DESIGN AND CONSTRUCTION OF A MOTORCYCLE DRUM TO DISC BRAKE CONVERSION

by

Matt Pekin

BioResource and Agricultural Engineering Department

California Polytechnic State University

San Luis Obispo

2016

TITLE	:	Design and Construction of a Motorcycle Disc Brake Caliper Mount
AUTHOR	:	Matt Pekin
Date Submitted	:	June 8, 2016

Senior Project Advisor ______________________ Signature ______________________

Date ______________________

Department Head ______________________ Signature ______________________

Date ______________________

ABSTRACT

This senior project discusses the design and construction of a motorcycle drum to disc brake conversion. The conversion involved creating a custom caliper mount and machining wheel spacers. The wheel, caliper and master cylinder were sourced from other motorcycles.

The project resulted in a motorcycle with a much enhanced braking feel and ability, thus increasing the operator's confidence while riding the vintage motorcycle.

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INTRODUCTION

Background

Motorcycles have been advancing technologically since their inception. The desire for better performance of the machine has led to new technologies. New inventions are tested and if they perform well, they're improved and utilized on future generations of bikes.

In the late 60s and early 70s, motorcycle brake systems were undergoing a transformation from drum to disc style brakes. As far as effectively scrubbing speed, disc brakes proved far superior to the drum brake. Evolution has effectively rendered the drum brake obsolete, reserving its use for only the most base model motorcycles, whose manufacturers cannot justify fitting the more expensive disc brake.

The motorcycle that is the subject of this senior project is a 1973 Yamaha CT3, a 175cc two stroke enduro style motorcycle. Produced during the transitional phase of motorcycle brakes, this motorcycle was delivered from the factory with drum brakes in both the front and rear.

Justification

Brakes are the most important system on a motorcycle. While riding, if other components break, like the engine or transmission, the rider can coast to a stop and be picked up. Conversely, if the brakes fail or do not perform well enough, a rider can find himself in a situation where crashing is the only option. Riding motorcycles is inherently dangerous but is made safer when the rider has better control over the machine. Upgrading the brakes objectively enhances the rider's control.

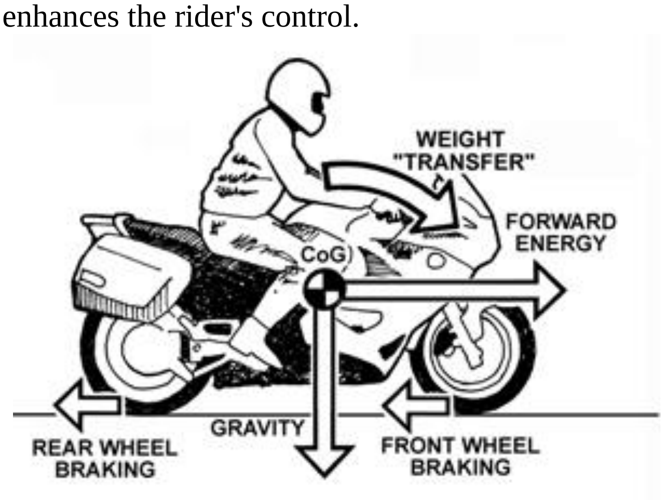

Figure 1, Braking Dynamics (Hough 2015)

As a rider presses the brakes, momentum wants to keep the rider and motorcycle moving forward. Braking creates a weight transfer about the motorcycle and riders combined center of gravity, shown in Figure 1. This transfer greatly increases the load on the front wheel while reducing the load on the rear wheel. This requires the front brakes to provide

60 to 80 percent of the total braking force (Halderman and Mitchell 2004). For this reason, this project involves converting the front brake, as it is the brake doing most of the work and will allow for the greatest increase in braking performance.

Objectives

This senior project converts a 1973 Yamaha's front end brake from a drum brake to a disc brake. The brake conversion does not alter any of the stock drum brake mounting points, allowing reversion to stock if desired. The goal is to reduce the spongy braking feedback caused by the mechanical linkages of the drum brake, and to achieve firm responsive brake feedback utilizing a hydraulic disc brake system.

LITERATURE REVIEW

Research was done to identify current commercially available disc brake conversions for motorcycles and to determine a material suitable for such a project.

CycleX, an internet based, vintage Honda motorcycle parts manufacturer in Wisconsin, produced a drum to disc conversion that utilized the original drum brake wheel. The rotor was mounted to a machined drum insert, and the caliper was mounted to a billet aluminum adapter (Cycle X 2015). Figure 2 shows the CycleX conversion kit.

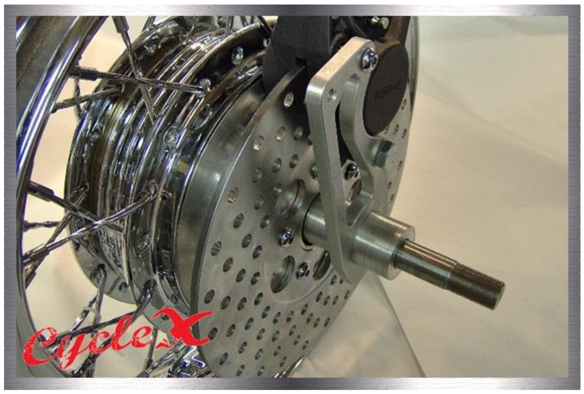

Figure 2: CycleX Honda Disc Brake Conversion

This solution was not satisfactory because the drum brake hub is not being used yet is still on the bike. Any person who analyzed the motorcycle would wonder why the owner went through all the effort to convert to a disc brake only to retain remnants of the drum brake.

