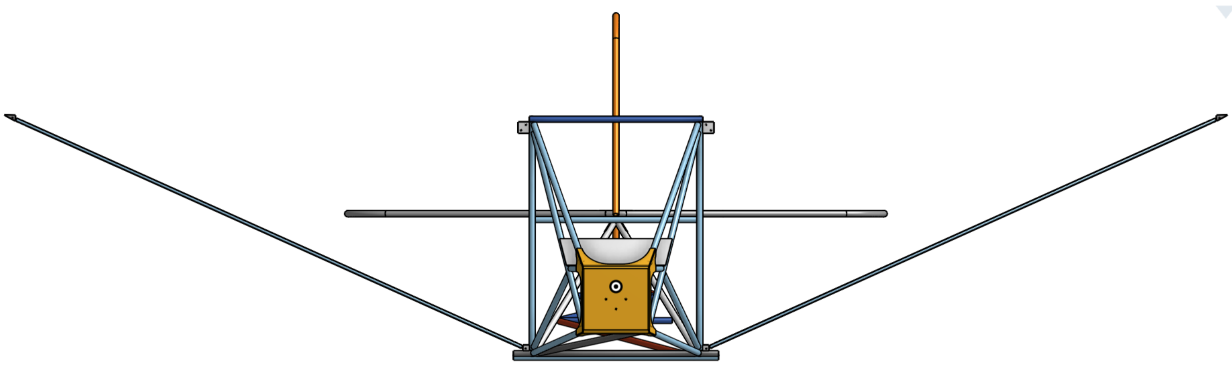
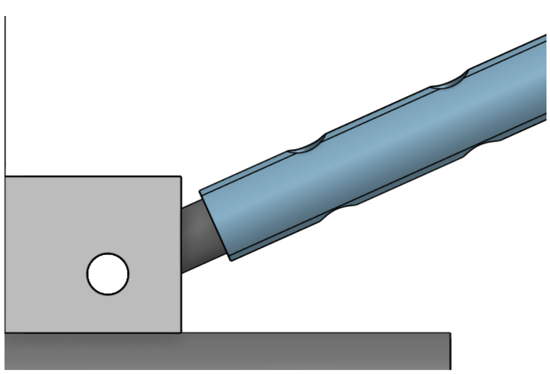
Fuselage Design Process

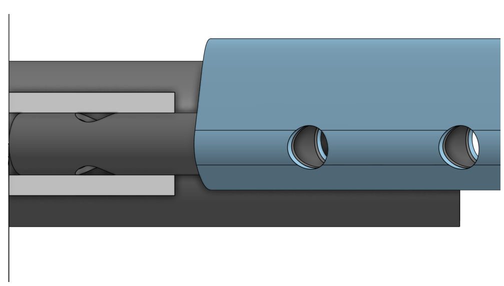
Fuselage Design April Summary

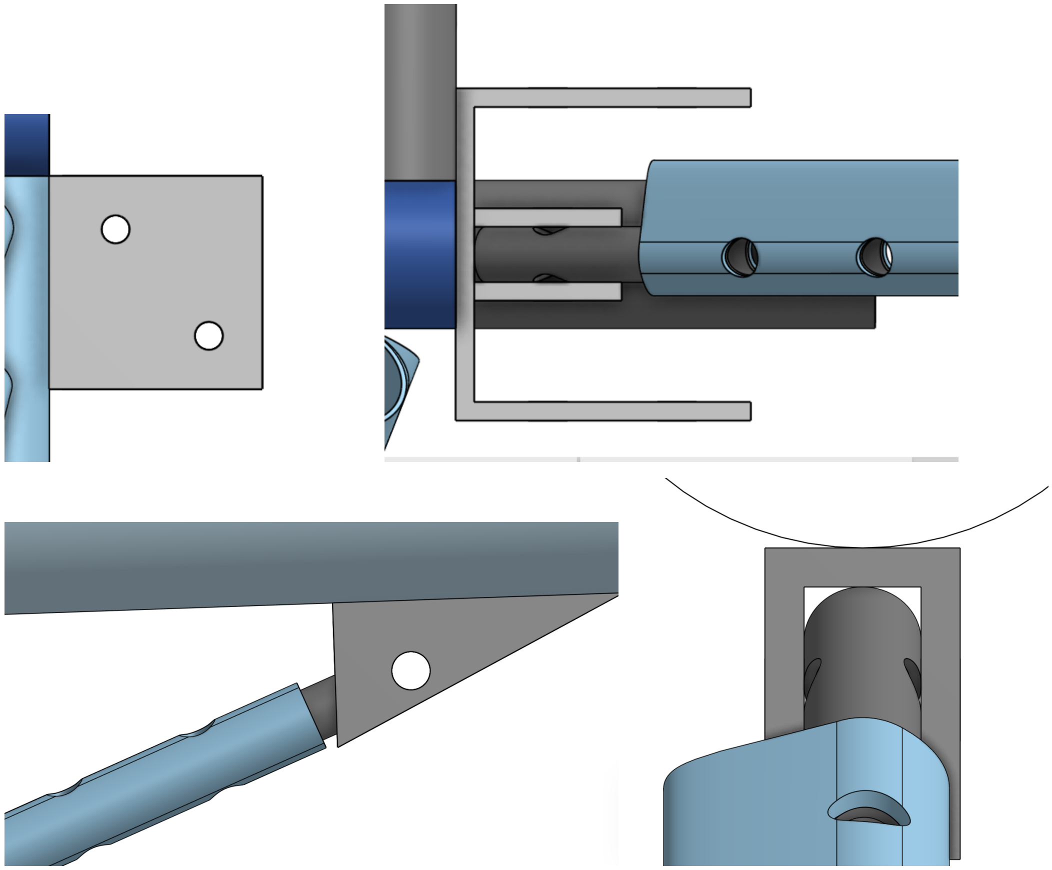
After doing some research into streamline struts, we found that it created much less drag but weighs substantially more than a fuselage beam of the same length. Like many other components, streamline wing support struts and jury struts have their pros and cons giving the Design Team an important decision to make. For example, the Affordaplane uses circular wing support struts, but the Legal Eagle uses streamline ones. We decided to CAD the streamline struts in the meantime while the Physics Team gets some specific numbers to inform our final decision. Because the streamline struts are so wonky in shape, they do not attach easily anywhere. To fix this, we decided to bolt a smaller circular beam to the inside of the streamline strut, so this beam can then attach easily into our U brackets. The strut-spar attachment is currently based on that used by the Legal Eagle since we'll likely be controlling our ailerons through cables running along the jury struts similar to the Legal Eagle. We decided to use their aileron control system because it uses cables rather than control rods, saving a little weight.

