

Hub Center Steering

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ABSTRACT

As motorcycles get faster and faster the need for safety becomes exponentially more important. The two most significant problems facing current front fork suspensions are lateral wheel displacement and extremely limited front wheel braking force. Hub center steering is designed to eliminate both of these problems. Although this project is built on a bicycle it is a proof of concept intended for larger scale applications.

Previous iterations of hub center steering systems were analyzed as thoroughly as possible. A complete custom system was then created. This process utilized SolidWorks software for design and stress analysis. The system was then tested and proven to be a success.

This hub center steering system has proven to work well to alleviate the major problems involved with front fork suspensions. Lateral wheel displacement is virtually eliminated and front wheel braking power is increased.

This hub center steering system lays a great base of groundwork for the evolution of high speed motorcycle chassis design. The two most significant problems with high speed motorcycles can be alleviated with this design. As motorcycles increase with speed so should they with safety, this design opens that door. From basic design to stress point analysis this report contains the basic concepts required to build the safest and fastest motorcycle of the future.

INTRODUCTION

BACKGROUND

The concept of Hub center steering has been around since the early 1900's and was first produced by Ner-A-Car. The Ner-A-Car was made under license by the Simplex Luxury Carmaker in Sheffield, England. The company lasted from 1921 to 1926 and went out of business due to lack of popularity. By the early 1950's hydraulically damped telescopic fork suspensions for motorcycles were becoming the standard. This was mostly due to improved ride over the un-damped systems used for hub center steering.

Although telescopic front fork suspensions were gaining popularity and were very commonly used, this type of steering system was not without its own drawbacks. These drawbacks are exponentially increased as motorcycles get heavier and/or faster. The most dangerous draw back to a telescopic front fork is lateral flex in the fork legs which will cause the tire patch in contact with the ground to move away from the steering axis (lateral displacement), as seen in figure 1 (1). This can cause the tire to wobble and the operator to lose control. The second most dangerous drawback to a telescopic front fork suspension is the force exerted at the steering head of the motorcycle while braking, also see figure 1 (1). Not only does this require a larger frame to resist these forces, but these forces can cause a moment around the wheel and cause the motorcycle to flip over itself and injure and sometimes kill the operator.

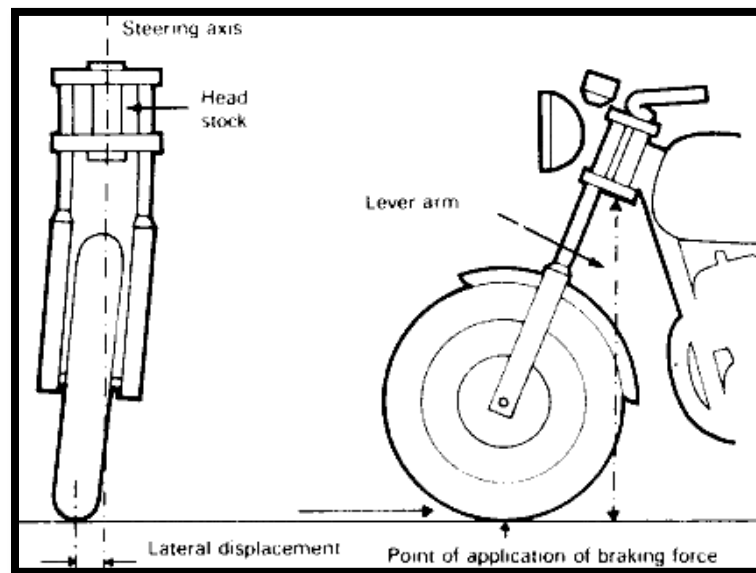


Figure 1 : Telescopic Front Fork Problems

With the rise in popularity in motorcycles, and the acknowledged problems of a telescopic fork front suspension, Jack Difazio saw a need for alternative steering systems. In 1968 there was a copyright made on the Difazio hub center steering concept, as seen in figure 2 (1).

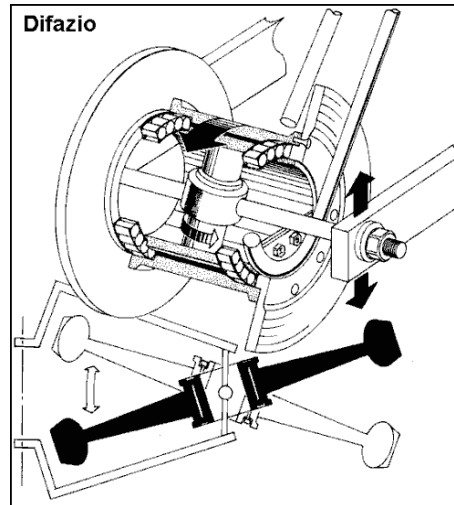


Figure 2 : Difazio design

This hub center steering concept is the backbone of most modern alternative steering systems, and is the basic concept used in this project. A large bearing is used and supported in the center by large A frame braces. This design produces very high stress on the king-pin when subjected to a lateral force (hitting a bump in a corner). This can result in the axle being bent into an S shape if improperly designed.

It is also noted that this design on a bicycle is impractical due to low speed and vehicle weight. This design is most properly utilized under high braking loads and is intended to be scaled for use on high performance motorcycles.

This design is intended to alleviate lateral displacement of the front wheel and increase useable braking force.

EXISTING DESIGN ITERATIONS

NER-A-CAR

Most likely the first attempt at utilizing hub center steering. The Ner-A-Car was designed by American Carl Neracher during World War 1 (WW1) with a seven year production run from 1921 to 1928. The Ner-A-Car was manufactured in England and the United States of America. It is estimated that around 16,000 Ner-A-Cars were produced and about 100 remain today. The last recorded sale of a Ner-A-Car was at a Dutch vintage motorcycle dealer that sold the Ner-A-Car for \$16,000.00 (US currency). The hub center steering system utilized on this vehicle seems similar to the Difazio design although it was patented in 1919, 49 years before Difazio's design was patented. A close up of the design can be seen in figure 3 (2).

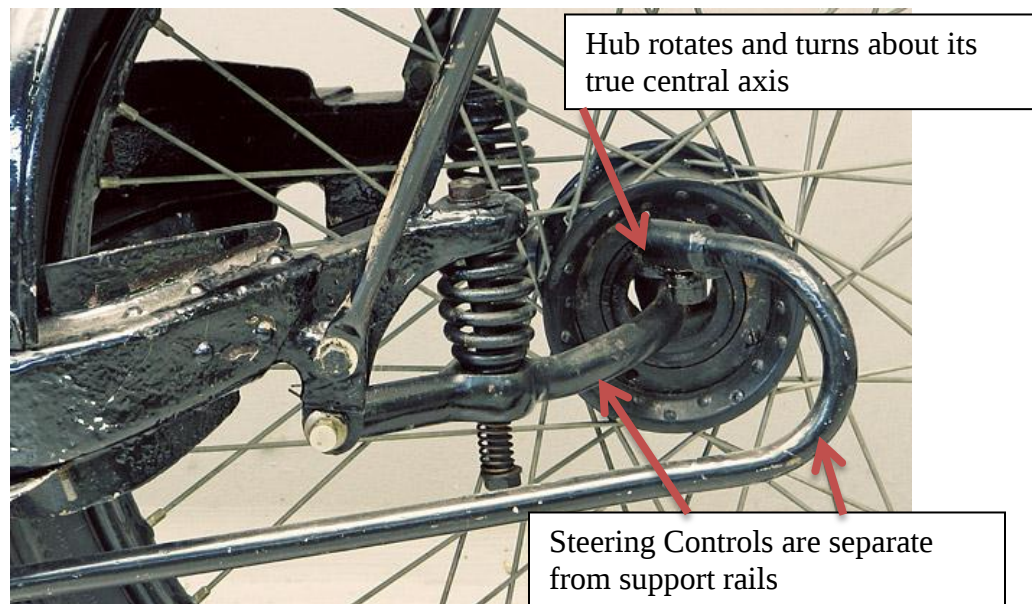


Figure 3: Ner-A-Car Hub Center Steering close-up

BRITTEN V1000

Designed in 1991 by John Britten, the Britten V1000 figure 4 (3) utilizes a double wishbone girder type front suspension and has a carbon fiber frameless chassis. In 1992 the V1000 won the Dutch round of the Battle of The Twins, and in 1994 the Daytona round. In between those victories, the V1000 set four motorcycle world speed records: the standing start quarter mile, mile, and kilometer, and lastly the flying mile at 302 kph (187.7 Mph). In 1995 John Britten died of cancer and development of the Britten V1000 stopped. Although this is not a hub center steering design, it was probably the rejuvenator of the motorcycle racing worlds desire to go faster, and realization that a traditional front fork design was not optimal and a modified version was far superior.

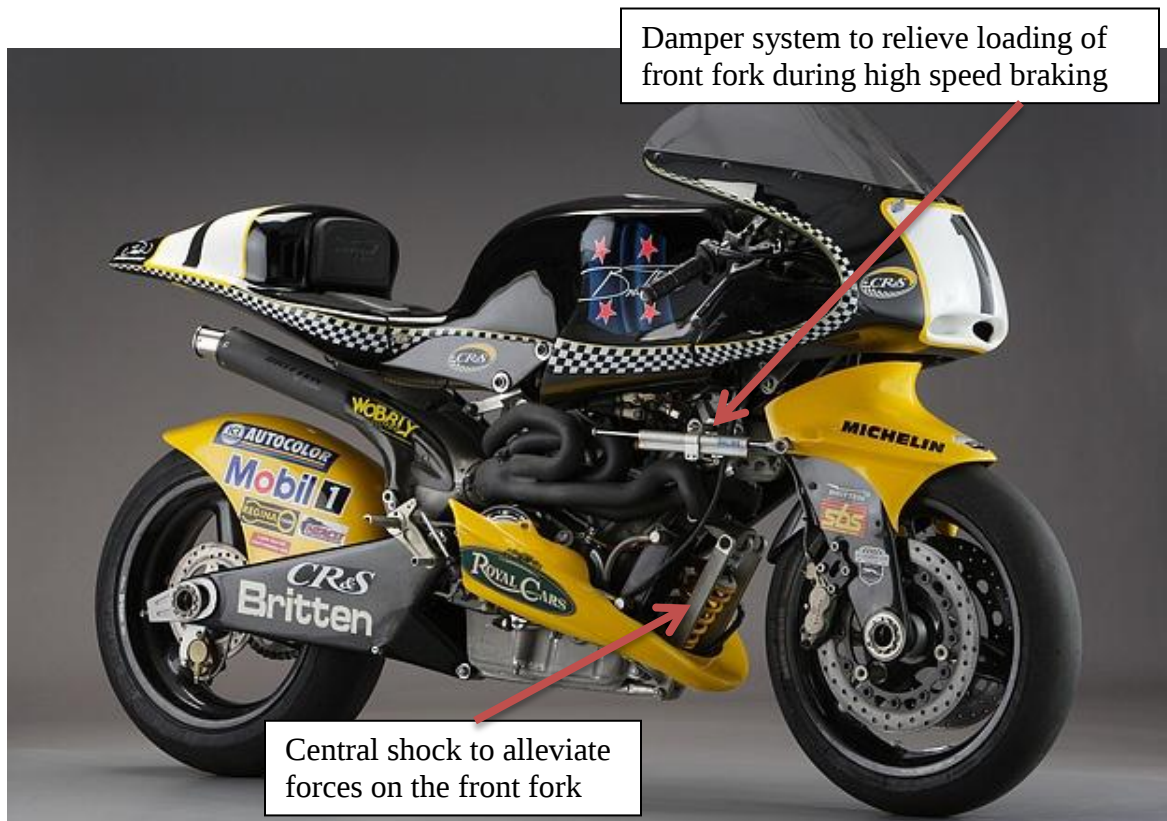


Figure 4: Britten V1000

HUB CENTER STEERING KIT FROM ISR OF SWEDEN

ISR is a Swedish based company established in 1968 that specializes in braking systems. They were the first company to produce and sell a universal hub center steering kit that could be fitted to just about any motorcycle. A close up of this design can be seen in figures 5 (4) and 6 (4). They also sell custom hubs, master cylinders, calipers, disc brakes, and miscellaneous fittings. This setup utilizes the Difazio design and is pictured below. This product utilizes the basic Difazio design with the main frame support bolted to a center bearing at the central axis of the vehicles wheel.

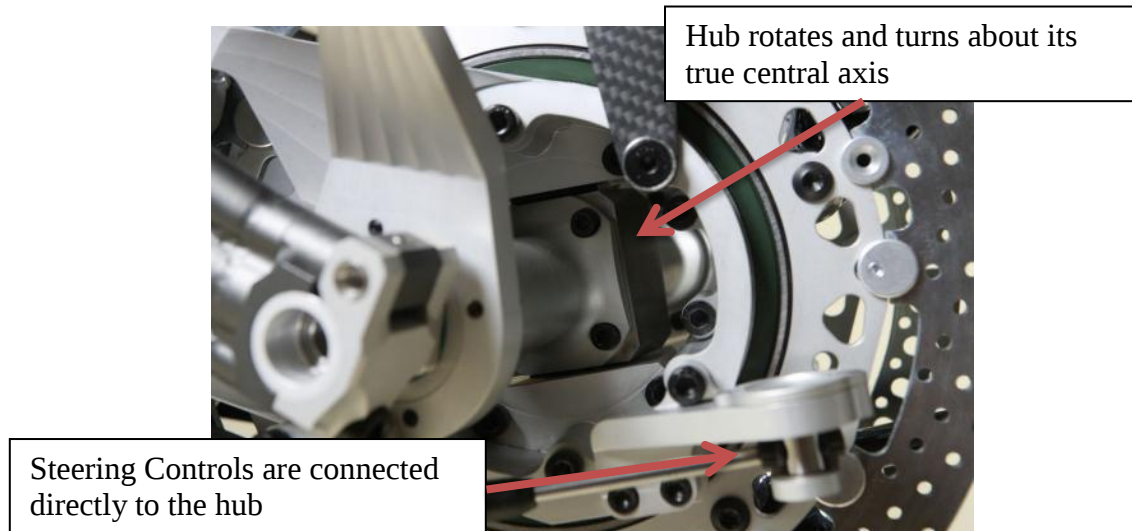


Figure 5 : ISR Front Hub close up

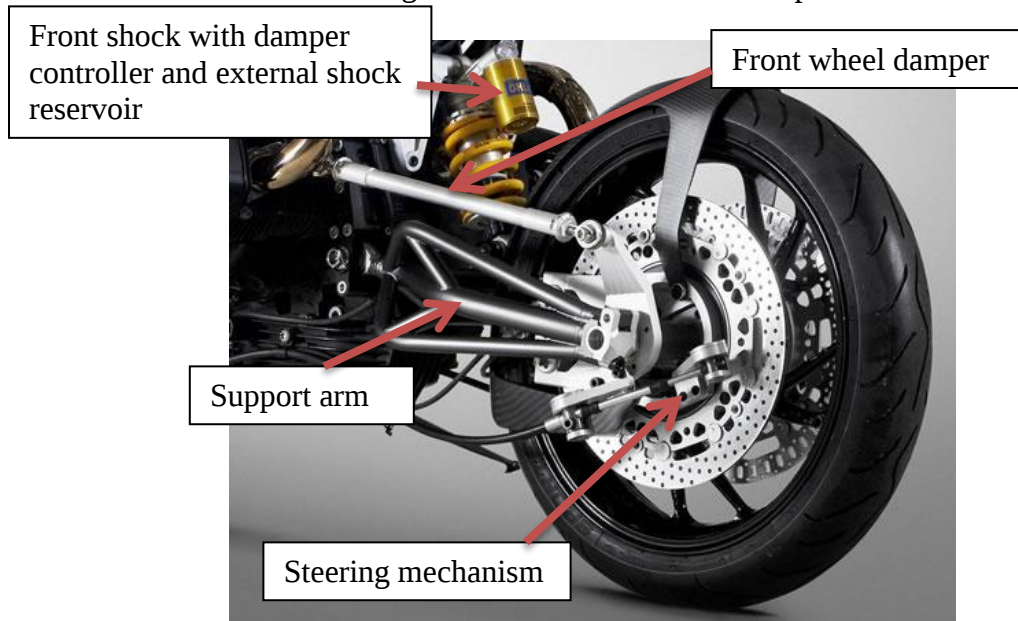


Figure 6 : ISR Hub center steering

STELLEN EGELAND'S BMW HARRIER

This was the first motorcycle to utilize the ISR kit, and acted as the prototype model for testing. It can be seen below in figure 7 (5). "Given the result of our testing, the bike was performing flawlessly with just the advantages that should be in the theory. This convinced me once again that hub centre steering is technically superior, given a proper development I am sure it can out perform the tele at the highest level of racing." (Acke Rising, owner ISR (4))

With this confidence in their system, ISR decided to mass produce the hub center steering kit. It costs around \$7500.00 for a basic setup, depending upon the motorcycle you have. It has not been race proven at this point.