Another company, Hitchcock Motorcycles, created a conversion kit for Royal Enfield motorcycles. This conversion kit utilized a custom wheel and spacers that align the wheel. The caliper was mounted to the motorcycle forks by customizing the drum brake anchor and the fender mounts (Hitchcocks Motorcycles, 2010). The components of the kit are shown in Figure 3.

Figure 3: Hitchcocks Motorcycles Conversion Kit Components

This solution does not necessitate a custom caliper bracket because the forks have sufficient mounting points for the caliper. That being said, altering stock configurations was not desirable because the ability to revert to stock is desired. Originality and authenticity were to be preserved.

The most relevant conversion found was produced by ScootRS, shown in Figure 4. Utilized on vintage Vespa type scooters, this brake kit used the axle and fork as mounting points for the brake. This kit's caliper mount is made from steel which is very robust. Installation of the kit required the removal and cutting of the fork in order for it to fit into the bottom supports. (ScootRS, 2016)

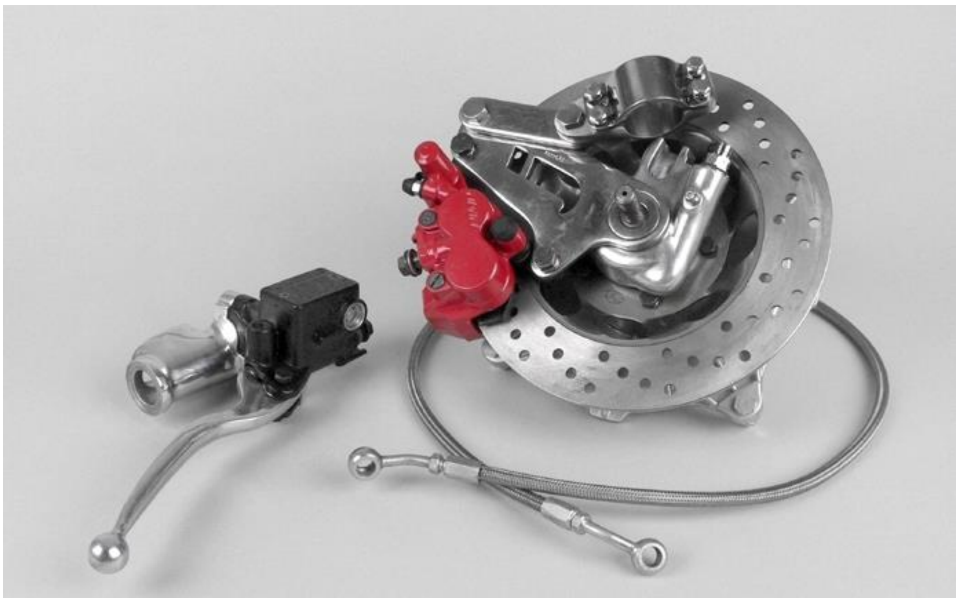

Figure 4. ScootRS Disc Brake Conversion

The steel caliper mount looked like a good idea. Potential issues utilizing this style design were interference and originality. Extra parts to be fitted between the fork stanchions needed to be well designed in order to ensure no interference between the caliper, mount and wheel. The ScootRS design required alterations to the fork that does not allow an easy reversion to stock, something that was required for this project. Furthermore, this design did not incorporate sliding mounts for a floating caliper so design had to be done to allow the caliper to be mounted on pegs instead of bolted to the mount.

Materials selection for the brake were based on materials availability and strength necessary to maintain integrity in the hardest braking conditions. To determine the most amount of force that the brake mount would be subjected to, Newton's second was used: F= m*a (NASA 2014).

The system mass is the sum of the rider's mass and the motorcycle's mass. The equation for solving the maximum deceleration of the motorcycle takes into account slope, wind loading, rolling resistance and drive train resistance, among other factors. For this calculation, maximum deceleration was assumed to b 0.7g. This is a value used by highway designers and accident reconstructionists as an average vehicles emergency braking friction coefficient. (Aycock 2010). See Appendix B: Calculations to view the calculations of the force utilized in the stress analysis.

Finite Element Analysis of the completed model showed that mild steel would be sufficient for this project. Research was done on 1018 steel. Table 1 shows the material properties for the selected metal. This material was easily sourced because its widespread use and in stock availability from any steel supply shop.

Mechanical Properties	Metric	English
Hardness, Brinell	131	131
Hardness, Knoop	150	150
Hardness, Rockwell B	73	73
Hardness, Vickers	136	136
Tensile Strength, Ultimate	450 MPa	65300 psi
Tensile Strength, Yield	310 MPa	45000 psi
Elongation at Break	20 %	20 %
Reduction of Area	45 %	45 %
Modulus of Elasticity	200 GPa	29000 ksi
Bulk Modulus	159 GPa	23100 ksi
Poissons Ratio	0.29	0.29
Shear Modulus	78.0 GPa	11300 ksi

Table 1. AISI 1018 Steel Mechanical Properties (matweb, 2016)

PROCEDURES AND METHODS

The conversion from drum to disc brakes required many steps. These included measurement, design, mock up, construction and evaluation.

Measurement

Before any design could take place, the wheel and forks of the motorcycle needed to be measured. The fork faces that clamp down on the axle spacers measured 4.75". The motorcycle's axle measured 12mm in diameter. The lower fork tubes measured 1.66" in diameter. Figure 5 shows the dimensions.

Figure 5. CT3 Front End Dimensions

Once these dimensions were measured, the internet was searched for a wheel that would fit between the forks. A Yamaha YZ85 front wheel was sourced from a local motorcycle dismantler after initial measurements were done to ensure it would fit between the forks. The wheels measurements were as shown in Figure 6.

