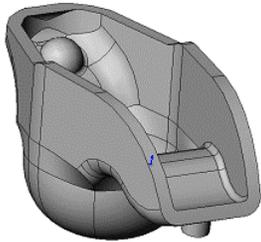
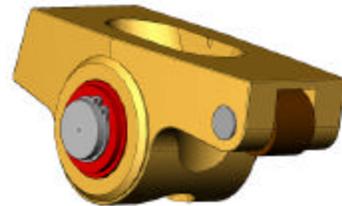


# Stock Rocker



Vs

# Roller Rocker



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Introduction to Finite Elements  
MANE-4240, Professor Suvaranu De  
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## **Executive Summary:**

Finite element analysis has become an important design and testing tool for the engineering community. When used correctly it can provide accurate results and can save time and money over the design and analysis of new products. This report involves the study of one of the major valve train components in a Chevrolet small block pushrod engine, namely the rocker arm assembly. The rocker arm is an extremely important component in the operation of an internal combustion engine because it is responsible for translating the profile of the camshaft into motion for opening and closing the intake and exhaust valves. This report focuses on two different types of rocker arms; the existing stock “from the factory” stamped steel rocker arm, and a roller rocker that is commonly used in a racing engine. Both the roller rocker and the stock rocker were modeled in Solid Works, and then analyzed using the finite element software Cosmos Works. The results for each rocker arm were completed and some of the various outputs are presented in this paper. The locations of stress concentrations were also studied in hopes of eliminating them and any possible flaws that could cause failure. As well as optimizing the design.

Since entering the racing community this past year, it has become apparent that any edge one competitor has over another competitor can be greatly beneficial to the success the competitor. This is the reason for modeling the race roller rocker along with the stock Chevrolet rocker. Any feasible optimizations will be incorporated into a new design for use in racing applications. The goal of the project is to find a way to increase motor performance that might give the authors of this report an edge in the racing community. The finite element process was also analyzed to prove that the model was of high accuracy.

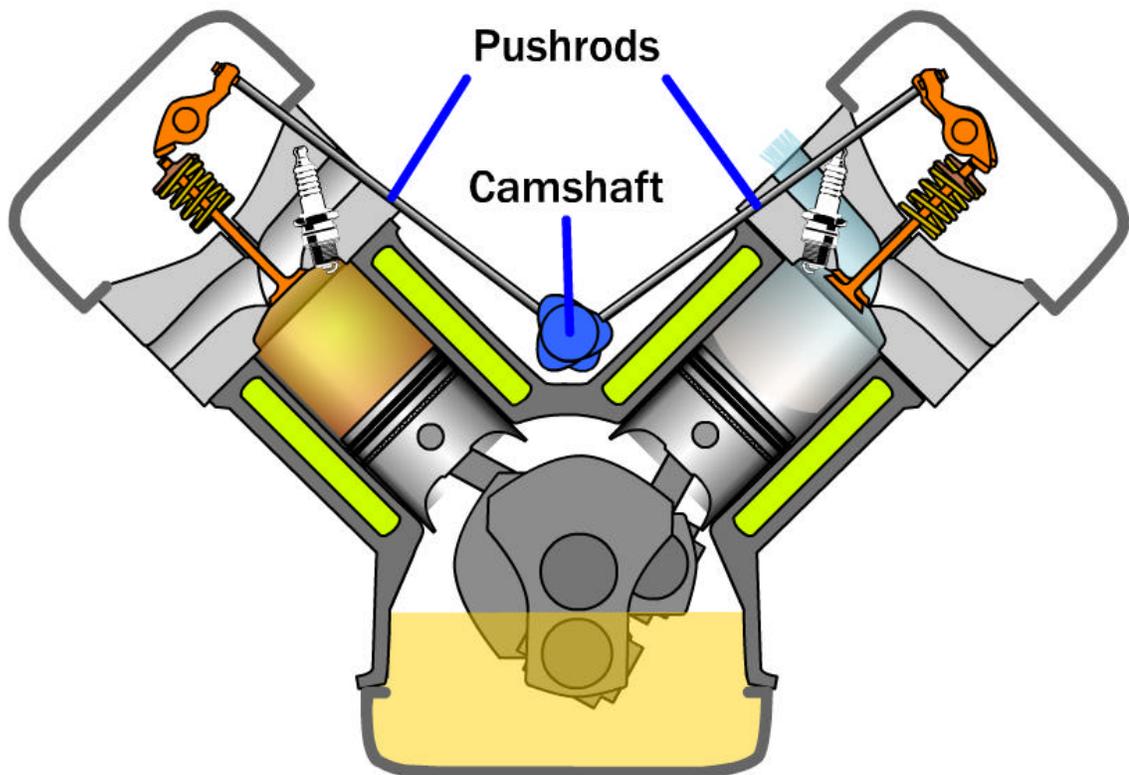
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## Introduction:

The major focus of this project is to study the rocker arm in a conventional Chevrolet small block push rod engine and a high performance roller rocker commonly used in racing applications. The pushrod engine is made up of many moving components, starting from the bottom: the crankshaft is where the work is done; it is driven at an angular velocity by the reciprocation of the pistons. The cam shaft is located directly above the crank; this is driven by the crank shaft at a 2:1 ratio. The cam shaft has a ground lobe profile that pushes the lifters up and down at precise intervals as it rotates. The pushrods ride on top of the lifters and transmits the motion to the heel of the rocker arm. The rocker arm then transmits the motion from the cam 180 degrees to push its respective valve open. The valves are connected and retained by a compression spring that attempts to hold the valve in the closed position. Because of this it acts against the rocker, which acts against the push rod, which acts against the lifter, which maintains pressure on the cam lobe. An example of how a push rod engine works can be seen in figure 1.