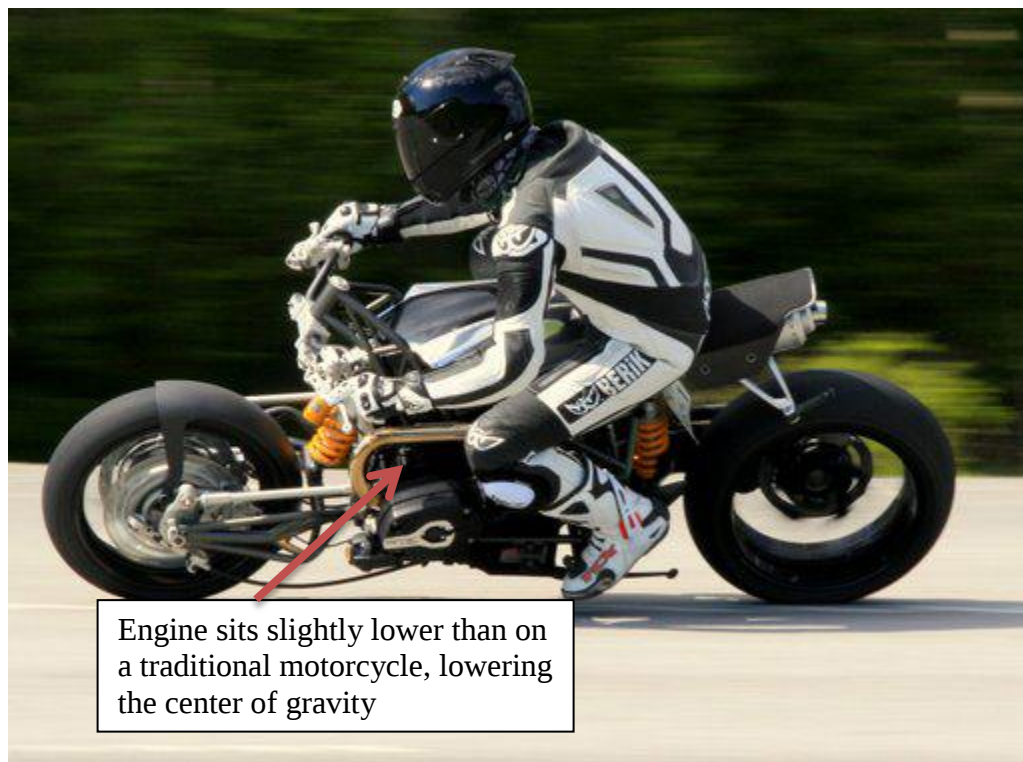


Figure 7 : Stellen Egeland's BMW Harrier

HONDA ELF

ELF was a motorcycle project born out of a conversation between Renault designer Andre de Cortanze and Renaults marketing boss Francois Guiter. It started as a small budget spare time motorcycle project for Andre de Cortanze. The motor utilized was originally a Yamaha TZ750, which was very unreliable and underpowered. However in 1980 Honda motor co agreed to supply Cortanze with 1000cc RSC endurance engines so they could compete in racing. This signified the beginning of the Honda ELF, which was the basis for many Honda motorcycle patents. The chassis however also proved to be unreliable and by 1983 production of the motorcycle had ceased. It was an ambitious idea, and Honda in 1985 signed a secret agreement to evaluate ELF's patented design with hopes of mass producing the motorcycle. The motorcycle was too expensive to produce, and had significant brake problems. In 1988 the ELF5 prototype was the final bike to be made and track tested. It got 11th place in 1988 in the 500cc World Championship, and then was retired. There have been a few attempts to recreate this motorcycle, none have been successful, but it offers a lot of potential and was a very ambitious project. The ELF can be seen in figure 8 (6) without its fairings attached.

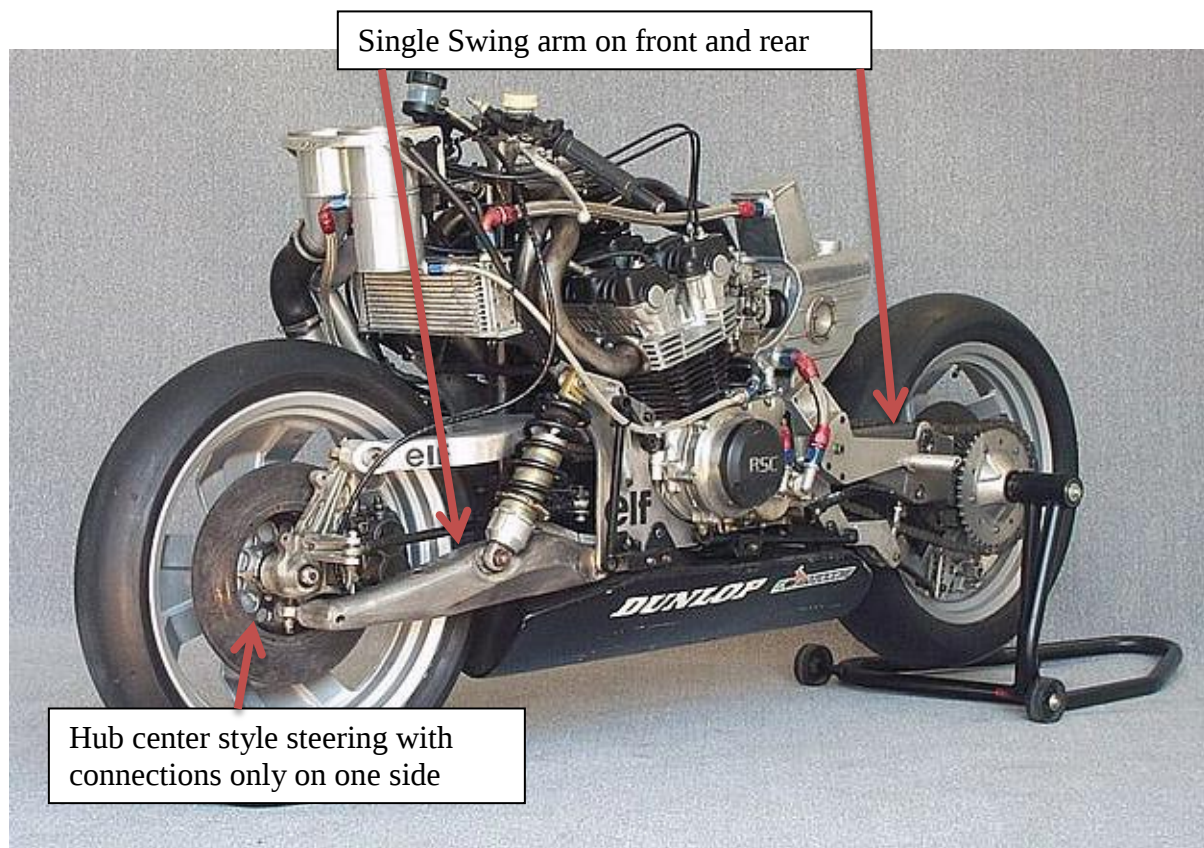


Figure 8 : Honda ELF

CHIQANE AND ZEPPLIN WORKS

ChiQane is a Dutch motorcycle company that specializes in hub center steering motorcycles. They do not have any US racing affiliation and very little is actually known about them. Through a rough translation of their website they started in 1999 with an intention to race and build custom hub center steering motorcycles. Figure 9 (7) is a picture of their most recent motorcycle which was made in 2005.

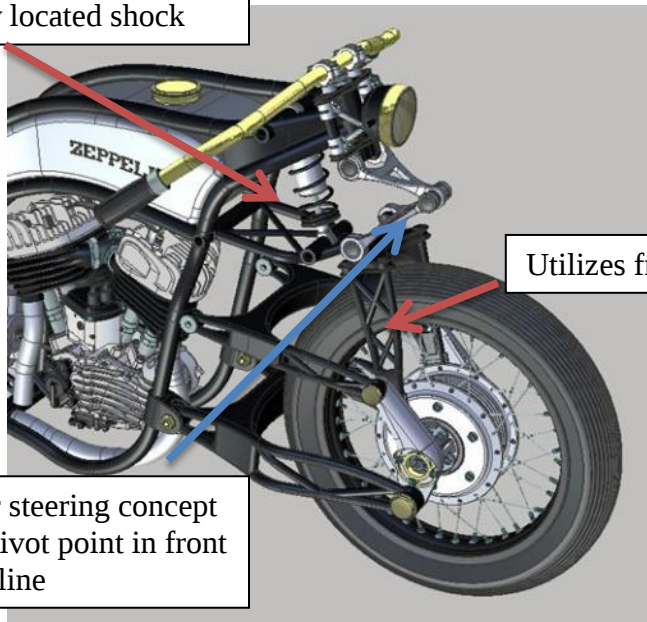
Swing arms on both sides, with shocks attached and a rotor and caliper on each side for stability during braking



Figure 9 : ChiQane motorcycle

Zeppelin Works is the daughter company of ChiQane and is attempting to build a hub center steering motorcycle called the Zeppelin Boardtracker, figure 10 (8). This is a direct design response to the ISR kit. It was designed by Roel van der Heide who was a designer for ChiQane motorcycles. The motorcycle is still in the process of being built.

Single Centrally located shock



Utilizes front fork to steer

First Hub center steering concept to put steering pivot point in front of wheel center line

Figure 10 : Zeppelin Boardtracker

BIMOTA TESI 3D

Bimota is an Italian motorcycle company that builds mostly custom super bikes but is working on a hub center steering system. The most current model is the Tesi 3D and can be seen in figure 11 (9).

The Tesi started concept in 1990 by two Italian Engineers, who called it “TESI” which is Italian for thesis. Later a Bimota mechanic named Rodrigo Ascanio produced a joint venture motorcycle between VDM, Bimota, and Vyrus called the Tesi 2D. This motorcycle had positive enough results for Bimota and VDM to produce a third project, currently known as the Tesi 3D. All Tesi concepts incorporated some form of the Difazio design.



Figure 11 : Bimota Tesi 3D

VYRUS 985

The Vyrus 985 is the latest concept from Ascanio Rodriguez who also was a Bimota mechanic and worked on the Tesi projects. The predecessor to this motorcycle was the Vyrus 984 which debuted in January 2003 and was later badged as a re-born Tesi 2D. Vyrus has sold more than 70 motorcycles in Europe and Asia, and 25 under the Tesi 2D badge. It is regularly raced at the rostrum in European twin-cylinder racing. This concept utilizes the Difazio design as its basic principles, and costs about \$67,750.00. Seen below in figure 12 (10) shows the Vyrus 985 on the race track at the rostrum in Europe.



Figure 12 : Vyrus 985

These existing design iterations act as the basis for this project. With so many previous iterations it proves there is a potential market for this steering system in high performance motorsports. It should also be noted that every successful design that has been produced has utilized some form of the Difazio design. This design will also act as the basis for this project and will be fitted to a bicycle for cost purposes.

All of these design iterations show that steering radius will have to be decreased and vehicle weight will increase. Also the Difazio design is the leading concept behind hub center steering. Lastly the only concepts that are used today utilize two control arms; this is most likely due to a single control arm not full alleviating lateral wheel displacement.

CUSTOMER FEEDBACK, FEATURES, AND OBJECTIVES

SURVEY ANALYSIS

Out of 39 surveys the most important features for customers were first reliability and second safety. The third was ease of operation but the value was adjusted by 20% by the designer. This was because if it is not simple and common to use no one will want it. Without the design multiplier ease of operation would be at 11%. Also ease of maintenance was enhanced due to design belief that simpler is better. Maneuverability was reduced in importance due to the inherent nature of hub center steering to reduce turning radius over telescopic front forks.

Table 1 : Survey Summary

	Customer importance	Designer's Multiplier	Current Satisfaction	Planned Satisfaction	Improvement ratio	Modified Importance	Relative weight %
Reliability	4.8	1.0	4.0	4.9	1.2	5.9	15%
Safety	4.9	1.0	4.5	5.0	1.1	5.4	14%
Ease of operation	4.2	1.2	4.9	5.0	1.0	5.1	13%
Ease of Maintenance	3.7	1.1	4.0	4.0	1.0	4.1	11%
Ease of Front Wheel Removal	3.9	1.2	4.3	4.0	0.9	4.4	11%
Appearance	3.4	1.0	3.6	4.5	1.3	4.3	11%
Corrosion Resistance	4.2	1.0	4.4	4.5	1.0	4.3	11%
Maneuverability	4.3	0.9	4.4	4.0	0.9	3.5	9%
Enviromental Friendliness	2.5	1.0	4.6	3.0	0.7	1.6	4%

Current satisfaction with current bicycles is very high with appearance being the lowest concern at 3.6 out of 5. The survey results show that current customer satisfaction for bicycles is high. The demand for reliability, safety, and ease of operation are the three highest priorities and must be considered at all times during the design process. Therefore they have been assigned a planned customer satisfaction rating of 4.9 or higher (5 being highest possible satisfaction). Cost was also a very important factor, and a \$700 production goal was set to potentially keep sale prices under \$1000 which was the customer spending ceiling according to the survey results. Complete survey results can be seen in appendix B.

PRODUCT FEATURES AND OBJECTIVES

1. Reliability - 15% Relative Weight
 - a. A safety factor of two will be utilized at minimum
 - b. All bearings and mechanical fasteners will be properly lubricated and fastened to proper torque specifications where required
 - c. Chassis will be painted upon final assembly to aid in corrosion resistance and pre mature deterioration of the materials.
2. Safety - 14% Relative Weight
 - a. Increase in useable braking force for the front brake
 - b. Increase in force required to create a moment around the front fork causing the vehicle to flip over its front end.
 - c. Increase in wheel stability
 - d. Decrease in lateral wheel displacement when wheel experiences a side force
3. Ease of Operation - 13% Relative Weight
 - a. Vehicle will operate in the same manner as a standard bicycle
 - b. All control locations will remain in same location
4. Ease of Maintenance - 11% Relative Weight
 - a. Parts will be in standard bicycle locations, with no specialty tools required.
 - b. Rubber bushings will be utilized where necessary, along with corrosion resistant materials.
5. Ease of Front Wheel Removal - 11% Relative Weight
 - a. Front wheel will utilize a quick release mechanism
6. Corrosion Resistance - 11% Relative Weight
 - a. Materials will be painted when necessary for protection from the environment
7. Maneuverability - 9% Relative Weight
 - a. The vehicle will retain a majority of its initial turning radius
 - b. Vehicle will weigh less than 40 lbs.
8. Environmental Friendliness - 4% Relative Weight
 - a. Paint used on chassis will be Eco-friendly
9. Cost N/A
 - a. The vehicle will be built for under \$700
10. Universal N/A
 - a. The hub center steering system will be able to attach to other bicycles
 - b. Steering system will be scalable for motorcycles

The engineering characteristics used to analyze the survey were safety factor, number of parts, use of standardized parts, part locations, recyclability, turning radius, time to remove front wheel, weight and material used. The safety factor utilized was the most important characteristic (22% relative importance) as it affected the two most important features (safety and reliability) at the highest possible level. The second most important feature was turning radius (14% relative importance), which was reduced mainly because the steering radius will have to be reduced due to the inherent nature of hub center steering. The third most important feature was material selected (13% relative importance) as it affected safety, reliability, corrosion resistance, and environmental friendliness. The other characteristics used to evaluate the survey had under a 10% relative importance. Complete results can be seen in appendix B – House of Quality.