Figure 6. Yamaha YZ85 Front Wheel Dimensions

The last part to be measured was the caliper. The most critical dimensions were the spacing of the floating mount pegs and the angle at which the pegs were in relation to the tangency of the rotor. AutoCAD was used to sketch relationships onto a picture of the caliper. This allowed for accurate measurements once a reference distance was established. Figure 7 shows the AutoCAD drawing that was created to aid in . The orientation of the image is as if looking at the caliper through the wheel. The mounting pegs were 2.6" away from each other and the caliper is at a 32 degree angle when the pegs are vertical. The YZ85 front wheel's rotor diameter was 8.625 inches.

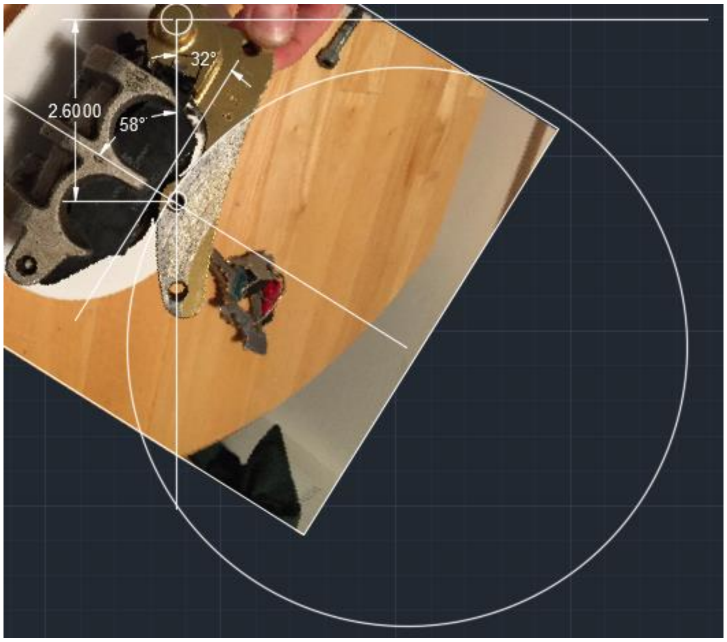

Figure 7. Caliper Mount Dimensions and Angle

With the wheel selected for the conversion and caliper dimensions sorted, design of the caliper mount could begin. The caliper used was from a Suzuki RMZ250. This caliper was chosen because of its float mount and availability. Floating mounts allow for a little flex of the wheel and lateral adjustment without having to manually adjust the brake. The caliper was left over from another motorcycle project.

Design

AutoCAD was utilized to perform the initial design work. Combining the dimensions, a side view of the caliper mount was created to get an initial design documented. Figure 8 shows the first sketch of the brake and caliper mount.

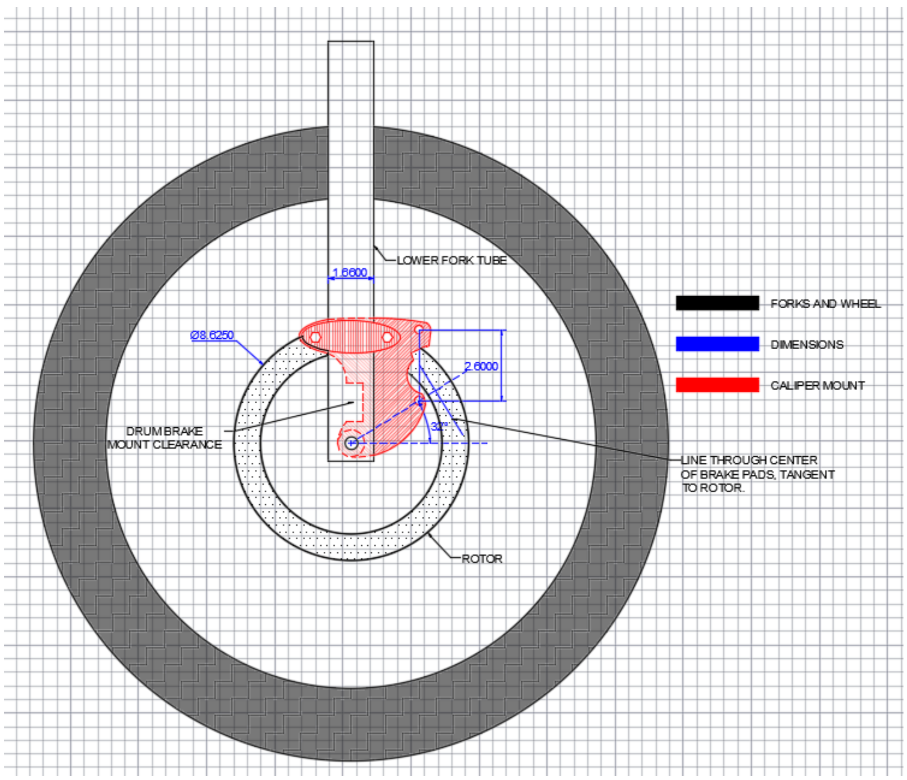

Figure 8. Initial Caliper Mount Side View

Figure 9 shows a detailed view of the caliper drawing with critical dimensions.

