Fatigue Analysis of an Aluminum Tricycle Frame

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Introduction: As a sustainable urban transport system, the tricycle might represent an adaptive mobility vehicle used to transport people and bulk load. In this work we develop a fatigue finite-element analysis to evaluate design improvements made to an aluminum tricycle frame. Both Stress-Life and Stress-Based (Findley) models are used to evaluate the long term durability of the design.

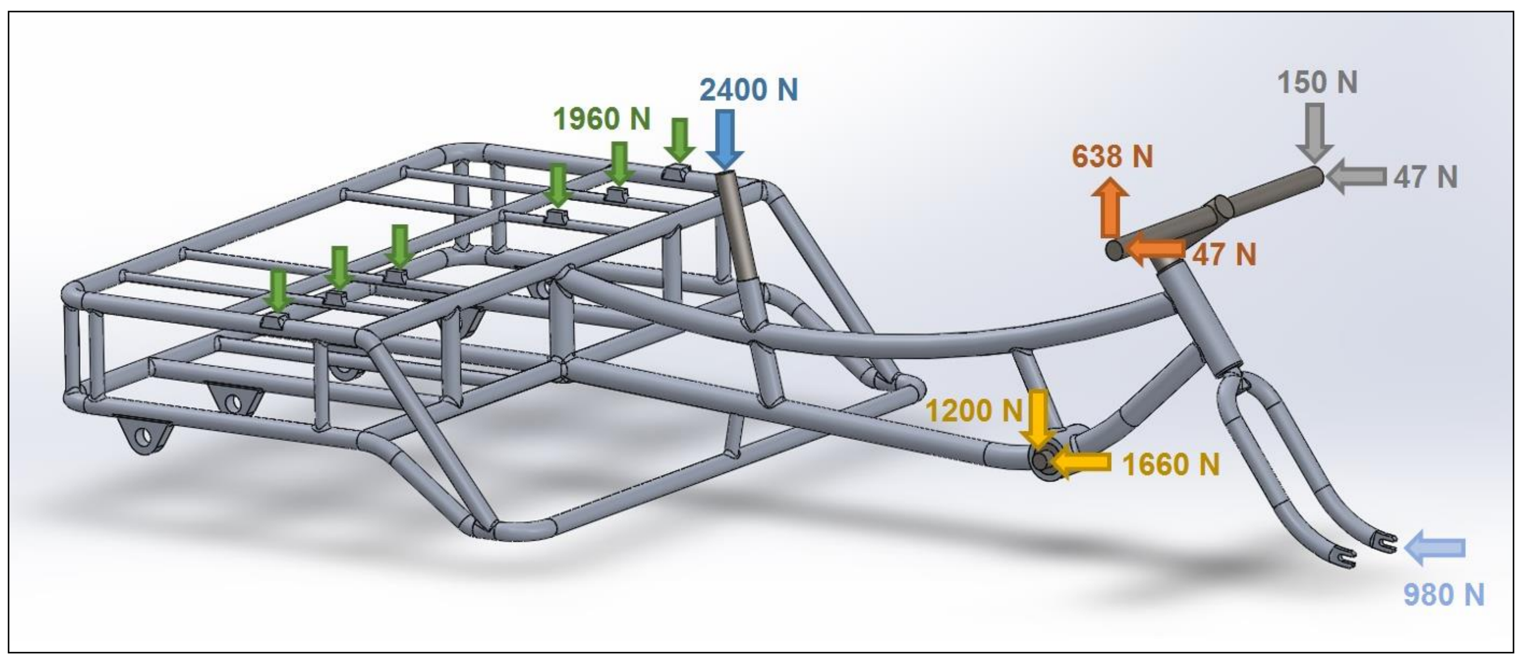

Figure 1. Loading values.

Computational methods: The tricycle consists of standard bicycle parts with a passenger/load zone on the back side. Only the frame is modeled, with the rest of the parts are used for the loading conditions. Aluminum 6063-T6 is the material of the frame while bottom bracket, fork and handlebars are made of steel 4130. The SolidWorks CAD of the tricycle is imported in Comsol Multiphysics, Solid Mechanics (SM) interface is used to define two different load cases, one applying vertical loads and the other applying horizontal loads. The results obtained from the SM interface are then used by the Fatigue interface to calculate either the cycles to failure (Stress-Life model) or Fatigue usage factor (Findley model).

