The goal of this project is to redesign the ENVE Aero Stem to allow for a clip-on aerobar to be securely mounted to the stem. The ENVE Aero Stem, as shown in Figure 1, alone is not an issue for mounting clip-on aero bars onto the bike as they usually go onto round handle bars, using the mounting set up shown in Figure 2. Unfortunately more modern aero setups do not use round handle bars opting to use more aero flat bars as shown in Figure 3.

Figure 1: ENVE Aero Stem. A photo of the stem and faceplate that will be the focus of the design [1]

The ENVE Aero stem poses unique problems for a redesign as it does not follow a standard stem design similar to other stems from other companies, instead choosing to use a 3 point mounting system versus the standard 4 point system used by other companies.

Figure 2A: Clip-on Aerobars. Two views of an example set of clip-on aerobars. [2]

This style of clip-on aerobars shown in Figure 2, are very common with two mounting bolts for each bar, used to position the clip-on bars on the handlebars while also allowing for adjustments to the positioning of the arm rests and reach length for the rider. With standard round handle bars using the normal clip-on method built into these bars is not an issue. When an additional aero choice is made for the handlebars, and a handlebar like the one depicted in Figure 3 is chosen, the Clip-on aero bars have nowhere round to mount to so a new solution is needed.

Figure 3: Flat Aero Bars. An example of the aerobars used that are incompatible with the style of clip on bars. [3]

The options of parts to redesign is limited without having to design a full aero cockpit. So redesigning the face plate, the removable piece from the front of the stem, to provide a location to mount the aero bars is the only option. The primary goal of this analysis is to evaluate the structural integrity of the aero bar attachment under various loading conditions, ensuring it can withstand both normal and extreme forces encountered during cycling. This involves identifying any potential points of failure or stress concentrations in the design. By performing this analysis we can verify the attachment is strong enough for its intended application while also providing us the opportunity to optimize the design for weight reduction, helping to meet performance goals.

The expected outcomes of this FEA include a detailed visualization of stress and strain distribution across the aero bar attachment, allowing us to pinpoint areas of high stress that may need reinforcement. We will also obtain data on the attachment's deformation under load, confirming that it remains within acceptable limits. Furthermore, we will calculate the factor of safety (FOS) to verify that the design is robust enough for cycling demands. Ultimately, the FEA should provide insights into potential design adjustments to improve both performance and safety.

The faceplate is made from aluminum, while the hardware (screws and bolts) is made from titanium. The stem has a standard clamp diameter of 31.8 mm, making it compatible with most handlebars, and the faceplate measures 38 mm in width. Torque specifications are critical to maintaining secure attachments; the faceplate's upper bolt is torqued to 10 Nm, while the two lower bolts are set at 6 Nm. The aero bar mounts are also made from AL-6066 aluminum, with a compact mount width of 10 mm. The mounting screws for the aero bar attachment are torqued to 7 Nm, securing each clip-on aerobar to the face plate extension. All aluminum parts will be assumed to have a Modulus of Elasticity (E) of 68.9 GPa and a Poisson's Ratio of 0.33 [4].

The analysis is simplified by assuming that the stem is fixed, with no movement or deflection. By isolating the analysis to the faceplate and the mounting plate, we focus specifically on deflections and stress points in these components. Each aero bar is attached to the mounting plate via two screws, which are assumed to form a fixed connection, making these points the focal area for structural analysis in this design. The load conditions are based on the rider's weight applied to the aerobar pads, oriented perpendicularly to the arm pads and offset from the mounting points. This setup results in both vertical forces and bending moments due to the leverage effect created by the offset. To simplify the model, we assume a flat road surface, disregarding extreme conditions like bumps. The assumed rider mass is 85.5 kg (188.6 lbs) [5], with only a portion of this weight (representing the head, neck, thorax, and upper arms) supported by the aerobars. From prior research [6], it's estimated that around 34.13% of the total body weight is distributed to the aerobars. Additionally, we include a force of 412 N [7] distributed between the two aerobars, which creates an extra moment at the mounting point, further contributing to the stresses experienced by the mounting plate and faceplate.

Additional simplifications and assumptions streamline the model without compromising the structural insights required. The arm pads are assumed to be rigidly fixed on their platforms, and no rotation or sliding is considered at these points. We will treat the materials as exhibiting linear elastic behavior, ensuring that the analysis focuses on realistic yet manageable stress and deformation responses in the structure. Minor deformations outside of the faceplate and mounting plate are neglected to emphasize the critical areas where stress concentrations and deflections are likely to occur.

To effectively model the aero bar attachment system, we will focus on several key components of the assembly. The model will consist of three main parts: the faceplate, the mounting plate, and the two individual aerobars. Each of these components will be modeled to capture their geometric and material characteristics accurately. Tetrahedral elements will be used for the faceplate which is modeled to duplicate the current faceplate, and should not be experiencing any large unexpected loads. The mounting plate and aerobars have more basic geometry but will be the more crucial areas to have accurate load and deformation results. Since we have simplified the model to not include loads experienced during bumps, a linear analysis is all that is required. Ideally the system will be expanded to account for dynamic loads from bumps or other disturbances while riding, but I do not want to over complicate the system to start.