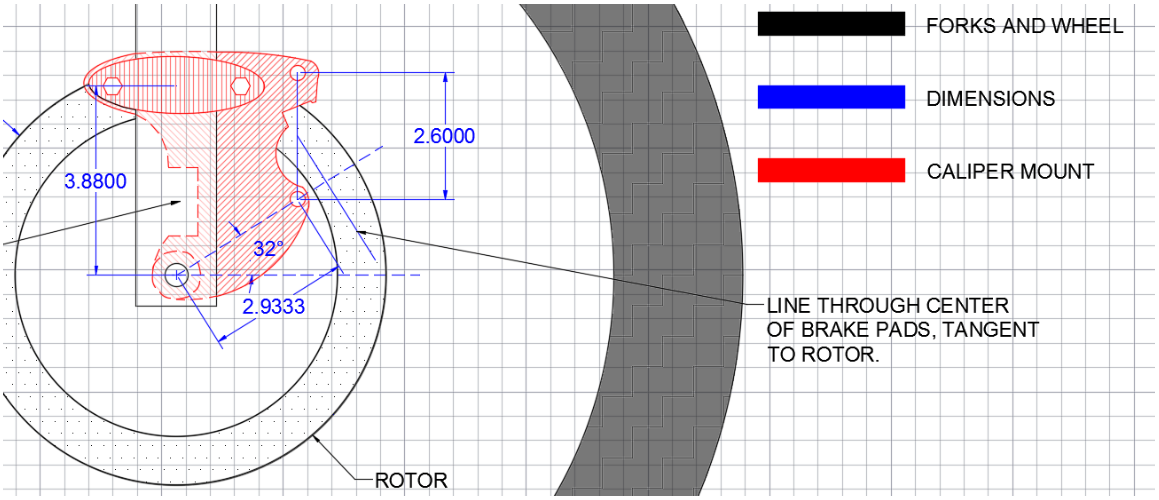

Figure 9. Critical Caliper Dimensions

Once the caliper mount was dimensioned, SolidWorks was utilized to create a 3D model of the motorcycle front end and caliper. Individual parts were drawn to the correct dimensions and then mated in an assembly, thus defining the parts relationships and degrees of freedom. The assembly was precisely dimensioned, as the machined design was to be a direct carbon copy of the 3D model. This design went through many iterations until the design looked feasible enough and to be built and tested.

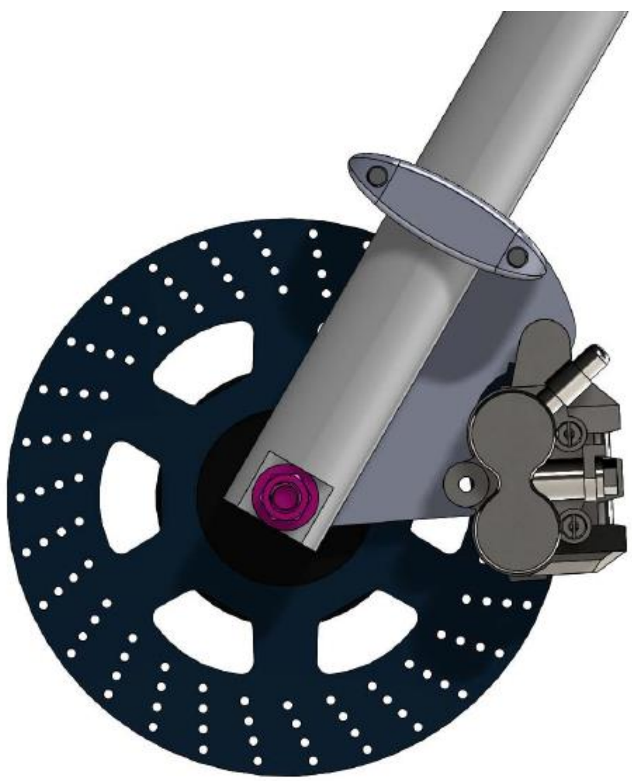

Figure 10: SolidWorks Model

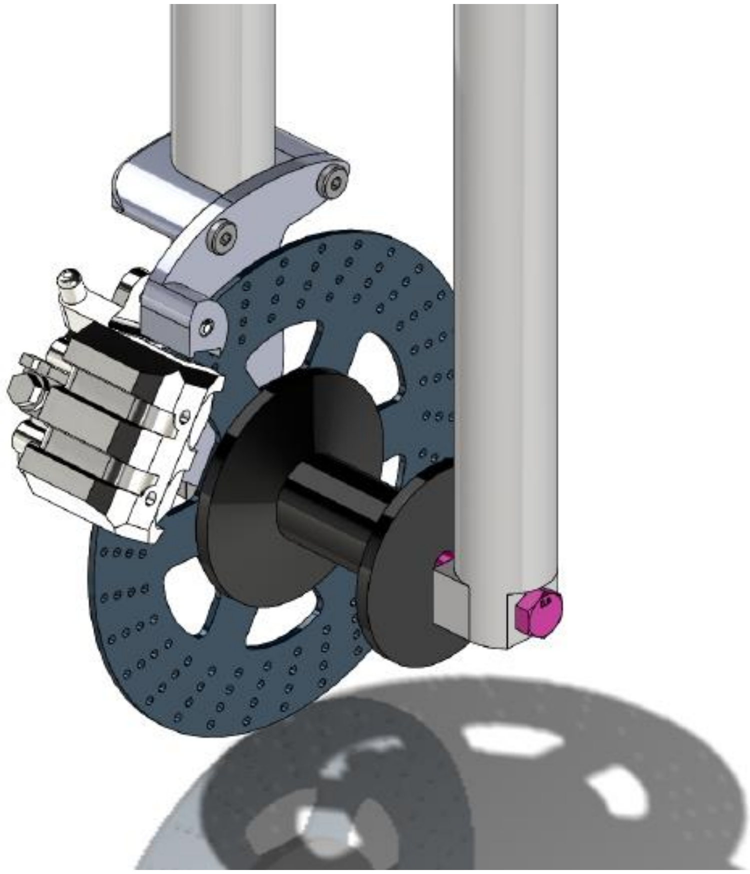

Figure 11: SolidWorks Model Isometric View

Design Calculations

The force required during braking was calculated in order to apply the accurate amount of force in the stress analysis. Using 0.7g as the maximum achievable deceleration, the force was calculated using Formula 1, Newton's second law. To view calculations, refer to Appendix B.

