Overview

This article is an overview of the analysis behind the Identify BMX cranks.

Outline

Background Information

The Q-Factor

The background discussion begins with understanding the Q-Factor and how it affects your rider… AND CRANKS! Q-factor affects my cranks?!? I was surprised to find this out too! Let me explain, but first, let's define Q-Factor just so we are on the same page. Most people define Q-Factor as:

> **Q-Factor** - distance from outside of non-drive side crank arm to outside of the drive side crank arm.

An image of the Q-Factor is shown in *Figure 1*.

***Figure 1**: Q-Factor*

The issue is, in my opinion, if the Q-Factor is defined this way, this is not good enough. A better “metric” to use is the stance, or the distance between your riders feet. This is a better metric because not all pedals are created equal. A good illustration of this is in *Figure 2* showing two pedals having drastically different axle lengths. If two bikes have the same Q-Factor but bike “A” has the pedal in Figure 2A and bike “B” has the pedal in Figure 2B, then bike “B” will have the narrower stance.

***Figure 2A**: Pedal with long axle length*

***Figure 2B**: Pedal with short axle length*

***Figure 2**: Example of pedals with different axle lengths illustrated by the distance of the red lines*

Let’s get to why this is important and why having a wide stance, or too narrow of a stance is not ideal, both for your rider and your rider’s cranks. In *Figure 3*, we have four riders. Each rider has a different Q-Factor or Stance. Ask yourself, which rider has the smallest/tightest Q-Factor/Stance? If you said rider D, you are correct! However, is rider D the setup you want to ideally obtain? Let’s figure this out - it’s math time!

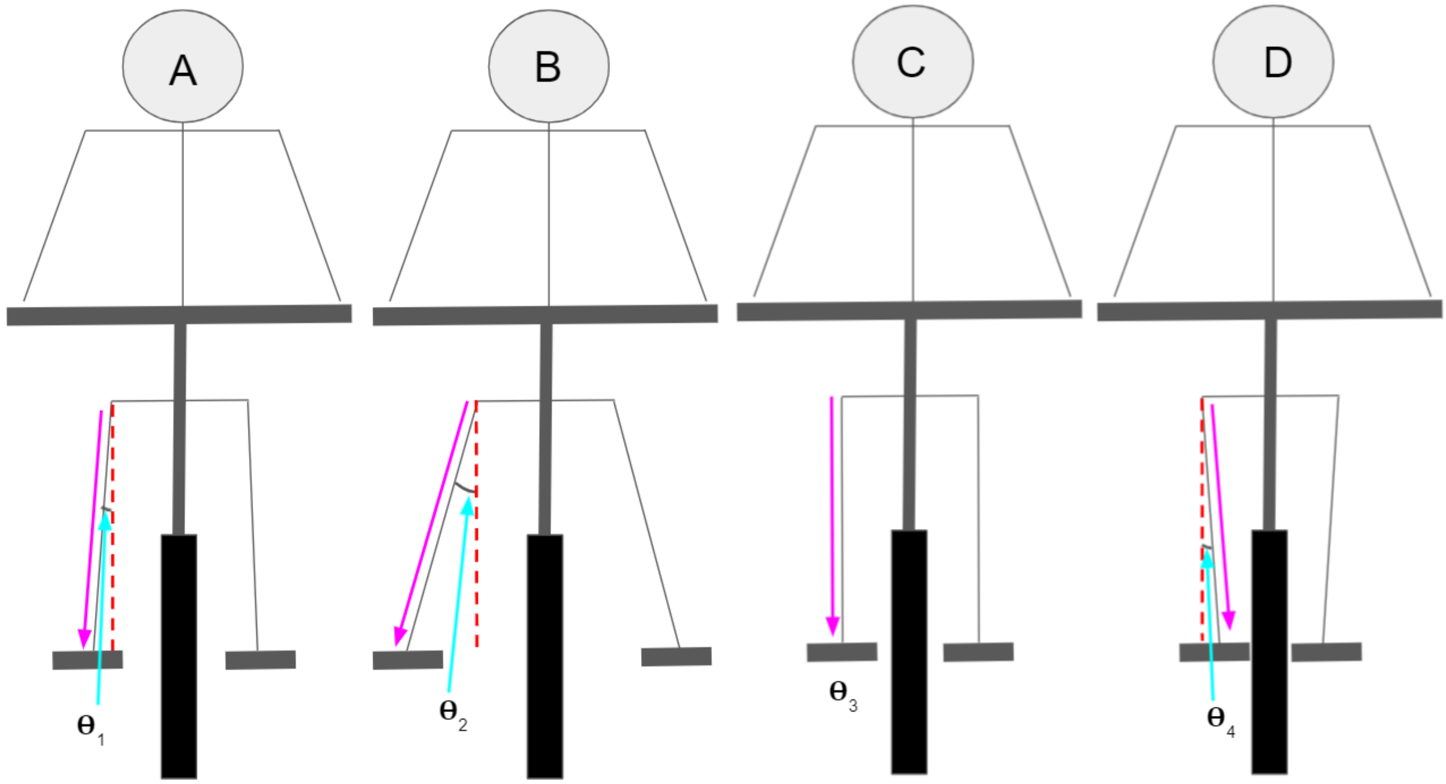


Figure 3*: Different Q-Factor / Stances showing the angle created for each setup.*

1. Rider A has a stance that is causing a slight outward angle, Θ_1, of the rider’s leg.
2. Rider B has a stance that is causing a large outward angle, Θ_2, of the rider’s leg.
3. Rider C has a stance that has no angle from the vertical of the rider’s leg or think of it as $\Theta_3 = 0$ degrees.
4. Rider D has a stance that is causing a slight inward angle, Θ_4, of the rider’s leg. Remember this rider has the “tightest” Q-Factor or stance.

Remember trigonometry? Welp, we need it. *Figure 4A* shows our triangle that riders A, B, and D are creating because of the different stances. In *Figure 4A* I am showing three forces:

1. $\mathbf{F}_{\text{Rider}}$ - This is the force that your rider is able to generate and push on their pedal with.
2. $\mathbf{F}_{\text{Transfer}}$ - This is the force that actually transfers to the drivetrain of the bike and gets your rider going. Why is this different from the force your rider can generate? It’s because of that angle. Think about this, consider *Figure 4B*, if I push a box and I want it to move it in the direction of the green arrow what’s the best, most efficient, way to do that? It would be to push on the box in such a way that you are actually pushing in that direction as force F1 is showing. If you push on the box at an angle, such as force F2 and force F2 is the same force as F1 just at an angle, the box will still move as far as it did overall, that is distance D1 and D2 represented by the light blue lines are the same, but the box won’t

move in the direction of the green arrow as far. What does that mean? That means that box 2 did not have as much force in the direction of the green line… This same principle applies to a bike and the force on a pedal!

3. **F_{Wasted}** - This is the force that does not transfer to your drivetrain of the bike and is literally wasted force. You may ask, where does this force go? Welp, this wasted force goes directly into your cranks, in the wrong direction!

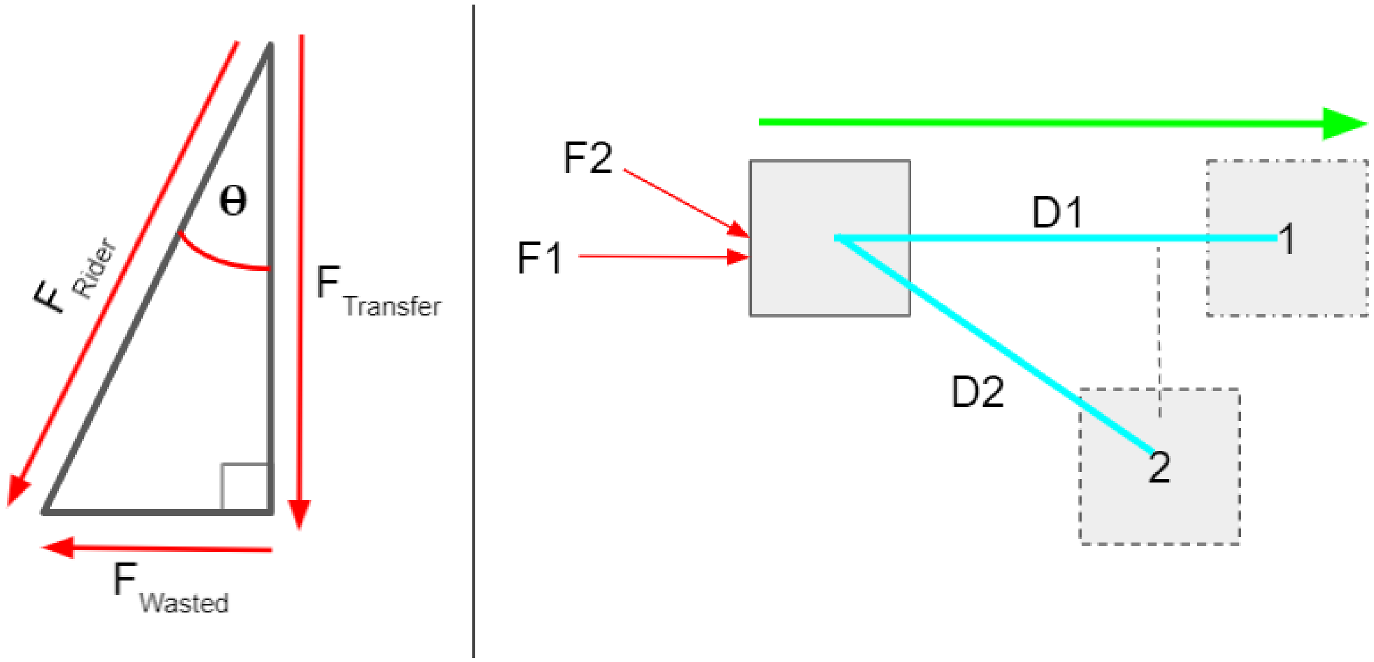


Figure 4A

Figure 4B

***Figure 4**: Right triangle showing how different angles from different Q-Factor/Stances affect forces from your rider to their pedals and drive train.*

So how do we calculate these forces? In comes trigonometry.

- $F_{\text{Transfer}} = F_{\text{Rider}} * \cos(\Theta)$
- $F_{\text{Wasted}} = F_{\text{Rider}} * \sin(\Theta)$

Let's get back to our riders, A, B, C, and D in *Figure 3* and put some numbers to their situations to see who has the best Q-Factor/Stance setup. The one assumption we are going to make is the one and only difference between all riders and that is the Q-Factor/Stance width. This means all riders are the same weight, all riders push with the exact same force on the pedal, etc. *Table 1* shows how the rider force is broken down into the transferable force and the wasted force.

***Table 1**: Comparison of Riders*

Rider	Angle (degrees)	F_Rider (pounds)	F_Transfer (pounds)	F_Wasted (pounds)
A	3	125	124.83	6.54
B	8	125	123.78	17.4
C	0	125	125	0
D	3	125	124.83	6.54

* Just noting this so there's no confusion. The rider force is 125 pounds but if you add the transfer force and wasted force directly you get something greater than 125 lbs. That's not how this works, remember trigonometry tells us that the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides of the triangle, that is $F_{Rider} = \sqrt{F_{Transfer}^2 + F_{Wasted}^2}$

Based on the results of this table, it is clear that Rider C has the ideal setup as this rider is transferring all of their force to the drivetrain of the bike and is wasting none of it because, just like box 1 in *Figure 4B*, this rider is pushing with a force perpendicular to the pedal. This is a little interesting because remember, Rider D had the tightest Q-Factor/Stance of all the riders! Rider B clearly has the worst setup as Rider B is transferring the least amount of force through the drivetrain and is putting the most amount of force on their cranks in the wrong direction. What does putting force on the crank in the wrong direction mean? *Figure 5* illustrates where $\mathbf{F}_{\mathbf{Wasted}}$ goes, it actually goes into bending the crank away from the frame causing stresses in it that are undesirable. Most crank designs, except for cranks with a circular cross-section, are not designed to take a significant load/force in this direction, and rightfully so as they should not have to. However, this side force on the crank does contribute to the maximum stresses in it and Identify BMX has realized this in our simulations to resemble real life use as closely as possible!

***Figure 5**: Direction of wasted force on a crank*

Topics of Analysis

Maximum Stress

Knowing the maximum stresses in the crank arms is paramount to understanding the performance of the crank. In the engineering world, you always have to give something to get something. For example, if you want a stronger crank to reduce the maximum stress at a given force applied to the crank, that usually means you need to add material which means they will be heavier. If you want a lighter crank then you give back on strength, i.e. increasing the maximum stress at a given force applied to the crank. It's the nature of the beast.

Finite Element Analysis (FEA) simulations were performed on most crank sizes Identify BMX offers, however, only a select few crank lengths are reported here since they give a general idea of the strength of the full scope of all of the lengths.

The Mesh

In FEA the mesh elements are crucial for a successful and realistic simulation. Without going into too much detail, a representation of the mesh in each crank is shown in *Figure 5*. There is a minimum of three mesh elements in areas of high stress. A good trick in FEA is to run a simulation with a coarse mesh to determine high areas of stress. Once these are known, put more mesh elements in those areas. When this is done the stresses will typically go up because they are more accurately being calculated.

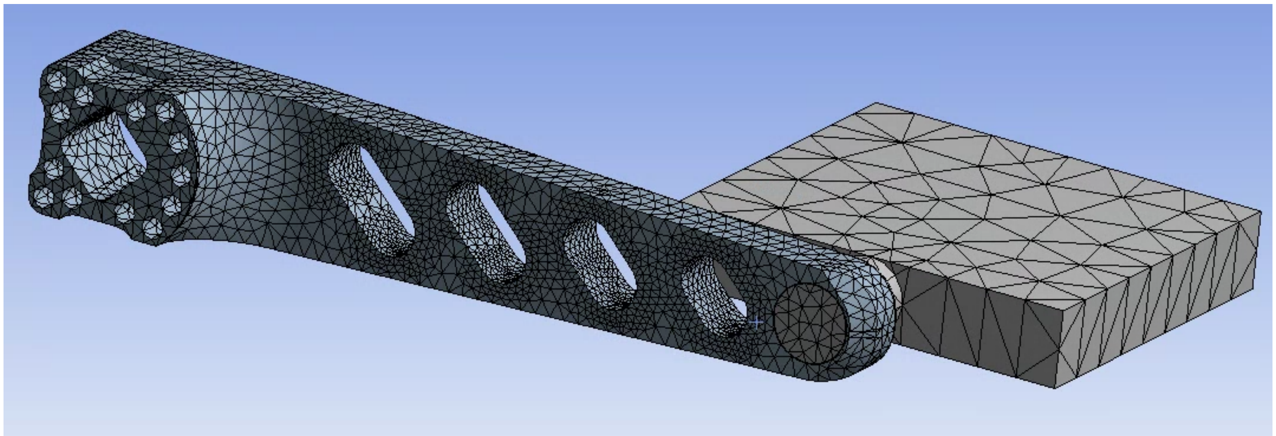


Figure 5: *Representation of mesh elements in FEA analysis*

The Analysis

All of the results are based on the following constants:

- In *Figure 6A* and *Figure 6B*, dimension **D** is the distance between the vertical line where the angle **ϴ** = 0, also known as the location of the ideal Q-Factor/Stance position, to where the riders foot is on the pedal. This dimension **D** is held to a constant 1" unless otherwise noted.
- The rider's force is always set to 125 lbs and the transfer force and wasted force is calculated based on the angle, **ϴ**.
- Analysis was done for a 21" in-seam and a 24" in-seam. To understand why this was done, consider the "taller" rider in *Figure 6A* compared to the "shorter" rider in *Figure 6B*. If the

dimension **D** is always 1”, how does this affect the angle, $\boldsymbol{\Theta}$? Consider *Figure 6C*, if dimension D is the same for all three triangles but the length, L is such that L_1 is longer than L_2 and L_2 is longer than L_3, it is clear that the longer the length L the smaller the angle, $\boldsymbol{\Theta}$. We learned in the background section, see *Table 1*, the bigger the angle, $\boldsymbol{\Theta}$, the more force that is wasted. So what does this mean? This means that if a taller rider with a 24” in-seam has the same Q-Factor/Stance as a shorter rider with a 21” in-seam, the taller rider will actually have less wasted force than the shorter rider!

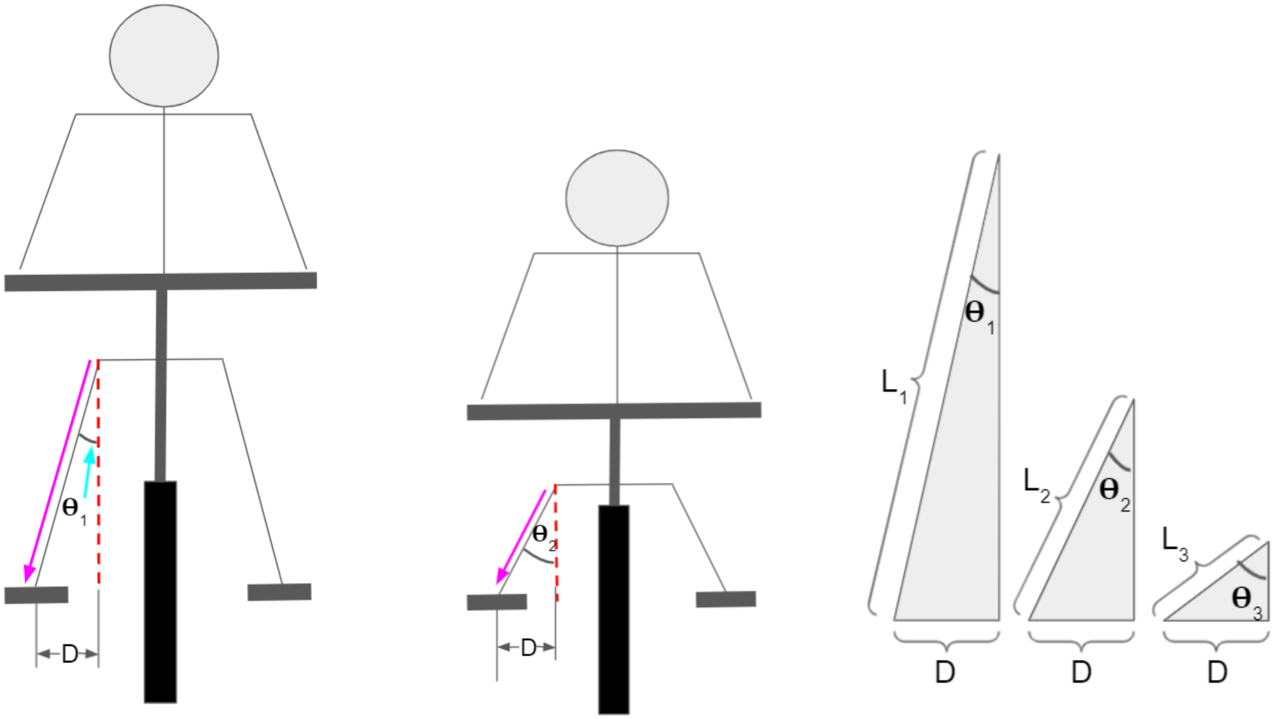


Figure 6A *Figure 6B* *Figure 6C*

Figure 6*: Variables in the FEA Analysis*

Figure 6C*: How the angle theta changes when dimension D is held constant and a rider’s in-seam changes.*

The simulation constraints are as follows:

1. The four square-tapered surfaces in the crank are confined to a fixed support. This means that these four surfaces are not allowed to move at all in the simulations. See *Figure 7*.

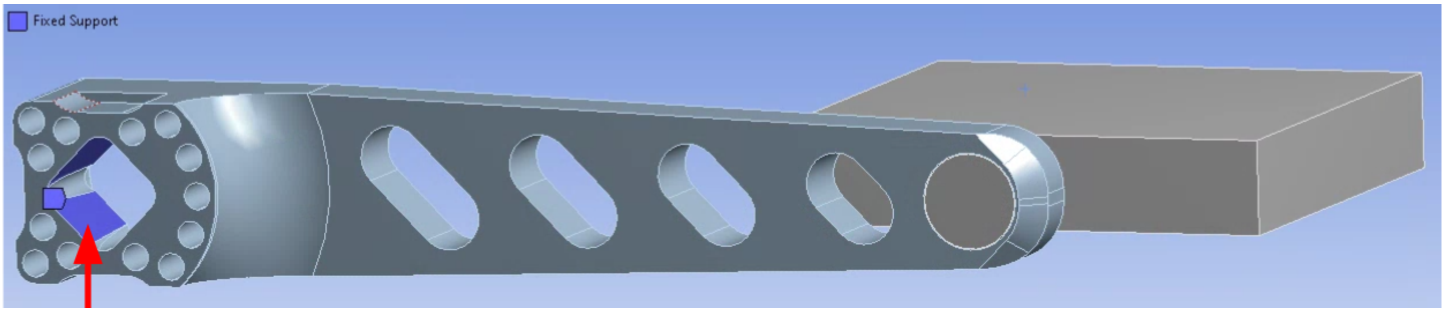


Figure 7*: Image showing the square tapered surfaces confined to a fixed support.*

2. The 125 pound force is dispersed on the pedal. It can be seen in the upper left corner of *Figure 8* that this 125 force is broken down into two components, the transferred force to the drivetrain (124.86 lbs) and the wasted force (5.9462 lbs).

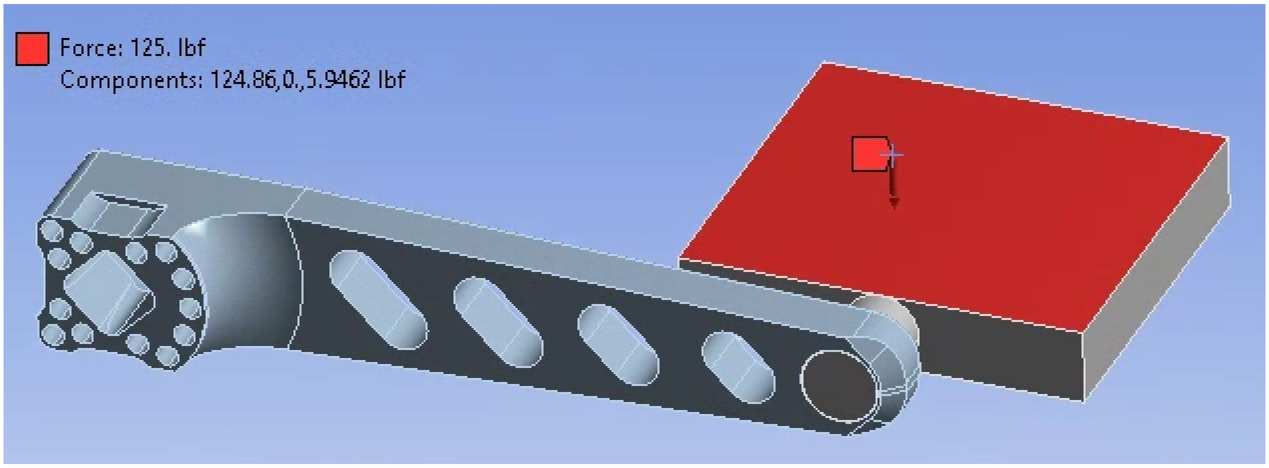


Figure 8*: Force location on the pedal*

Fatigue Analysis

Understanding that fatigue analysis is a difficult topic to discuss briefly, we will not go into too much detail here. However, because the fatigue analysis was done, we are sharing it! The criteria used to determine the approximate number of cycles the cranks can handle before failure is the Modified Goodman criteria. This criteria was chosen since it is easily applicable to our data since the FEA analysis calculates the maximum Von-Mises stress. A few other comments on fatigue analysis:

1. Correction factors were applied in this fatigue analysis.
2. The results in *Table 2*, # of Cycles to Failure, is only an approximation, however, is considering a worse case scenario by assuming that every single time the rider pedals they exert 125lbs of force on the pedal. We know this to not be the case so the actual # of cycles to failure should realistically be greater than the reported number.

Results

Finally… if you’re still reading, let’s take a look at the results! Note that the maximum stress is in units of MegaPascals. The yield stress of AL6061 is ~276 MPa and AL7075 is ~503 MPa. The yield stress is the stress in which if you exceed this stress the material will not go back to its original shape. If a crank arm experiences a stress greater than 503 MPa, it will stay bent.

***Table 2**: Results Table*

Crank Length (mm)	In-Seam (in)	Theta, Θ (Degrees)	F_Transfer (lbs)	F_Wasted (lbs)	Max Stress (MPa)	# Cycles to Failure**
100	21	2.73	124.86	5.95	240	5,500
100	24	2.39	124.89	5.21	239	5,500
100	NA*	0	125	0	236	6,500
100	NA*	0	50	0	94	2,700,000
127.5	21	2.73	124.86	5.95	279	66,000
127.5	NA*	2.73	60	0	131	2,800,000
130	21	2.73	124.86	5.95	283	62,000
130	21	2.73	59.53	2.86	136	2,400,000
147.5	21	2.73	124.86	5.95	262	93,000
147.5	24	2.39	124.89	5.21	261	95,000
147.5	NA*	0	125	0	250	120,000
160	21	2.73	124.86	5.95	263	92,000
160	24	2.39	124.89	5.21	260	97,000
160	NA*	0	125	0	245	133,000

* Note in the case where **Θ** = 0 the length of the in-seam doesn’t matter

** This is the approximate number of cycles to failure if 125 lbs of force was exerted on the pedal every cycle over and over again until failure.

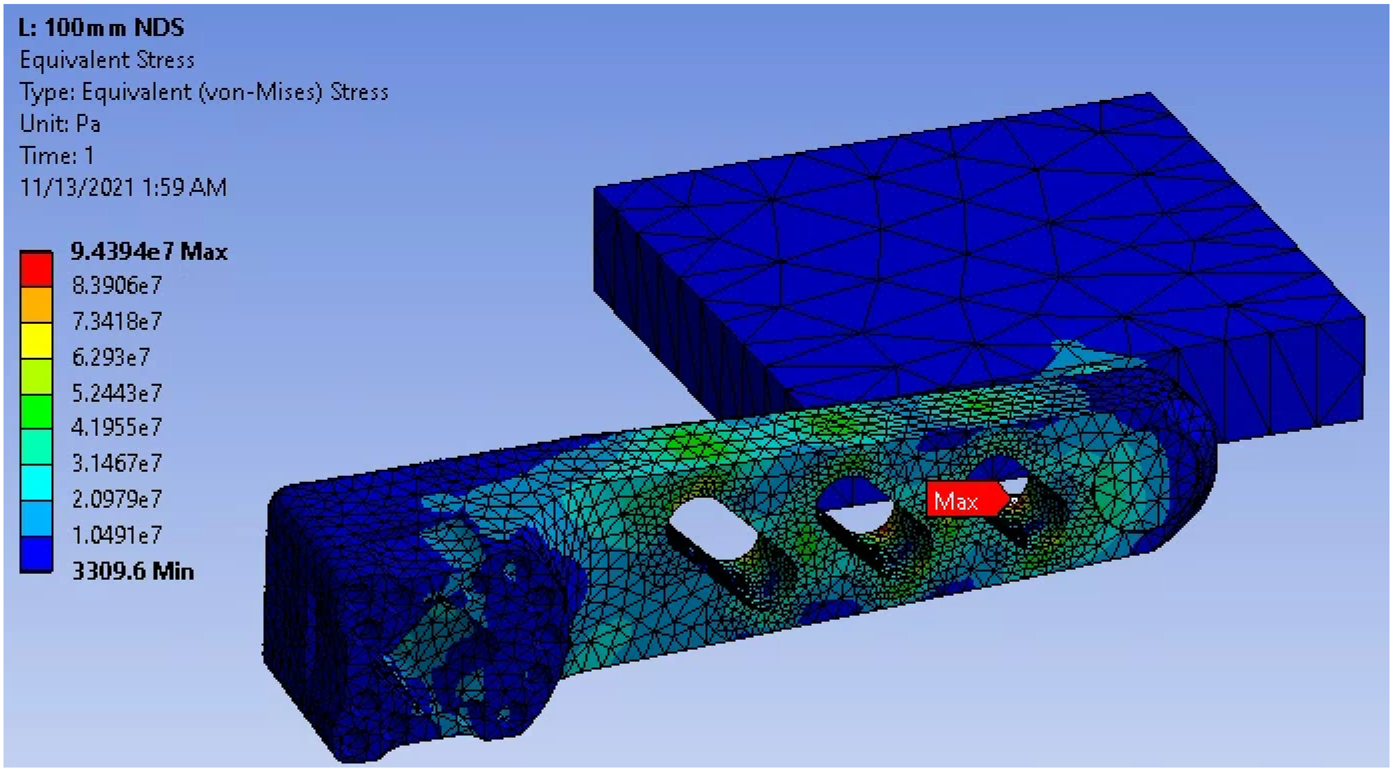
After reviewing these results, it is pretty obvious how much the Q-Factor/Stance width affects the overall longevity of the cranks as the cranks get into some of the longer lengths. The reason for this is because when the angle theta = 0 the crank is in pure bending in only one direction and torsion (torsion is a twisting motion) but when theta is greater than 0 the crank goes into bending in two directions plus in torsion on top of that! This is a general statement for any and all cranks not just Identify BMX cranks so you’re not only going to want to get that Stance width just right for your rider but also for their cranks!!!

Final thoughts

- Reviewing the results in Table 2, the reality of a kid with a 21” in-seam is they are probably a 5 or 6 year old and highly unlikely to be able to generate a force on the pedal any higher than 30, 40... maybe 50 lbs maximum. This is why for some of the smaller cranks sizes some additional results are shown for forces less than 125 lbs to give an idea of how the cranks will actually perform. Since we rate our cranks to 125 lbs we wanted to show results for that rating, no matter the crank length.
- A rider with a 21” in-seam would never be on a set of 160mm cranks, we understand that. All we are doing with these numbers is showing how the in-seam length at a given Q-Factor/Stance width affects the cranks.
- **Don’t be afraid of the slots!!!** Just because the maximum stress is found at the slots, which is expected, it is the value of the maximum stress at the slot that matters. As long as the maximum stress is well below the yield stress, the crank will not fail and as shown in this article this is the case for the Identify BMX cranks!
- Just like any other BMX bike component, our cranks are made of a material that has a well-defined yield stress. If your rider experiences an impact that exceeds the yield stress it is possible irreversible damage can be done.

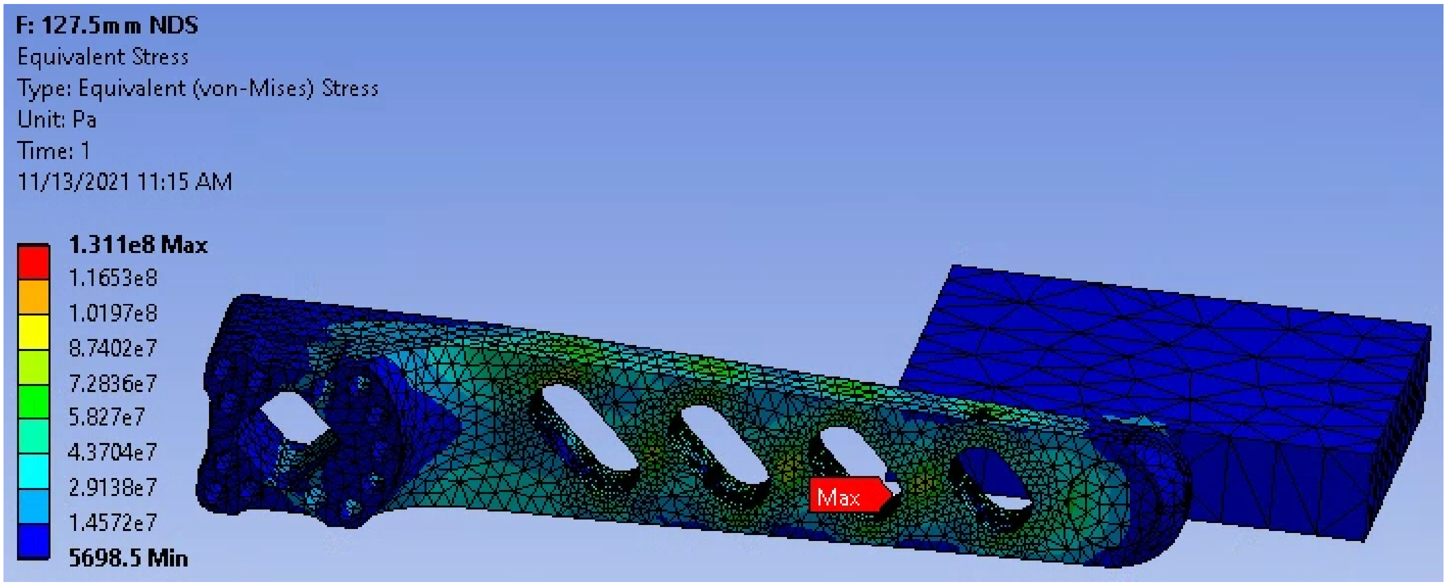
Simulation Images

In all of the images below, the color bar on the left side of the image is showing the stress level in the crank. It is color coded to easily see in the crank how the stresses are distributed throughout it. This bar is showing the stresses in Pascals to convert it to MegaPascals it must be divided by 1,000,000. For example, if the max stress is found to be 9.4394e7, this is in scientific notation so what it really means is to move the decimal over to the right 7 times so 94,394,000 Pascals. To get to MegaPascals divide this number by 1,000,000 to get 94.394 MPa. It is interesting to note that as the cranks get longer the maximum stress moves incrementally from the outermost slot on the 100mm cranks eventually to the innermost slot on the 160mm. Trends like this are nice to find in Engineering data because it allows the Engineer to design around these trends to get the most out of their design!



L: 100mm NDS
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
11/13/2021 1:59 AM

100mm Crank with 50 lbs and theta = 0. The maximum stress is found to occur in the outermost slot.



F: 127.5mm NDS
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
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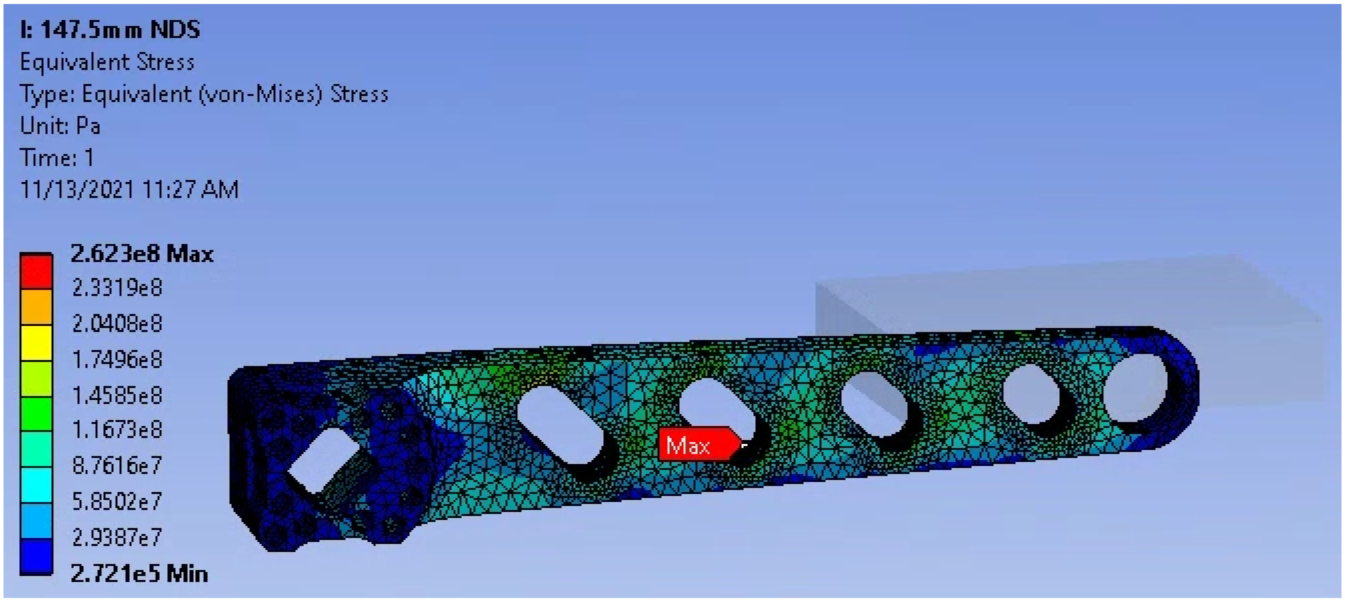
127.5mm Crank at 60 lbs and theta = 0 degrees. The maximum stress is found to occur in the third slot.



I: 147.5mm NDS
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
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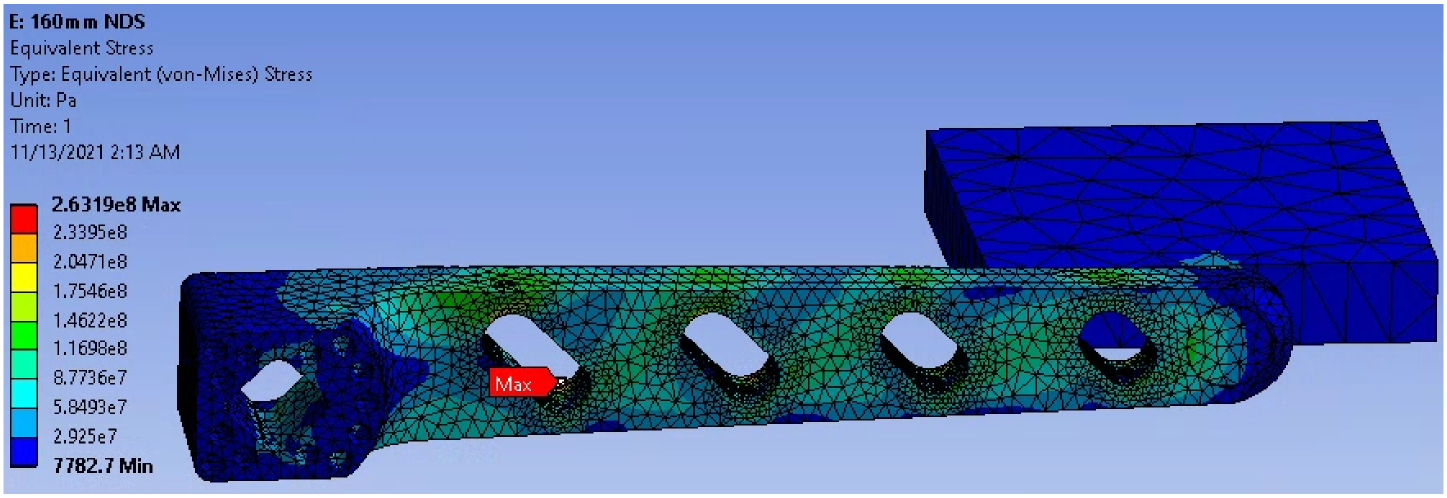
147.5mm Carnk with in-seam = 21” at 125 lbs and theta = 2.73 degrees. The maximum stress is found to occur in the second slot



E: 160mm NDS
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
11/13/2021 2:13 AM

160mm Crank with in-seam = 21” at 125 lbs and theta = 2.73 degrees. The maximum stress is found to occur in the first slot.

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