Bellcrank Design 2024/25

The main design objective of the bellcranks, aside from the obvious connections (push rod, ARB, shock), is to achieve a desired motion ratio - defined as the ratio of shock:wheel travel. The motion ratio determines the effective ride rate along with the ride frequency - formulae shown below.

Motion ratio:

$$MR = \frac{Spring\ Compressi}{Wheel\ Displaceme}$$

Wheel rate (first term can be ignored with a linear motion ratio):

$$k_w = F_s * (\frac{\Delta MR}{\Delta \delta}) + k_s(M)$$

And, of course, the **ride rate** which combines the wheel rate and tire rate as springs in series:

$$k_r = \frac{k_w * k}{k_w + k}$$

Ride frequency:

$$f_r = \frac{1}{2\pi} \sqrt{\frac{k_r}{m_i}}$$

Our goal for the bellcranks in the 24/25 design cycle was to achieve a motion ratio which:

1. Complied with rules, achieving at least 50mm of wheel travel (therefore a maximum motion ratio of ~1)
2. Allowed us to achieve a linear motion ratio (rising rates talked about below)
3. Allowed us to achieve desired ride frequencies of 3-3.5 hz
4. Had a high enough motion ratio (preferably close to 1) such that the shock had enough movement for ideal damping. See the dyno curve here (C12/R12 sweeps for our shocks): 📄 Oh lins_Europe_pruefstandsdiagramme-oehlins-automotive-ttx25-mkii.pdf - It could certainly be possible to reduce the motion ratio if desired, though note that your damping range will be more limited.

Our motion ratio, determined from the criteria above (selected ride frequency + desirability to have MR close to 1 for damping while still having sufficient wheel travel), ended up as:

Front Motion Ratio	0.827
Rear Motion Ratio	0.847

See ⊟ 2024/25 Suspension Design Cycle Review for more information about selected parameters.

Selected ride frequencies shown below:

Setup	Front Ride Frequency	Rear Ride Frequency
Soft	3.0 Hz	3.2 Hz
Firm	3.27 Hz	3.41 Hz

Spring rates on our soft setup are 250/300 lbs/inch front/rear, and 300/350 on the firm setup.

Desirability of a higher rear ride frequency is demonstrated in the image below; want the delayed response of the rear suspension to "catch up" to the oscillation of the front to avoid pitching.
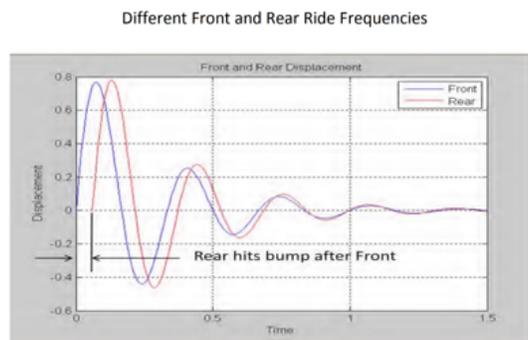

Figure 14

After determining the motion ratio, we move on to determining the rocker points to the push rod, shock, and ARB. See 〰Rising Rate Suspension: A Design Guide . This was a good resource which helped with a rough excel model (see 24-25 Suspension Stats) based on our suspension geometry, however, it was not fully accurate and therefore warranted going in the CAD

kinematic to manually adjust our wheel travel to determine the shock travel - it is certainly possible to model this such that manual inputs in CAD is not required, but there are quite a few effects you need to consider - therefore the excel model was simply a tool to help determine what angles/lengths we could change to achieve certain effects, and not a tool to determine the exact motion ratio throughout the stroke.

- For the 24/25 design cycle, we decided against progressive rates due to too many complex resultant effects. Mild rising rates may be a good consideration for the future but definitely needs more work for a proper justification of using - could very well be feasible though, especially if anti-like properties are desired without adjusting geometry/kinematics such that the linkages take additional load under braking/acceleration/roll etc.
- Looked at 200mm to 143mm (57mm is full compression) of our shocks (see ⬡ Professional Motorsport TTX25 MkII FSAE Formula Student 200/57 mm - Öhlins Onlineshop), modeling the motion ratio through the changes to shock length from adjusting the wheel travel in the CAD kinematic model

Feel free to also check out RCVD (Ch. 16) and Tune to Win (pg. 64) - lots of useful information here.

Once all suspension parameters / rocker points were set up, it was simply determination of the material, thickness, and optimization cutouts - long story short, we went with 1/8" 7075 T6 Aluminum due to its extremely high strength to weight ratio.

▤ 2024 Suspension DR2 gives a good overview of the process in determining these cutouts, where we performed multiple structural optimizations in Ansys given the loading scenarios considered - these forces were taken at maximum compression given the highest spring rate used (as these were the rear bellcranks, 350 lbs/inch * 57mm was used, divided into two bellcrank plates per shock).