Hand Calculations

HAND CALCULATIONS

OLIVER PILON

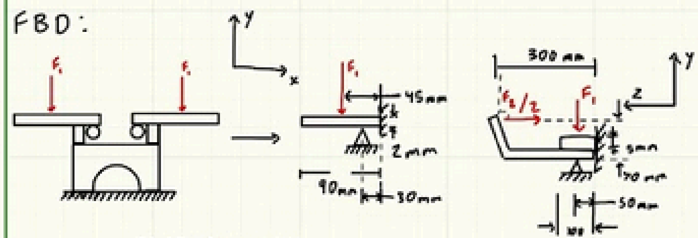
1 NOV 2024

GIVEN: $E = 68.9\ GPa$ $\quad m = 85.5\ kg$ $\quad$ 34.13% of m applied to bars

$\nu = 0.33$ $\quad F_2 = 412\ N$

$m_1 = 0.3413m = 29.1811\ kg$

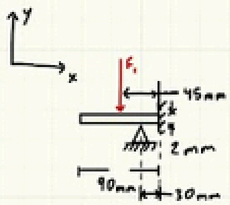
FBD:



$$F_1 = \frac{mg}{2} = \frac{29.1811\,(9.81\ m/s^2)}{2} = 143.134\ N$$

$$F_2/2 = \frac{412\ N}{2} = 206\ N$$

1)

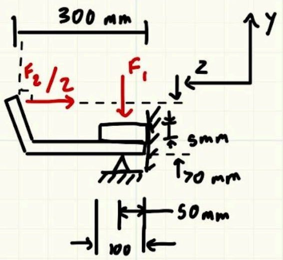


$$M_1 = F_1(45mm - 30mm) = 2.14701\ Nm \qquad I = \frac{bd^3}{12} = \frac{(90mm)(3mm)^3}{12} = 202.5 mm^4$$

$$\sigma_1 = \frac{M_1(0.25mm)}{I} = \frac{2.147\ Nm\,(0.25\ mm)}{202.5\ mm^4} = 8.94587\ MPa$$

$$\varepsilon = \frac{8.94587\ MPa}{68.9\ GPa} = 0.000129838$$

$$\delta_{max} = \frac{F(45mm)(3(90mm) - 45)}{6EI} = \frac{143.134\ N\,(45mm)^2(3(90mm) - 45mm)}{6\,(68.9\ GPa)(202.5\ mm^4)} = 0.779031\ mm$$



$E = 68.9 \text{ GPa}$ $\quad m = 85.5 \text{ kg}$

$\nu = 0.33$ $\quad F_2 = 412 \text{ N}$

$F_1 = 143.134 \text{ N}$ $\quad F_2/2 = 206 \text{ N} = F_3$

$$d = \sqrt{250 mm^2 + 70_{mm}^2} = 259.615 mm$$

$$A = 15mm(300m + 70mm - 15mm) = 5325 mm^2$$

$$x_c = \frac{300^2 mm + 70mm\,15mm - 15^2 mm}{2(300mm + 70mm - 15mm)} = 128.218 mm$$

$$y_c = \frac{70^2 mm + 300(15) mm^2 - 15^2 mm}{2(70mm + 300mm - 15mm)} = 13.2183 mm$$

$$M_z = F_3 d = 53.48 \text{ Nm}$$

$$I = \frac{1}{4}\left[300^2_{mm}\, 70^2_{mm} - (300 mm - 15mm)^2 (70mm - 15mm)^2\right] - A(300mm - x_c)(70mm - y_c)$$

$$= -5.794 \times 10^8 \ mm^4$$

$$\delta = \frac{ML^2}{EI} = 0.00012057 \ mm$$

$$\sigma = \frac{M(35 \ mm)}{I} = -0.00322062 \ MPa$$

$$\varepsilon = \frac{\sigma}{E} = -4.688 \times 10^{-8}$$

Sources:
[1] “Aero Stem,” *ENVE Composites USA*, 2020.
https://enve.com/products/aero-stem?variant=45111154376988 (accessed Nov. 02, 2024).
[2] “Vuka Clip with Alumina Evo Extensions,” *Sram.com*, 2019.
https://www.sram.com/en/zipp/models/hb-vkal-clpe-a1 (accessed Nov. 02, 2024).
[3] “Roval Rapide Handlebars,” *Specialized.com*, 2024.
https://www.specialized.com/us/en/roval-rapide-handlebars/p/205446?color=329928-205446 (accessed Nov. 02, 2024).
[4] “Aluminum 6066-O,” *Matweb.com*, 2024.
https://matweb.com/search/DataSheet.aspx?MatGUID=cbd5de5b95ae41e5bb071ce0320b7e45 (accessed Nov. 02, 2024).
[5] “Anthropometric reference data for children and adults : United States, 2015-2018,” *stacks.cdc.gov*.
https://stacks.cdc.gov/view/cdc/100478
[6] S. Plagenhoef, F. G. Evans, and T. Abdelnour, “Anatomical Data for Analyzing Human Motion,” *Research Quarterly for Exercise and Sport*, vol. 54, no. 2, pp. 169–178, Jun. 1983, doi: https://doi.org/10.1080/02701367.1983.10605290.
[7] *Sciencedirect.com*, 2023.
https://www.sciencedirect.com/science/article/pii/0021929079900411/pdf?md5=3076ad1e50a6314106365afd1362ff77&pid=1-s2.0-0021929079900411-main.pdf