Table 1. Load cases.

Loading cases						
1. Vertical load				√	√	√
3. Horizontal load	√					

The two models consider the load cases of Fig. 1 and Table 1. The frame is constrained from movement in the rear axle, the fork tips are connected by a rigid connector (allowed to slide only along the horizontal X) and displacement is set to zero on Y axis and the vertical Z.

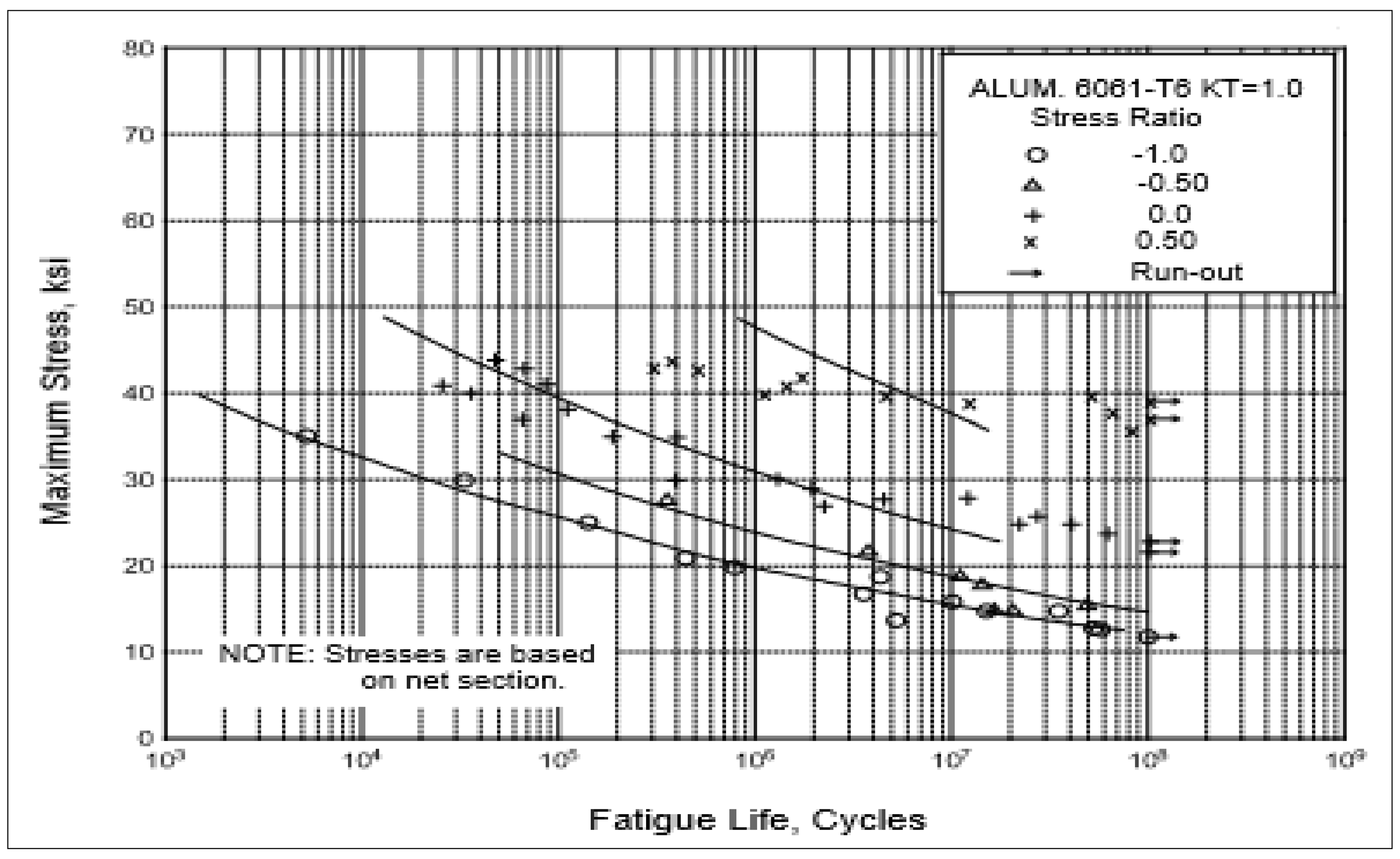

Figure 2. S-N curves for unnotched 6061-T6 aluminum alloy (MMPDS-01, 2003).