The force on the contact patch of the front tire, when braking very hard, is approximately 300 lbs. Calculating moments about the axle (Figure 12), the force on the caliper mounting pegs was determined to be approximately 913 lbs total, or 457 per peg.

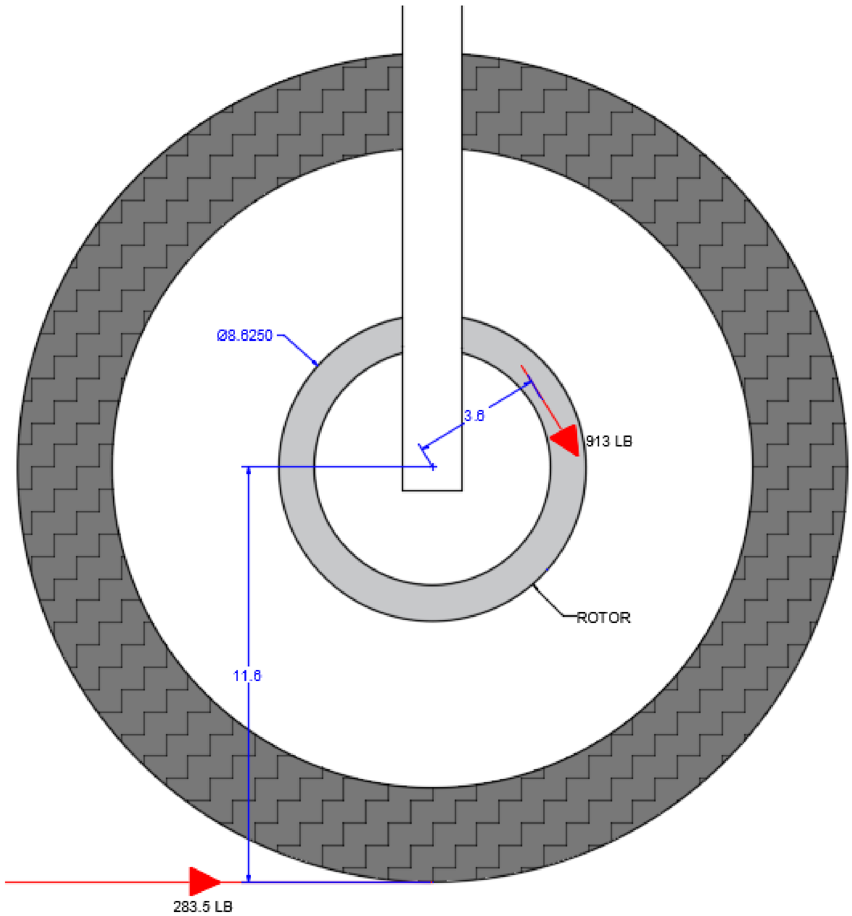

Figure 12: Brake Force With Respect to Radius

At this point, the design was tested in SolidWorks using Finite Element Analysis. Running the analysis meant designing a loading scenario just like it would experience in real life. This included assigning the appropriate material to the model and setting up connection types and geometric relations. The force used in the analysis was 700lbs per peg, not the actual 457lbs. This was done to incorporate a significant safety factor and keep numbers simple and easy to remember. The force was applied in a direction tangent to the brake pads' contact point with the rotor. This insured that the model was stressed in the same direction that the physical mount would be stressed in situ.

Deflection and stress analyses showed that the bracket is not going to operate anywhere near where failure could be expected. It was expected that the steel material would sufficiently handle the loading because the original mount was made out of cast iron, whose strength more variable and less known than steel of the same size. Figure 13 and Figure 14 show the results of the analysis. Stress maxed out at 10,500 psi around the rear clamping bolt hole. Yield strength was 32,000 psi. Displacement was determined to be maximum at the brake pad guides. The deflection was determined to be 3.411E-2 mm. Deflection of 0.034 millimeters was so small that the bracket was deemed worthy of production.