To add these wing attachments, we also had to change the length of the cabin so that the attachment points for the struts are located on the vertical beams, rather than horizontal ones to prevent buckling. If the struts are to be normal to the cabin, then the cabin must be the same length as the distance between the leading and aft spars of the wing.





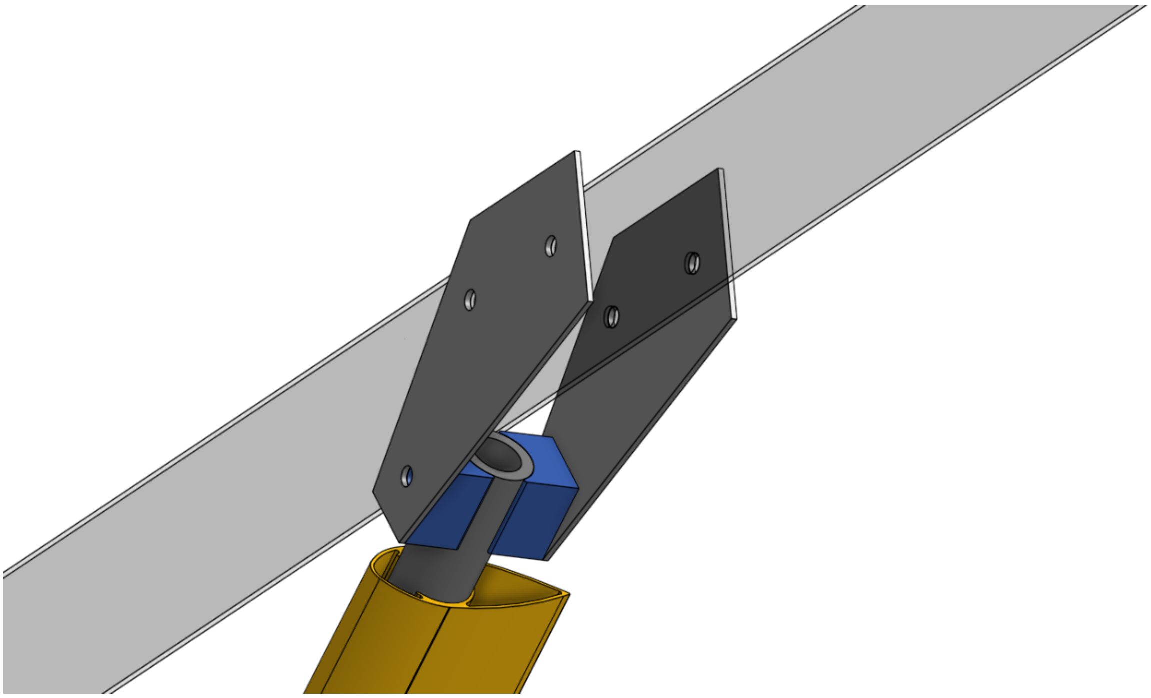




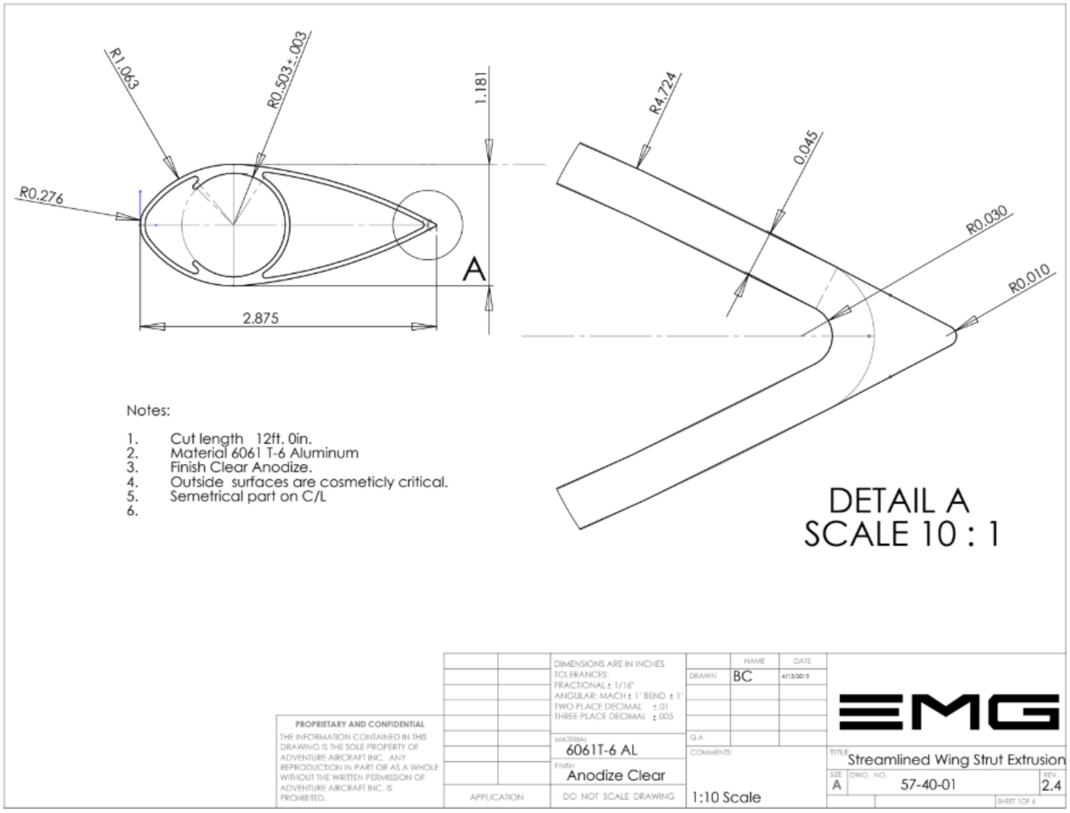
Fuselage Design April-May Summary

Fuselage April-May Support Strut Revisions

Streamlined Struts



When we began the wing strut design, we had to choose between streamlined struts or regular circular beams. Generally speaking, Ultralight airplanes are inherently "draggy" aircraft. Designers often favor simplicity over potential efficiency losses since they are limited to a maximum speed of 54 knots in which drag forces aren't very strong. To make our plane more accessible to the average home builder, we too have prioritized design simplicity over drag in most cases. In the case of our wing support struts, however, we opted to go the low drag route since using streamlined struts would add only a couple additional parts to attach the asymmetrical streamlined strut to the fuselage and wing spar. To our dismay, we struggled finding exact dimensions for streamlined struts since many had oddly shaped cross sections, making them difficult to attach. The Iolani High School E-Hawk team, which is constructing an EMG-6, referred us to the EMG-6 streamline wing struts they use. The benefit of their struts is that they are specifically designed to fit around a 1" circular beam, making it super easy to attach. Additionally, the strut comes with a small groove down the middle for ease of drilling, which will be a huge help while attaching jury struts and drilling bolt holes.