CONCEPT GENERATION AND SELECTION

FRAME DESIGN AND SELECTION

The first item designed was the frame as it is the main determiner for the loading conditions. Welding torques had to be kept under 2.39 Kip due to material thickness. This required that more than just two control arms could be utilized. Therefore the weight of the bicycle had to be increased as more materials had to be added. Eventually making the final design looks very similar to Stellen Egeland's BMW Harrier as can be seen below in figure 13.

The original front fork will remain but will only be used for steering. For complete force resolutions and calculations see next section "Calculations - Manual". For complete SolidWorks analysis see "Calculations - SolidWorks™ (CAD)" section. Also it should be noted that the control arms on a motorcycle would experience less torque. This is due to the pedaling room required for the bicycler.

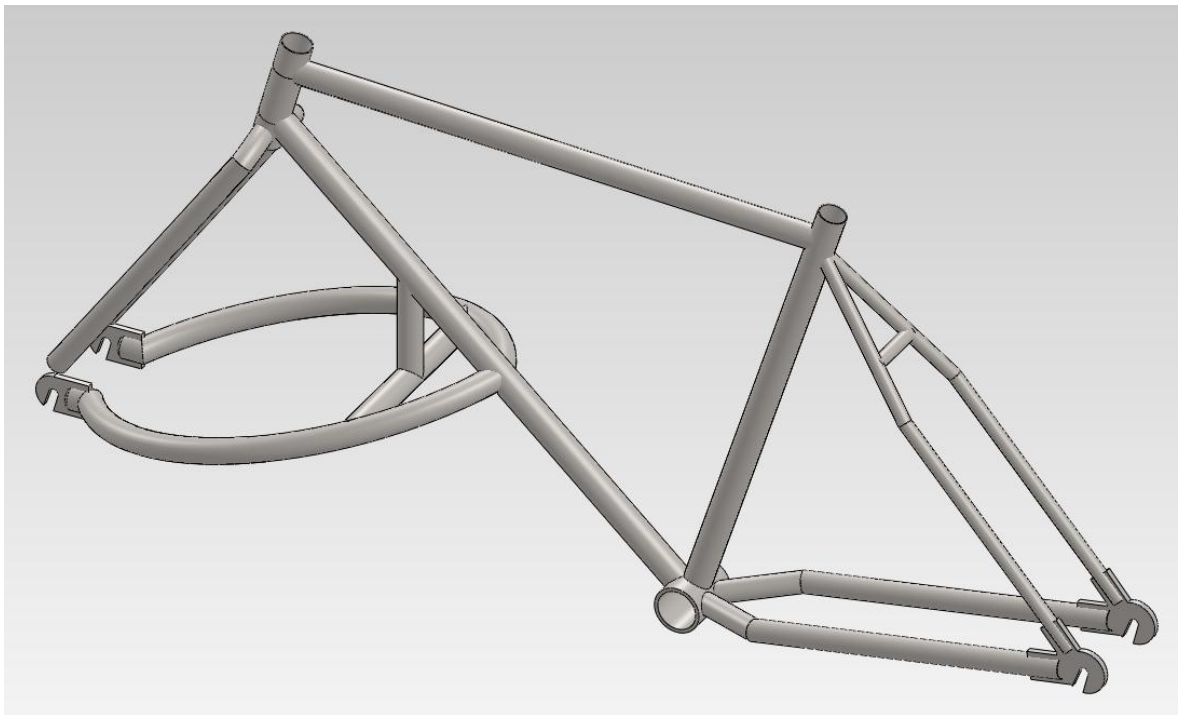


Figure 13: Final Frame Design

HUB CENTER DESIGN

Many of the concepts originally generated had to be instantly discarded due to their custom manufacturing requirements. Budget became the lead design constraint as it was not feasible to obtain a custom manufactured bearing. Some of this process can be seen below in figure 14.

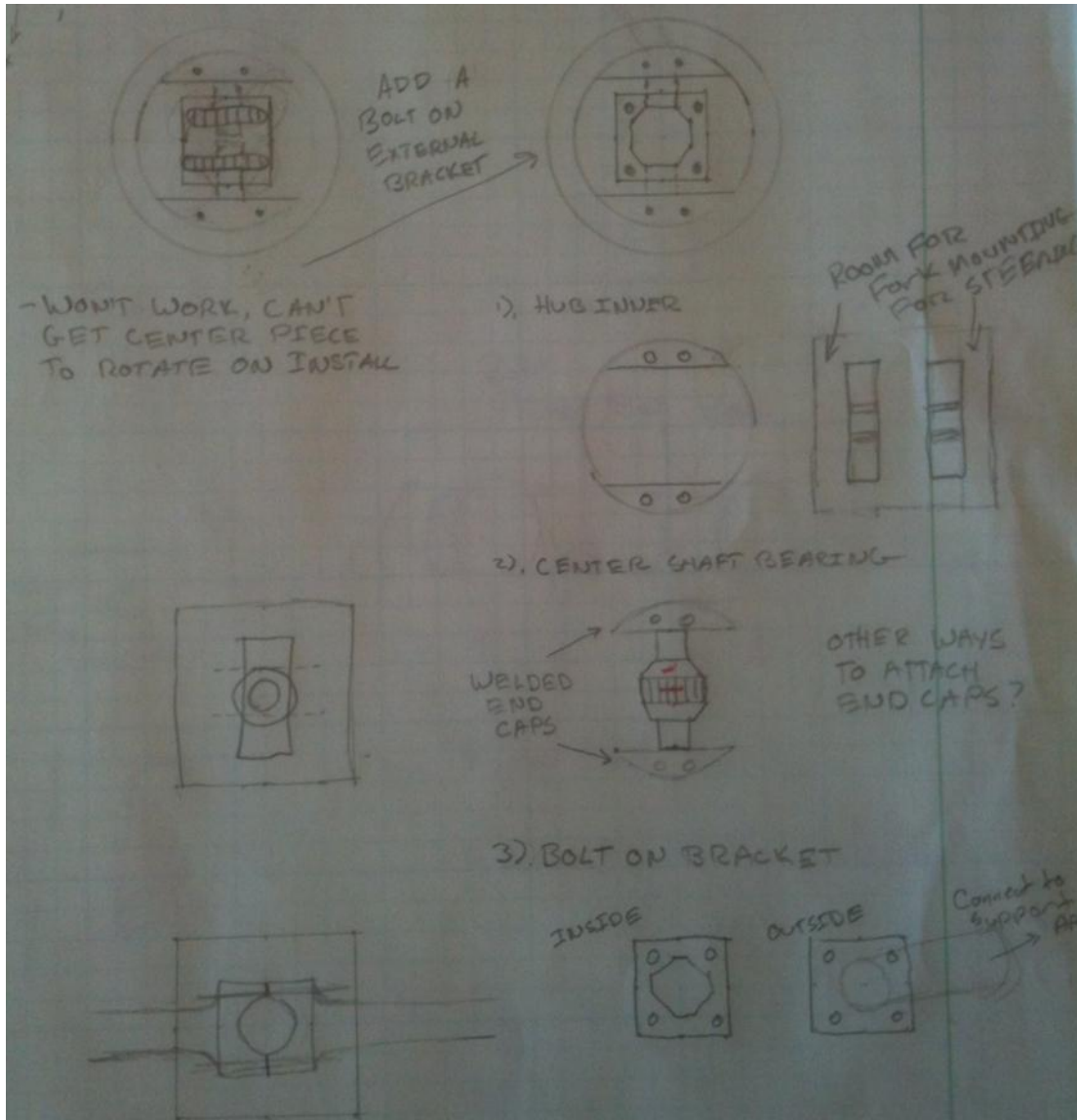


Figure 14: Hub Center Starting Concepts

Eventually the pages of concepts came to one general leading design that could use all standard bearings. This can be seen below in Figure 15.

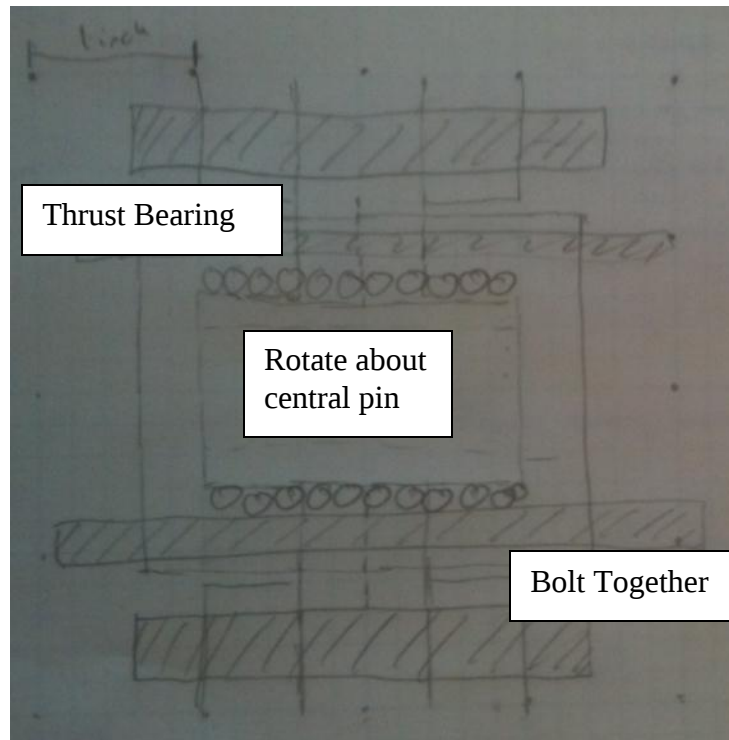


Figure 15: Hub Center Guiding sketch

Once the forces on the frame were resolved and an assembly guideline was formed the bearings could be officially selected. Due to budget constraints custom bearings could not be fabricated; therefore, off the shelf items were utilized. The dimensions of these items were then the determining factors for the remainder of the design process. For complete bearing specifications see “Assembly Design”.

FINAL SELECTION

The final selection was based around safety, budget, and part availability. This combination led almost directly to the final design which can be seen below. Detailed parts list can be seen under “Budget” and assembly information can be found in the “Assembly Design” section.

Originally four bolts were utilized but the SolidWorks drawings showed only room for two $\frac{1}{4}$ ” bolts maximum. This led to the final design that can be seen in Figure 16.

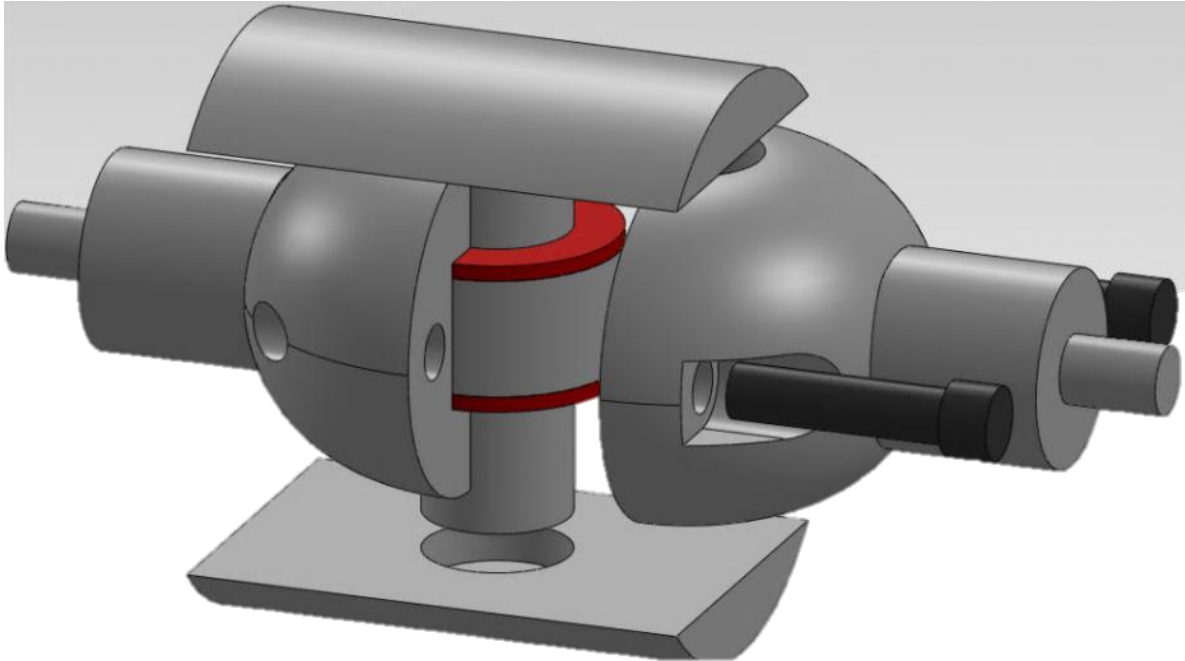


Figure 16: Final Hub Center Concept

Figure 16 is drawn to scale. For a complete list of parts involved and assembly instructions please refer to the “Assembly” portion of this report.

CALCULATIONS

MANUAL

Force resolution on original chassis when normal force on rear wheel is equal to zero. Proving torque is too large and will break welds. These calculations acted as the frame design modification guidelines which were later verified by SolidWorks.

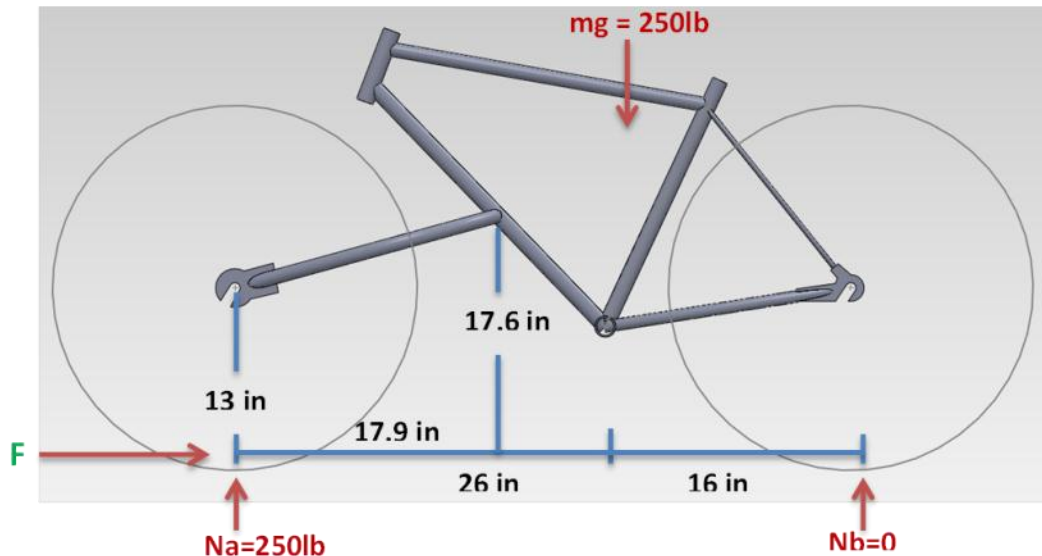


Figure 17: Force Resolution on Original Frame

Torque from rider sitting on bicycle

$$250\text{ lb} * 17.9\text{ in} = 4475\text{ in} * \text{lb}$$

Stopping force required to create moment around front wheel

$$\Sigma M_a = 0 = (F * 13\text{ in}) - (250\text{ lb} * 26)$$

$$F = 308\text{ lbf}$$

Torque created by stopping force on welds

$$308\text{ lb} * 17.6\text{ in} = 5420\text{ in} * \text{lb}$$

Assuming pure Kinetic Energy stopping speed verified

$$KE = \frac{1}{2}mv^2$$

$$v = 8.9 \frac{\text{ft}}{\text{s}} \approx 6\text{ MPH}$$

The worst case loading conditions were assumed to be the rider raised the front wheel two feet in the air and came down with all of the weight translating through the wheel.

