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The Bike Frame Design and Manufacturing

Introduction

Have you ever ridden a bike that just didn't quite fit you right? Maybe it was too big or too small for your body size, perhaps it was wildly uncomfortable, or you might have simply wanted a high performance bike. Many frame builders have had these problems so they decide to take matters into their own hands and engineer their own custom bike frame. For this project, we became frame builders; we wanted to design a bike frame that was perfectly designed to achieve a balance between comfort and performance. We researched about all of the different bike tube lengths and angles that influence these factors and to create a bike that was perfectly fitted for our body sizes. Additionally, we chose to create a hybrid style bike as we wanted to create a bike that was versatile (ridden on a wide variety of terrains). Hybrid bikes were the perfect choice as they are essentially a combination between road bikes which are designed for racing on smooth surfaces and mountain bikes which are designed for rocky terrain riding. This document will walk you through all the decisions we made for our bike frame geometry, how we made those decisions, the SolidWorks model, the manufacturing process, and the fully welded chromoly steel frame.

Design Measurements

The table below shows the measurements used in designing the geometry of the frame for the hybrid bicycle design project. The measurements in the table are the final values we chose and reflect the CAD model. These measurements were determined based on research from online bicycle articles, measurements from a hybrid bicycle that was borrowed, and measurements from a mountain bike available at home.

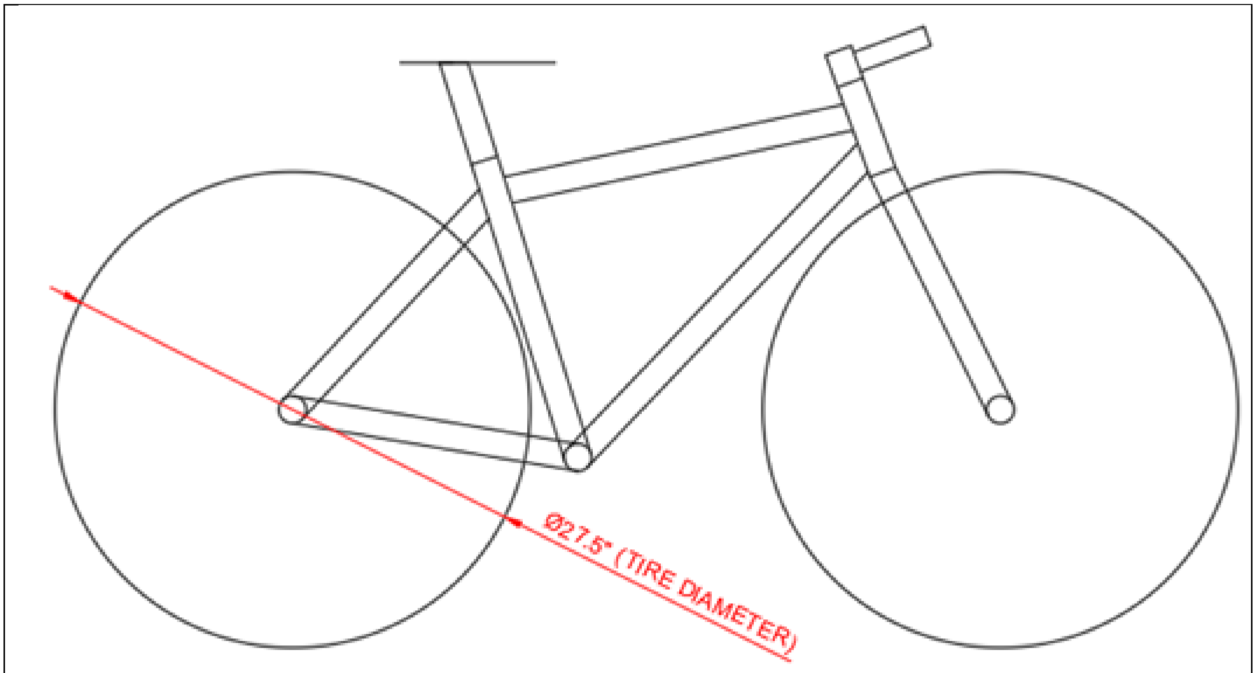
Measurements for the preliminary design of the hybrid bicycle	
Characteristics	**Measurements**
Tire Diameter	27.5 in
Crank Arm Length	172.5 mm
Stack	540 mm
Reach	400 mm
Standover Height	725 mm
Seat Tube Length (C-T)	18 in
Seat Tube Angle	73 deg
Head Tube Length	121 mm
Trail	80 mm
Wheelbase	1041 mm
Head Tube Angle	70 deg

Fork Offset	44 mm
Chain Stay Length	425 mm
Bottom Bracket Drop	70 mm
Down Tube Length	630 mm
Stay Stay Length	435 mm
Top Tube Length	552 mm
Effective Top Tube Length	573 mm
Fork Length (A-C)	398 mm
Rear Wheel Hub Length	135 mm

Measurements that Impact Ergonomics

Tire Diameter

The tire diameter is the distance from one side to the opposite side of the tire through its centre as shown below.



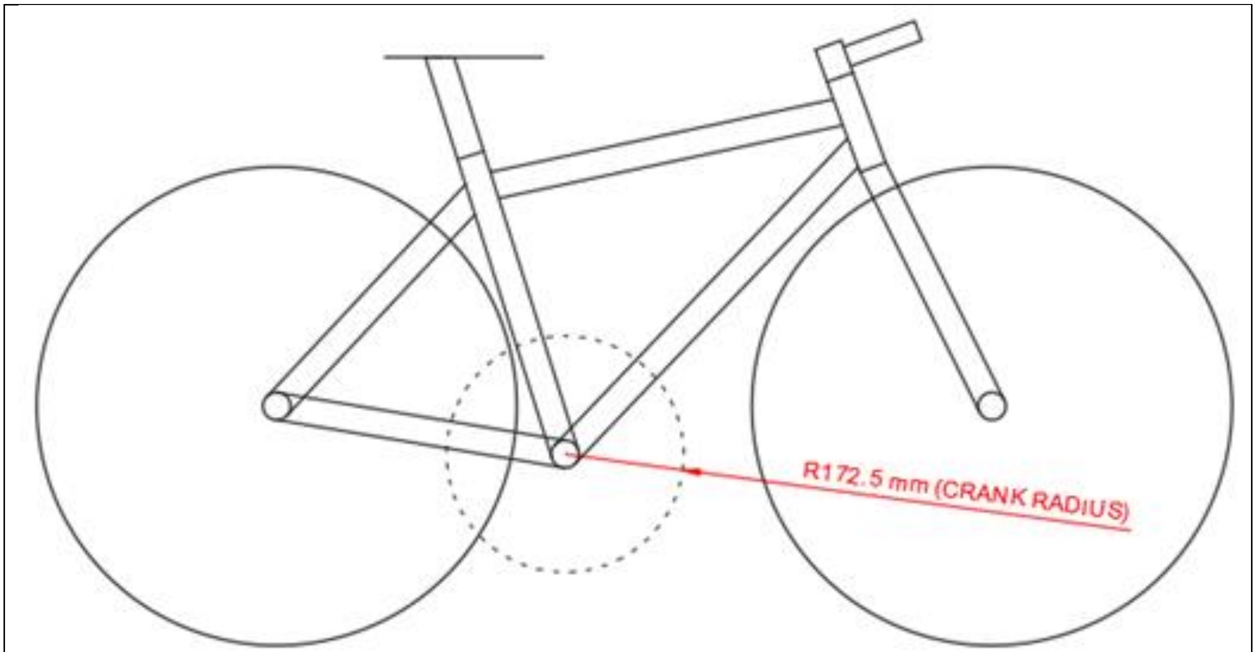
Tire diameter measurement of 27.5" for the hybrid bicycle design

The tire diameter is an important measurement to establish at the beginning of the design since the bicycle frame needs to accommodate for the size of the wheels. Important measurements like the chain stay length, the fork offset, and standover height are a few examples that would be influenced by the tire diameter.

Tire diameters can range anywhere from 16 inches (commonly found on children's bikes) to 36 inches (usually found on custom built frames for very tall riders) [1]. For this bicycle design, a tire diameter of 27.5 inches was chosen as this was the same tire diameter as the borrowed hybrid bike, which had a comfortable fit for our given sizes. Based on this information, we determined that it would be feasible to design a bicycle frame with comfortable geometry using this tire size.

Crank Arm Length

The crank arm length is the distance from the crank arm's rotational axis to foot pedal axis as shown below.

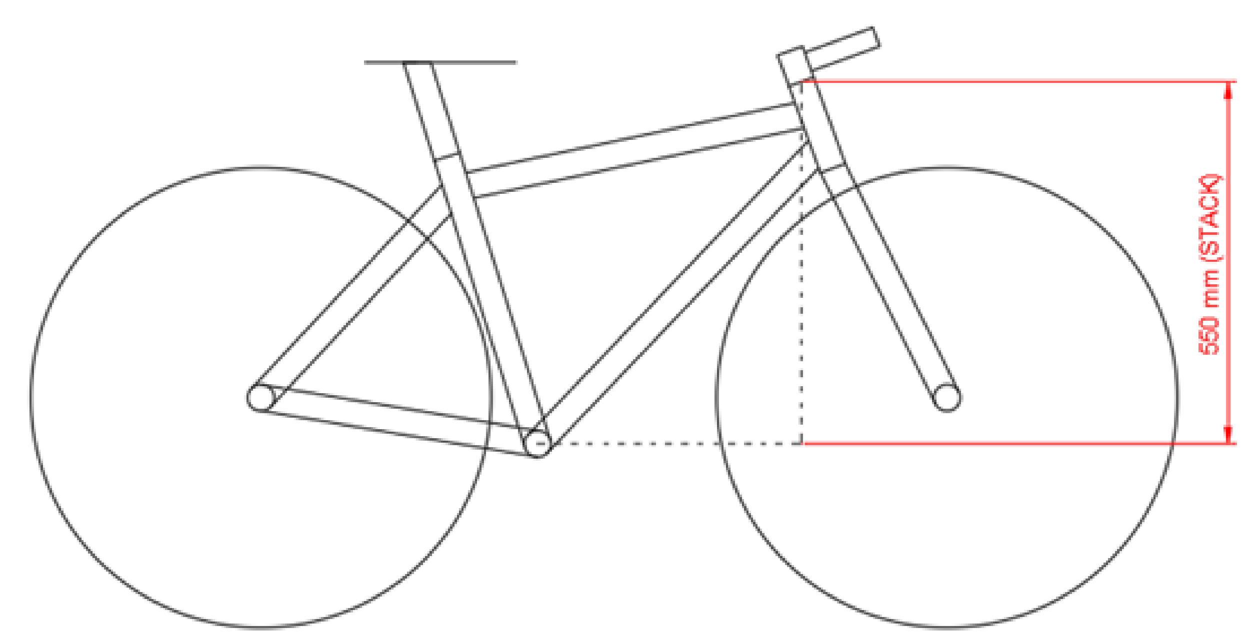


Crank arm length of 172.5 mm for the hybrid bicycle design

The majority of crank arm lengths are between 170-175 mm but can also range from 165-180 mm depending on the rider's preference. Like the tire diameter, the crank arm length is also important to know because it can influence other frame geometry measurements such as the bottom bracket drop [2]. Additionally, crank arm length influences the range of motion at the hip, knee, and ankle joints which determines the comfort of the rider; choosing an inappropriate crank arm length can cause injury. The crank arm length chosen for the bicycle design was 172.5 mm based on a sizing chart by using 5'10" as the average height for the both of us [3].

Stack and Reach

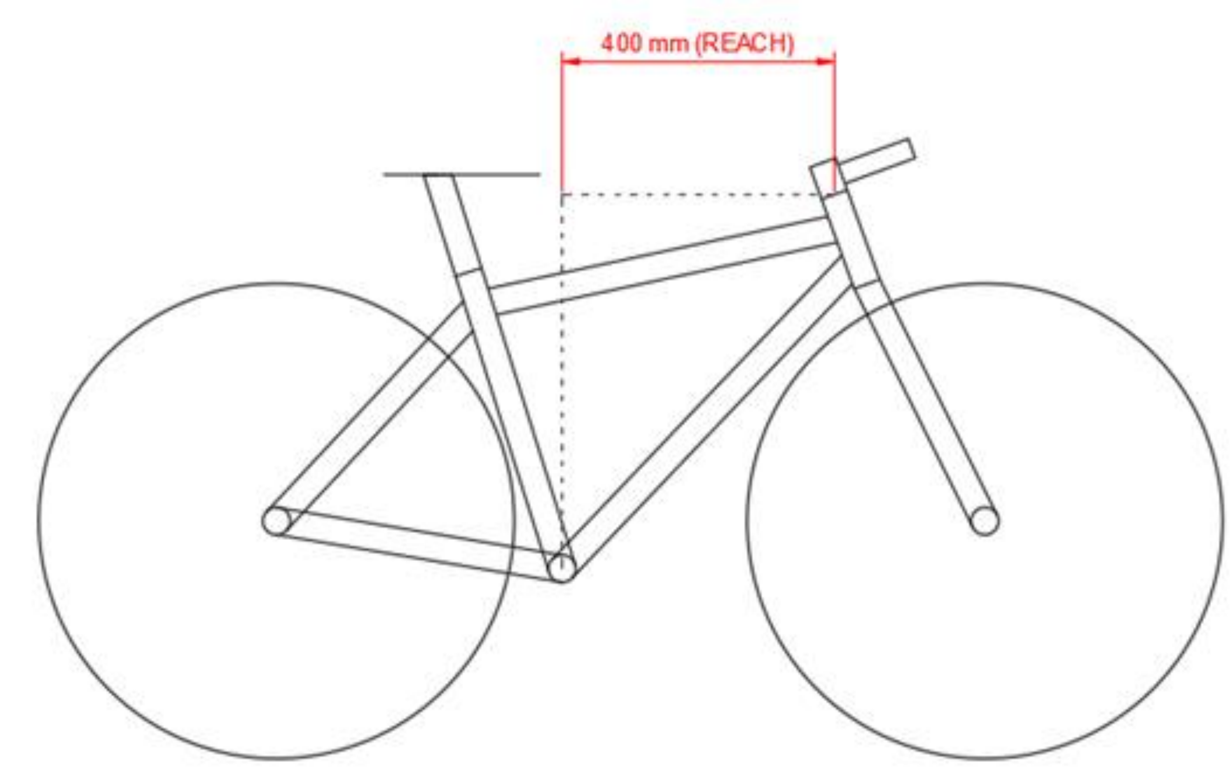
The stack is the vertical distance from the centre of the bottom bracket to the top of the head tube's centreline as shown below.



Stack measurement of 550 mm for the hybrid bicycle design

Update: This stack measurement has since been changed to a length of 540 mm. This was because the fork we ended up purchasing would move the head tube up for it to fit which caused the head tube to look too tall. Changing the stack to 540 mm solved this problem.

The reach is the horizontal distance from the centre of the bottom bracket to the top of the head tube's centreline as show below.



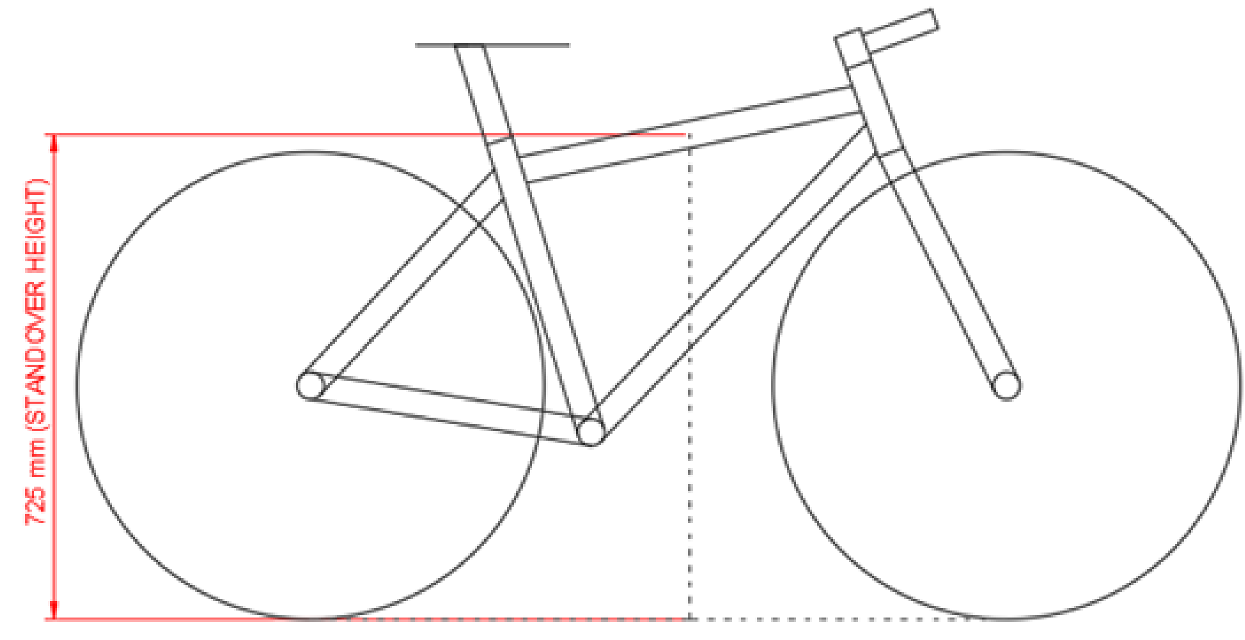
Reach measurement of 400 mm for the hybrid bicycle design

The bigger the stack is on a bicycle (with constant reach), the more relaxed and upright the rider will be in the seated position. It's common for bicycles that are designed to be comfortable for extended periods of time to have a larger stack relative to reach. On the flip side, the bigger the reach is on a bicycle (with constant stack), the more stretched and aerodynamic the rider will be in the seated position. It's common for bicycles that are designed for racing to have a larger reach relative to stack [4].

The stack and reach measurement for the hybrid bicycle were chosen to be 550 (since updated to 540 mm) and 400 mm, respectively. This was determined observing how comfortable sitting in the borrowed hybrid bicycle felt and then using its stack and reach numbers to choose measurements that we felt would accommodate the both of us while prioritizing comfort over aerodynamic performance. The stack recorded on the borrowed bicycle was about 530 mm and the reach was about 380 mm.

Standover Height

The standover height is the vertical distance from the ground to the midpoint of the top tube as shown below.

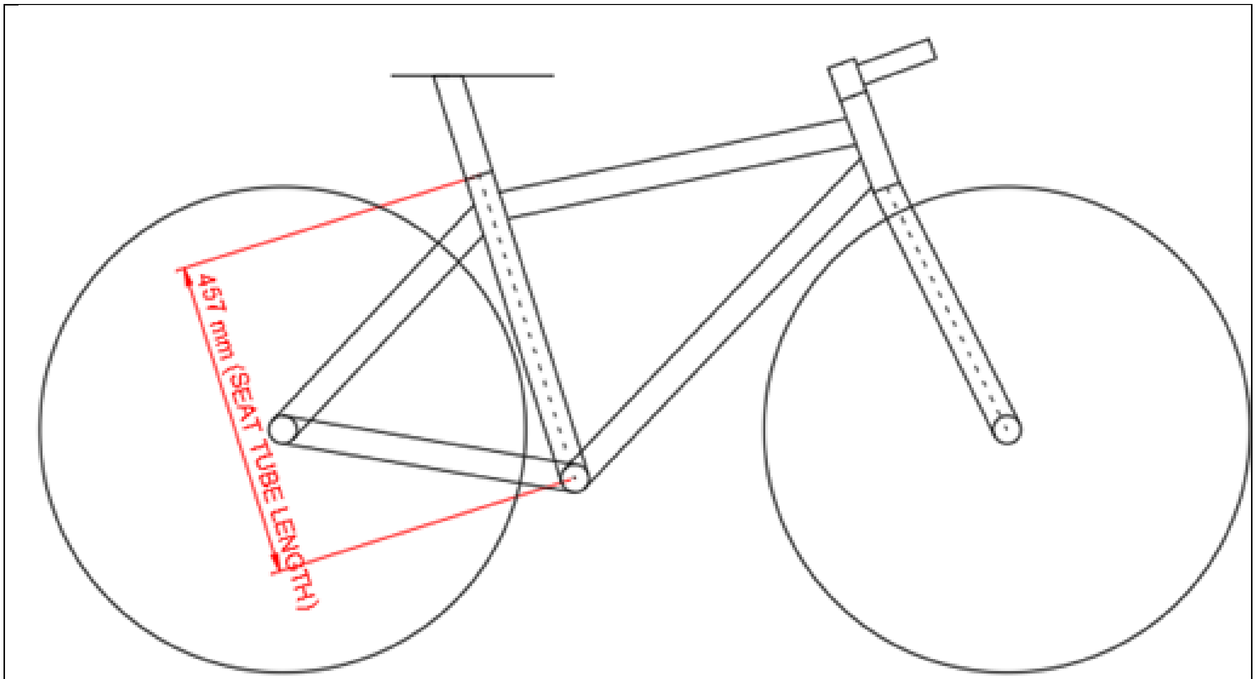


Standover height measurement of 725 mm for the hybrid bicycle design

Ideally, the standover height should be low enough to allow for some clearance for a rider to easily hop on and off their bike [5]. With this idea in mind, the standover height for the bicycle design was chosen to be 725 mm based on the shortest inseam length within the group, which was 750 mm.

Seat Tube Length (C-T)

The seat tube length from centre-to-top (C-T) is the distance from the centre of the bottom bracket to the top of the seat tube along its centreline as shown below.

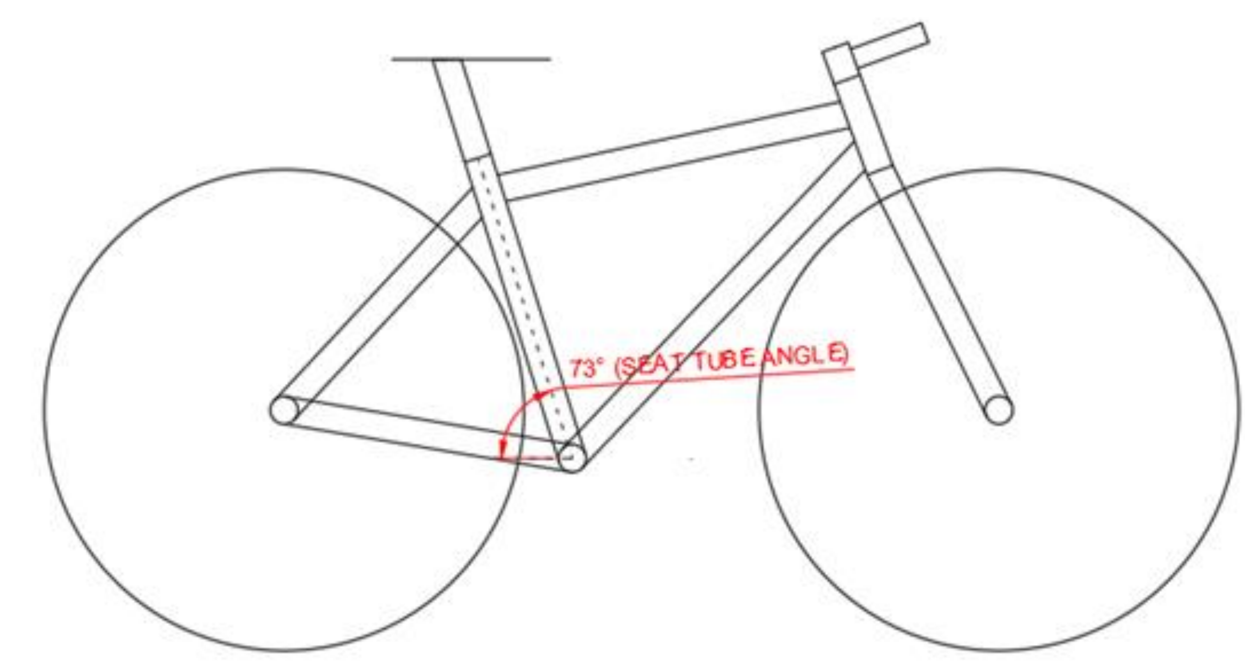


Seat tube length (C-T) of 457mm for the hybrid bicycle design

This measurement is often used by bicycle manufacturers as the standard for determining the labelled size of a bike. The seat tube length also dictates the lowest position the saddle can be set to [6]. A seat tube length of about 18 inches was chosen based on a hybrid bike sizing chart to accommodate both of our heights [7].

Seat Tube Angle

The seat tube angle is the acute angle measured from an imaginary horizontal line and the centreline of the seat tube as shown below.

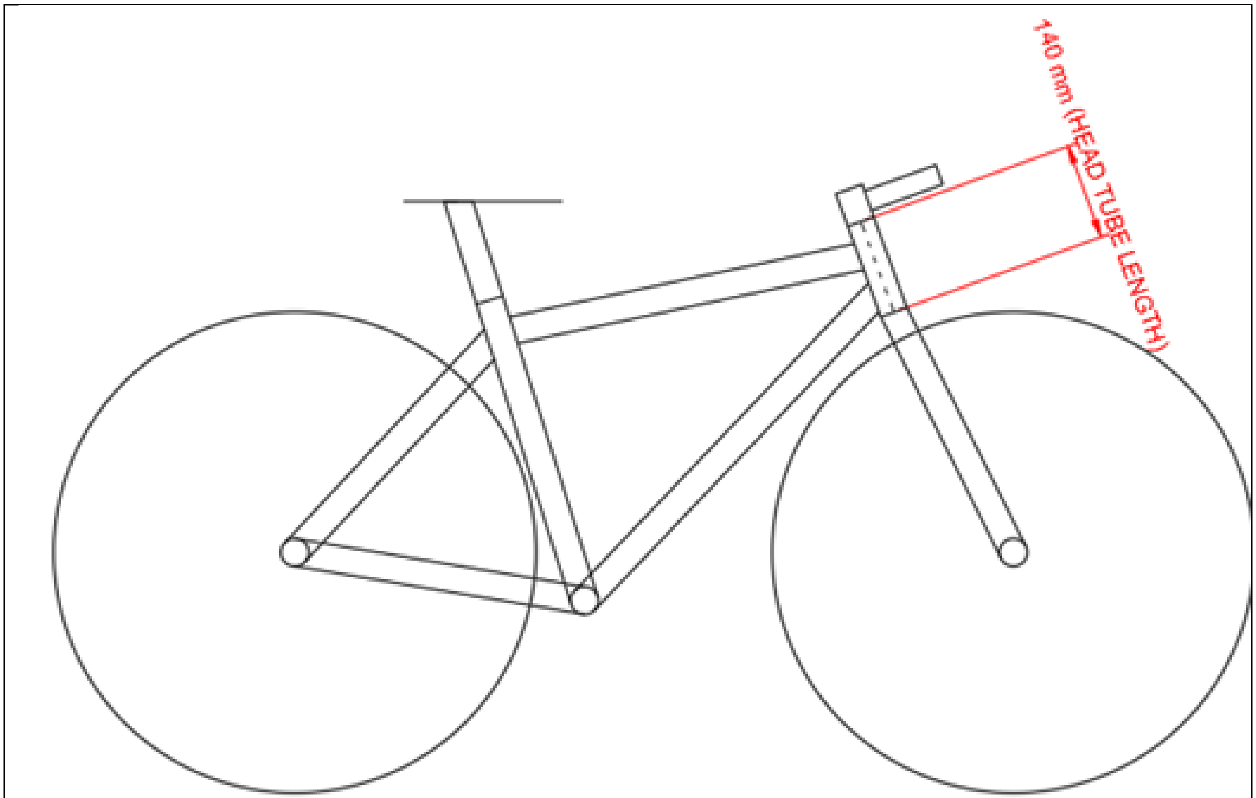


Seat tube angle measurement of 73 degrees for the hybrid bicycle design

Typically, seat tube angles range from about 70-75 degrees [8]. Seat tube angles do not vary much across different types of bikes since the position for optimal peddling efficiency isn't too different. A steep seat tube angle uses more glutes and hamstrings to pedal, whereas a slack seat tube angle uses more quadriceps to pedal. Choosing an angle in the middle of this range would allow the rider to use all these muscle groups and make it easier to pedal, therefore, a seat tube angle of 73 degrees was chosen.

Head Tube Length

The head tube length is the distance from the bottom to the top of the head tube along its centreline as shown below.



Head tube length measurement of 140 mm for the hybrid bicycle design

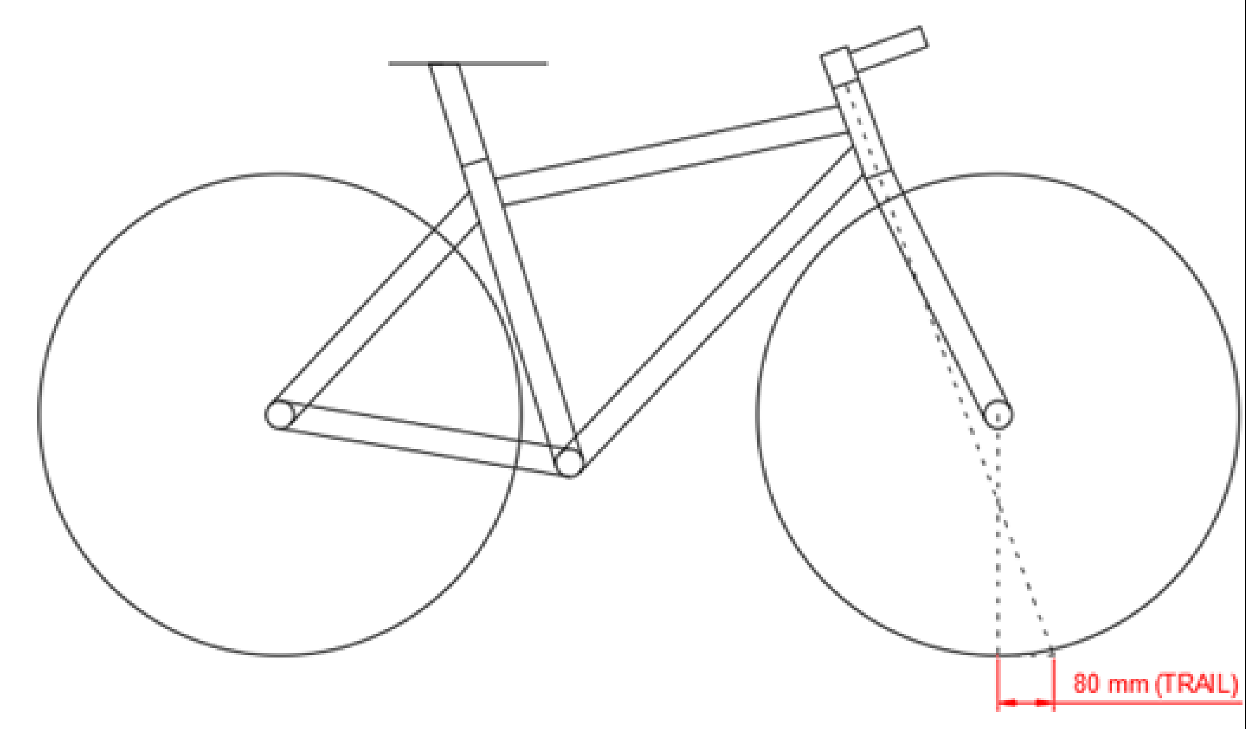
A taller head tube length would provide more comfort for the rider, whereas a lower head tube will improve the rider's aerodynamics by reducing their frontal profile [9]. Since the bicycle design will prioritize comfort, a head tube length of 140 mm was chosen as this seemed adequate to keep the rider in an upright position based on the geometry of the bike in the conceptual design.

Update: Once we reached the stage of finding components to fit onto our bike, we realized that choosing a head tube length does not make sense (it should not be an independent variable). This is because the length of your head tube will influence the forks that can fit on your bike. Depending on where the bottom of your head tube is located from the ground, then the axle-to-crown fork length of whatever fork you use might be too long or too short which would cause your bike to be dipped forwards or backwards. For this reason, the final design makes the axle-to-crown fork length an independent variable and the head tube length a dependent variable instead. The new head tube length is measured at 121 mm.

Measurements that Impact Performance

Trail

The trail is the horizontal distance between the head tube's centreline and the front tire contact patch as shown below.



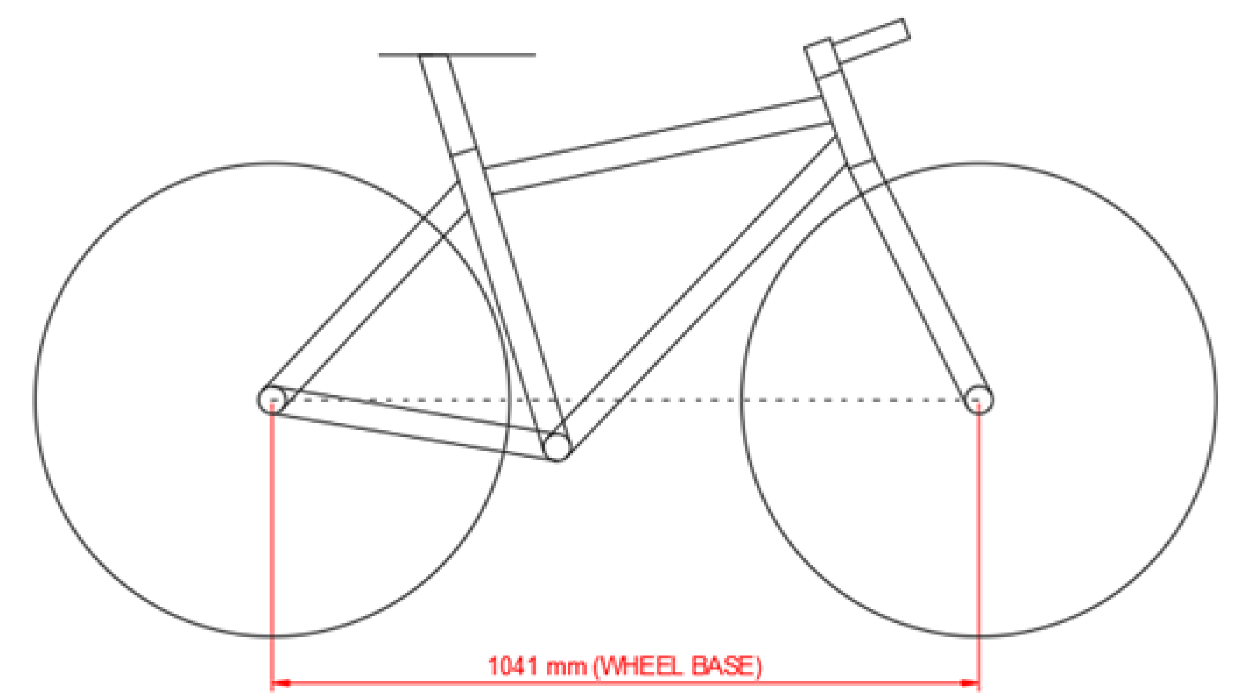
Trail measurement of 80 mm for the hybrid bicycle design

Trail is a combination of the head tube angle and fork offset. It is used as an indicator for how a bike will handle. A smaller trail would make a bike nimbler and faster to steer, whereas a bigger trail would make the bicycle more stable and slower to steer [8].

Road bicycles, which are designed to have fast steering typically have a small fork trail of 50-60 mm [10]; the trail on the borrowed hybrid bicycle was approximately 80 mm; and the trail on a mountain bike at home had a trail just over 100 mm. Using this information, it was assumed that most hybrid bicycles have a trail close to 80 mm to strike a balance for the handling performance of road and mountain bicycles. Therefore, the hybrid bicycle design aimed to have a trail of 80 mm.

Wheelbase

The wheelbase is the horizontal distance between the centre of the front and back wheel axles as shown below.

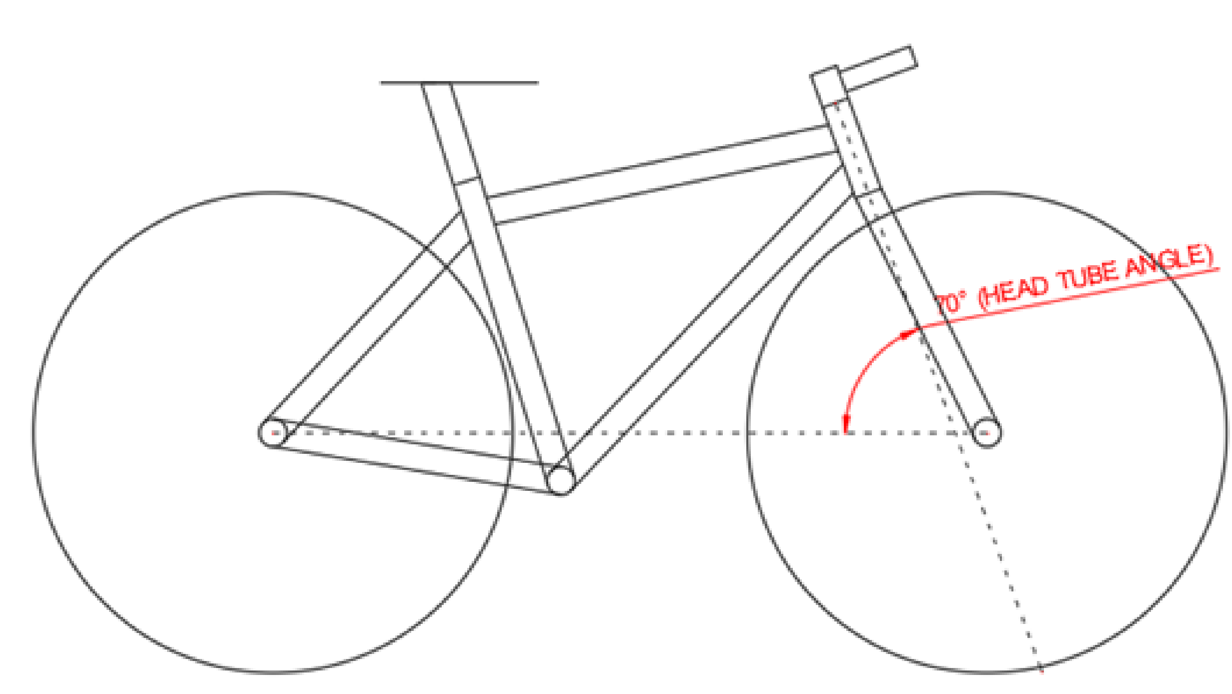


Wheelbase measurement of 1041 mm for the hybrid bicycle design

Road bikes typically can have a wheelbase of around 996 mm [10] and the wheelbase of a mountain bike measured at home was about 1110 mm. For the bicycle design, we aimed to have a wheelbase close to the middle of this range (1053 mm) to ensure moderate stability. Once the fork offset, head angle, and chainstay lengths had been determined, the wheelbase length was measured to be 1041 mm, which was determined to be close enough to the middle value to achieve the performance desired. The wheelbase is a combination of the fork offset, head angle, and chainstay length. This measurement determines the stability of a bike. The longer the wheelbase is, the less the distribution of the rider's weight is affected by braking or bumpy terrain which allows for a more stable, comfortable ride and vice versa [11].

Head Tube Angle

The head tube angle is the acute angle measured from an imaginary horizontal line to the centreline of the head tube as shown below.

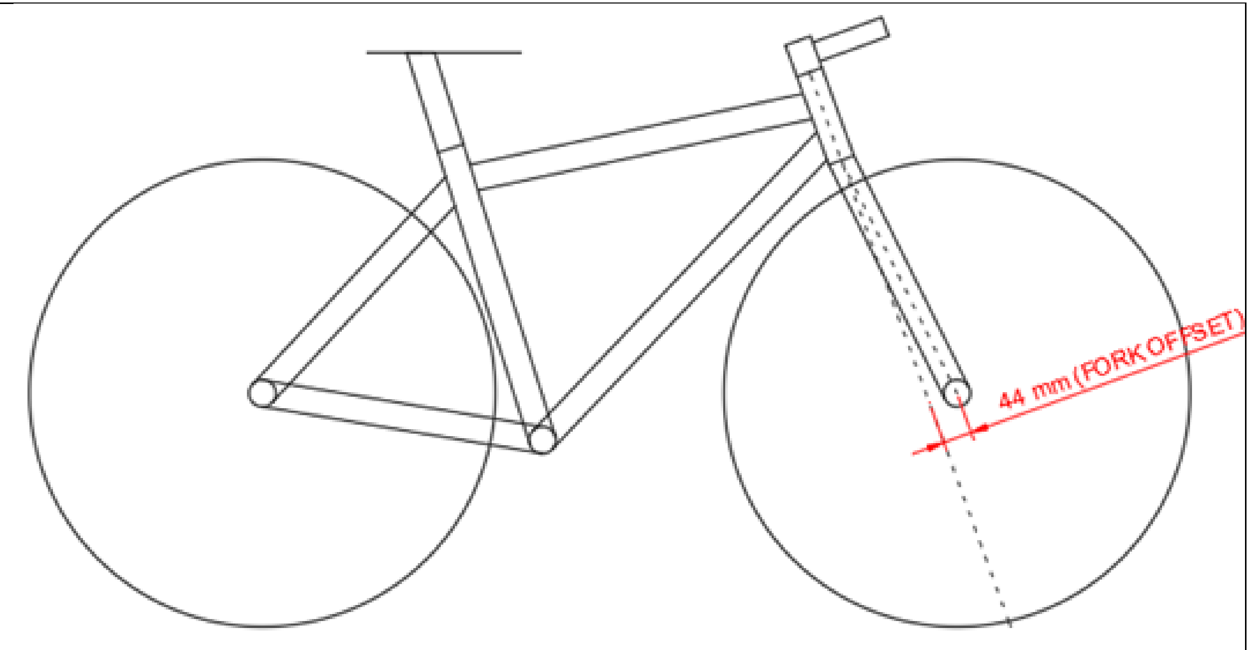


Head tube angle measurement of 70 degrees for the hybrid bicycle design

Head tube angles usually range anywhere from 66 degrees for mountain bikes to 74 degrees for road bikes. A slack head tube angle requires more effort to steer (slower steering) and a steep head tube angle requires less effort to steer (faster steering) [8]. Since hybrid bicycles combine the stability of mountain bikes and the sharp steering of road bikes; and the objective of the project is to design a bicycle with versatility in mind, a head tube angle of 70 degrees was chosen by taking the middle value in this range.

Fork Offset

The fork offset (or rake) is the perpendicular distance between the centreline of the head tube and the centre of the front wheel hub as shown below.



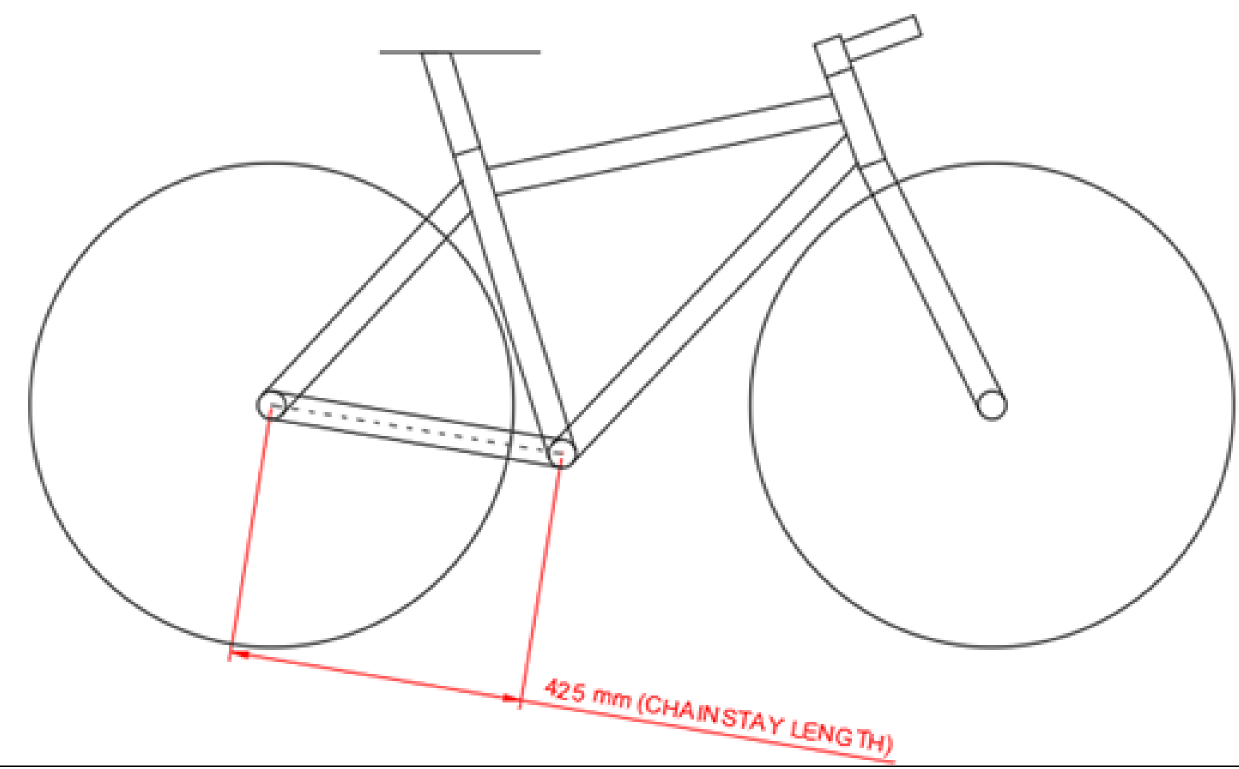
Fork offset measurement of 44 mm for the hybrid bicycle design

Fork offset values usually range from 44-46 mm for mountain bikes [12] and 40-45 mm for road bikes [10]. A higher fork offset would make the bike steer faster, whereas a lower fork offset would make the bike steer slower. The fork offset value was manipulated until a trail of approximately 80 mm was achieved. This resulted in a fork offset of 44 mm which was approved since it was within the range for typical fork offset measurements for mountain and road bikes.

Update: We have since realized that choosing your own fork offset doesn't make sense unless you're making your own fork. Otherwise, it makes more sense to find a fork first that is within the range of offsets you want and then go with that. In our case, we were lucky enough to find a fork that matches the fork offset we desired so that still remains at 44 mm.

Chain Stay Length

The chain stay length is the distance from the centre of the bottom bracket to the centre of the rear wheel axle as shown below.

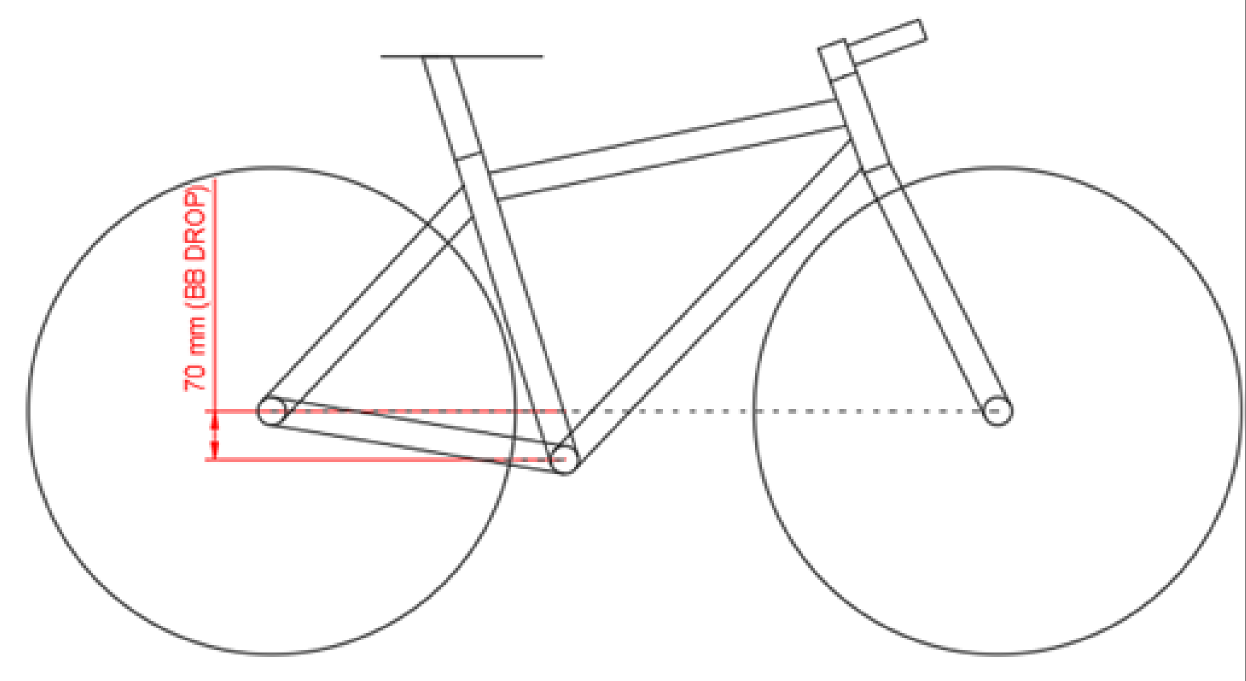


Chain stay length measurement of 425 mm for the hybrid bicycle design

Chain stay lengths normally range from 405-415 mm for road bikes [13] and 430-450 mm for mountain bikes [14]. Like head tube angle and fork offset, the chain stay length affects the handling of a bike. A shorter chain stay reduces the turning radius for quicker handling and a larger chain stay length would increase the handling stability of the bike [15]. A chain stay length of 425 mm was ultimately chosen by taking the middle value of the two ranges. It was also determined that the chain stay length would be long enough to allow for clearance between the seat tube and the rear wheel.

Bottom Bracket Drop

The bottom bracket drop is the vertical distance from the centre of the bottom bracket to an imaginary horizontal line between the front and rear wheel axles below.



Bottom bracket drop of 70 mm for the hybrid bicycle design

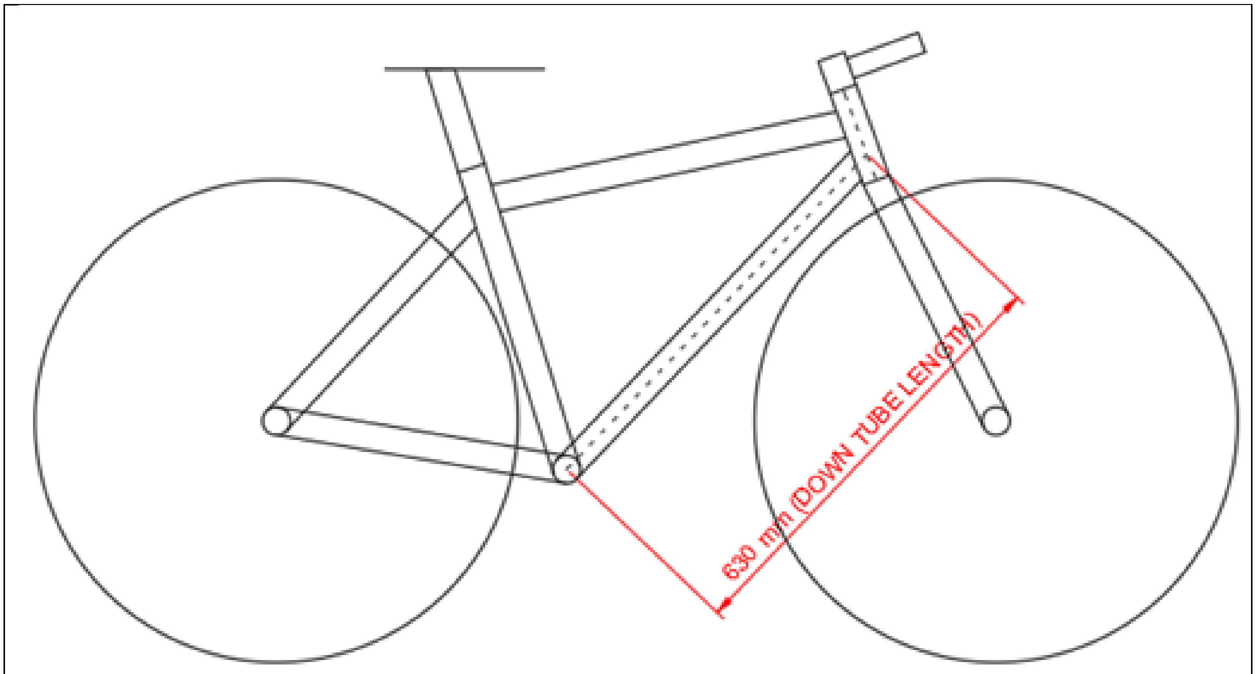
Most bicycles have a bottom bracket drop ranging from 60-80 mm depending on its purpose. This measurement determines how low the centre of gravity of the bike is. A larger bottom bracket drop lowers the centre of gravity, increasing the stability of the bicycle and vice versa. Typically, the lower the bottom bracket is, the better, but this needs to be balanced with the pedal clearance when the bike corners [2]. As a result, the bottom bracket drop of the hybrid bicycle's design was chosen to be 70 mm by taking the middle value of the range to provide adequate stability and pedal clearance when cornering.

Other Measurements

The measurements included in this section are all dependent variables as they are not necessary in fully defining the design. Additionally, they are not used as determining factors for the comfort or performance of the bike. However, the measurements are included in this report as supplemental information. The only exception in this section is the rear wheel hub width.

Down Tube Length

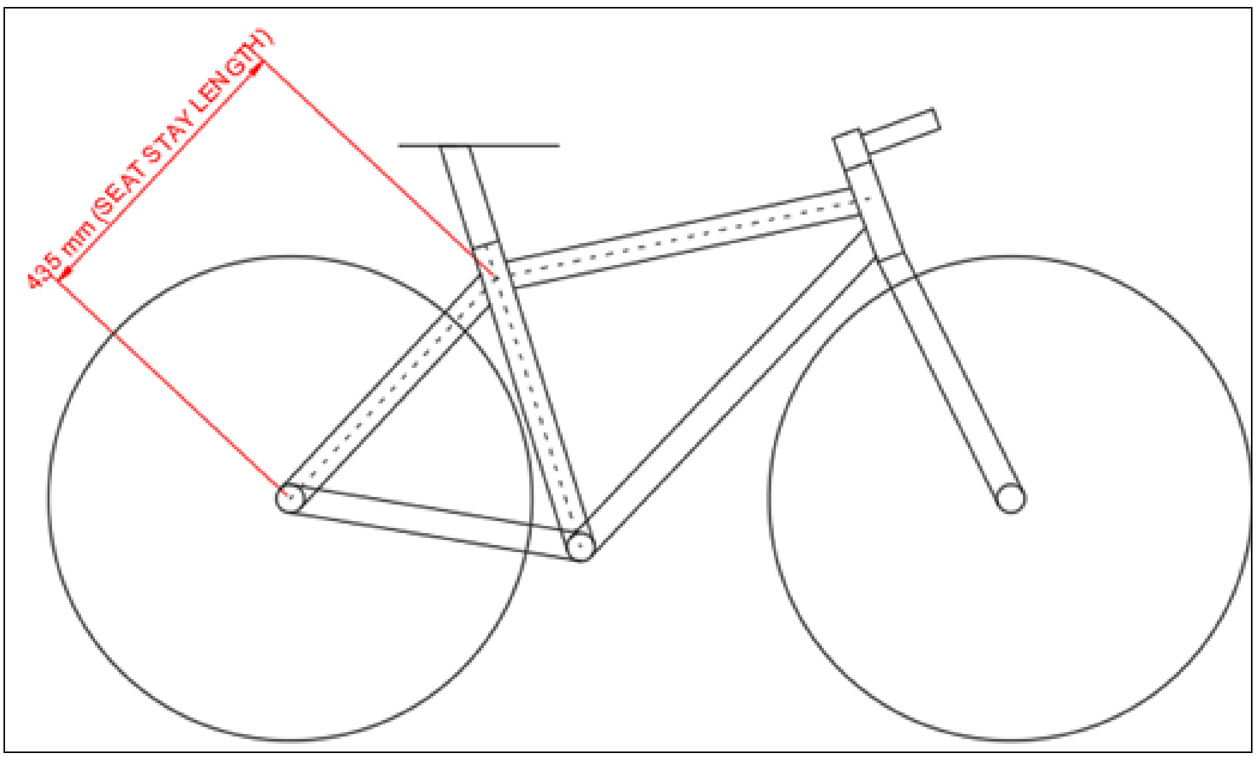
The down tube length is the distance from the centre of the bottom bracket to the intersection of the down tube and head tube centrelines as shown below.



Down tube length measurement of 630 mm for the hybrid bicycle design

Seat Stay Length

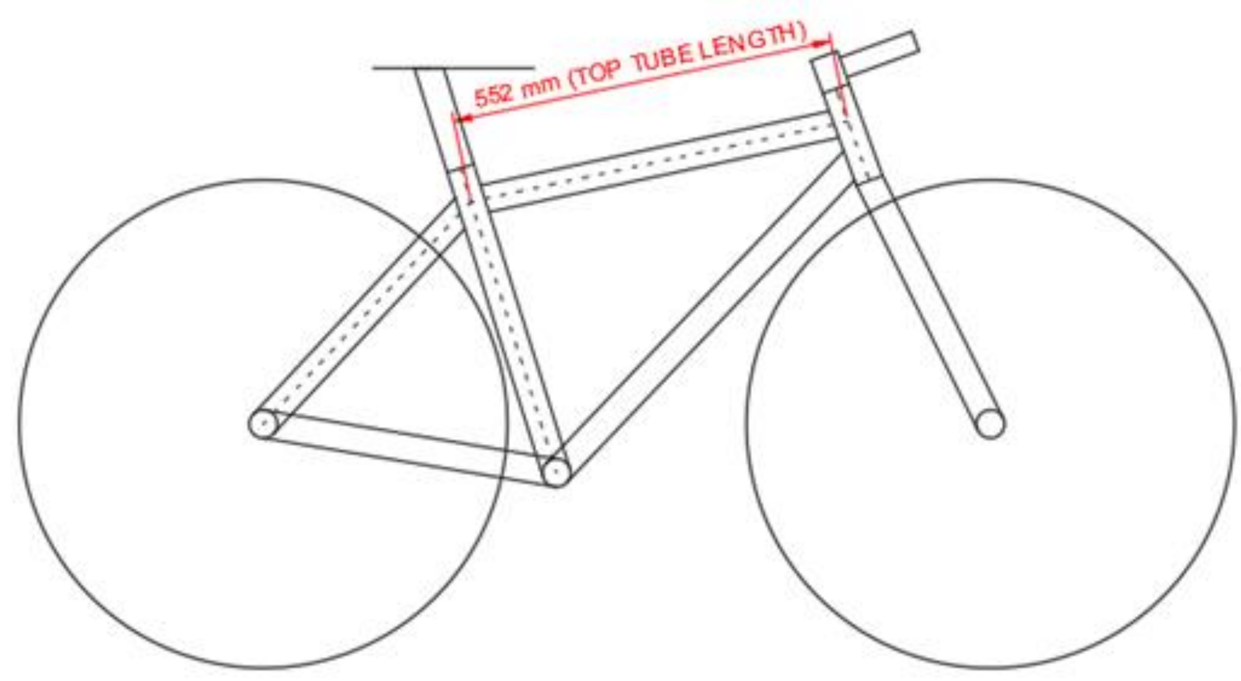
The seat stay length is the distance from the rear wheel axle to the intersection of the seat stay, top tube, and seat tube centrelines as shown below.



Seat stay length measurement of 435 mm for the hybrid bicycle design

Top Tube Length

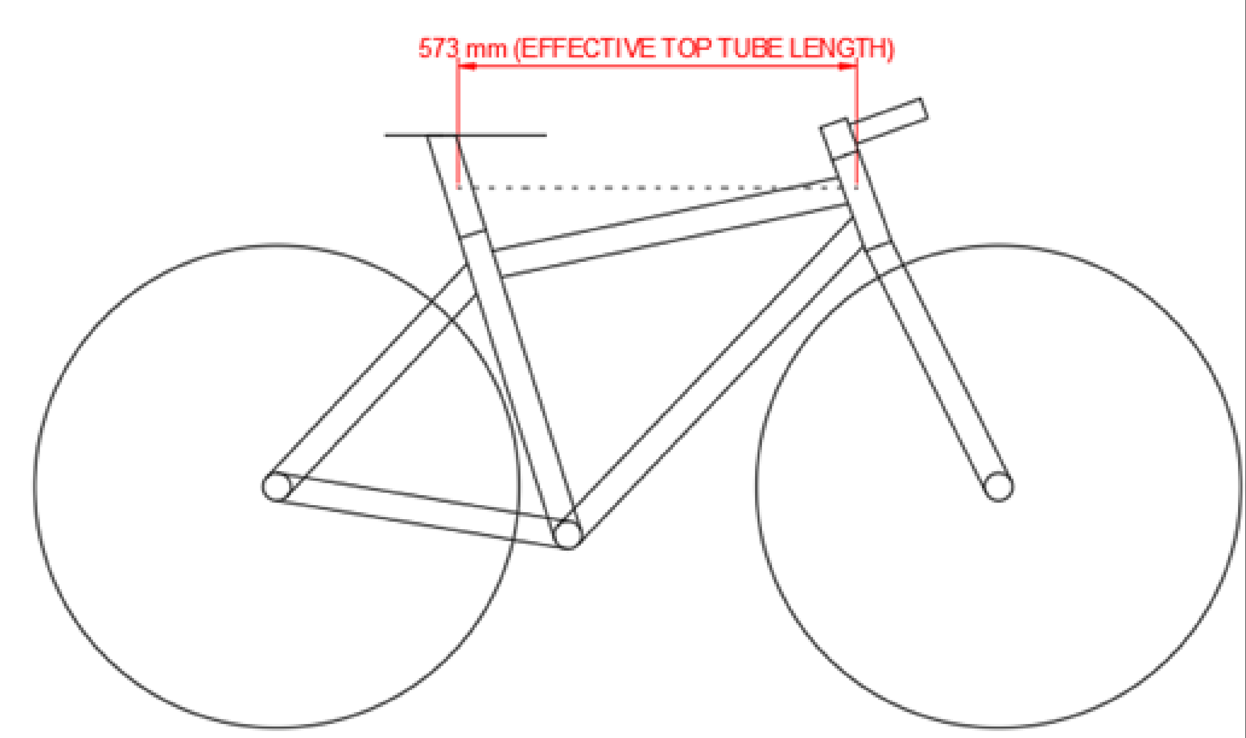
The top tube length is the distance from the intersection of the seat stay, top tube, and seat tube centrelines to the intersection of the top tube and head tube centrelines as shown below.



Top tube length measurement of 552 mm for the hybrid bicycle design

Effective Top Tube Length

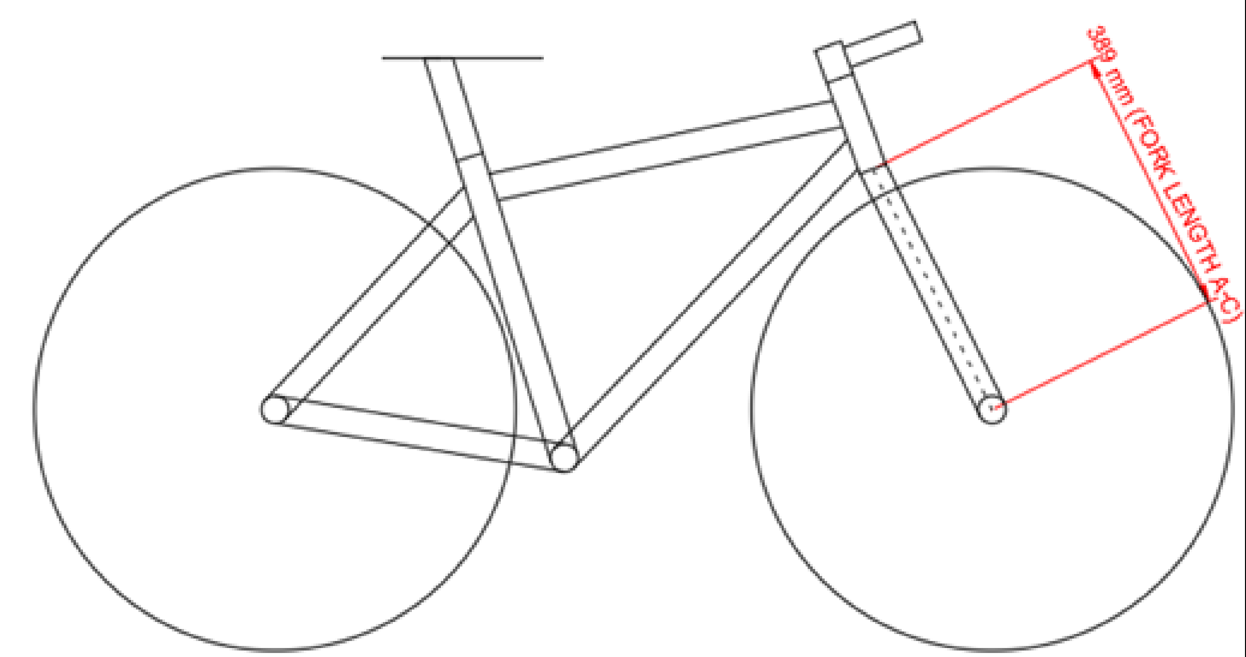
The effective top tube length is the horizontal distance from the intersection of the top tube and head tube centrelines to the centreline of the seat tube as shown below.



Effective top tube length measurement of 573 mm for the hybrid bicycle design

Fork Length (A-C)

The fork length from axle-to-crown (A-C) is the distance from the fork crown to the front axle as shown below.



Fork length (A-C) measurement of 389 mm for the hybrid bicycle design

Update: It makes more sense to make this an independent variable and the head tube length a dependent variable instead. Especially if you are buying an off the shelf fork and not designing your own.

The Rear Wheel Hub Width

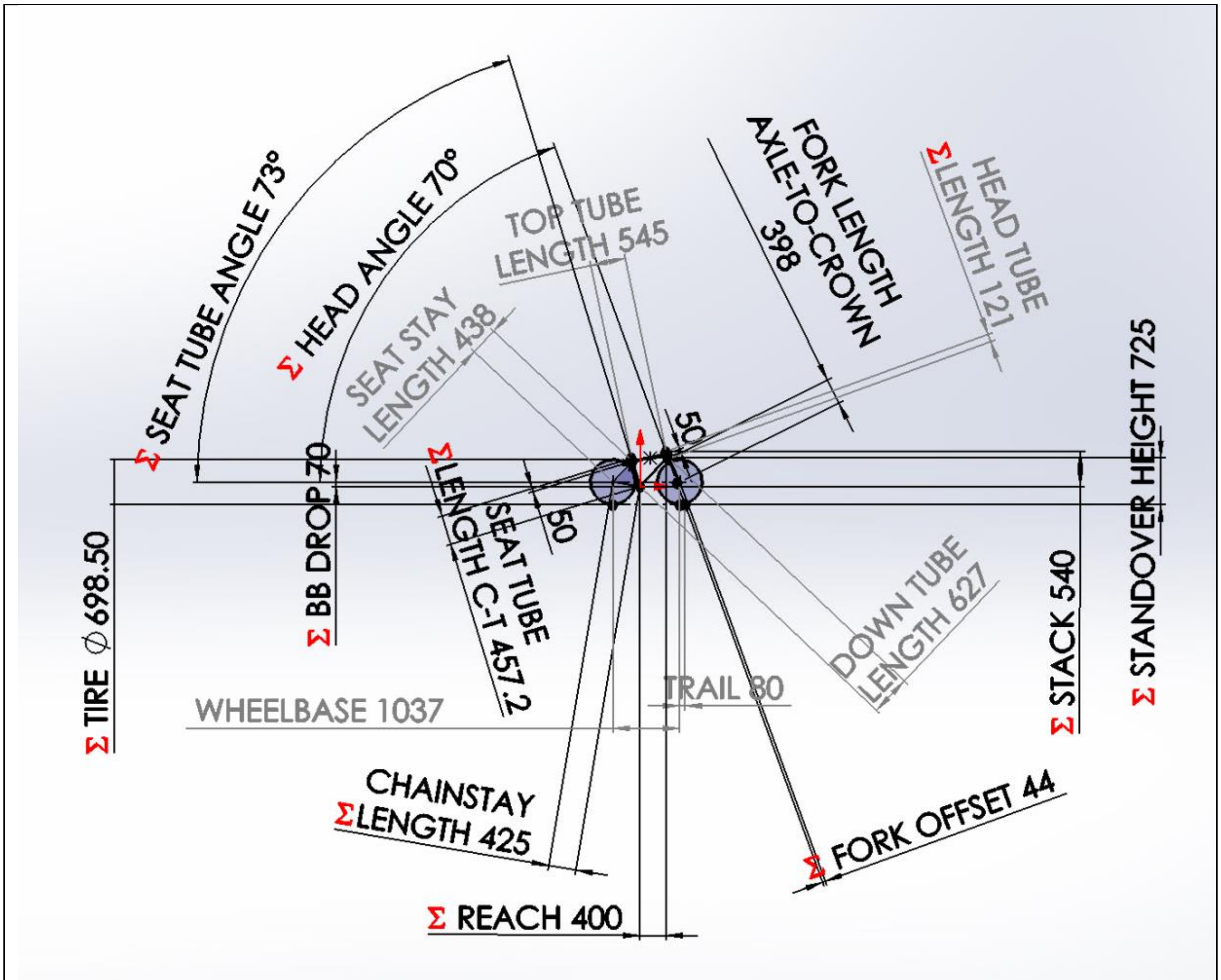
Rear wheel hubs comes in standard sizes, some of which include 135, 142, and 145 mm. For this bike we decided to go with a 135 mm rear wheel hub spacing. This measurement is very important to get correct for a frame because it dictates the spacing between the inside faces of your rear dropouts.

The 3D SolidWorks Model

Here is what the final 3D render of the bike frame looks like in SolidWorks.

The final 3D SolidWorks render of the bike frame

Here is the sketch that defines the geometry of the bike frame in SolidWorks. The black measurements are all the independent measurements that fully define the frame geometry. The greyed out dimensions are driven (dependent), so they are not used to fully define the frame but we added them in there for reference.

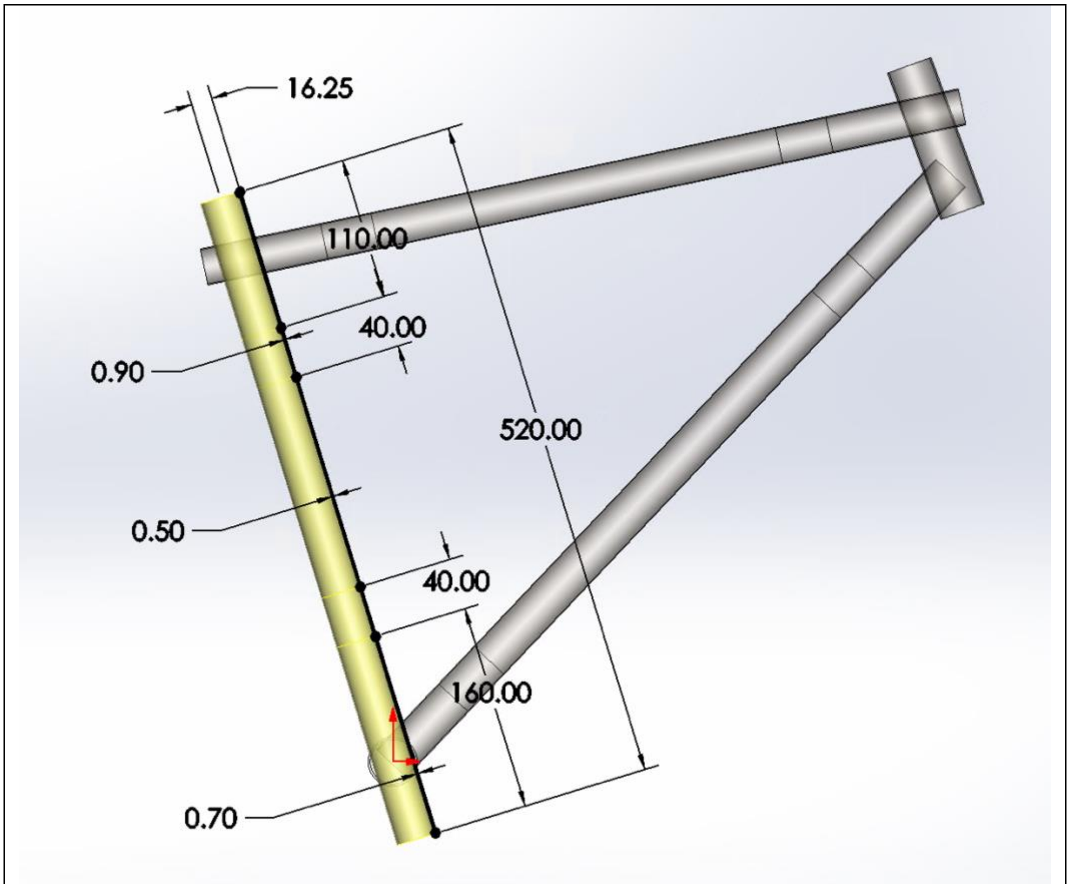


The sketch that defines the frame geometry in mm

Once we had the overall frame geometry of the bike finished, we had to find a supplier that we could purchase bike tubes from to actually build the bike. Ultimately, we ended up purchasing our tubes from Framebuilder Supply as they had a nice selection of tubes to choose from and also provided detailed drawings for these tubes which would allow us to model the tubes in CAD accurately. Here is a list of each of the parts we purchased from Framebuilder Supply as well as a fork from Jenson USA:

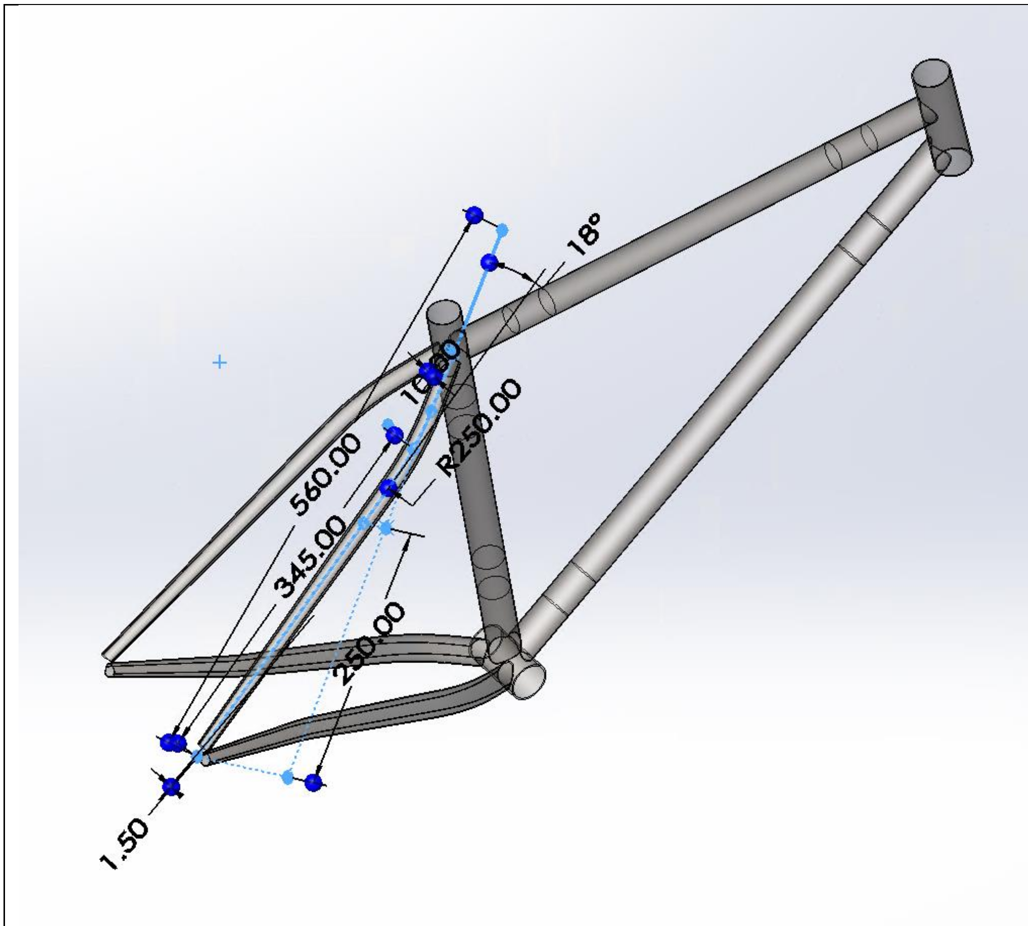
Components used for building the bike frame		
Part	**Specifications**	**URL**
Top Tube	Columbus Zona. OD. 28.6mm. Thickness .8/.5/.8mm. Length 600mm.	https://framebuildersupply.com/collections/top-tubes/products/columbus-zona-top-tube-28-6-dia-8-5-8-length-600
Down Tube	Columbus Life. OD 31.7mm. Thickness .7/.45/.7mm. Length 630mm.	https://framebuildersupply.com/collections/down-tubes/products/columbus-life-top-down-tube-31-7-dia-7-45-7-length-630
Seat Tube	Columbus Spirit HSS. OD 31.7mm. Thickness .7/.5/.9mm. Length 520mm	https://framebuildersupply.com/collections/seat-tubes/products/columbus-hss-externally-butted-seat-tube-31-7-dia-7-5-9-length-520
Head Tube	Columbus Zona. OD 36mm. Thickness 1.1mm. Length 200mm. Threadless	https://framebuildersupply.com/collections/head-tubes/products/columbus-zona-headtube-36-dia-1-1mm-wall-length-200
Seat Stay	Columbus Zona Fatbike. OD 19mm. Thickness 0.6mm. Length 560mm.	https://framebuildersupply.com/products/columbus-zona-fatbike-seatstays-19-od-6-wall-length-560?_pos=6&_sid=eb017a61d&_ss=r
Chain Stay	Columbus Zona Fatbike. OD 24mm. Thickness 0.9mm. Length 470mm.	https://framebuildersupply.com/collections/chain-stays/products/columbus-zona-fatbike-chainstays-oval-round-24-od-9-wall-length-470
Bottom Bracket Shell	ISO BB Shell. OD 38.1mm. Length 69mm.	https://framebuildersupply.com/products/bottom-bracket-shells-69mm-74mm-101mm-38-1mm-od-iso?_pos=2&_sid=9c02b0db6&_ss=r
Rear Dropouts	Rear Dropouts - Hooded Style with Replaceable Hangers	https://framebuildersupply.com/collections/rear-dropouts/products/rear-dropouts-hooded-style-with-replaceable-hanger
Fork	44mm offset, 398 fork length (A-C), 1-1/8" steerer tube, 700C, 45mm wide tire fit	https://www.jensonusa.com/Surly-Straggler-Disc-Fork?_br_psugg_q=surly+straggler

We knew that if we wanted to manufacture this frame successfully, we needed the CAD to be as accurate as possible and had to model it in a way where we can figure out how to notch these tubes. As a result, we modelled each of the tubes to the exact length that they would come in and then sized them down to length using cut extrudes. This way, when the tubes arrive we can figure out where to locate our cutter with respect to the length the tube would come in. For example, the seat tube would arrive with a length of 520 mm but it would need to be cut down to length when we assemble it with the frame. If we just modelled the tube to the desired length immediately, then it would be difficult to figure out where to position the cutter with respect to the tube in order to get the correct mating profile. Many of the tubes also came butted (have varying wall thicknesses) so we modelled that as well for the purposes of having an accurate model for finite-element analysis.



The sketch of the seat tube dimensions in the SolidWorks frame model in mm

This same modelling idea was especially critical for the seat and chain stays, which was an entire beast in of itself to notch correctly (more on the manufacturing later).



The sketch of the seat stay dimensions in the SolidWorks frame model in mm

Manufacturing the Frame

It felt like Christmas when the bike tubes finally arrived at the IDEAs Clinic, this was when we knew we could finally get started on turning this bike frame into a reality.

The ordered bike tubes fresh out of the delivery box

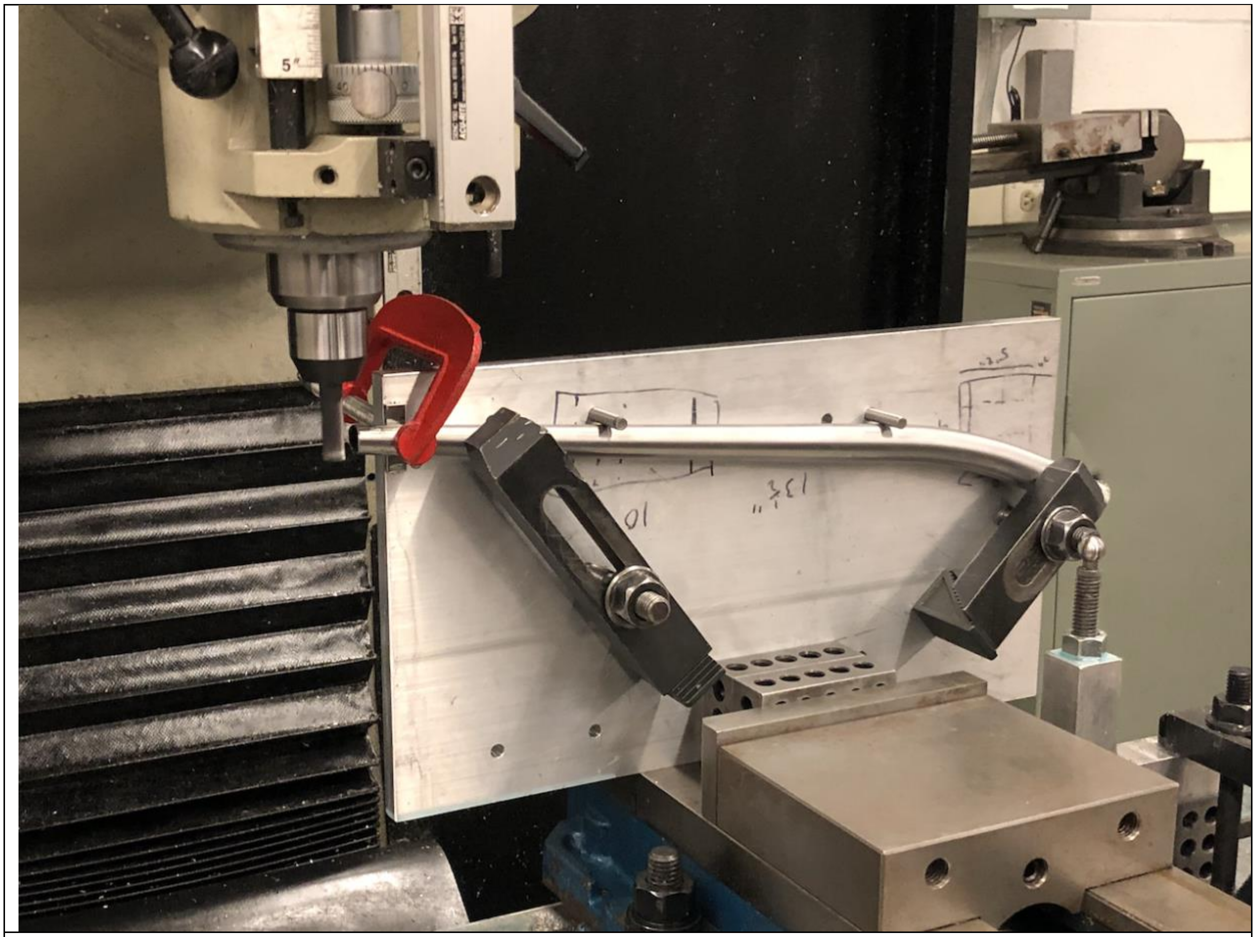
Having the correct notches on our bike tubes was extremely critical. Any slight errors would've caused the tubes to fit poorly which would change the geometry of the frame drastically and cause large gaps between the tubes, making it not weldable; both of which is extremely undesirable. Luckily, we were able to get the tubes that make up the front triangle of the bike frame notched fairly quickly as we were able to borrow a CNC Tube Notcher machine which was a capstone project completed by Waterloo students.

Unfortunately, the CNC Tube Notcher was only limited to straight tubes so we couldn't use that to notch the seat and chain stays since they came pre-bent. A word of caution: If you plan on creating your own bike frame and want to make things easier for yourself, buy straight seat and chain stays! We cannot stress this enough; it was a challenge to figure out how we were supposed to notch the pre-bent stays manually as accurately as possible. After speaking to the machine shop technicians, we came to the conclusion that we needed to create a fixture to hold these stays in position in order to notch them correctly. At this point, there were only a few days left in the work term and we needed to get a fully finished frame before that so we created a fixture as quickly as possible; here's what that looks like:

The chain and seat stay fixture we quickly made for notching

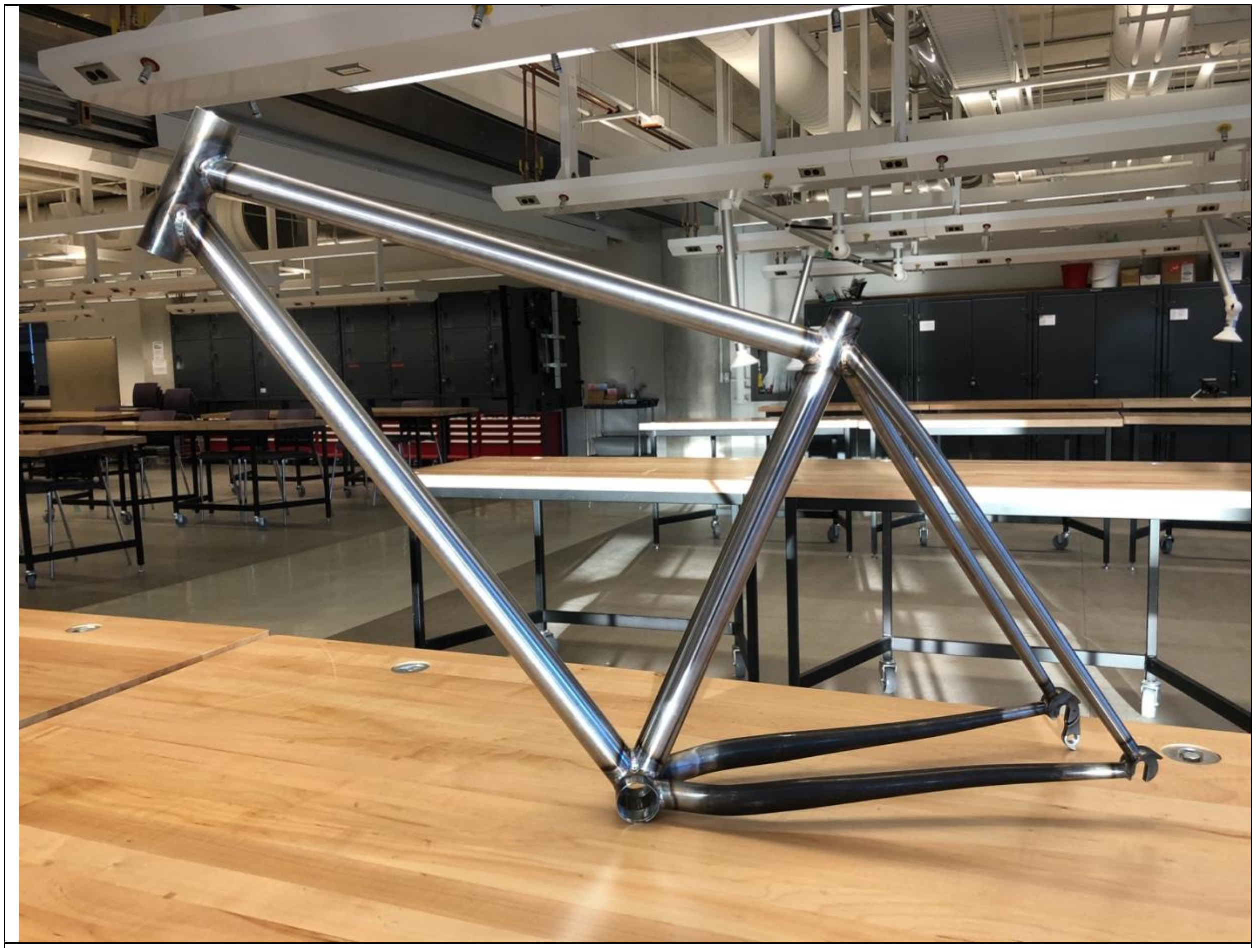
It's certainly not the most glamorous design but it got the job done. The dowel pins are used as guides for the stays so that they are positioned in the exact orientation as they would be when they're on the bike frame. The dropout ends of the stays were positioned exactly 1 inch from an edge of the plate. And there are threaded holes in the middle which are used to secure toe clamps to hold the stays to the plate. Then using the CAD of the frame and the fixture, we were able to get the necessary x and y coordinates in order to set our datum on a CNC milling machine. Here is what the CAD and milling machine setup looked like:

The fixture setup matched with the frame CAD

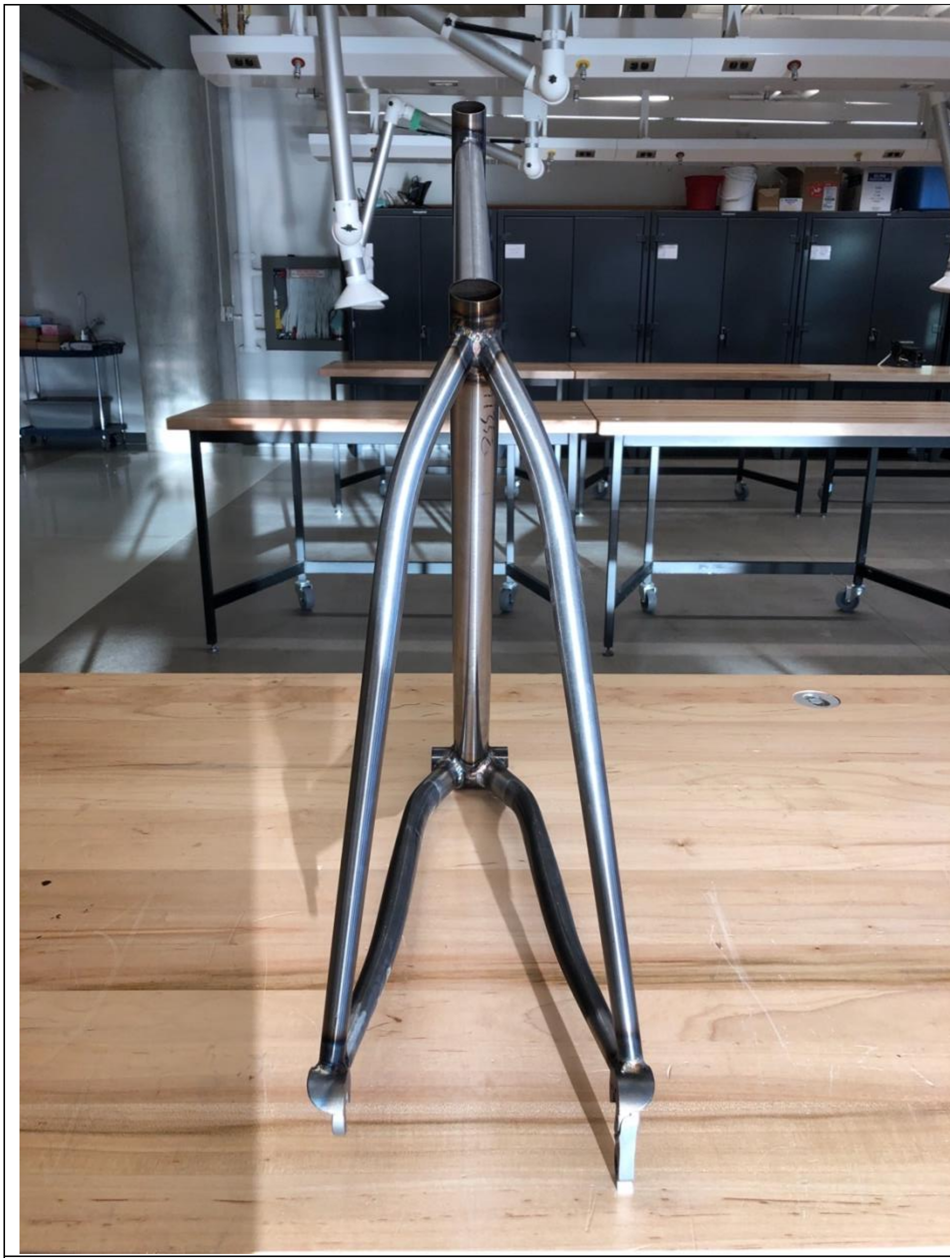


The CNC milling setup for cutting the seat stays

And here is what the final welded frame looks like!



Side view of the fully welded bike frame



Back view of the fully welded bike frame

Close up of the rear dropouts on the frame

Close up of the bottom bracket joint

References

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