Results: For the vertical load case, the Stress-Based Findley model seems to be more conservative than the Stress-life model, as can be seen on a close-up of the lower headtube area in Fig. 3.

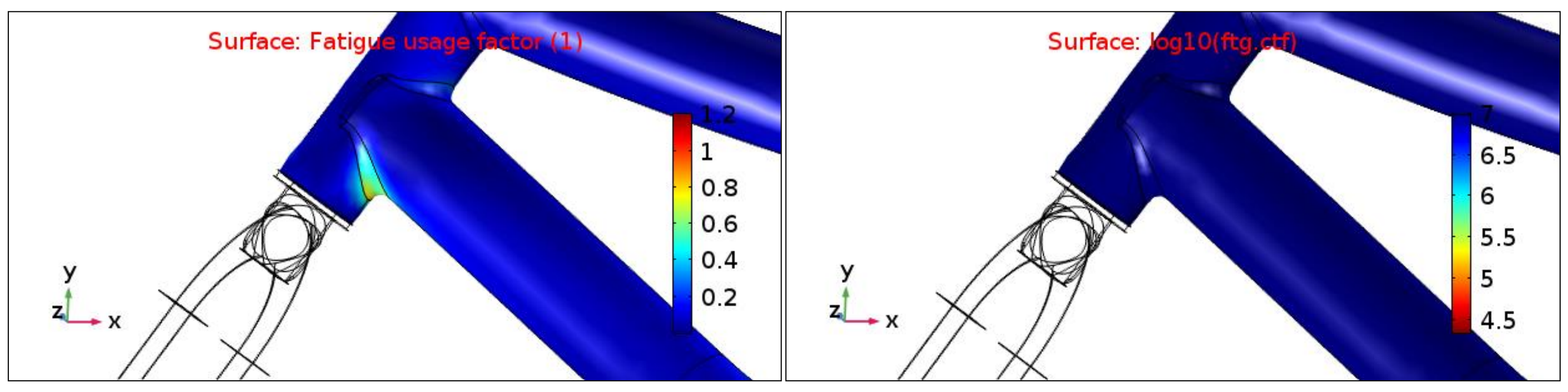

Figure 3. Stress-Based usage factor on left, Stress-Life predicted log10 cycles to failure on left.

While the Stress-Based model shows a small area of the weld bed with a usage factor above 1, predicting possible failure, the Stress-Life model gives more than 10^7 cycles before failure.

For the horizontal load case, a very small area on the weld bed shows a usage factor above 1, which indicates the need of reinforcing the area, changing the tube geometry or adding reinforcement material. As expected, the horizontal load case does not affect the rear part of the structure, since only one load is applied at the fork. The vertical load case has more effect on the rear cage welds since loads are higher and distributed along the structure.