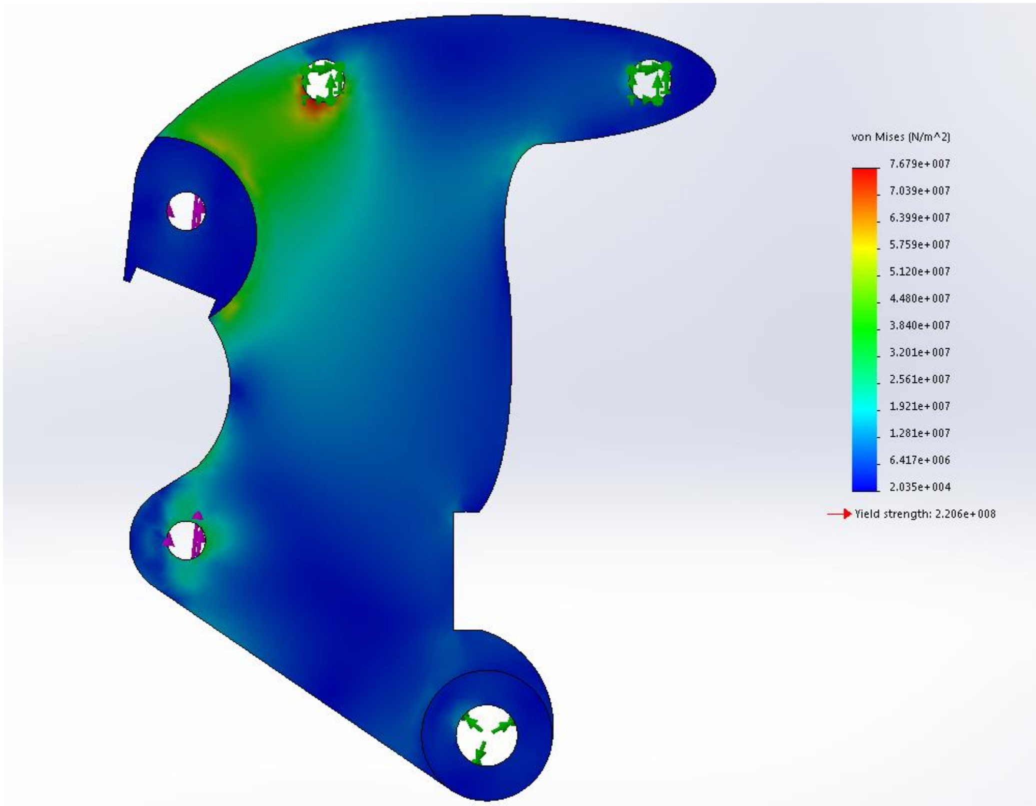

Figure 13: Finite Element Analysis Stress Results

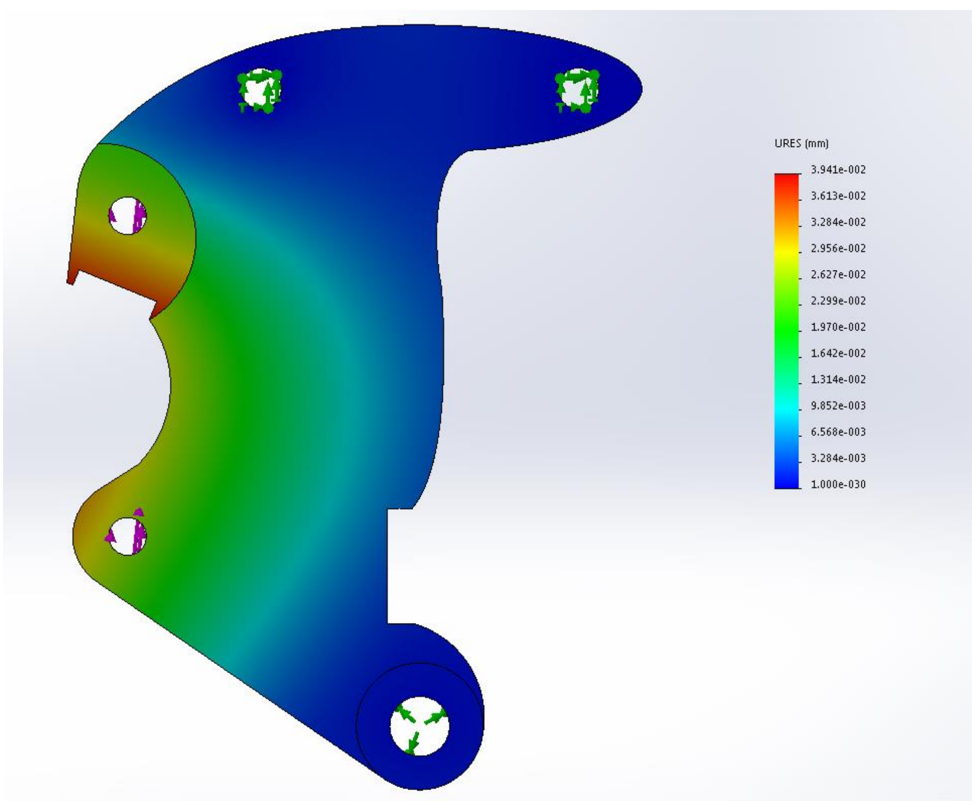

Figure 14: Finite Element Analysis Displacement Results

<u>Mock Up</u>

After SolidWorks modeling was satisfactory, it was desired to mock up the system before spending money and time fabricating the bracket out of steel. CNC laser cutting machines make rapid prototyping relatively easy and time efficient so this tool was utilized for the mock up process.

Laser cutting the file required that the SolidWorks model was first converted into a drawing. The drawing then needed to be saved as .dxf format in order to be opened in AutoCAD. AutoCAD was utilized to adjust line types and colors in order to plot correctly to the CNC laser drivers, which only cut red polylines with a set. Figure 15 shows the file used to print to the CNC laser

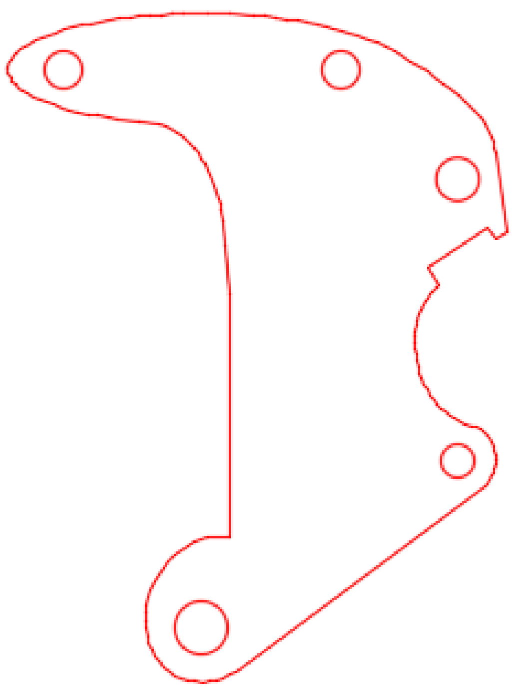

Figure 15: Laser Cutter Drawing

The CNC laser made quick work of cutting out the mock mount. The mock up process proved valuable because there was oversight regarding the original drum brake mounting peg. The width had not been checked since the initial design and proved to be marginally larger than designed for, causing interference with the caliper mount. Once the dimensions were altered, another mock up was cut, proving that the mount design was viable. Figure 16 and Figure 17 shows the caliper mock mount with and without the caliper.

Figure 16: Caliper Mock Up Installed Without Caliper

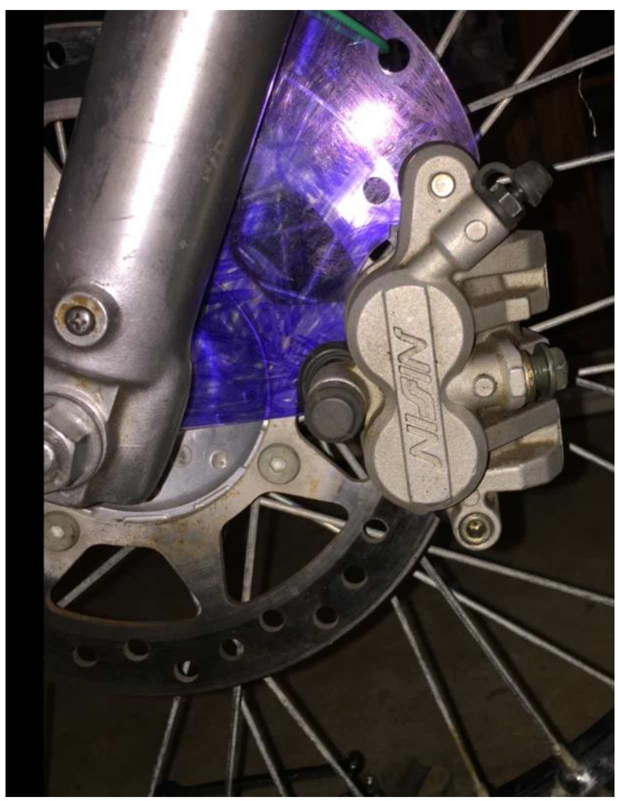

Figure 17: Caliper Mock Up Installed With Caliper

Construction

Drawings detailing the caliper design were created. It was decided that milling the entire bracket would be not time effective, so the outline of the mount was cut out via a CNC water jet, owned and operated by Ian Goodyear at Creative Cutting. Similar to a plasma cutter or a laser cutter, material is cut utilizing up to 40,000 psi of water mixed with garnet sand. Garnet sand is introduced to the water after it passes through a diamond orifice via the venturi effect. The sand adds an abrasive capacity to the high pressure water, accelerating cutting speed. The water jet method is more precise and the cut edge is not undesirably heat treated like parts that are plasma cut. A non heat treated edge allowed for further machining or cutting to be carried out without worrying about the hardness that would be encountered using plasma cutting.

Once the outline was machined, ancillary parts were welded on using a TIG welder. These ancillary parts included the axle wheel spacer and brake pad retainer. It was important for the holes to be lined up well in order for the caliper to be able to slide on its pegs so prior to welding, the parts were clamped together with the pin installed so that the holes were concentric.

The holes that needed to be threaded were machined and threaded appropriately. To get the holes in the correct location, a Bridgeport knee mill was used. Once a datum was set via an edge finder, accuracies up to a thousandth of an inch allowed the Bridgeport to create holes in close to perfect relation to one another. If these holes were not within a couple thousandths of an inch tolerance or parallel, the pins that allow the caliper to float would bind. Binding of those pins would result in a brake that never disengaged and could catastrophically fail if the caliper was misaligned with the rotor.

Select holes were threaded using the correct size pilot drill bit and tap. Keeping the tap engaged perpendicular to the metal was accomplished by installing a live center on the mill and keeping it in contact with the hole on the back of the tap handle. This made sure that when the rod was threaded into the hole, it would be perpendicular, not skewed in any direction.

Figure 18 and Figure 19 show the completed caliper mount and the brake system and motorcycle prior to the brake being fitted.

Figure 18: Completed Caliper and Mount

Figure 19: Brake Caliper, Mount and Master Cylinder Ready for Installation

RESULTS

The motorcycle was ridden with the new brake. The hydraulic disc brake system outperformed the drum brake in many aspects. The braking feel and feedback of the new system were crisp and communicative, unlike the spongy dull feeling drum brake. Converting bike lingo into engineering terms, feel and feedback are the terms used to describe the brakes friction creating capabilities and the brakes reaction to inputs. The onset of braking also had a nice bite, meaning friction was created with a small lever input, unlike the old system that required the rider to really put some force on the lever to get the brakes to sufficiently create friction and slow the motorcycle. Previously, the rider could jam the brake lever to the handlebars, lean back, and come to a very quick stop. The new system had that braking ability at a fraction of the lever pull. If the rider were to brake as hard as possible, the front end would skid out from under the motorcycle or the rider and motorcycle would tumble over the front end. Figure 20 shows the brake system installed on the motorcycle.

Figure 20: Caliper and Mount Installed On 1973 Yamaha CT3

These improvements achieved the desired result, increased friction and speed scrubbing ability. The motorcycle feels much more confident when slowing down. The rider no longer has to question whether the old linkage is going to snap or if the system will perform in time to avoid an accident.

DISCUSSION

Lacking information and references for disc conversions on this type of motorcycle made this project a truly one-off creation. When searching for dimensions of the brake caliper and mounting, none were available. One would think the documentation of the designs would be readily accessible for parts of new, common motorcycles. This resulted in much more time spent measuring and drafting in SolidWorks than initially expected. Inserting photos into AutoCAD and then using drawing and dimensioning tools made the dimensioning process much easier and will be used on many future projects.

The catchphrase "measure twice, cut once" was revered during this project. It was very important that the work was completed the first time around because it was highly undesirable to have to redo work in order to progress. That being said, mocking up the caliper before committing wholly to machining metal was a beneficial exercise. Using the CNC laser cutter to mock up the caliper and get a feel for how it would look allowed for design changes that led to a more cohesive, well put together result.

During construction, the fork mounting clamp was modified to be created out of eighths inch tube cut in half and eighth inch angle iron, instead of machined from a large piece of billet. The tube was cut in half on the band saw and cleaned up on the belt sander. The angle iron was measured to the dimension where it would be flush with the mount, cut and cleaned. The half tube and angle iron were welded together on both sides, resulting in a clean, highly functional clamping bracket. Edges were trimmed to match the caliper mount shape. This decision was made in order to minimize the amount of hours machining. The shop was being kept open by a shop tech named Chase solely as a favor to his friend and it was much appreciated. Time was of the essence, so machining the bracket for a couple hours was not an option.

While tapping the holes, it was necessary to use the live center to achieve the correct angle of the threads. Initially, threads were tapped without the live center support resulting in a peg that was angled a couple degrees from perpendicular when installed. The skewed peg bound while the caliper was sliding on the pegs, resulting in an ineffective brake system. This necessitated a second mount being fabricated, this time paying strict attention to the orientation of the tap while threading the holes.

Determining friction created was not easily directly measured. To determine pressure, master and slave cylinder would need to be disassembled and pistons measured. Next, recording force on the brake lever while slowing; no easy task. Coefficient of friction would need to be determined at normally operating temperature between the brake pad material and rotor steel, another procedure not easily achieved. This resulted in conclusions that were less scientific and more ride quality based. That being said, ride quality improvement was a main goal in the project.

RECOMMENDATIONS

To improve this project, it is recommended to cut the caliper mount out entirely using a CNC milling machine. If entirely CNC milled, special features like lightening holes and decorative engravings could be added with minimal effort. Additionally, using a CNC mill and cutting out in one process keeps the tolerances perfect. CNC mills make it easy to alter the design and quickly have another part cut out once the fixturing has been figured out.

Another recommendation is to take pictures while building. It was very easy to open files after creating them and go and insert them into a report. While constructing, machining, water jetting and welding, zero pictures were taken. Filthy hands and an emphasis on getting the project done, as I was in the lab after hours after work, took priority and photographs slipped through the cracks. An easy remedy would be to purchase a cheap digital camera for less than $50 solely for use in the shop. This would mean getting it filthy and not worrying about it.

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

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BRAE Project Requirements

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project adresses these issues as follows.

Establishment of Objectives and Criteria.

Project objectives and criteria are established to meet the needs and safety requirements of a motorcycle braking system. See *Design Parameters and Constraints* below for specific objectives and criteria for the project.

Synthesis and Analysis.

The project incorporates consideration for alternate caliper mount designs, stress modeling of the model and analysis of the completed device.

Construction, Testing and Evaluation.

The brake conversion was designed, constructed, tested and evaluated.

Incorporation of Applicable Engineering Standards.

Capstone Design Experience.

The BRAE senior project is an engineering design project based on the knowledge and skilled acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge / skills from these key courses.

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Design Graphics
- BRAE 151 Agricultural Engineering CAD
- BRAE 152 3-D Solids Modeling
- BRAE 234 Agricultural Mechanical Systems
- BRAE 240 Open Shop
- BRAE 421/422 Equipment Engineering
- CE 204/207 Strength of Materials
- ME 211/212 Engineering Statics/Dynamics
- PHYS 141/132/133 Physics
- ENGL 149 Technical Writing

Design Parameters and Constraints.

This project addressed a significant number of the categories of constraints listed below.

Physical.

The wheel, caliper mount and caliper had to not only fit between the fork stanchions but also had to be located in positions which were strong enough and allowed for the perfect functioning of the brake system.

Economic.

It was desired that the cost of the project not exceed $300. The project cost $276 total; the goal was achieved.

Environmental.

A benefit to the environment is the removal of asbestos. Asbestos dust is linked to lung and respiratory problems and is found in brake linings of 70s motorcycles. Reducing the operators and environment's exposure reduces the likelihood of inhaling asbestos dust.

Sustainability.

The modern disc brake components are easily sourced and cheap, lending the motorcycle to extended use and easy repair.

Manufacturability.

The opportunity to manufacture is very relevant for this project. The motorcycles of the seventies lack braking performance and this is a viable option for braking upgrades. Mass manufacturing would take some optimization to get the design and build time down.

Health and Safety.

Health and safety were paramount in this project. If the caliper mount broke and jutted into the rim while riding quickly, catastrophic failure would occur, assuredly injuring the operator. The brake upgrade was designed to have many factors of safety built into the mount. A quicker deceleration also makes the motorcycle more capable and able to get out of dangerous situations.

Ethical.

The disc brake reduces the likelihood of crashing or getting into an uncontrolled situation. Reducing possibilities of pain and suffering are ethical endeavors.

Social.

Sharing new methods of improving old motorcycles is appreciated by the community involved with restoring and modifying vintage bikes.

Political.

Asbestos is highly regulated and currently illegal for use in brakes.

Aesthetic.

It was important that the modification looked as good as it performed. The modification adds a modern touch to any knowledgeable spectator.

APPENDIX B:
CALCULATIONS

Force acting to slow the motorcycle at 0.7g

F = m * a			
			solving for mass
W = m * g			
W =	405	lb	weight of rider and motorcycle
g =	32.174	ft/s^2	accekeration due to gravity
m =	12.58780382	slug	mass of rider and motorcycle
			plugging into F = m * a
a =	.7 * g		where g is gravitational acceleration
a =	22.5218	ft/s^2	
F =	12.59 * 22.52		
F =	283.5	lbf	pounds force at tire

The force required at the caliper was determined via a moment calculation about the wheel's axis.

	11.6	inches	radius of tire
	3.6	inches	radius of rotor's center
ΣM =	(11.6*283.5)/3.6		
F(caliper) =	913.5	lbs	force required at caliper