I honestly do not recommend you use the maximum shock compression scenario to determine your safety factor as I did. With this loading scenario, a safety factor of 1 here could have been reasonable given the loading scenario is absurd especially given 350 lbs/inch springs (and I'm pretty sure the control arms break before it can occur, if that says anything) - I would recommend using maximum loading cases on the push rod translated from the wheel, as is done in the design in our control arms (see ▤ Control Arm Design - 2024/25) - and determining a reasonable safety factor from there.

Regardless, you can see that the cutouts are quite extreme despite the bellcranks being 1/8"
thick and us taking a safety factor of about 2 with a maximum shock compression scenario -
while taking a more realistic force case can definitely help you out in optimizing, I'd be surprised
if you could get rid of more than 10g per plate from our current design.

Quick note that the forces shown (for the rear bellcrank) in the 2024 Suspension DR2 document
were not in the correct direction; please be careful when determining force directions from the
dynamic CAD model, as the condition you pull the forces from at your compressive loading
scenario will be at a certain bellcrank rotation from the ride height condition - I decided on using
a rotation matrix to translate the forces.

There is most likely a better way of doing this - potentially exporting the bellcranks from CAD in
the loading case tested if that is possible.
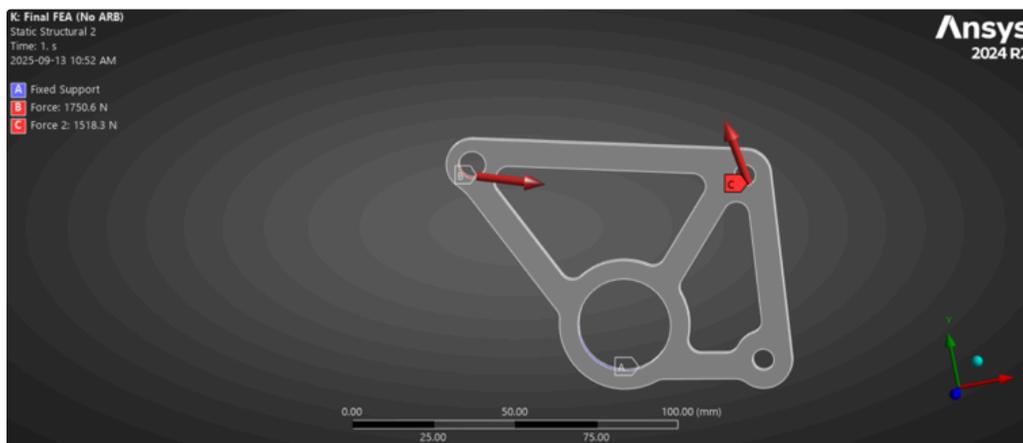
The above image shows an accurate loading scenario at maximum shock compression in heave
(in roll, need to add the ARB load on the third connection - therefore need to test 2 cases, and
potentially in-between's as I believe it is possible for a case where neither maximum heave/roll
to be the maximum loading scenario depending on the geometry of your bellcrank - although
feel free to prove this wrong).

Below may be a more obvious sign that the forces have to be translated, as the ARB force is
assumed to act along the z-axis; modeling with the unadjusted (ride height) bellcrank, this force
needed to be rotated.
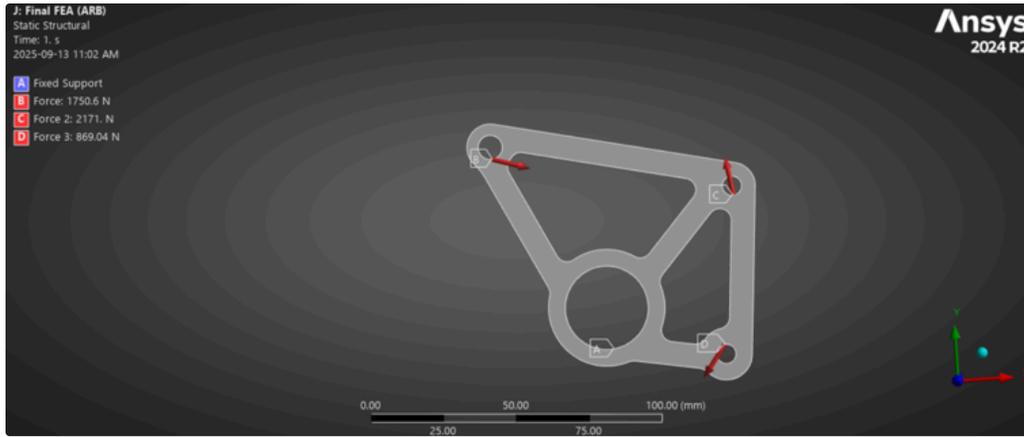
That's it for bellcrank design, feel free to contact me with any questions you may have.