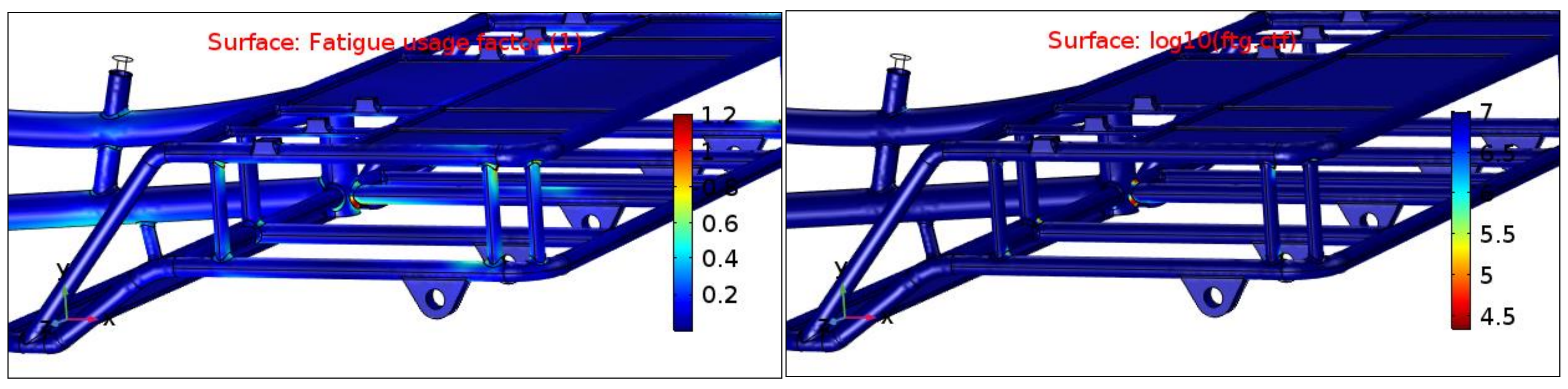

Figure 4. Horizontal load case, Stress-Based usage factor on left, Stress-Life log10 cycles to failure on right.

Fig. 4 plots the results for the horizontal load case. The maximum usage factor for the Stress-Based model is 1,2, predicting failure, while the Stress-Life model gives zones with a life of low as $10^{4.5}$ cycles, that could be considered too low for the application. Fig. 5 shows a close-up of the weld beds for the Stress-Based model, showing that these should be redesigned or reinforced with additional material.

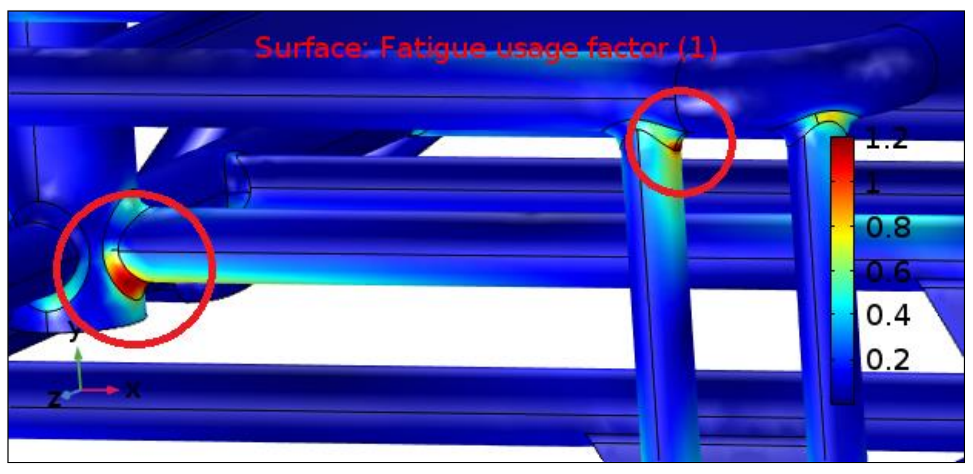

Figure 5. Passenger/load area, close up of weld beds, Stress-Based model, vertical load case.

Overall, the Stress-Life model has two benefits, by allowing: the evaluation of the number of cycles that the structure might resist; the inclusion of correction or modification factors for aspects that the CAD or FEA models might overlook, such as surface finish, environmental factors, reliability and safety factors among others.

Conclusions:

- Certain regions of the frame will not withstand the loads, requiring to reinforce the frame geometry.
- For two different load cases, the effects of stresses on the service cycle of the design have been evaluated with the Stress-Life and Sress-Based Fatigue interfaces.
- The FEM simulations provide useful insights learning about fatigue models available to evaluate long term life of a structure, gathering knowledge for future studies.

References:

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ASTM, *Standard Test Methods for Bicycle Frames*, ASTM F2711-08 (2012).
MMPDS-01, U.S. Department of Transportation, *2003 Metallic Materials Properties Development and Standardization (MMPDS-01)*. Online version available at: