58: displacement results plot screenshot

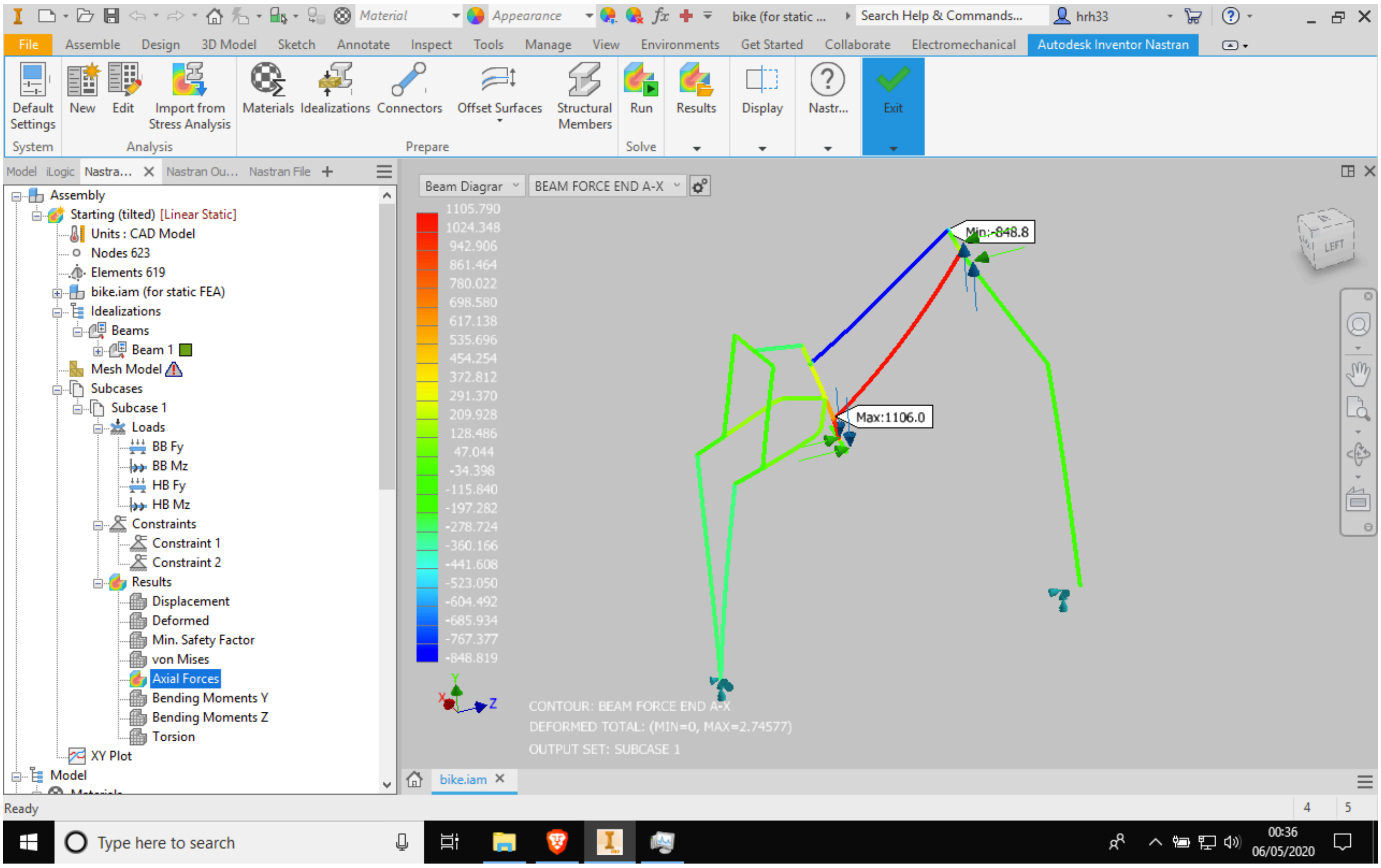


Figure 59: axial forces results plot screenshot

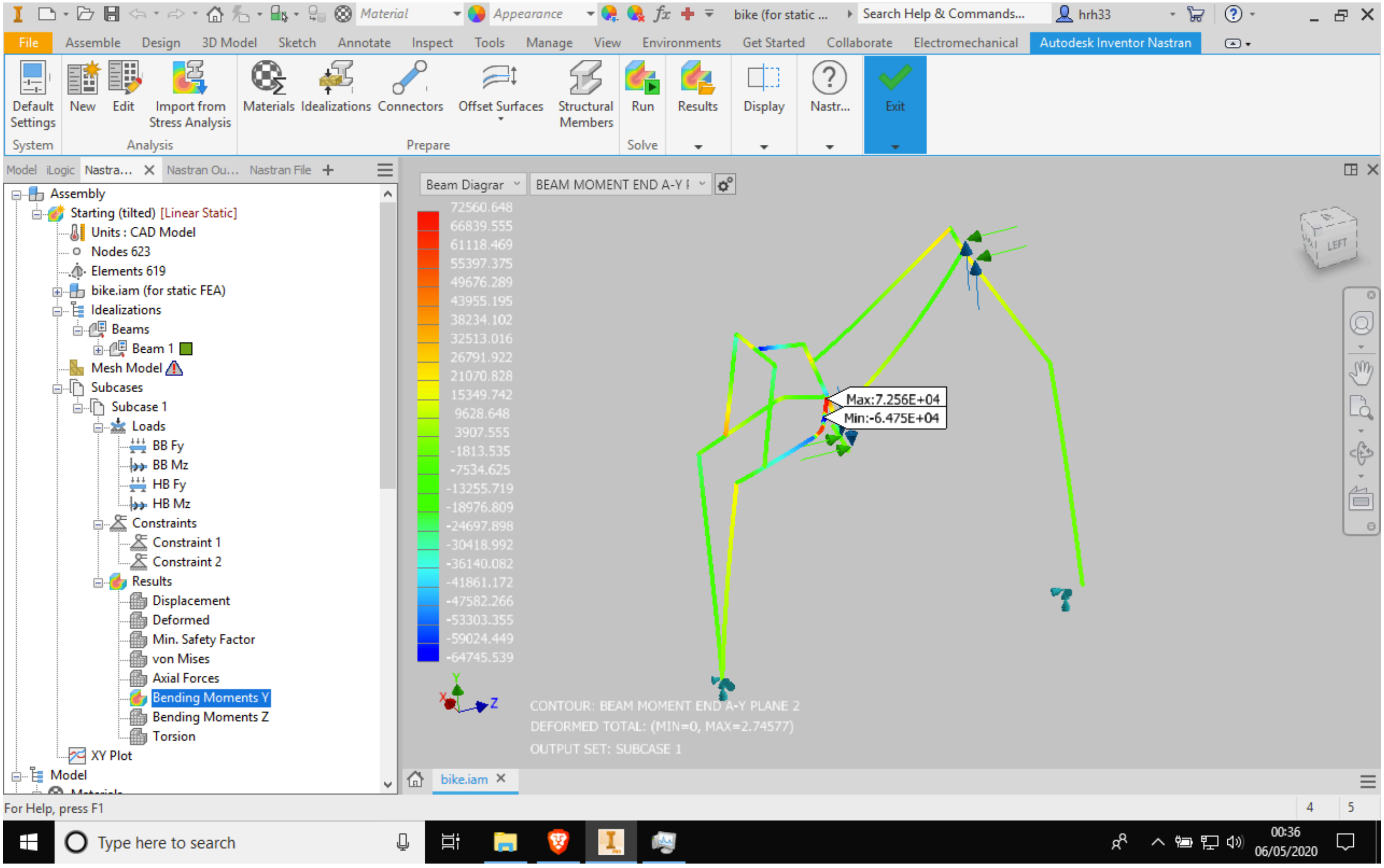


Figure 60: bending moments y results plot screenshot

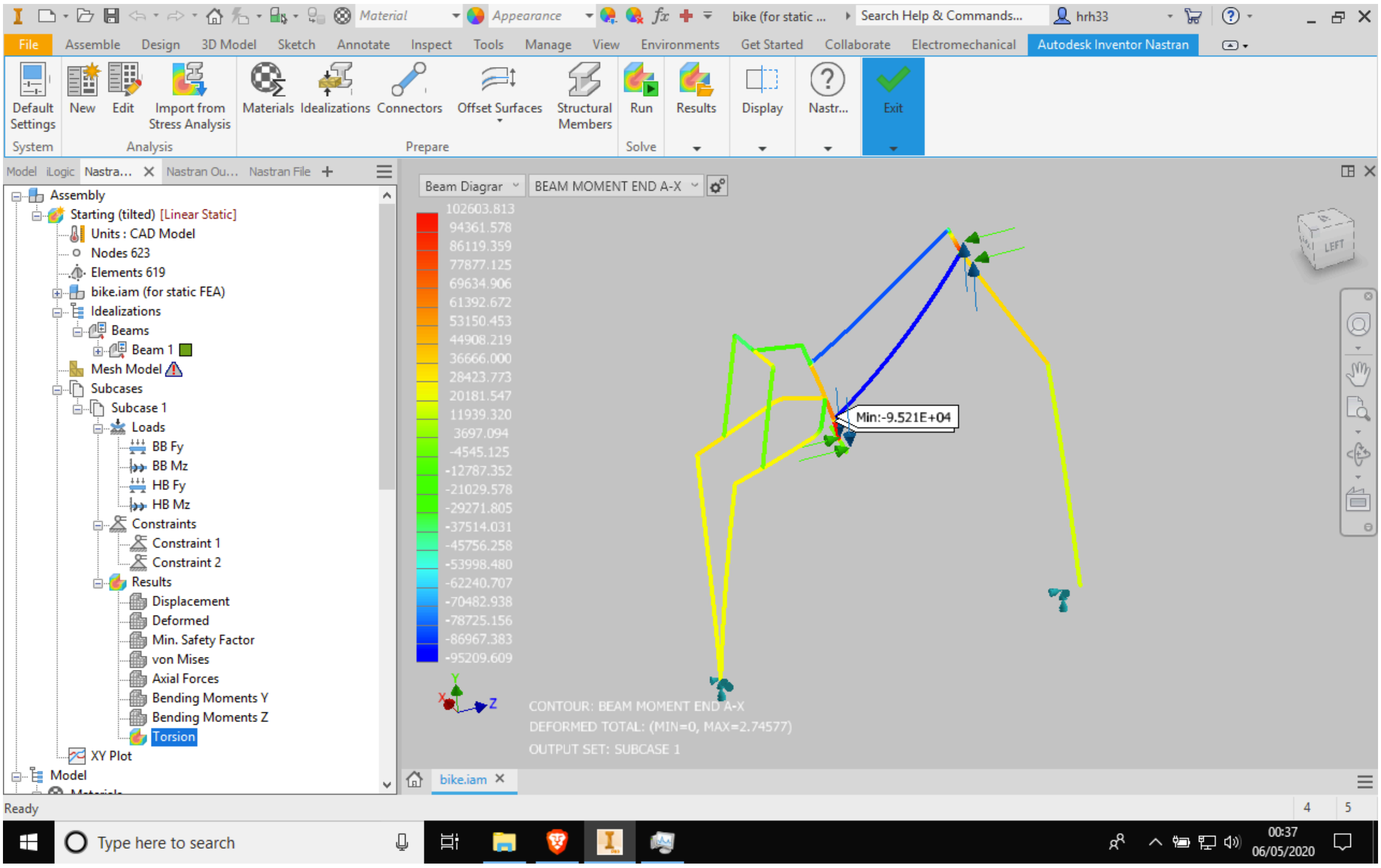


Figure 61: moments x (torsion) results plot screenshot

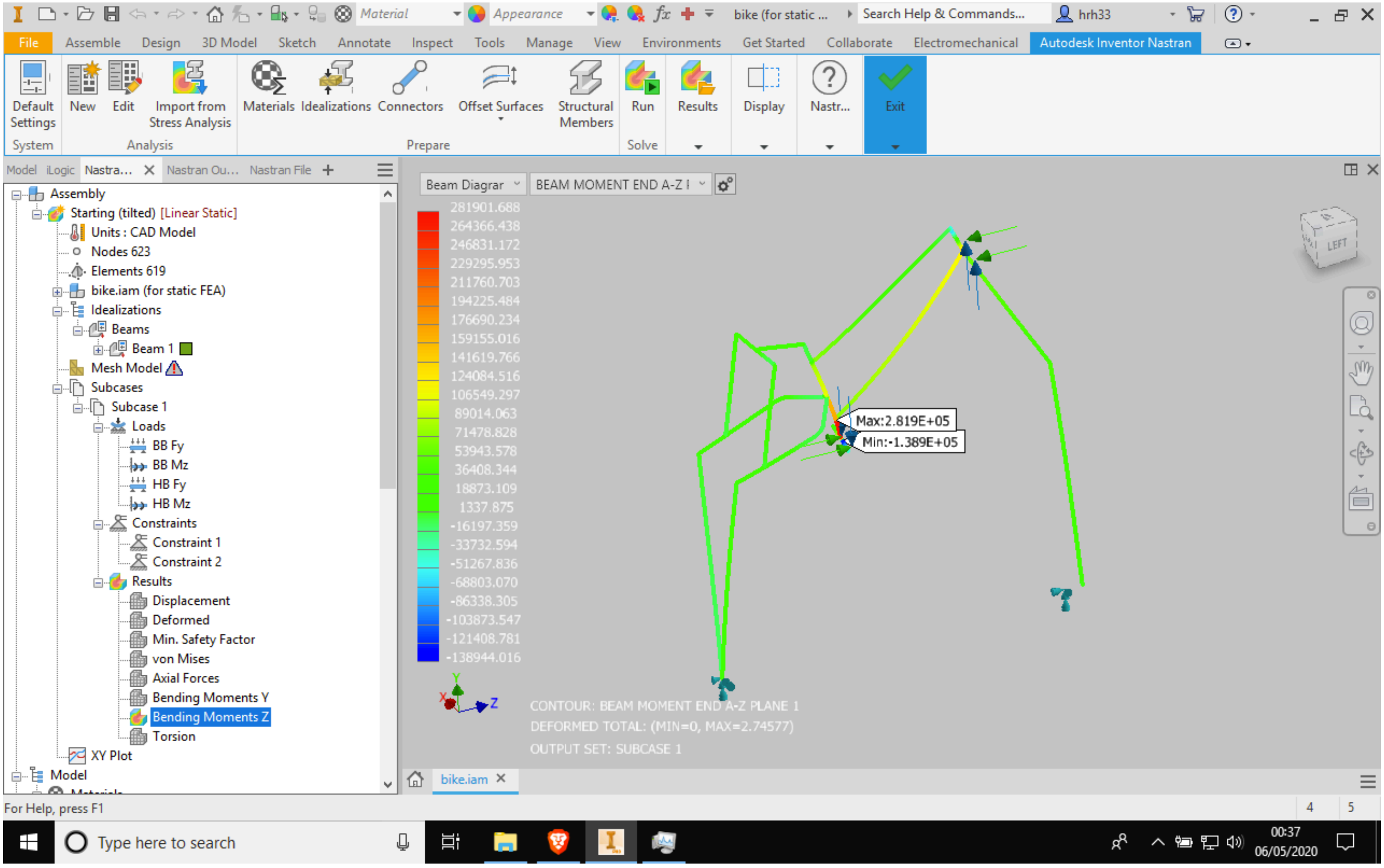


Figure 62: bending moments z results plot screenshot

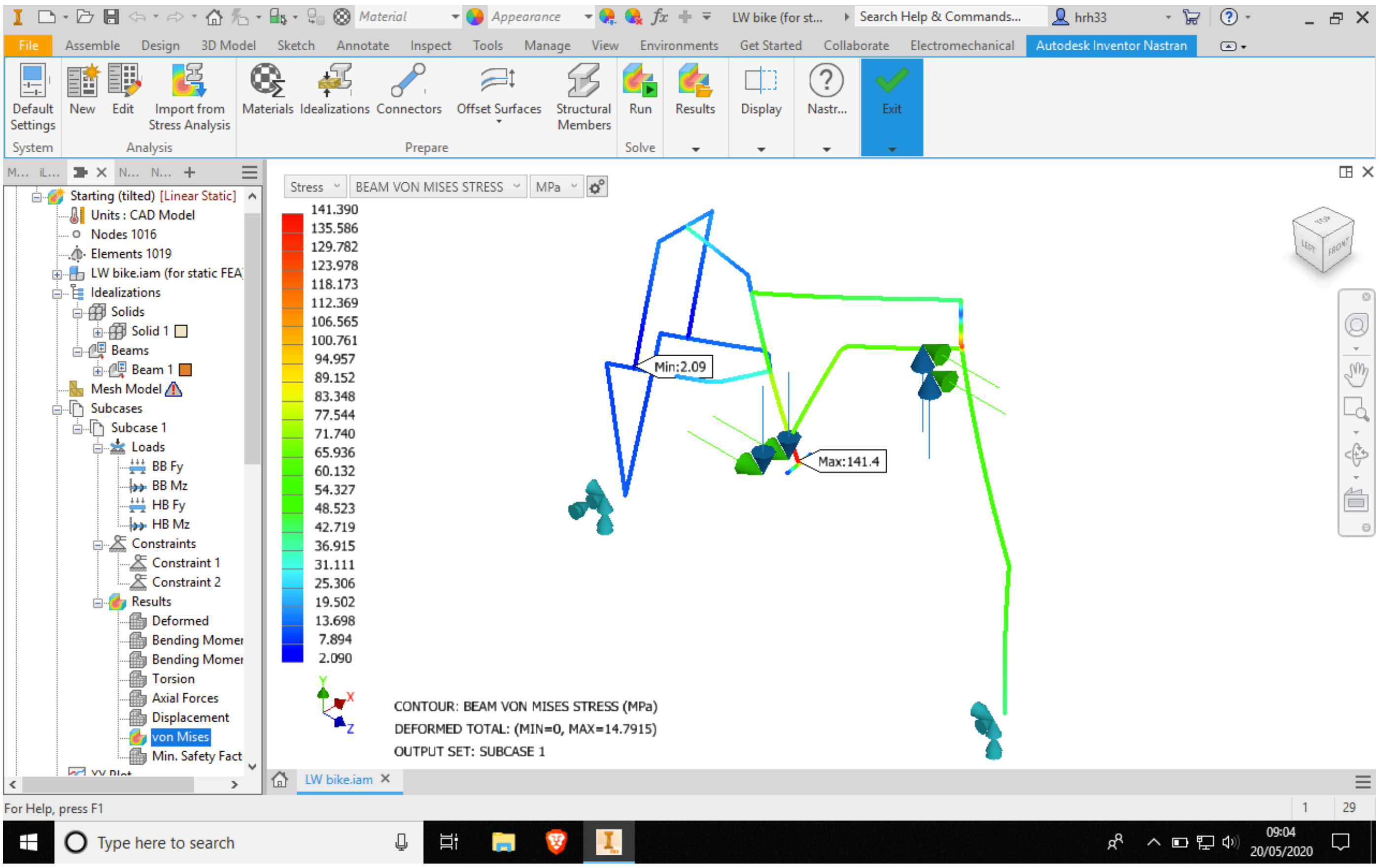


Figure 63: Von mises stress for new, lighter design

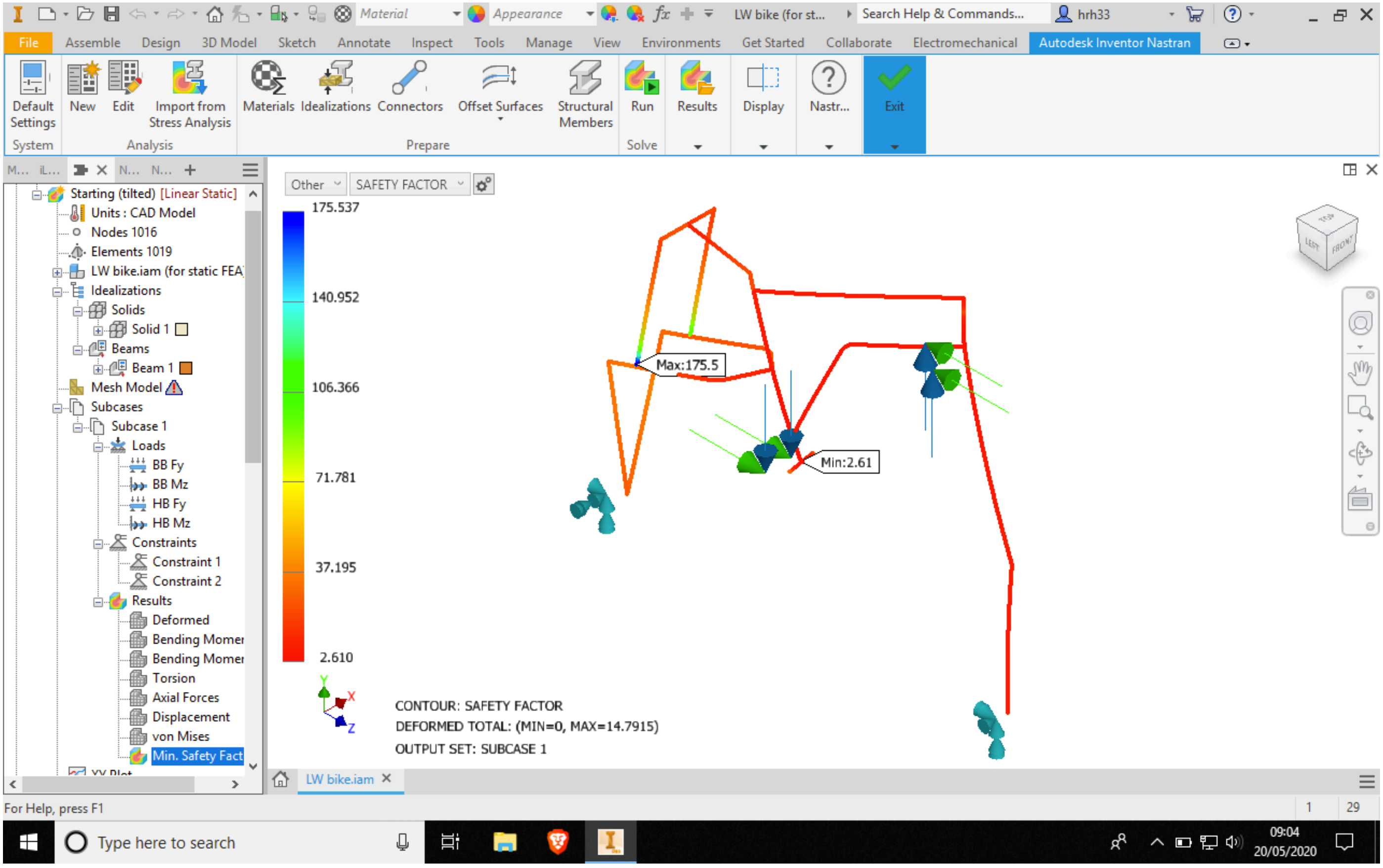


Figure 64: safety factor for new, lighter design

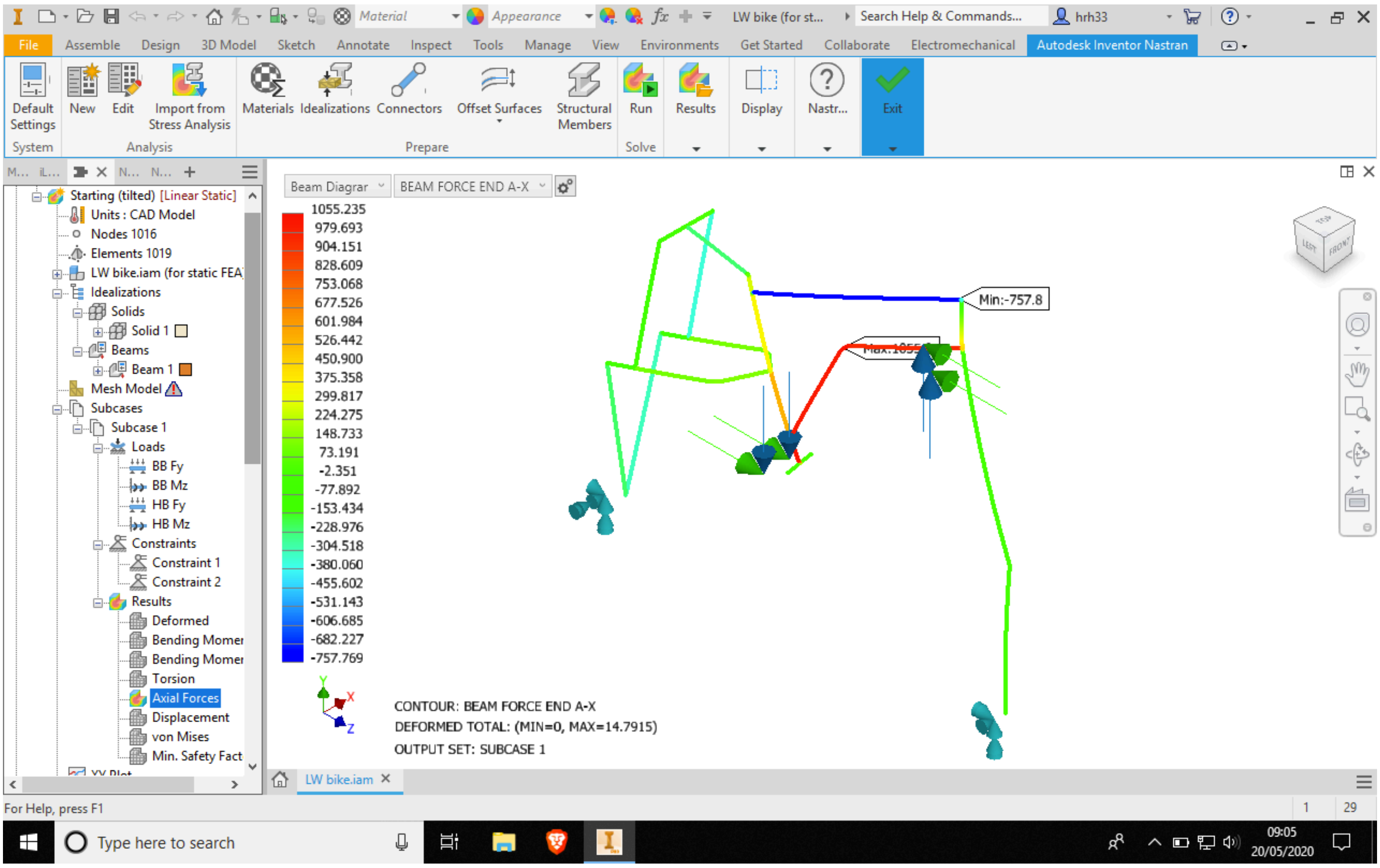


Figure 65: axial forces for new, lighter design

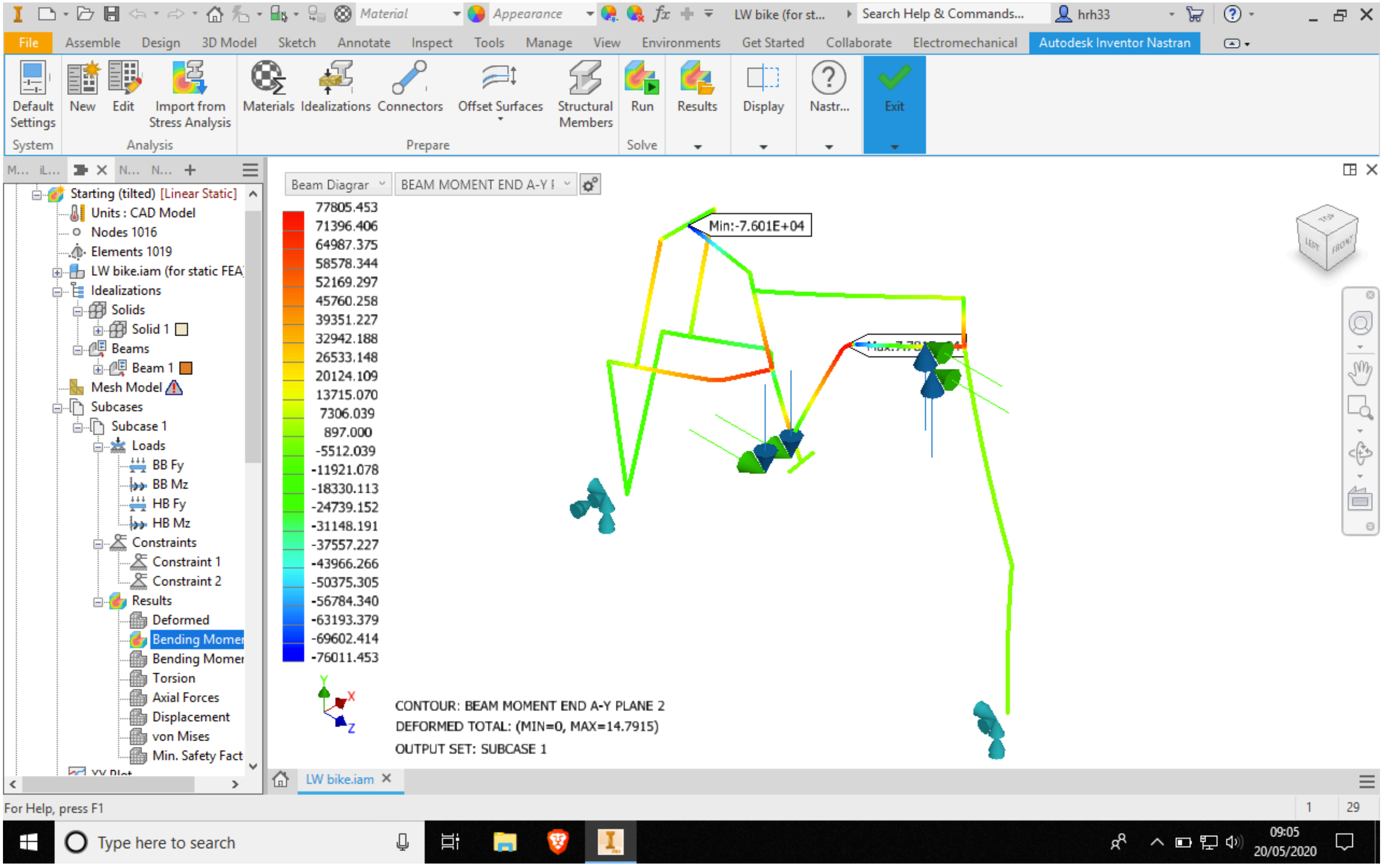


Figure 66: bending moments in y for new, lighter design

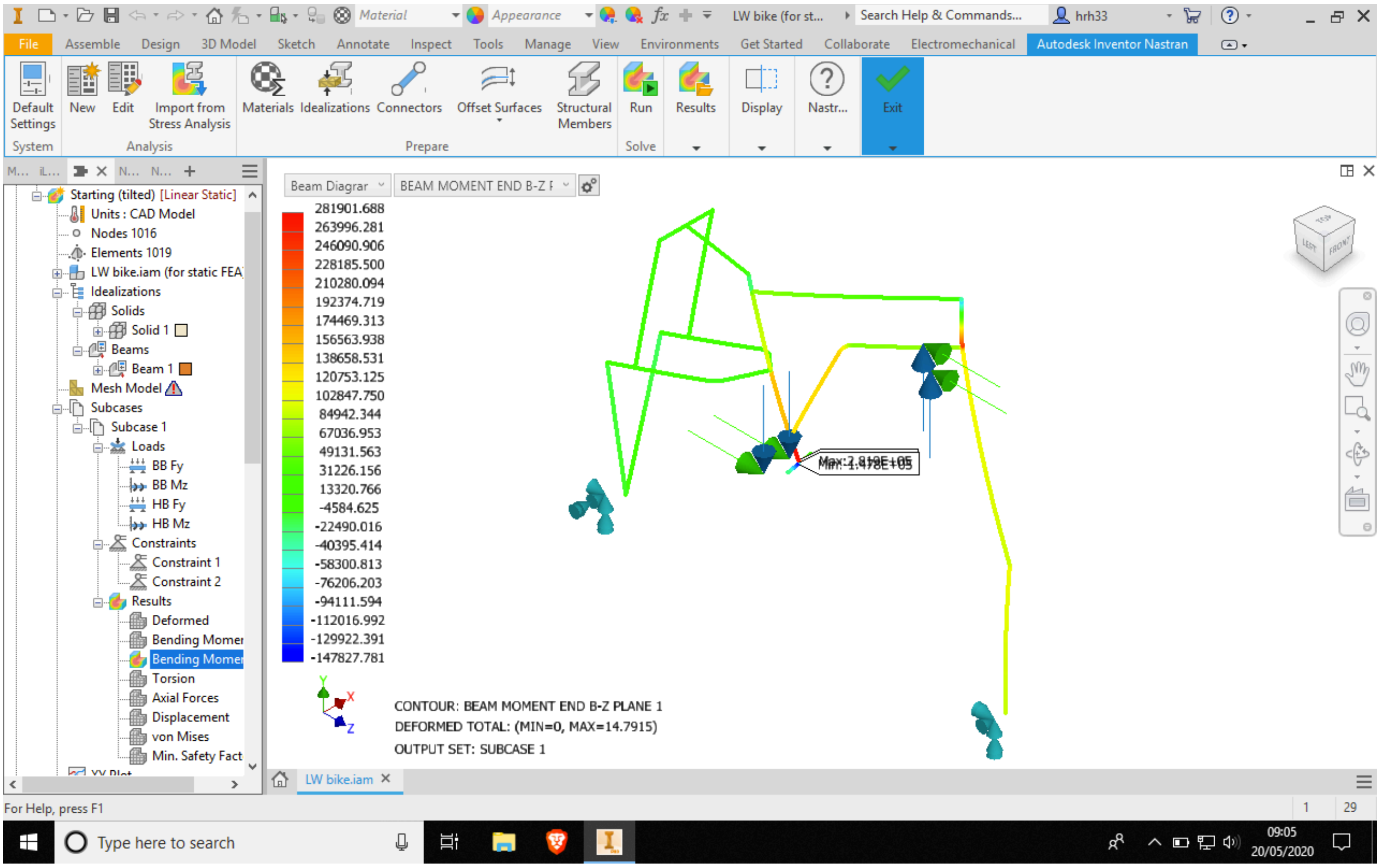


Figure 67: Bending moments in z for new, lighter design

Optimising Design

When the FEA analysis showed that the design had large safety factors, I redesigned the frame to use all size 6 tube and aluminium clamps when possible. This required some changes to the geometry. Refer to the assembly drawings in the appendix. This design update significantly reduced the weight and cost. The new design was analysed with FEA again and showed that it should be safe, but further testing is needed.

Final Design

The final design is documented in the assembly drawing and BOM in the appendix. It weights approximately 8.4kg and costs approximately £276 (frame only). It uses mostly aluminium size 6 clamps and aluminium size 6 tubing. The weight and cost were calculated using data from the manufacturers and Autodesk iLogic scripts, so is fairly accurate – apart from shipping costs. There is detailed information on the assembly drawings about finding compatible components such as wheels and a third party fork. A cargo rack could easily be added onto the back with a couple extra clamps.

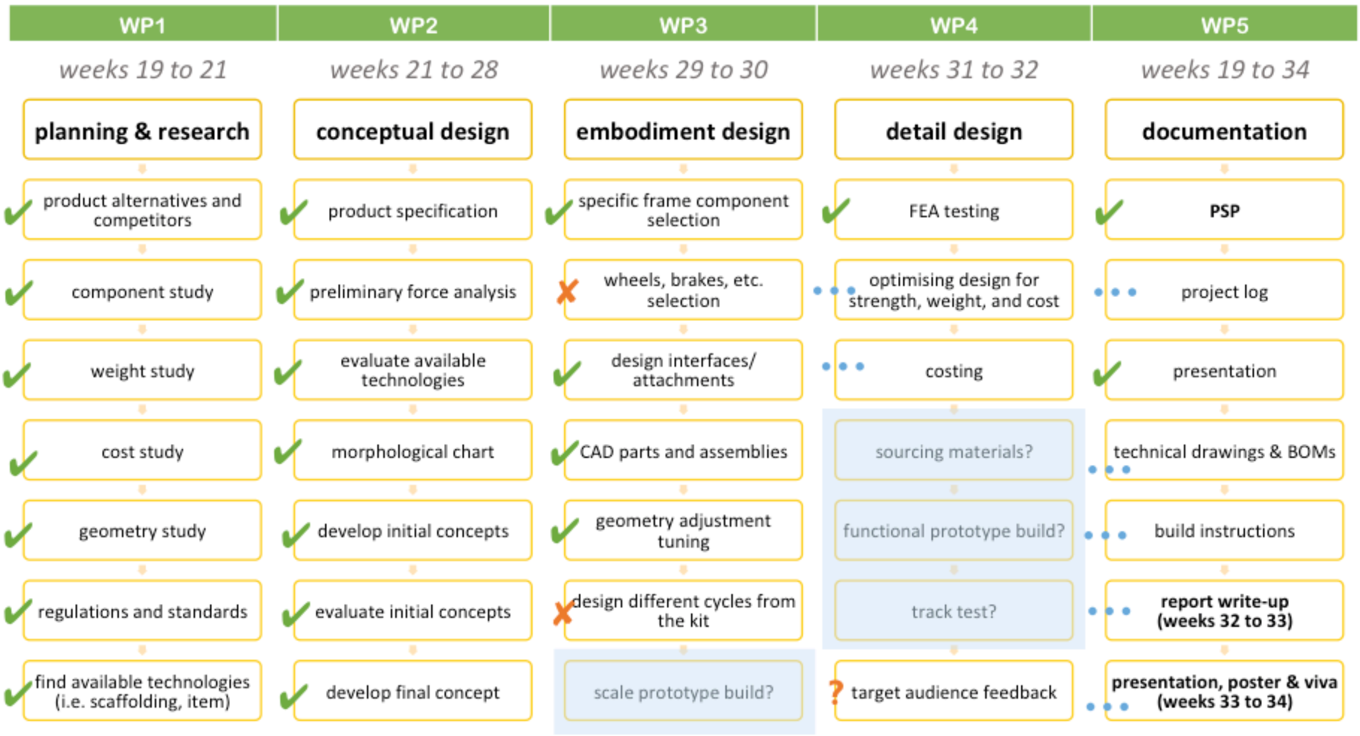
Figure 68: New optimised design

Open Source Hardware Documentation

Throughout the project the progress has been documented on github at:
https://github.com/hannahrosen57/AdjustaBike-2.0/tree/master/CAD

The CAD files (raw and stl), drawings, BOMs with full details and web links to purchase parts, part drawings, and this report will be made freely available to anyone who wishes to continue the work. Great care has been taken to ensure that the drawings will make sense even to someone with no engineering training. It should be enough that anyone will be able to build a bike or develop their own design from the design files.

Reflection



Further Work

- More in-depth FEA, such as impact analysis, fatigue analysis, and more validation
- Develop alternative designs such as “Design for Adjustability” and a recumbent tricycle
- Prototyping
  - Full functional prototype
  - Scale model – cardboard or 3D printed
- Get feedback from target audiences on prototypes

Did I accomplish my Aims and Objectives?

- I have shown that an open source, DIY bicycle kit is feasible
- I have fully developed a design
- I have conducted FEA analysis
- I have optimised the design based on the
- Most of the specification requirements were met
- The design focuses on being low cost and DIY, at the expense of some adjustability
  - A more adjustable design was developed to the final concept stage, but the added complexity would result in additional weight and cost

Conclusion

This project was undertaken to investigate the feasibility of an open source, low cost, DIY cycle kit. I have succeeded in developing a design for a bicycle frame constructed from handrail clamps, and documented the design so that anyone can continue the work or build a prototype. The design can be customised by the user, and sample geometries were included in the assembly drawings. FEA was used to analyse the design, and the bicycle frame was optimised in response to the results. The final design weighs approximately 8.4kg and costs approximately £276 for the frame alone. Further work could include building and testing prototypes, further FEA analysis, espescially focusing on the bottom bracket clamp in dynamic loads, and designing other geometries using the same components such as a cargo bike or recumbent tricycle.

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