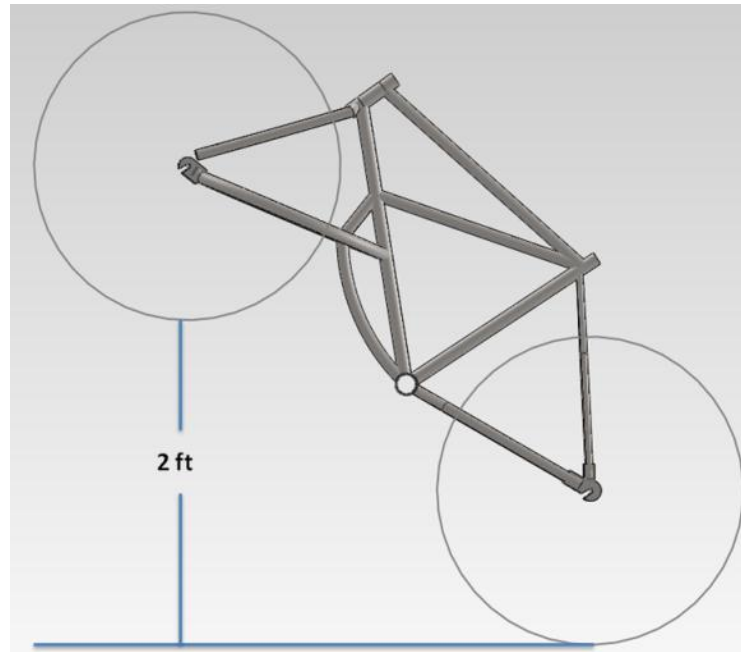


Figure 18: Worst Case Loading

Velocity of bicycle from two feet

$$v = \sqrt{2gh}$$

$$v = \sqrt{2 * 32.2 \frac{ft}{s^2} * 2ft}$$

$$v = 11.3 \frac{ft}{s}$$

Kinetic Energy produced from hitting the ground

$$KE = \frac{1}{2} * \left(\frac{250lb}{32.2 \frac{ft}{s^2}} \right) * \left(11.3 \frac{ft}{s} \right)^2$$

$$KE = 500 ft - lb \text{ force}$$

For final assembly press fit calculations were performed. The manufacturer of the roller bearing had specifications for press fitting onto shafts and these loads translated as light for this application. However the outer shaft became a problem. With no way to manufacturer an outer ring one had to be purchased off the shelf. Six inch sch 120 was selected with an inner diameter of 5.501 inches.

Equation for pressure from press fit

$$P = \frac{\epsilon \delta}{R} * \left[\frac{(ro^2 - R^2) * (R^2 - ri^2)}{2 * R^2 * (ro^2 - ri^2)} \right]$$

$$\left(\frac{30500000psi * .005in}{2.756in} \right) * \frac{(2.750906^2in - 2.755118^2in) * (2.755118^2in - 2.755906^2in)}{2 * 2.755118^2in * (2.750906^2in - 2.755906^2in)}$$

$$\approx 13 psi$$

It was also determined that 45 psi was needed to stop the 308 lbf previously calculated. Therefore a disc brake was eliminated and a rim brake was utilized. First to alleviate slipping during breaking, secondly 45 psi of complete radial pressure would seize the bearing.

SOLIDWORKS™ (CAD)

Utilizing previously calculated values SolidWorks simulations were utilized to provide an even more in depth analysis.

Frame Analysis

The frame experiences the highest pressure at approximately 53.2 Ksi in the worst case loading scenario. The force required to make a moment from previous calculations was translated to the rear wheel connector. This result is unrealistic however because the front end would not actually be pinned; it would be free to rotate when enough force was applied. If the bicycle was actually pinned in this scenario you have experienced a catastrophic wreck and the frame is no longer a concern. Utilizing 52100 chromoly steel the safety factor is 1.85.

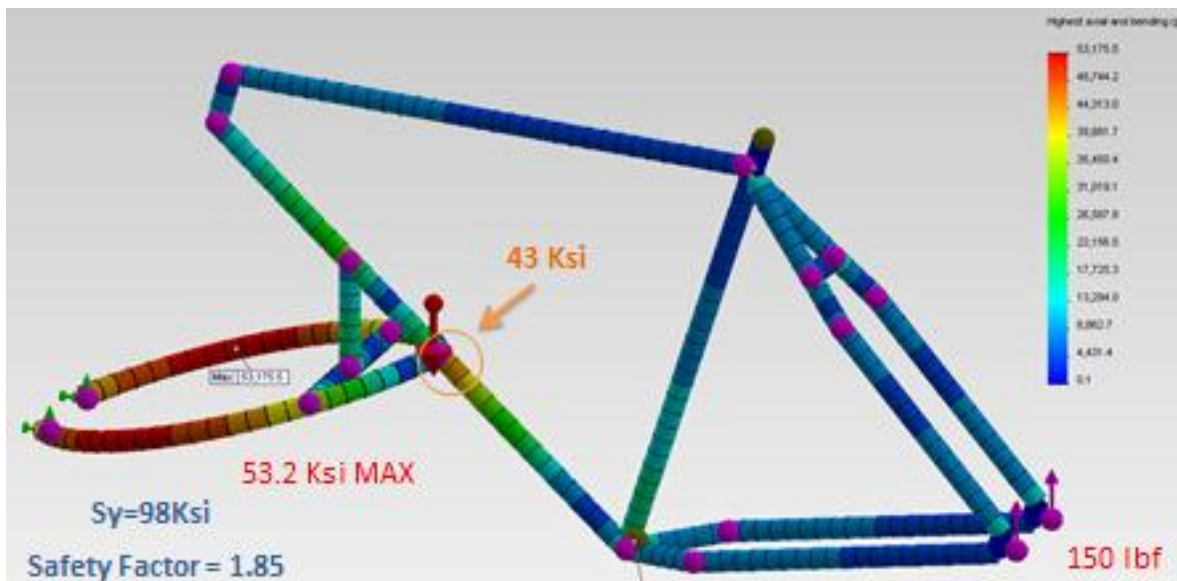


Figure 19: Final Frame SolidWorks Analysis

The force on the central section of the down tube during this catastrophic event is increased to 43 Ksi. It should also be noted that the forces on the seat stays are doubled. This takes the safety factor from 10 down to 5 which is still acceptable.

Center Pin Analysis

Combined stress by hand yielded 1400 psi, but the SolidWorks simulation calculated 1650 psi. SolidWorks will be utilized to make decision decisions for the remainder of the design.

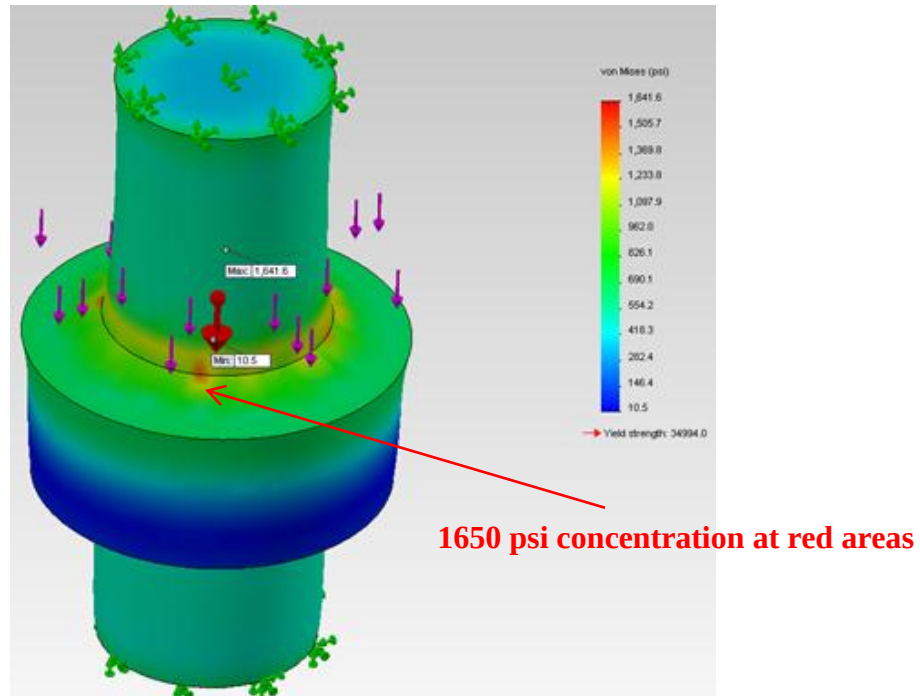


Figure 20: Center Pin Analysis

End Cap Analysis

The end caps resulted in random point stresses of 22 Ksi at maximum.

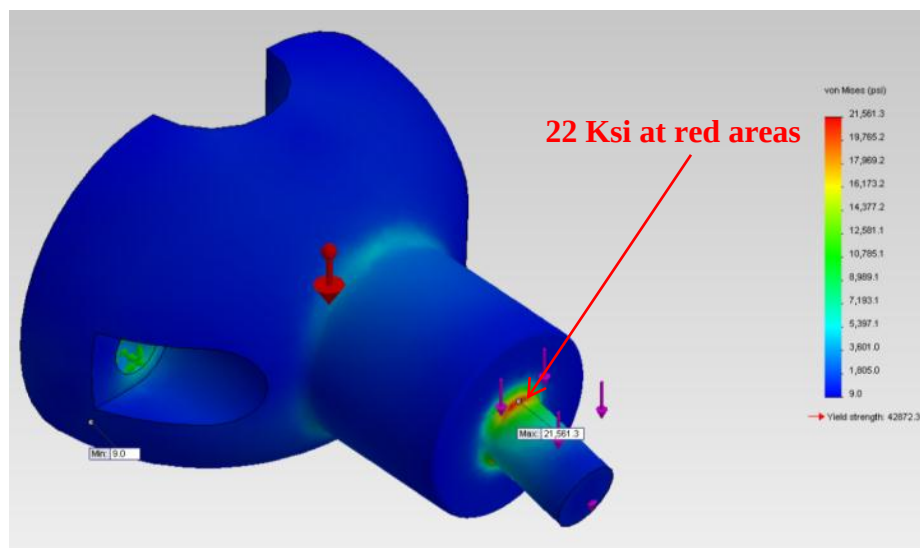


Figure 21: End Cap Analysis

Safety Factor Analysis of points of concern

After analyses of all the components were complete areas of concern were identified and safety factors were assessed. The only true area of concern is the frame which as discussed previously will not actually experience conditions this intense.

Table 2: Safety Factor Summary

Component	Max Pressure (Ksi)	Yield Strength (Ksi)	Safety Factor
Frame	53.2	98	1.84
Center Pin	1.7	98	57.6
End Cap	22	98	4.5
Hex bolt	14	139	9.9
	Max Load (lb)	Allowable Load (lb)	
Thrust Bearing	500	1600	3.2
Roller Bearing	500	59500	119.0

COMPONENTS AND ASSEMBLY

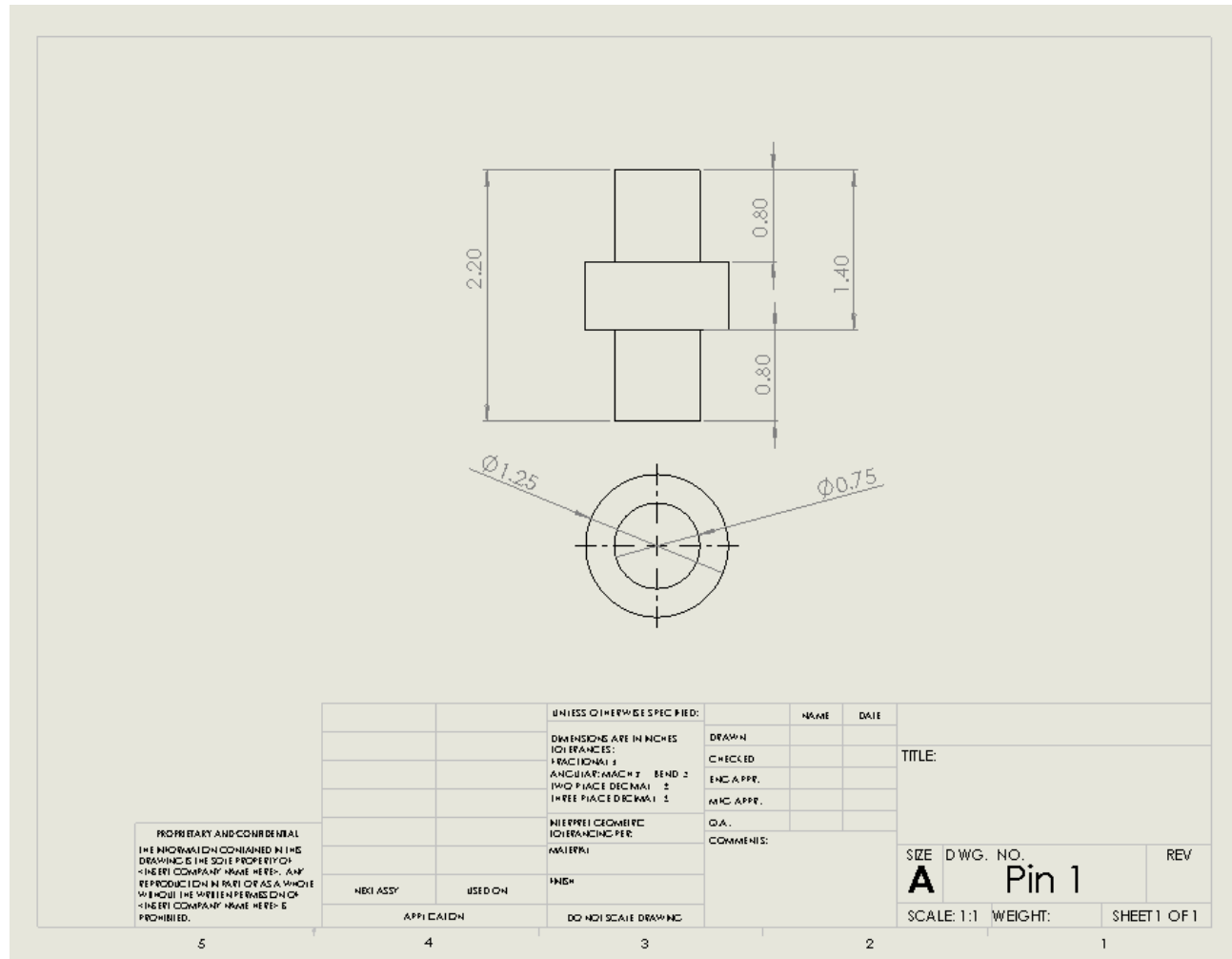
DESIGN DRAWINGS

Figure 22: Center Pin Design Drawing

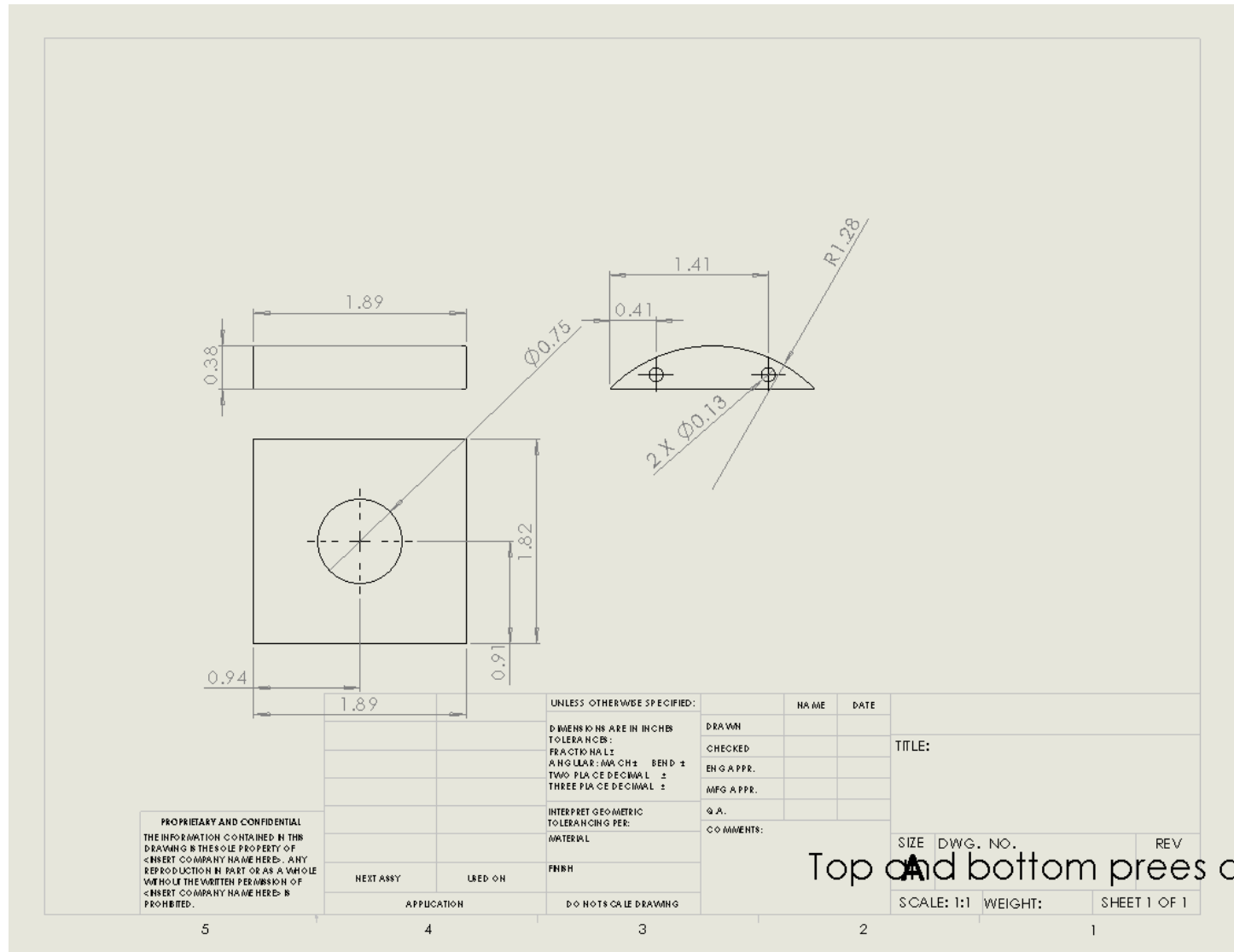
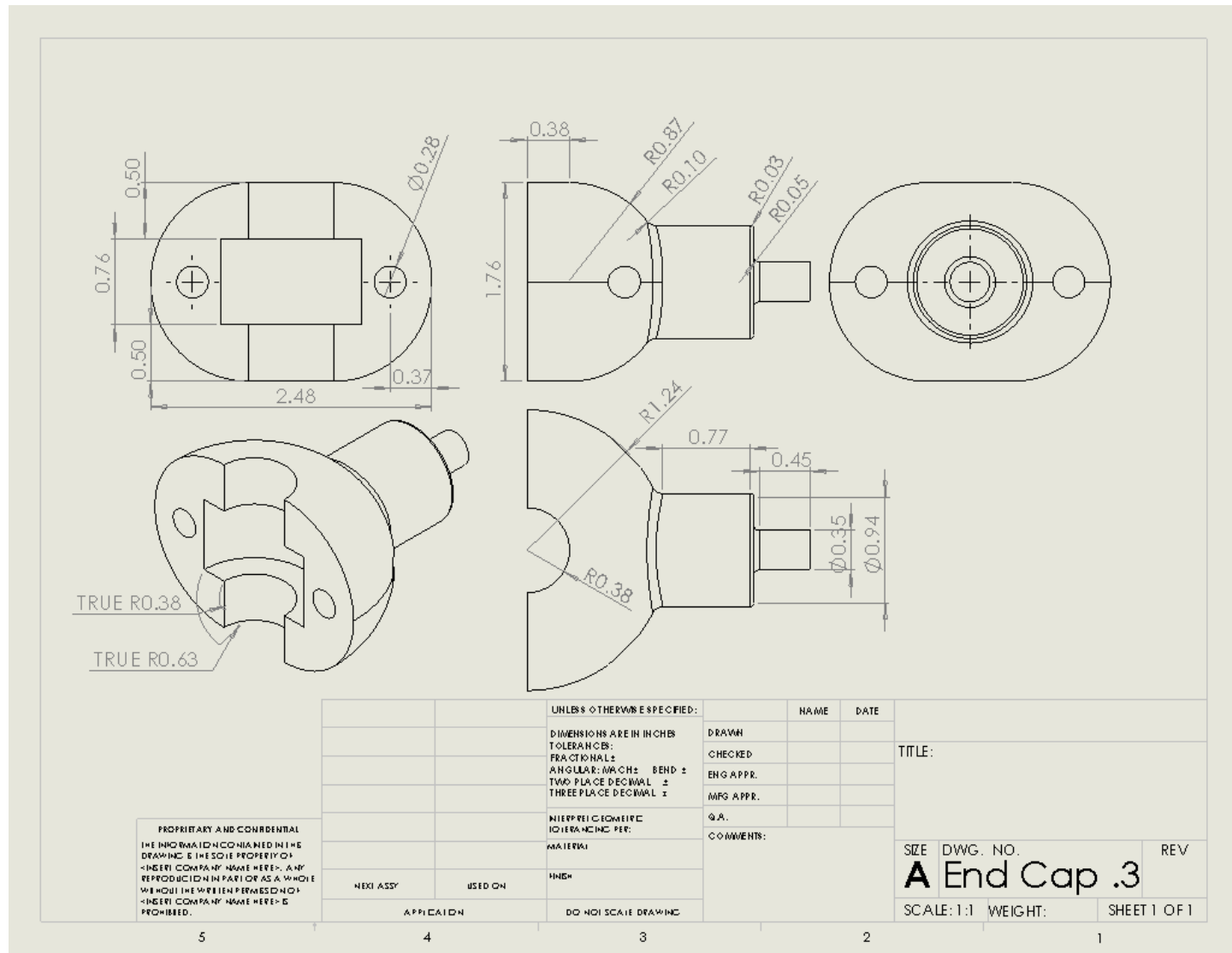


Figure 23: Top Cap Design Drawing



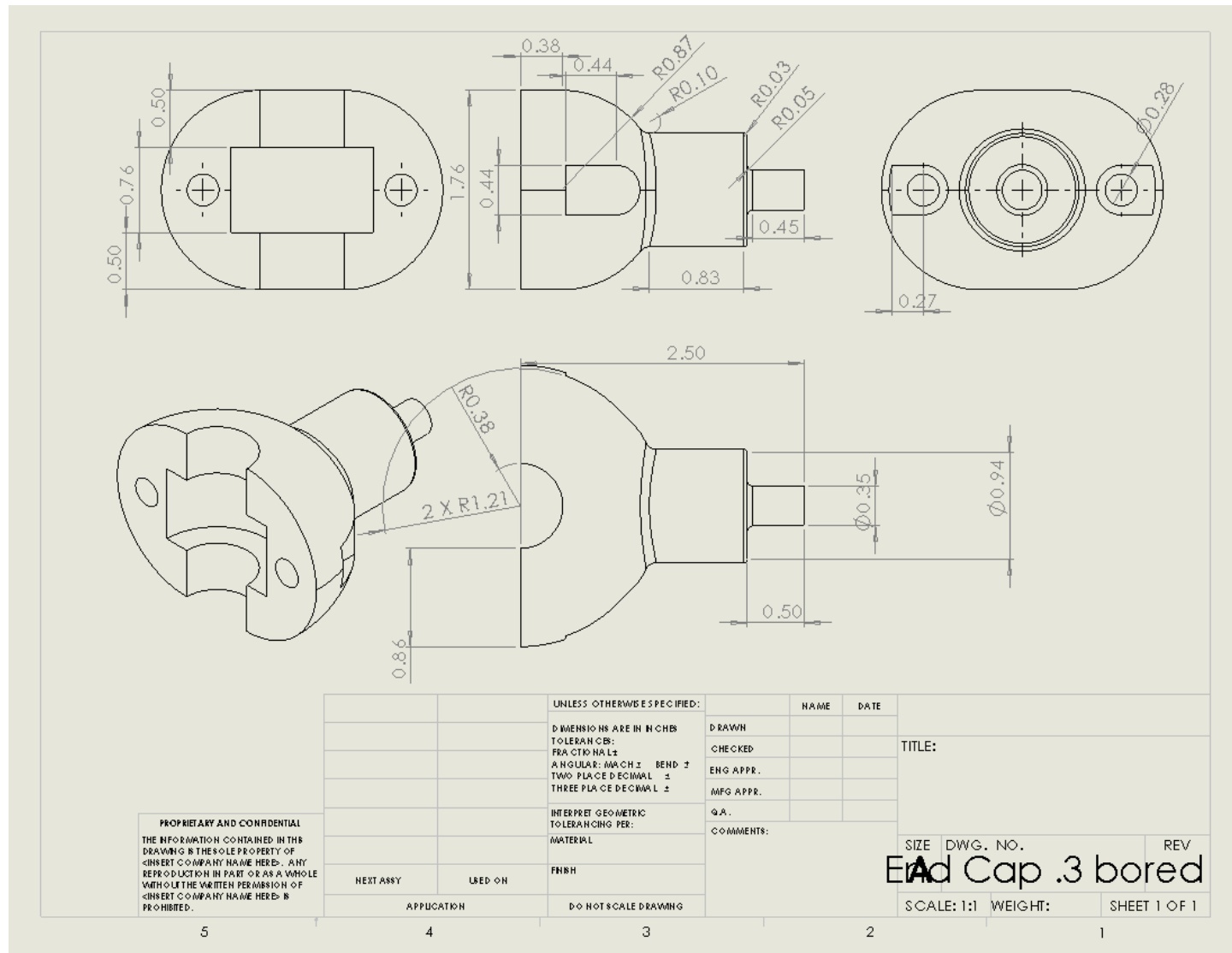


Figure 25: End Cap Bored Design Drawing

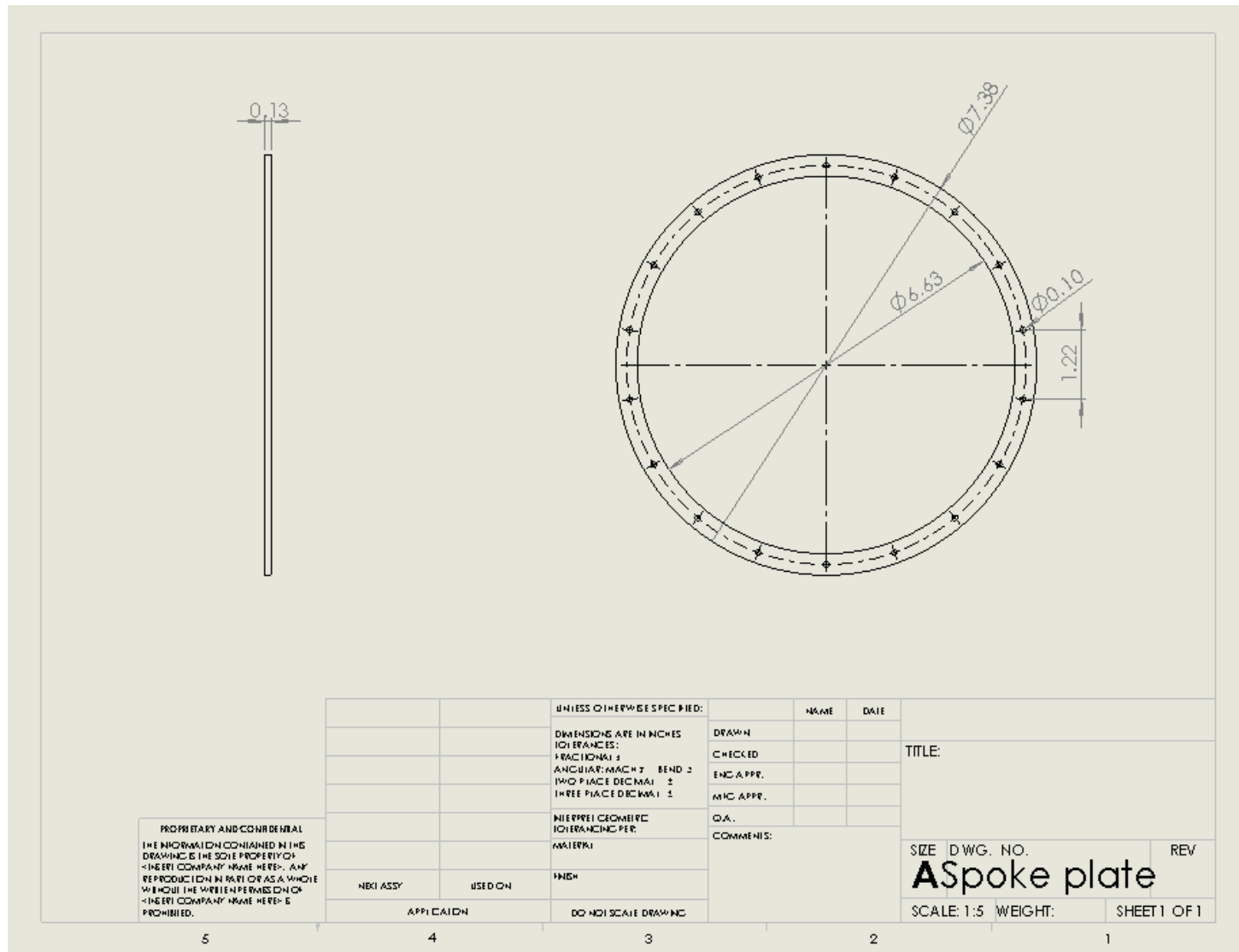


Figure 26: Spoke Plate Design Drawing

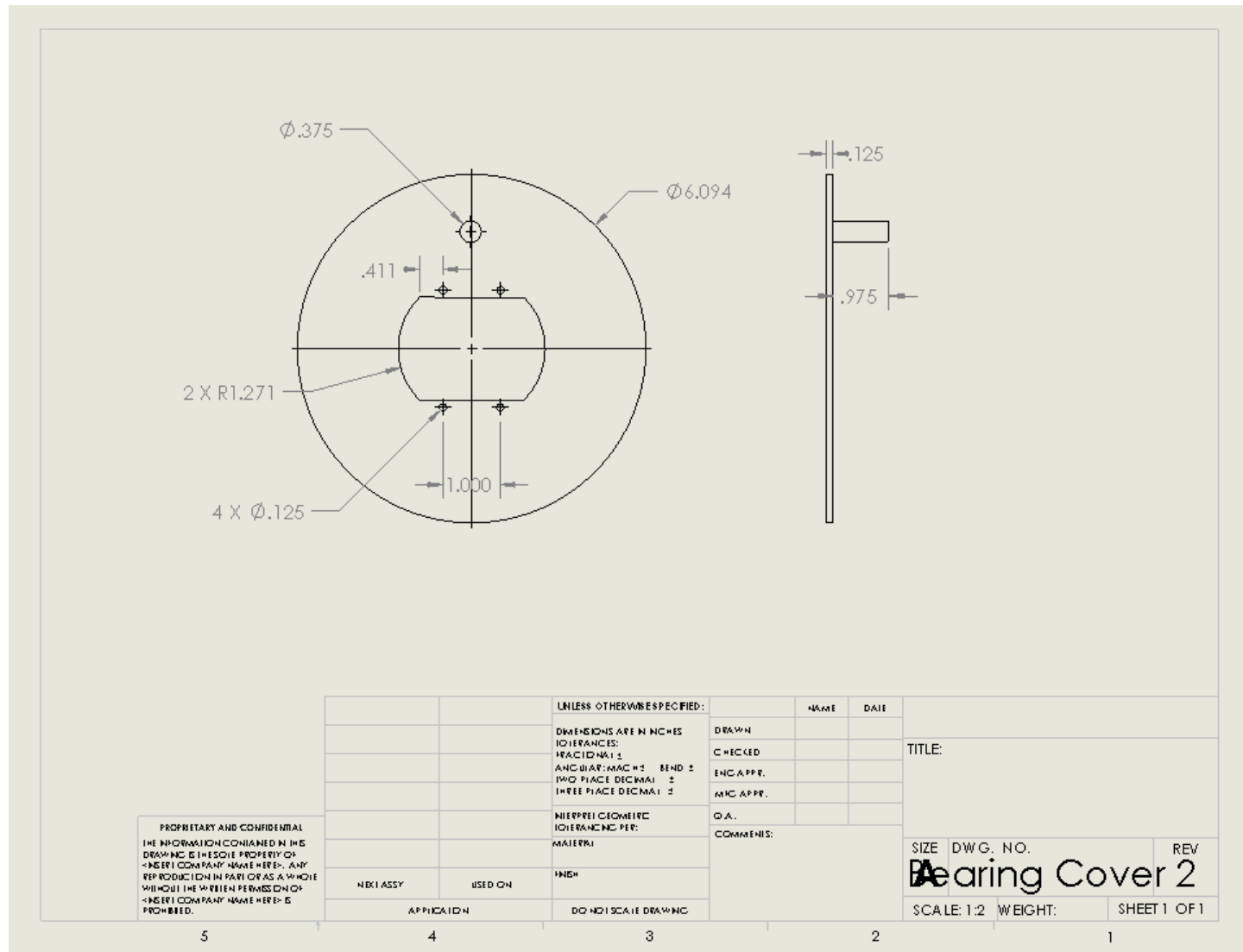


Figure 27: Bearing Cover Design Drawing

The following dimensions show critical dimensions for creating a complete custom frame utilizing a standard bicycle frame. The frame used in this project did not require a complete front frame re-build as the donated bicycle utilized oversized chromoly tubing.

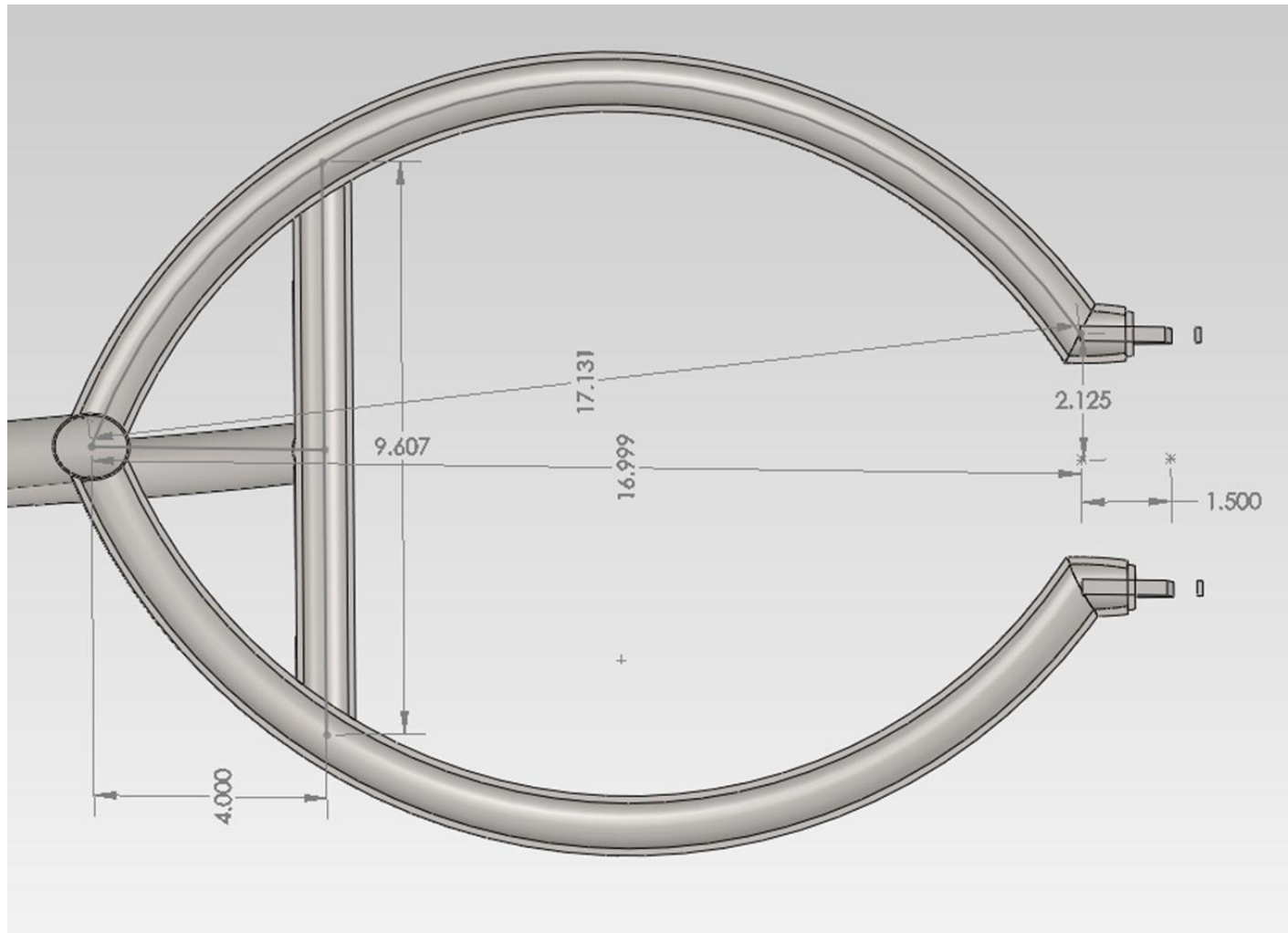


Figure 28: Control Arm Critical Planar Dimensions

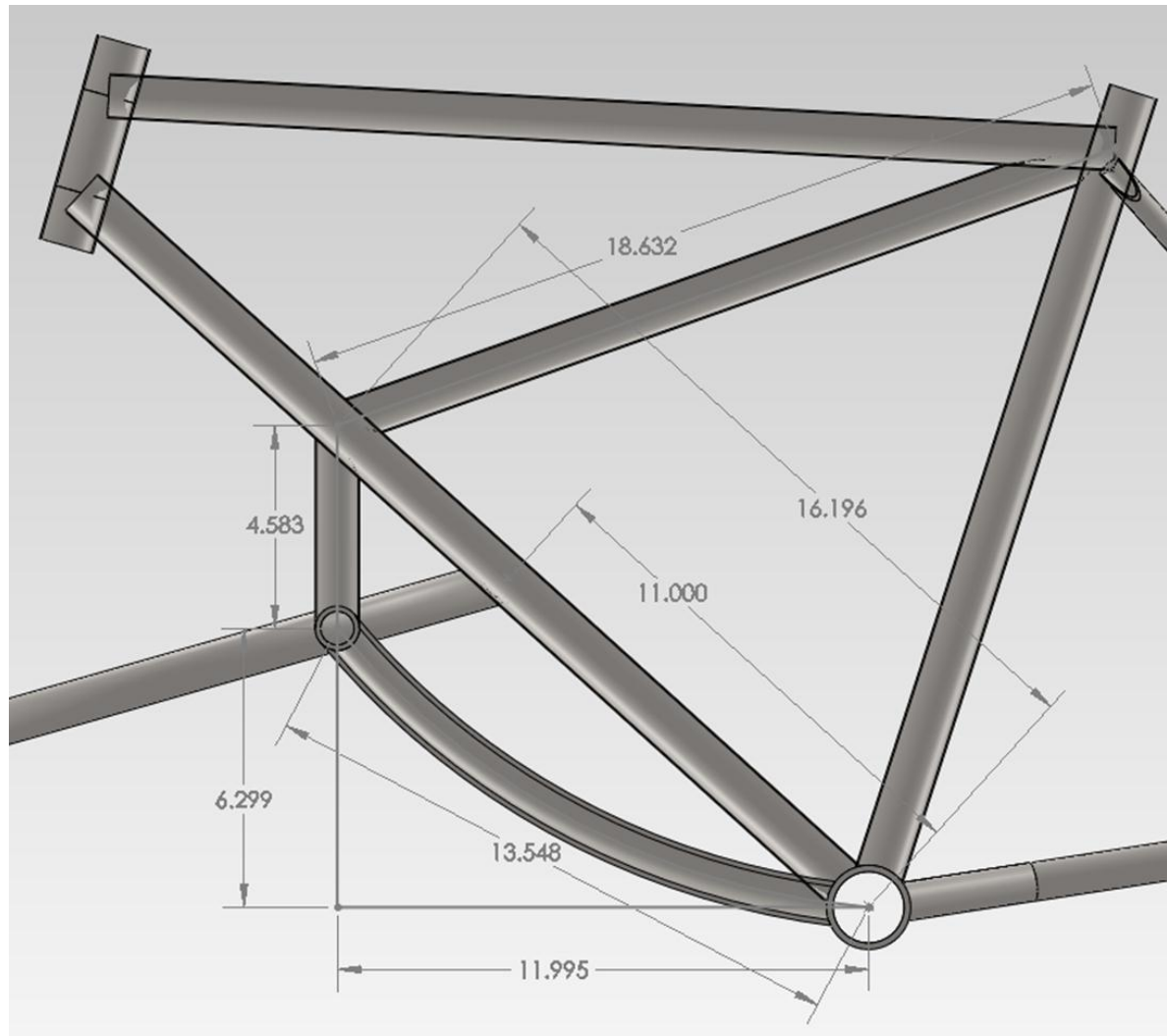


Figure 29: Frame Side Profile Critical Dimensions

PURCHASED COMPONENTS

NTN Spherical Roller Bearing Bore 65 mm

Spherical Roller Bearing, Open, 22300 Series, Bore 65 mm, Bore Dia 2.5591 In, Outside Dia 140 mm, Outside Dia 5.5118 In, Width 48 mm, Width 1.8898 In, Dynamic Load Capacity 59,500 Lb, Static Load Capacity 71,000 Lb, Temp Range -20F - 250 F, Bronze Cage Material

Item	Spherical Roller Bearing
Type	Open
Series	22300
Bore Dia. (In.)	2.5591
Outside Dia. (In.)	5.5118
Outside Dia. (mm)	140
Width (In.)	1.8898
Width (mm)	48
Dynamic Load Capacity (Lb.)	59,500
Static Load Capacity (Lb.)	71,000
Temp. Range (F)	-20F - 250
Cage Material	Bronze
Lubrication	Not Lubricated
Agency Compliance	ISO



Figure 30: Roller Bearing

INA Needle Thrust Bearing, Bore.750 In

Thrust Bearing, Needle Roller, Axial Direction, Bore Dia. 0.750 In., Outside Dia. 1.250 In., Height 0.078 In., Dynamic Load Capacity 1,664 Lb., Static Load Capacity 3,350 Lb., Max. RPM 9500, Steel Cage Material, Temp. Range -5 - + 250 F, OIL Lubrication

Item	Thrust Bearing
Type	Needle Roller
Direction	Axial
Bore Dia. (In.)	0.750
Outside Dia. (In.)	1.250
Height (In.)	0.078
Dynamic Load Capacity (Lb.)	1,664
Static Load Capacity (Lb.)	3,350
Max. RPM	9500
Cage Material	Steel
Temp. Range (F)	-5 - + 250
Lubrication	OIL

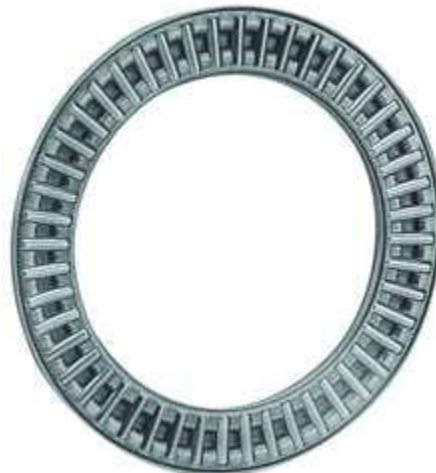


Figure 31: Thrust Bearing

41-1-1875 ROUND CHROMOLY TUBE 4130N,
1 x 0.1875

1 in. Outside Diameter
0.1875 in. Wall thickness
0.625 in. Inside Diameter
1.3580 lbs. per foot



Figure 32: 41-1-1875 Chromoly

6" Schd. 120 Pipe made with high carbon steel

8" square of steel (any type)

1/4" or larger steel rod for steering connector

ASSEMBLY

Inner Hub Assembly

1. Place thrust bearings on each side of the center pin.
2. Press endcaps onto each side of center pin.

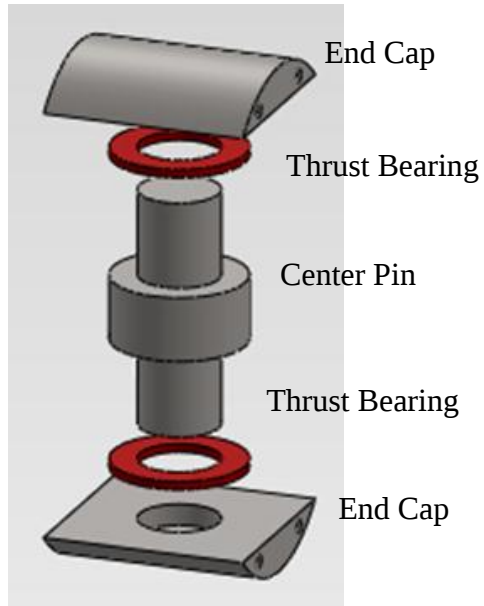


Figure 33: Inner Hub Assembly diagram

Outer Hub Assembly

1. Weld spoke bracket onto each side of the pipe

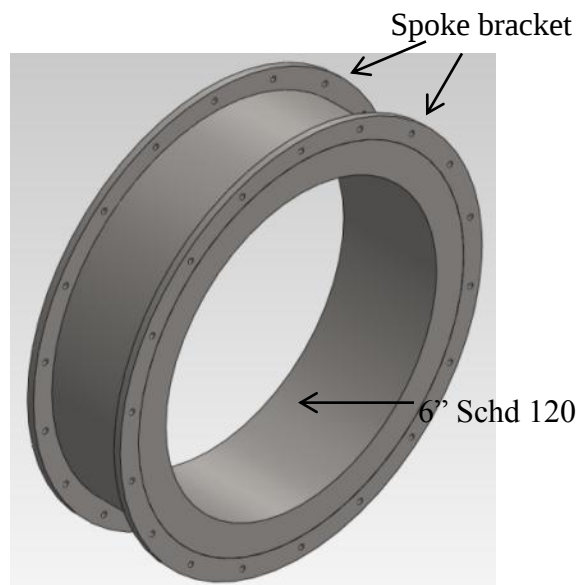


Figure 34: Outer Hub Assembly

Press fit center hub

1. First Press inner hub assembly into roller bearing
2. Second press outer hub assembly onto roller bearing

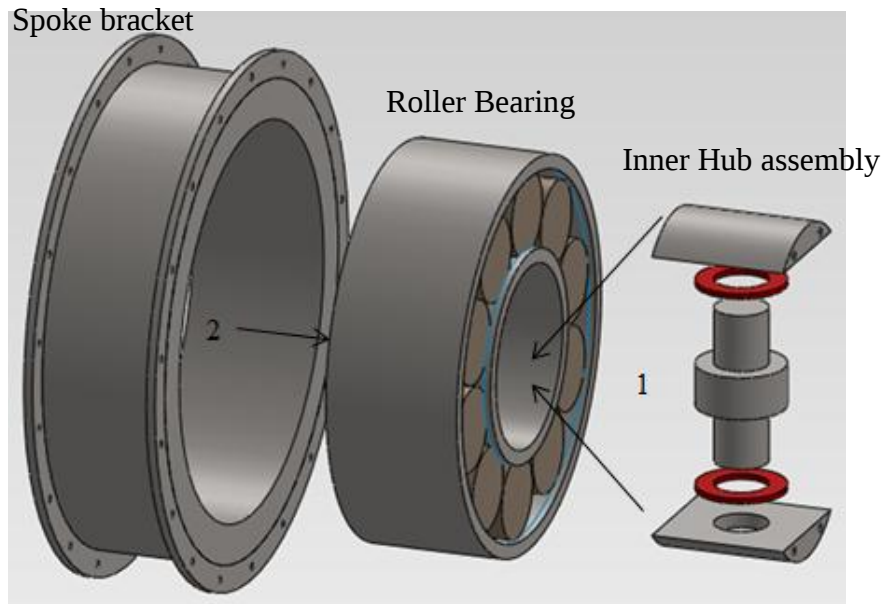


Figure 35: Press Fitting Center Hub

Bolt on End Caps

1. Bolt on End Caps using two $\frac{1}{4}$ " Hex head machine screws, fine thread, 1 $\frac{1}{8}$ " long

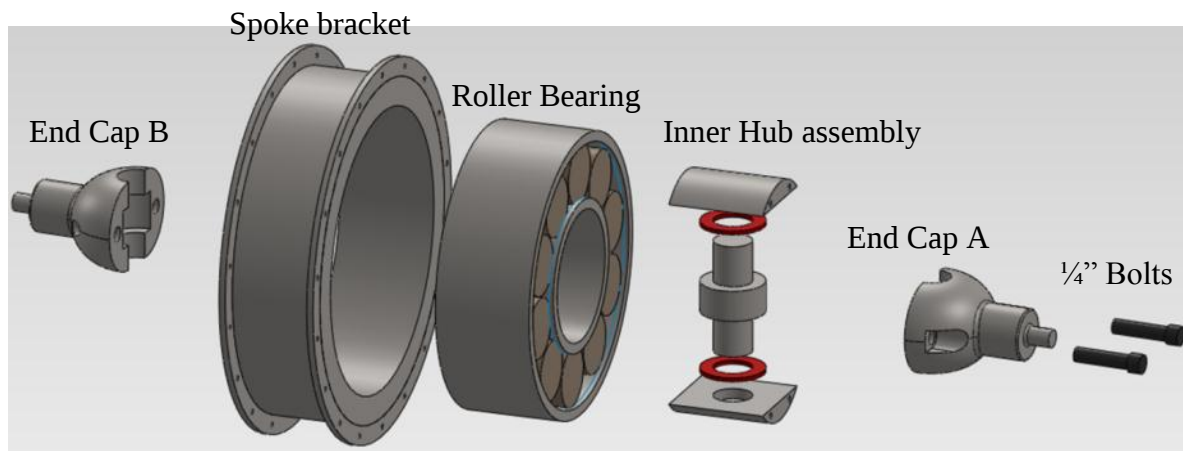


Figure 36: End Caps and everything in-between

Final Hub Assembly

Without Cover and colored for convenience

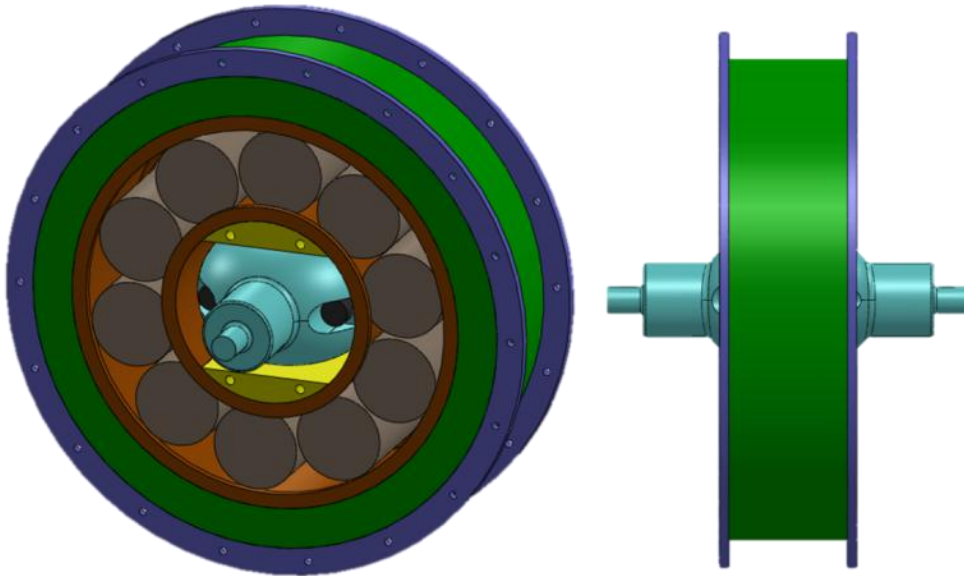


Figure 37: CAD Final Hub Assembly without cover

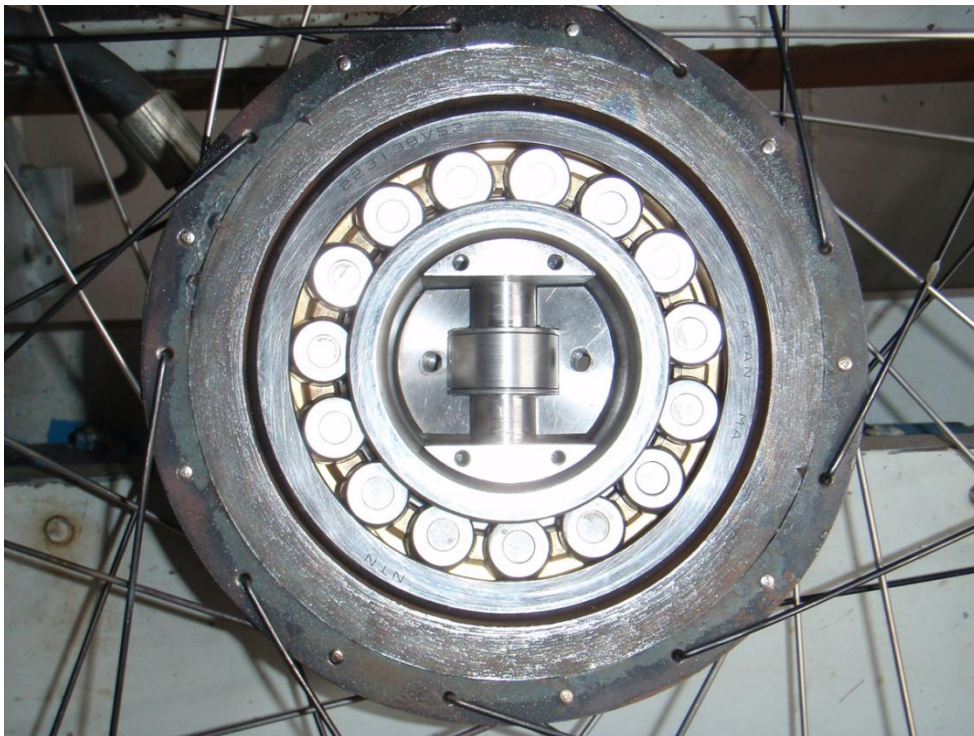


Figure 38: Actual Final Hub Assembly

The actual final hub assembly picture does not have the other end cap on it to illustrate the features of the completed design.

With Cover

1. Bolt on Cover using four 1/8" hex cap screws, coarse thread, 1/2" long



Figure 39: CAD Final Hub Assembly with cover



Figure 40: Actual Hub Assembly with cover

Figure 40 is upside down because it is easier to see the components.

Final Assembly

1. Attach center hub to wheel using custom length spokes (easily cut to length)
2. Connect wheel to bicycle frame
3. Ride and enjoy!



Figure 41: CAD Frame and complete wheel assembly



Figure 42: Final Frame and Wheel Assembly

TESTING METHODS

1. The bike will be ridden for a prolonged period of time to prove it works.
2. Bicycle will also be flip tested and compared to a standard bicycle with a rim brake.
3. A wheelie will be performed in which the front wheel will be slammed to the ground vigorously in an attempt to simulate the estimated 500 ft-lb force.

TESTING RESULTS / PROOF OF DESIGN

1. The bicycle was ridden and the hub center steering system does work. Originally the steering connections were slightly offset which made the wheel very hard to turn. This was an unexpected bonus as it proves the large center pin also helps to eliminate unwanted wheel displacement. This proved that the hub center steering system will only allow for unidirectional displacement of the wheel, exactly what the primary goal of this project was.
2. The bicycle was not flipped over because it could not be done. The rim brakes utilized were not strong enough to create a moment. This is a success as the bicycle could not even create a moment.
3. A wheelie was attempted but due to all steel construction it was virtually impossible to lift the front wheel off the ground.

RECOMMENDATIONS

The largest problem was a result of the weight of the all steel construction and the extremely oversized bearing. A custom wheel bearing would be extremely conducive to a new design. It would not only decrease weight but allow for much more efficient wheel connections. Aluminum construction would also help, but the control arms would need to be modified. I-beam style control arms should be utilized and therefore thinner tubing yielding a light design.

The second largest problem was the rim breaks. They were not capable of using the maximum breaking force available. Therefore a disc break should be utilized, which can be integrated into the custom bearing.

Bushing and bolts should be utilized instead of welds allowing for less tension at the joints. Also if bolts and bushing are utilized a suspension should be added as well. It can simply be substituted for the control arm support bar.

Lastly it would be easiest to build a complete custom chassis instead of modify existing bicycles. It would allow for better fitment of parts and reduced weight as stress areas change with a hub center steering system,

CONCLUSION

Hub center steering is a great idea, but it holds limited applications. It is impractical to produce a bicycle in this fashion because it makes it too heavy and expensive. However when this steering system is scaled up for a high speed motorcycle it becomes more practical as higher velocities are obtained. Removing lateral wheel displacement at high speeds is very

important and increases safety exponentially. Secondly more useable braking power yields a shorter stopping distance which is always wonderful for both vehicle operator and bystanders.

As time progresses on the need for new steering systems will arise. It can be speculated that hub center steering is starting its slow rise in popularity because we are at the threshold of speed where standard front fork suspensions are becoming obsolete due to safety concerns.

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13. **Shannon, Shawn.** *Cycling enthusiast*. Cincinnati, 11 23, 2011.

APPENDIX A - RESEARCH

Interview with original project developer, Sep. 24, 2011

Ryan Lindenberger, motorcycle enthusiast/project originator, University of Cincinnati, 2600 Clifton Ave. Cincinnati, Oh 45221. (12)

After seeing Stellen Egeland's BMW Harrier, realized the potential for hub center steering.

No affordable models exist to date.

The separation of braking, suspension, and steering provides longevity of many parts.

Hub center steering eliminates the front fork acting as a lever arm, increasing the rider's safety dramatically.

The design should be intended to be scalable for use on a motorcycle.

Design would be most suitable on a high performance motorcycle.

Interview with cycling enthusiast Shawn Shannon, Nov. 23, 2011

Shawn Shannon, cycling enthusiast, ex-mountain bike racer, Cincinnati, Oh 45221 (13).

Used to race mountain bikes recreationally.

Has always been looking for a way to increase useable braking power, especially for downhill events.

Thinks there could be potential for a hub center steering design, but fears weight may be the biggest downfall.

Affordability will most likely be the main factor for determining customer's desire for a product this radical.

<http://thekneeslider.com/archives/2009/01/28/stellen-egelands-bmw-harrier/>
9/26/11 Stellen Egeland's BMW Harrier
Thekneeslider.com



Figure 43 : Stellen Egeland's BMW Harrier 2

Complete custom bike that utilize hub center steering, created and built by Stellen Egeland of SE Service.

Created from a BMW 1200RS, this is a very unique and rare build.

This particular hub center steering system is now sold by ISR of Sweden as a conversion kit.

Complete custom build

Very expensive

Very rare

Proof it can be done

Suggests possible market for this product

Very little information available

Designed and built in Europe

<http://www.isrbrakes.se/products/ns2/>
9/26/11 Hub center steering kit from ISR of Sweden
Isrbrakes.se



First and only conversion kit offered to turn a motorcycle from front fork suspension to hub center steering.

Same system used on the BMW Harrier.

Complete custom built front ends

Very expensive, \$6700 for cheapest possible set up

Proof there is a market for this kind of item

Expensive to import/ship

Designed and built in Europe

<http://www.britten.co.nz/>
9/26/11 Britten V1000



Figure 44 : Britten V1000

The Britten V1000 was not a hub center steering motorcycle, but was the first to utilize a double wishbone front suspension. This motorcycle won numerous racing titles in 1991, 1992, 1993, and 1994 proving that a traditional motorcycle front fork was indeed a design worth reconsidering.

Race tested and proven

Front fork is less of a lever with this design

Extremely Rare

Priceless, and unable to be obtained.

Designed and built in Europe

<http://www.zeppelin-works.nl/II/Verstegen-1.htm>
9/26/11 ChiQane Prototype
www.zeppelin-works.nl



Eric Versteegen, maker van de tekeningen in deze website,
mocht zich de winnaar noemen
van de designwedstrijd voor de ChiQane II.

Figure 45 : ChiQane Prototype

This is a picture of a motorcycle made by ChiQane motorcycles, a Dutch company that apparently specializes in hub center steering and makes custom motorcycles. From a rough translation of their website, they started in 1999 and specialize in hub center steering.

ChiQane seems to be the parent company to “Zeppelin Works”.

Extremely rough translation of website is only information available.

Specialize in hub center steering

Dutch company that seems to be starting a hub center steering race team

Proof there is a market for similar items

<http://thekneeslider.com/archives/2010/02/02/zepelin-board-track-racer-with-hub-center-steering/>
9/26/11 Zeppelin Board Track Racer with Hub Center Steering
Thekneeslider.com

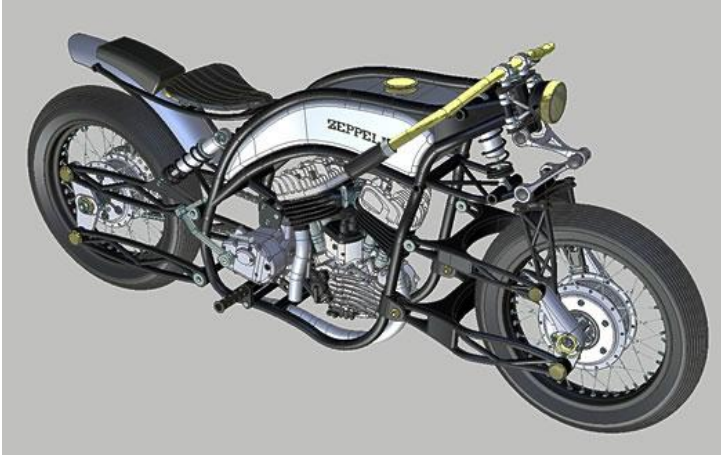


Figure 46 : Zeppelin Boardtracker 2

Roel van der Heide is the inventor of this motorcycle, which is attempting to launch a company called “Zeppelin Works”, they seem to be affiliated with a Dutch company called “ChiQane” who makes custom motorcycles that utilize hub center steering.

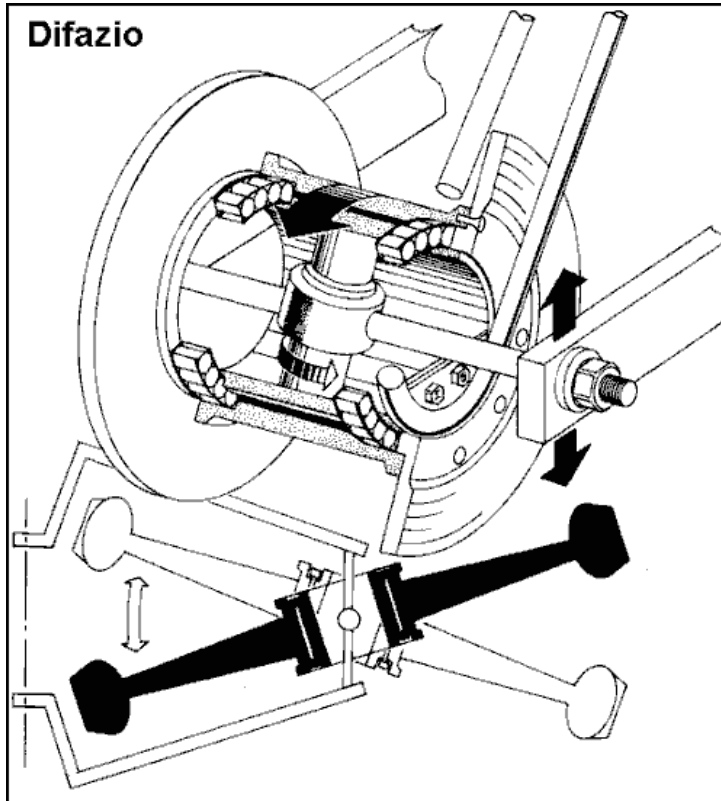
Still just a concept

This concept was the launch by a Dutch Company called “Zeppelin Works”, which seems to work with ChiQane motorcycles.

Use of front fork is still used in this concept, but eliminates it acting as a lever arm during braking.

European design

<http://www.tonyfoale.com/Articles/Steer/STEER.htm>
9/26/11 Steer For The Future
www.tonyfoale.com



This design is from the late 1970's and was designed by Jack Difazio. It seems to be the basic building block for modern hub center steering systems.

Old design that has been re-modified several times

Large bearings are need

Large bearings are expensive

Automotive bearings may have similar size requirements, and are very common

http://en.wikipedia.org/wiki/File:Ner-A-Car_1924_01.jpg
9/26/11 Ner-a-Car
En.wikipedia.com

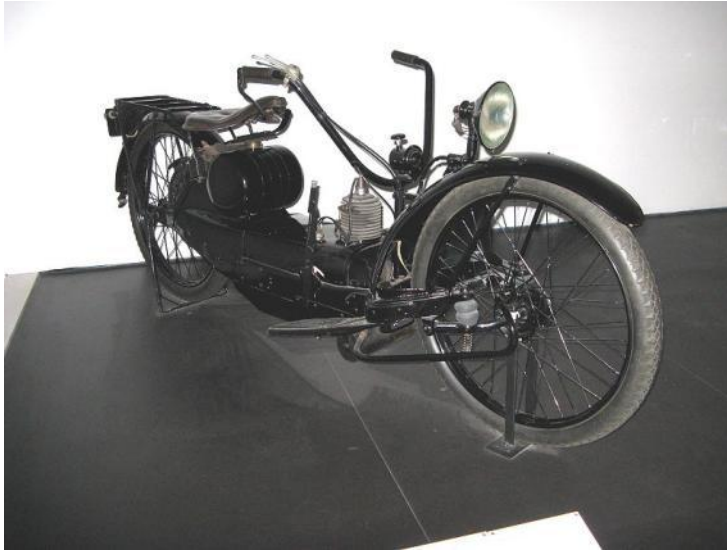


Figure 47 : Ner-A-Car

This is a 1924 Ner-A-Car, the original company to utilize hub center steering. It was first built in 1921 and then went out of business in 1926, “due to lack of popularity” (11)

Original motor vehicle to utilize hub center steering

Bulky, heavy, and slow

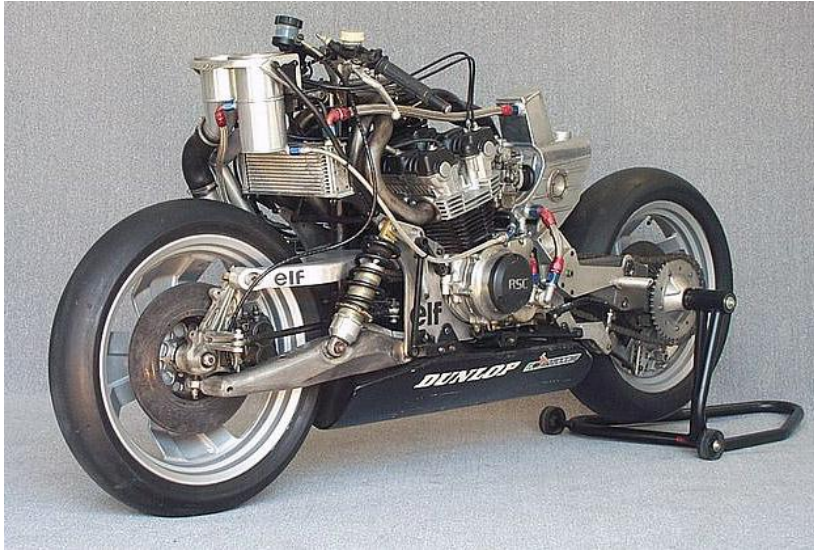
Went out of business due to lack of interest

British Design

<http://www.bikeexif.com/elf-honda>

11/3/11 Honda Elf

www.bikeexif.com



The Honda Elf was produced from 1981 to 1983, and produced a number of patents for Honda. The motorcycle was created by Renault designer Andre de Cortanze. Though the ELF was very fast, often qualifying on pole and leading early laps, the chassis was unreliable, and production was stopped in 1983. It was analyzed by Honda under secret contract in 1985 and saw one last race in 1988 then was retired.

1000cc motor was too powerful

Chassis is unreliable

Only in production 3 years (1981-1983)

Six world-speed records at Italy's Nardo test track in 1986

Highest place in race was 3rd at Mugello in 1983

http://www.bimota.it/it/modelle/tesi_3d_e.htm
11/3/11 Bimota Tesi 3D
www.bimota.it



Figure 48 : Bimota Tesi 3D close up

This is the third hub center steering motorcycle made by Bimota. There was the Tesi, Tesi 2D, and Tesi 3D. It is intended to be raced but has not recorded racing heritage currently.

3rd design iteration by Bimota

Has hub center steering in rear wheel also

Only distributed in Europe

Proof there is a market for this design concept

Direct competitor to ChiQane

http://www.motorcyclistonline.com/firstrides/122_2006_bimota_vyrus_985/index.html
11/11/11 Vyrus 985
www.vyrus.it



Figure 49: Vyrus 985

Vyrus 985 is the latest invention of an ex-Bimota mechanic Ascanio Rodriguez and ex-Ducati designer Sam Mathews. The first hub center steering bike they produced was in 2003. They claim 70 bikes like this have been made and sold.

Latest design for
hub center steering
motorcycle

Semi-popular in
Europe for a
custom bike

Proof of market for
this concept

APPENDIX B – SURVEY AND HOUSE OF QUALITY

CUSTOMER SURVEY WITH RESULTS

The purpose of this survey is to discover if there is any interest in a bicycle with hub center steering. The primary objective is to establish satisfaction with current bicycles on the market and discover what improvements customers desire most.

How important is each feature to you in the design of a bicycles front suspension?

Please circle the appropriate answer. 1 = low importance 5 = high importance

							Avg.
Safety	1	2	3(1)	4(2)	5(36)	N/A	4.9
Reliability	1	2	3	4(9)	5(30)	N/A	4.8
Ease of maintenance	1	2(4)	3(10)	4(17)	5(8)	N/A	3.7
Ease of operation	1	2	3(9)	4(12)	5(18)	N/A	4.2
Environmental Friendliness	1(7)	2(19)	3(2)	4(8)	5(3)	N/A	2.5
Maneuverability	1	2	3(4)	4(21)	5(14)	N/A	4.3
Ease of front wheel removal	1	2(1)	3(5)	4(28)	5(5)	N/A	3.9
Appearance	1(1)	2(3)	3(14)	4(10)	5(7)	N/A	3.4
Corrosion resistance	1	2	3(9)	4(13)	5(17)	N/A	4.2

How satisfied are you with your current bicycles?

Please circle the appropriate answer. 1 = very UNsatisfied 5 = very satisfied

							Avg.
Safety	1	2(3)	3(1)	4(8)	5(27)	N/A	4.5
Reliability	1(1)	2	3(8)	4(19)	5(11)	N/A	4.0
Ease of maintenance	1(1)	2	3(2)	4(31)	5(5)	N/A	4.0
Ease of operation	1	2	3(1)	4(2)	5(36)	N/A	4.9
Environmental Friendliness	1	2	3	4(14)	5(20)	N/A(5)	4.5
Maneuverability	1	2	3(3)	4(16)	5(20)	N/A	4.4
Ease of front wheel removal	1	2(2)	3(5)	4(13)	5(19)	N/A	4.3
Appearance	1(1)	2(3)	3(14)	4(12)	5(9)	N/A	3.6
Corrosion resistance	1(1)	2(2)	3(1)	4(12)	5(23)	N/A	4.4

How much would you expect to pay for a bicycle?

\$200- \$400(6) \$401 - \$600(21) \$601 - \$800(8) \$801 - \$1000(3) over \$1000(1)

How much would you expect a bicycle to weigh?

Under 20 lbs.(1) 20 – 25 lbs.(13) 26 – 30 lbs.(18) 31 – 35 lbs.(7) 35 – 40 lbs.
Over 40 lbs.

Thank you for your time

House of Quality

Table 3 : House of Quality

Craig Davis Hub-Center Steering 9 = Strong 3 = Moderate 1 = Weak	Safety Factor	Reduced number of components	Use of Standardized Parts	Parts located in Standard Location	Recyclability	Turning Radius (ft)	Time to Reomve front wheel (s)	Color	Material	Weight (lb)	Customer importance	Designer's Multiplier	Current Satisfaction	Planned Satisfaction	Improvement ratio	Modified Imporance	Relative weight	Relative weight %
	Safety	9				3			3	1	4.9	1.0	4.5	5.0	1.1	5.4	0.14	14%
	Reliability	9	3						1		4.8	1.0	4.0	4.9	1.2	5.9	0.15	15%
	Ease of Maintenance		3	9	3		1			1	3.7	1.1	4.0	4.0	1.0	4.1	0.10	10%
	Ease of operation			1	9	1				1	4.2	1.0	4.9	5.0	1.0	4.3	0.11	11%
	Enviromental Friendliness		1			9			1		2.5	1.0	4.6	3.0	0.7	1.6	0.04	4%
	Maneuverability					9				1	4.3	1.2	4.4	4.0	0.9	4.7	0.12	12%
	Ease of Front Wheel Removal						9				3.9	1.2	4.3	4.0	0.9	4.4	0.11	11%
	Appearance							9			3.4	1.0	3.6	4.5	1.3	4.3	0.11	11%
	Corrosion Resistance								9		4.2	1.0	4.4	4.5	1.0	4.3	0.11	11%
	Abs. importance	2.62	0.81	1.05	1.31	0.38	1.62	1.11	0.98	1.61	0.48	12.0				38.9	1.0	
	Rel. importance	0.22	0.07	0.09	0.11	0.03	0.14	0.09	0.08	0.13	0.04	1.00						

APPENDIX C – PRODUCT OBJECTIVES AND SCHEDULE

Product Objectives Hub-Center Steering for a motorcycle

The following is a list of product objectives and how they will be obtained or measured to ensure that the goal of the project was met. The product objectives will focus on hub-center steering system for a bicycle as opposed to the standard front fork suspension. The bicycle is intended as a proof of concept to be utilized on high performance motorcycles.

Reliability: 15%

- 1.) A factor of safety of at least 2 will be utilized and proven by COSMOS to show that structural components of the steering system will not fail.
- 2.) Mechanical assembly will follow allowable torques of mechanical fasteners and the use of proper lubricants and lock fasteners where required.
- 3.) Chassis will be painted upon final assembly to aid in corrosion resistance.

Safety: 14%

- 1.) Increase in useable braking force for front brake.
- 2.) Increase in force required to create a moment around front fork, causing vehicle to flip over its own front end.

Ease of Operation: 13%

- 1.) Vehicle will operate in the same manner as standard bicycle.
- 2.) All control locations will remain in same location.

Ease of Maintenance: 11%

- 1.) Parts will be in standard bicycle locations, with no specialty tools required.
- 2.) Rubber bushings will be utilized where necessary, along with corrosion resistant materials.

Ease of Front Wheel Removal: 11%

- 1.) Front wheel will use a standard quick release system.

Maneuverability: 9%

- 1.) The vehicle will retain at least 80% of its previous turning radius.
- 2.) Vehicle will weigh less than 40 lbs.

Environmental friendliness: 4%

- 1.) Paint used on chassis will be Eco-friendly.

Cost: N/A

- 1.) The vehicle will be built for under \$700.

Universal: N/A

- 1.) The hub-center steering system will be able to attach to other bicycles.
- 2.) Steering system will be scalable for motorcycles.

APPENDIX D – SCHEDULE AND BUDGET

The project schedule for calculations and design begin January 3, 2012 with the completion of a weighted objective method and proof of design statement. The project timeline ends June 4, 2012 when the final report is submitted. Complete schedule can be seen below. The yellow is the original estimations and the white underneath is the actual day it was finalized or revised.

Craig Davis Hub Center Steering	Nov 20-26	Nov 27- Dec 3	Dec 4 - 10	Dec 11 - 17	Dec 18 - 24	Dec 25 - 31	Jan 1 - 7	Jan 8 - 14	Jan 15 - 21	Jan 22 - 28	Jan 29 - Feb 4	Feb 5 - 11	Feb 12 - 18	Feb 19 - 25	Feb 26 - Mar 3	Mar 4 - 10	Mar 11 - 17	Mar 18 - 24	Mar 25 - 31	Apr 1 - 7	Apr 8 - 14	Apr 15 - 21	Apr 22 - 28	Apr 29 - May 5	May 6 - 12	May 13 - 19	May 20 - 26	May 27 - Jun 2	Jun 3 - 9
TASKS																													
Proof of Design to advisor	23																												
Concept sketches to advisor	23						3																						
Bearing Selection		9						9																					
3D Modeling				24					16																				
Engineering Calculations				24				9																					
Material Selection				24			9																						
COSMOS Testing						6					30																		
Design Modification							13					6																	
Order Material and Bearings								9 26	23 30	6 13	20 27																		
Build hub for wheel										10								19		9									
Build Connecting Links												24								1 8 15 22 29									
First assembly ready for testing														9						1 8 15 22 29									
Parts finished and painted																	23									16			
Final Assembly																			6							16			
Test bicycle																				13						16			
Oral															9		9									16			
Report																	16										21		
Demo to Adviser																									7				
Demo to Faculty																										17			
Oral Final Presentation																											21		
Final Report																											21		4

Key milestone dates:

Table 4: Key Milestone Dates

	Start	End
Concept Development	10/15/2011	12/11/2011
Proof of Design Agreement	11/23/2011	
3-D modeling	12/11/2011	1/3/2012
Calculations and Design	1/3/2012	1/5/2012
Material Selection	1/5/2012	1/6/2012
Order Materials	1/20/2012	
Fabrication begins	2/10/2012	3/9/2012
Winter Oral	3/9/2012	
Winter Report	3/16/2012	
Final Assembly and Modification	4/6/2012	5/28/2012
Spring Oral	5/28/2012	
Final Report	6/4/2012	

Preliminary Budget

Material, Components or Labor	Forecasted Amount
Bicycle	\$0.00 Donated
Custom front wheel bearing	\$200.00
Small press in bearing x 2 \$30 ea.	\$60.00
Front Disc brake system	\$85.00
Extra Steel tubing	\$100.00
Custom wheel spokes	\$60.00
Steel cable	\$20.00
Bolts	\$15.00
Bushings	\$20.00
Misc parts	\$100.00
Total	\$660.00

Revised Budget

Qty	Item	Price	Total
2	1/4-28, 1-1/8" Hex bolt	7	14
2	52100 Chromoly Block (2x2x4in)	80	160
3	52100 Chromoly Block (2x2x2in)	50	150
2	Thrust Bearings	3.24	6.48
2	6" schd 120	10	20
1	Roller Bearing	371.5	371.5
2	Sheets of 1/8 Steel (8x8in)	3	6
2	.2" Diameter Steel rods	2.5	5
140	1x .12 Chromoly tubing	0.72	100.8
8	1/8 hex bolt 1/2"	6.5	52
		Total	885.78
		Previous	660
		\$ over	225.78