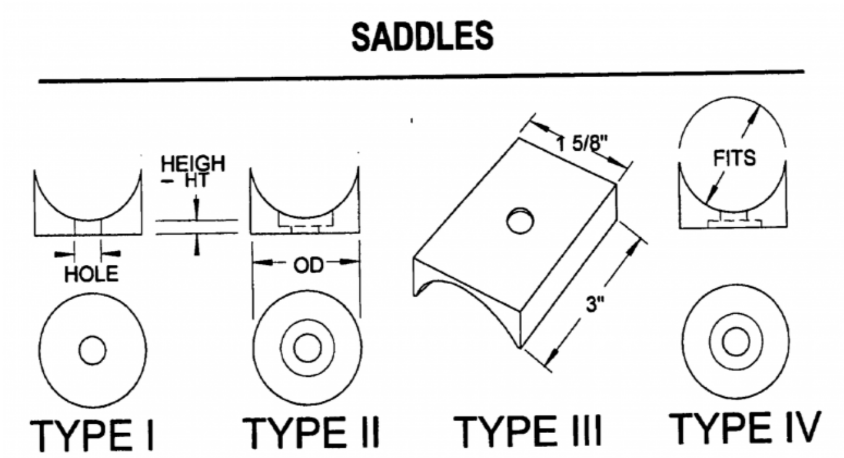
Credit: Rainbow Aviation EMG-6

Spar-Strut Attachment

After we decided on the specific strut, we had to CAD the cross sectional view, which were conveniently provided by EMG-6's drawings! We noted that there were 3 main strut-spar attachment methods: U brackets, gussets, and finger-style. Here are some of their inherent pros and cons:

U bracket:

The U bracket would be the simplest to design as the only steps would be to cut the bracket the right size and drill holes through the spar. However, because there is a large bending moment on the spars, the U bracket is most susceptible to give in, as it would only be connected along a single line tangent to the spar. After consulting the Home Built Airplanes forum, they informed us that the absolute minimum requirement to use this attachment would be to utilize saddles like these:



Additionally, U brackets would require drilling mounting holes at the top and bottom of the spar. The danger here is that the upwards lift force exerts the greatest tension and compression forces on the lower and upper surfaces of the spar respectively. Therefore drilling holes for the U brackets may weaken the spars at best and compromise their structural integrity at worst. That being said, it is still a viable option as many ultralights use this attachment, such as the Texas Parasol, shown below.

[Credit: Texas Parasol Build Manual]

Fingerstyle/bent gussets:

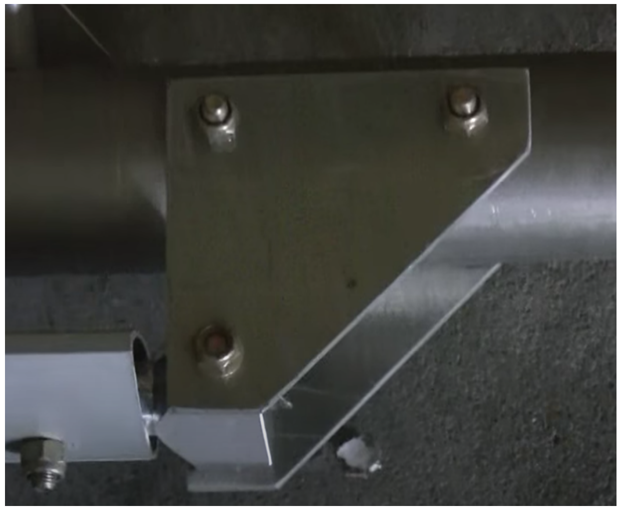
The most well known airplane that uses this attachment style is the Affordaplane with their strut circular tubing.

Credit: TA-1's Affordaplane recreation

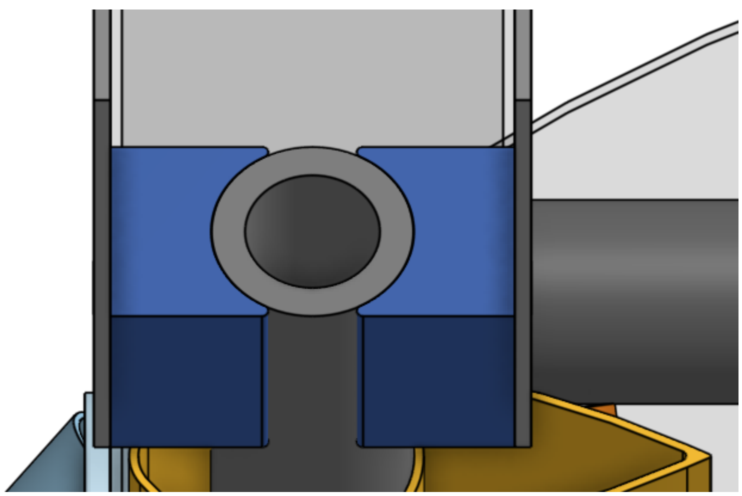
The main con is that this attachment relies on using a bent attachment gusset which could potentially extend under large forces. It is also very specific to the Affordaplane's design. For example, the spar and wing support strut must be tangent on at least one side for one of the gusset-like steel plates to be straight. Our wing support struts are planar with the spars such that both gussets would need to be bent if we were to use this attachment method. We were concerned that if both were curved, the tension from lift would cause the finger sheet metal to extend and deform. More broadly speaking, the Home Built Airplanes forum pointed out that the Affordaplane uses some pretty questionable design techniques. We've been learning from them by figuring out the strengths and shortcomings of their time-tested design and working from there.

Straight gussets:

Because our strut tubing is an inch in diameter, compared to our spars which have a two inch diameter, we would need to create an adapter. This is called a straight gusset and would add extra weight. The benefit of this type of gusset is that it would be stronger due to the bolt structure, and how it would distribute lift forces. Below is an example of wing attachment gussets being used in the Excalibur LSA kit plane.



After much deliberation and communication with the HBA forum, we decided to go with the straight gusset for the spar-strut attachment. In the end, the added weight is worth the structural stability it adds. We CADded an aluminum adapter that would be bolted between the gusset and our circular strut tubing. This adaptor will eventually be machined using 6061 T-6 aluminum and a CNC mill.



With our attachment method determined, we then faced the task of designing a gusset that would be strong enough. We needed to account for a substantial amount of shear, bearing, and tearout stresses on the gusset. The first thing we calculated was bearing stress, which is the stress on the edge of a bolt hole. To calculate bearing stress, we used this equation: $f_{br} = \frac{P}{dt}$ where

- f_{br} is the bearing stress (psi)
- P is axial load (lbf, can be converted into lbs with no problem, as we wont be flying this plane on another planet)

- d is diameter of the hole (in)
- t is the thickness of the plate (in)

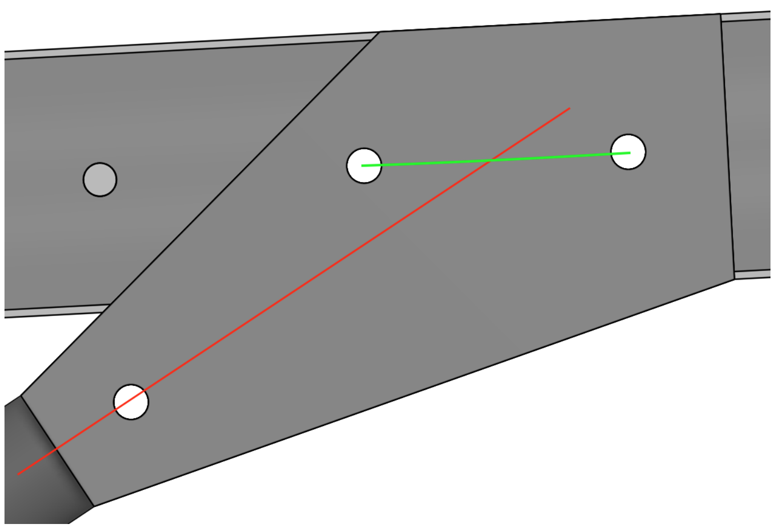
P = 1076.7 lbs on the aft spar and 864.4 on the front spar with a 3.8 load factor (see truss analysis blog, tension on fore and aft struts) we will use 1076.7 lbs to ensure safety.
d = 0.25”
t = 0.058”

$\therefore f_{br} = \frac{1076.7 lbs}{0.25\ in * 0.058\ in} = 74,255.2$ psi

By adding an extra bolt, the contact surface between bolts and gusset will double, which will then double the denominator. Considering the yield bearing strength of our aluminum spars is 56000 psi, we will need 2 bolts, which will result in a 37,127.6 psi load, which is nearly exactly a 1.5 factor of safety.

We moved the bolt holes so that the strut center line (red below) intersects directly in between the bolts (green below). This allows for the load to be evenly distributed across both bolts so the calculated bearing stress matches the actual bearing stress.

Tearout stress will be equal to bearing stress, but it will affect the surrounding gusset material. To ensure tearout stress won't be an issue, a edge to hole diameter ratio of 1.5 is implemented. This means that the distance from any given hole to another hole or to the edge of the gusset is at least 1.5 x the diameter of that hole.



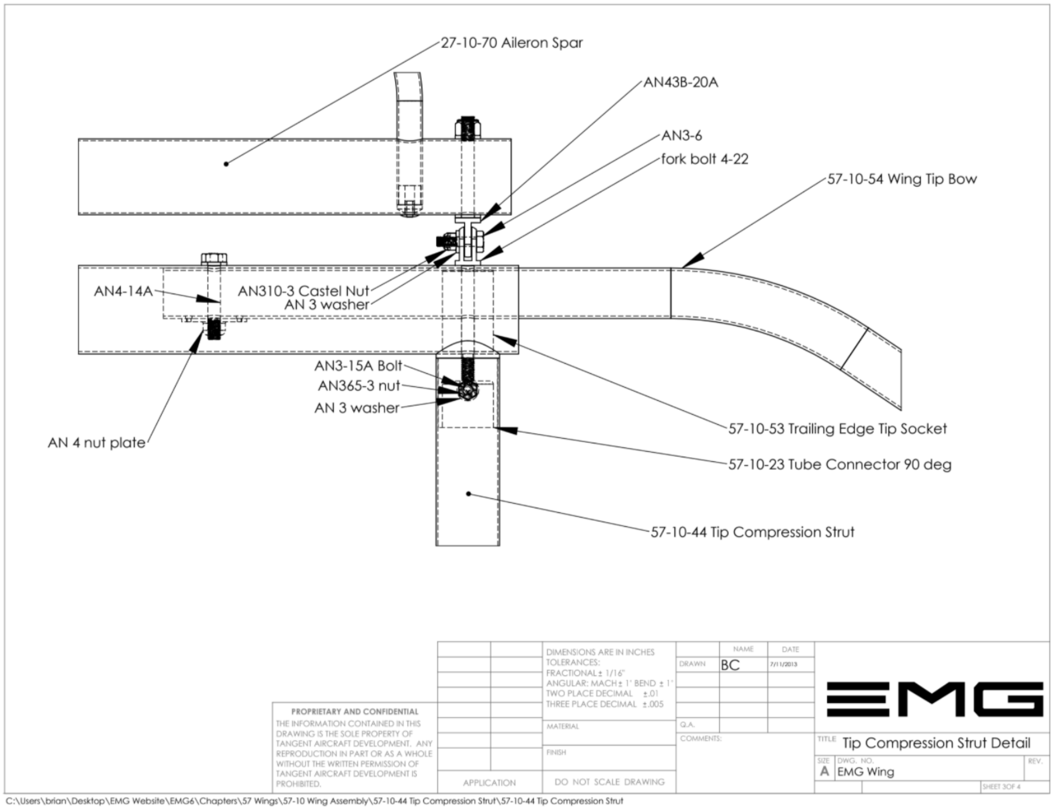
Jury struts

Jury struts are smaller structural struts that connect the wing spar to the wing struts (see vertical beams under the wing on the Fleet Canuck). During landing and in turbulence, the wing support struts can take large compressive loads which may cause them to buckle. By attaching jury struts, we effectively cut the length of the column in half and therefore quadruple its Euler column buckling strength.

Fleet Canuck aircraft

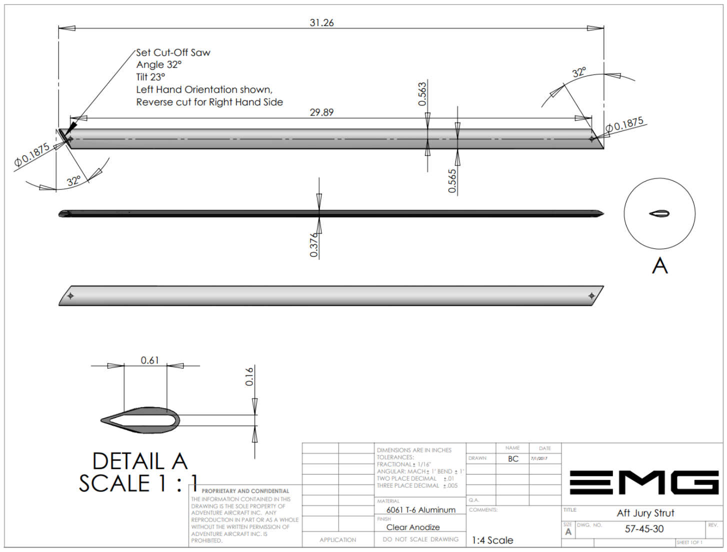
Without jury struts, our support struts' column buckling strength was already over 300 kips, so adding them would provide no real benefits. This may be different for other aircraft with different struts and weights, so we will outline the process we went through before realizing they weren't necessary

As a starting point, we decided to use the same size jury struts as the EMG-6 since we're already using their wing support struts. They can be found at Wick's Aircraft, as the smallest available 6061 T-6 streamline strut. While we weren't able to locate the exact jury strut drawings for the ENG-6, we came across their aileron hinge drawings which made everything clear. For their aileron hinges, they use the AN43B-20A, an eye bolt which is coincidentally also the same shape of bolt they use to attach their jury struts to their main strut (shown below on the Iolani E-Hawk).



Credit: Rainbow Aviation EMG-6

Based on the [EMG-6 Jury cross sectional drawing] (see photo below), we [CADed the jury strut and used it as a beam profile].

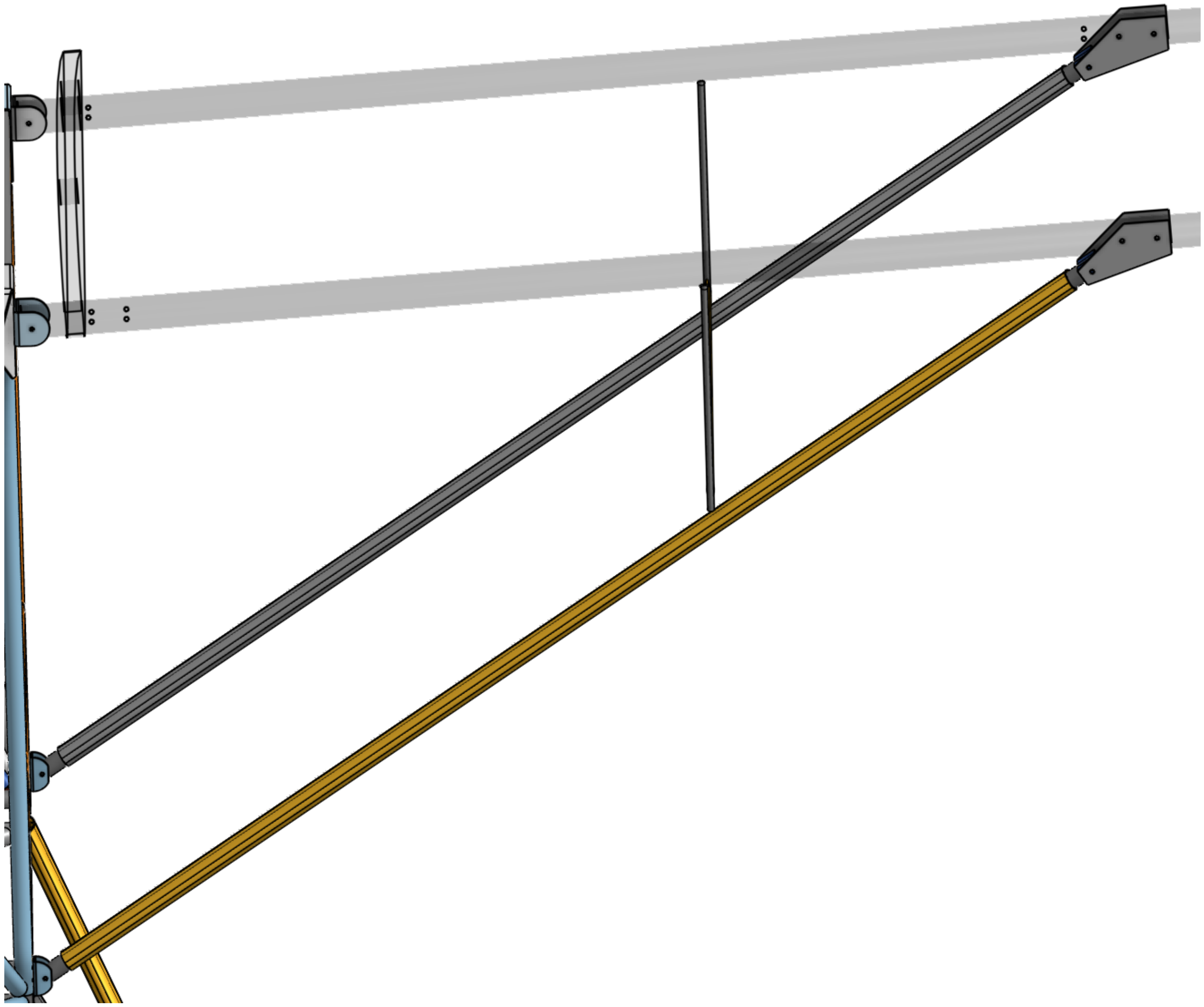


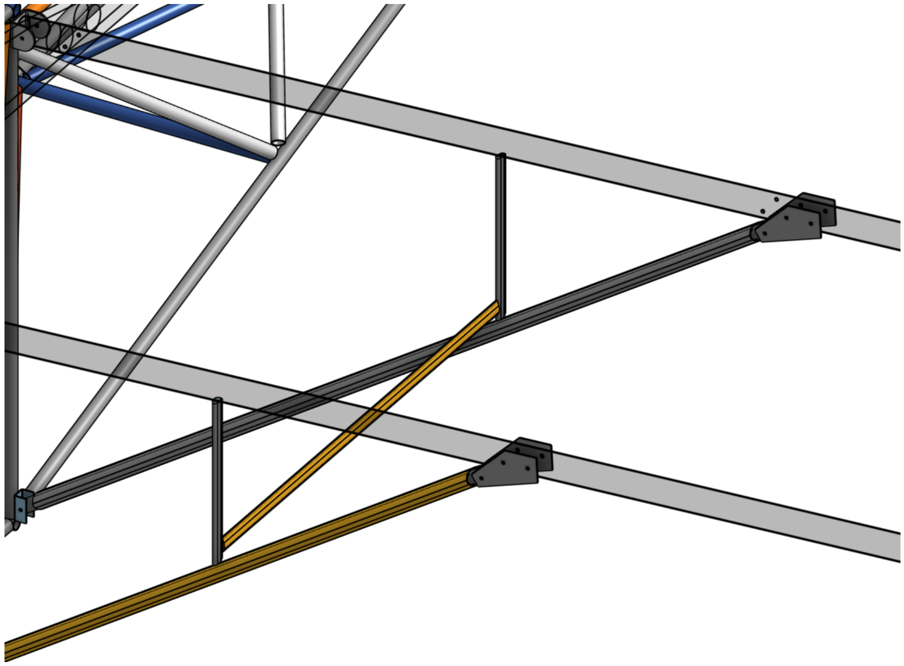
Although the EMG-6 has very well documented gussets, we cannot use them verbatim because they use a different wing chord and their struts meet at a single point, where ours remain completely parallel. You can see the difference between our struts and the EMG-6's below.

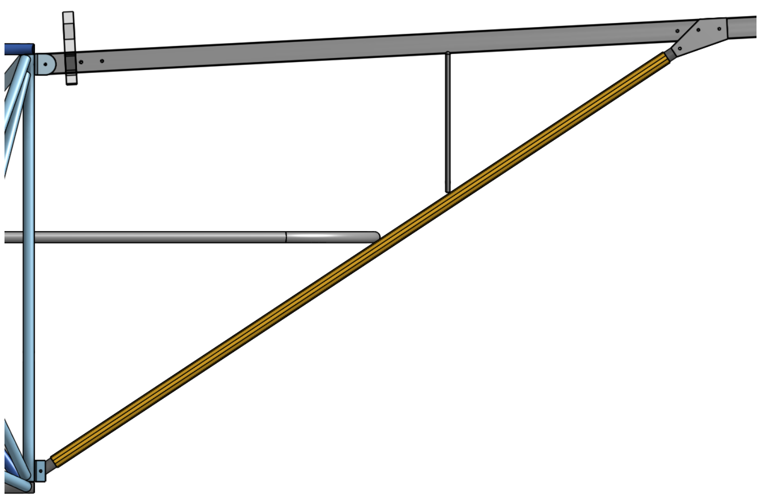
EMG-6 struts:

Credit: Ultralight Aircraft magazine

Our struts:





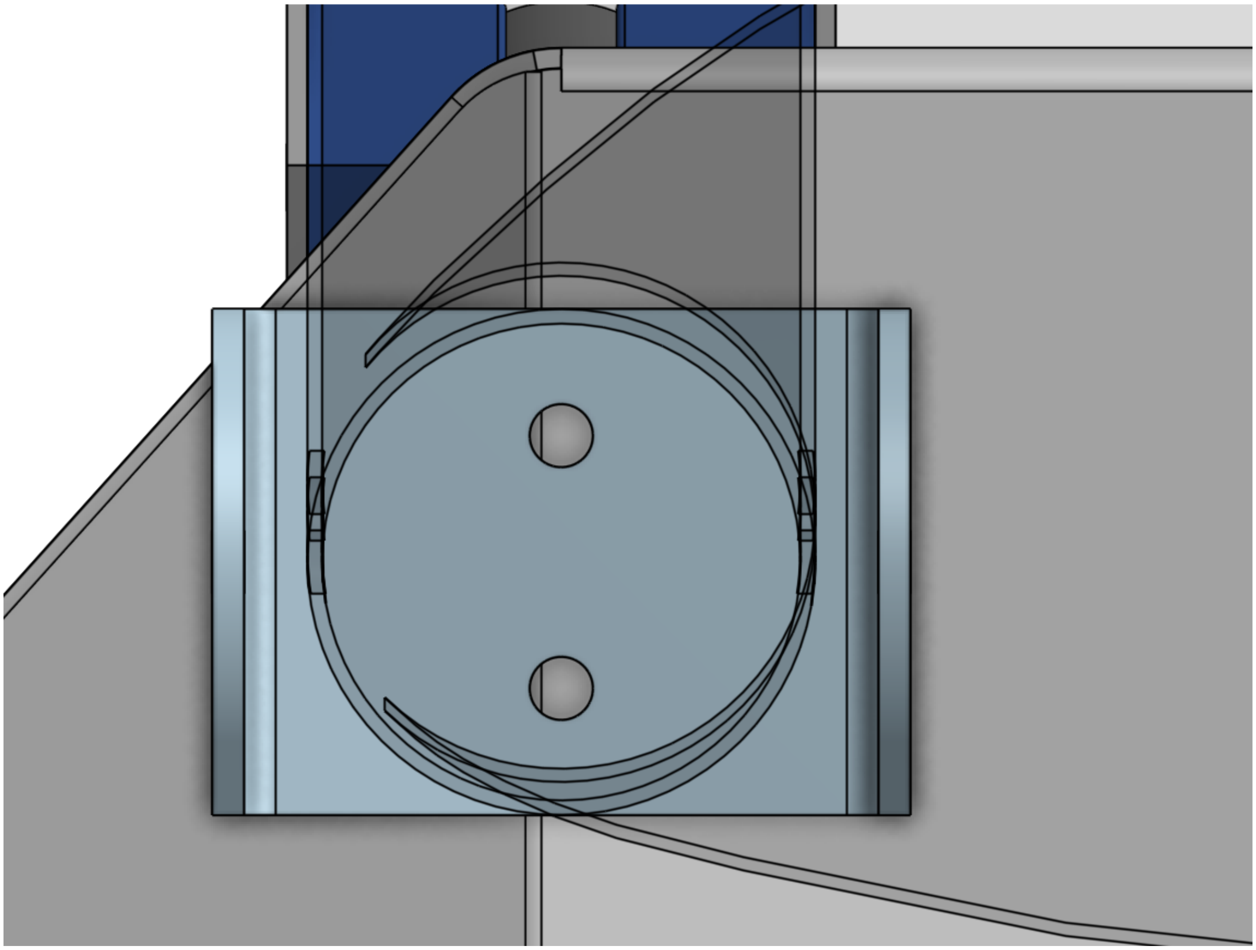


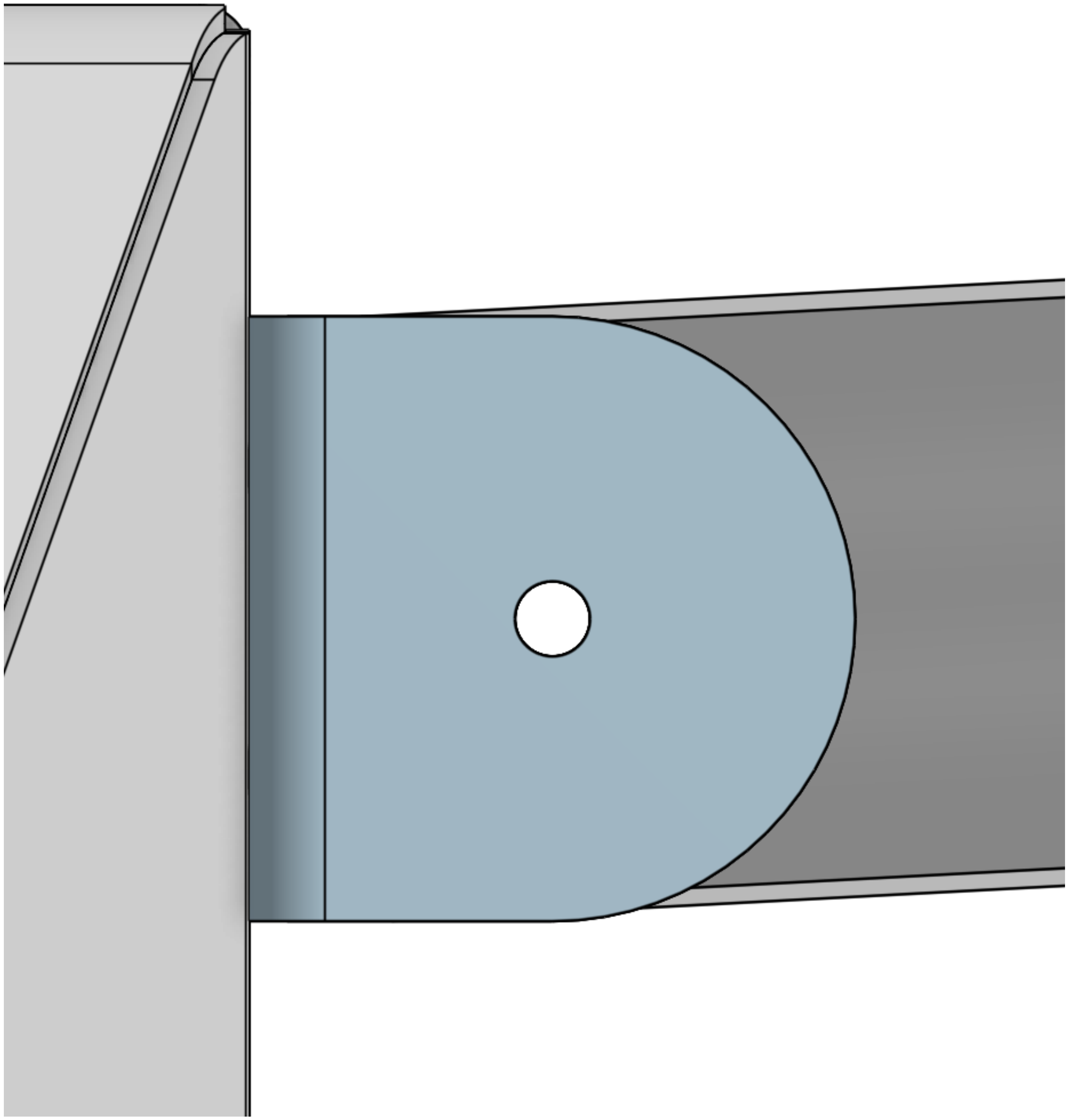
We decided against using an additional diagonal jury strut because the EMG-6 weighs almost twice as much as our plane (see photo above). This additional jury strut would primarily be opposing drag forces and we are already going to be using drag struts (see drag strut article).

This is as far as we got before realizing we wouldn't need jury struts. If your design requires jury struts, we would be happy to develop our jury strut model for your purposes.

Spar cabin attachment

The spar cabin attachment is based on that used by the Affordaplane. Simple U bracket wing attachments are actually quite common in ultralight airplanes and are much favored over more complex methods. As mentioned above,some of the lift loads will be distributed onto the cabin-spar attachments while most will be carried by the wing support struts. Since we have not done most of these calculations, we are just going to assume for now that about half will be distributed to this attachment. Please note that the calculations above with spar-strut attachments were assuming that all of the load will be on their attachment. Since the cabin tubing is much thinner, we needed to use two bolts at each U bracket attachment point to account for the large bearing stress. We used the desmos to calculate the number of bolts needed.





Wing support strut lower U channel attachment:

Because the wing support strut U channel will be carrying the other half of the lift load, we decided to extend its length and use two bolts to secure it to the fuselage truss frame. The circular edges are implemented because again, the U channel would only touch the strut circular tubing at one line so the edges unnecessarily add weight.