**Figure 1** How a Pushrod Engine Works



The roller rocker is designed to be used in a high performance application and therefore it is designed with the smallest amount of material possible so as to limit the rotational inertia of the part. The stock rocker was designed for a normal everyday driving application, so it has qualities that reflect the desired 100,000 miles or greater life for the motor, as well as cheap and fast manufacturing. Another aspect that needs to be considered as well is that the dynamic loads on the stock rocker are not going to be as great as the dynamic loads that the roller rocker experiences. Typically in a stock Chevy small block motor, the revolutions per minute (RPM) do not usually exceed 4000, under normal driving conditions. In the racing motor, the engine will run consistently at speeds of 7,000-8,000 RPM. This creates a substantially larger dynamic loading on the roller rocker. Since the calculations of dynamic loads are not relevant to this course, they were not considered in these models; however, it should be known that they may influence the accuracy of the results.

The goal of this project is to study differences between the stock rocker and roller rocker and then optimize the roller rocker from the information learned. Both the stock rocker and the roller rocker will be modeled using Solid Works and Cosmos Works software. The parts will be built and analyzed using the software and critical points will be determined.

### **Solid Works Modeling:**

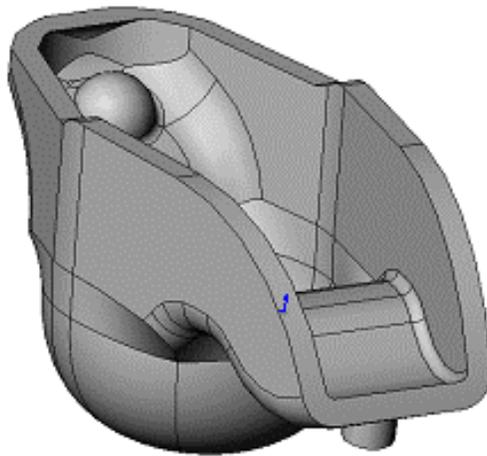
The rocker arm is an extremely important component in the operation of an internal combustion engine; it is responsible for the opening and closing the intake and exhaust valves. There are several different ways to open and close the valves on an internal combustion engine. The type discussed and analyzed for this report is a conventional stock Chevrolet 350 cubic inch push rod engine, and a Chevrolet 358 cubic inch racing engine.

#### ***Stock Rocker Arm Modeling***

The stock rocker is made by stamping a flat piece of steel with a large die. Stamped steel parts are never identical and the part is usually designed so that high tolerance is not important. The first step to modeling the stock rocker arm was measure the part; this is done using a digital caliper accurate to 0.001". The rolling center was estimated since the rocker pivots on a stud and does not have a readily measurable center. Also the contact point where the nose of the rocker

contacts the tip of the valve was estimated. The software Solid Works was then utilized to construct a three dimensional model of the part. The stock rocker was an extruded entity for the side profile of the rocker, which was then cut away at the edges to create a solid block of the same dimensions as the actual rocker. Next, fillets were created on all edges to the correct radii and the inside of the rocker was cut away using the shell command. This created a relatively thin stamped steel part that was 1/8<sup>th</sup> of an inch thick. See figure 2 for a diagram of the stock rocker.

**Figure 2** Stock Rocker 3-D Model



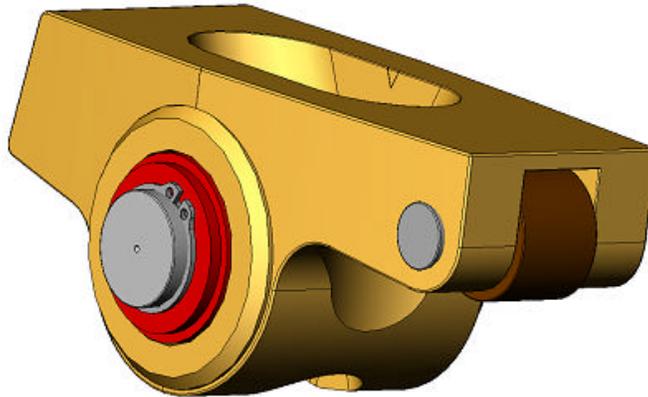
### ***Roller Rocker Arm Modeling***

The roller rocker is designed significantly differently from the stock rocker. The roller rocker contains friction reducing components, stiffening components, and weight/inertia reduction aspects. This type of rocker is typically used in racing applications and areas where the highest possible efficiency and power output is desired.

The first step was to examine the part and take the necessary measurements to construct the part. The body of the rocker was an extruded entity and had the front, side, and top profiles cut away. Then holes were cut out to allow for the roller pin and the needle bearing housing to fit inside the body of the rocker. Once these were cut, the fillets were placed on all surface edges

to the proper dimensions. After the body of the roller rocker is created, the next step is to make all the other components, consisting of the roller pin, roller, needle bearing housing, bearing cover and the snap rings to hold everything together. These components were created using a simple set of extrusions, cutouts, and fillets. After each separate part was created the rocker arm in its entirety can be assembled using the assembly feature in Solid Works. See figure 3 for a diagram of the roller rocker.

**Figure 3** Roller Rocker 3-D Model



### **Finite Element Model:**

#### *Actual Part Loading:*

The pushrod internal combustion engine works by transferring a load through the rocker arm to open and close the valve. To determine the load that would be seen by the rocker arm we found the spring rate that would be forcing against the rocker arm. With the spring constant  $k$ , a cam profile that gave us the maximum lift of the valve and the seat pressure of the valve, we were able to determine the maximum load on the rocker arm. The cam profile plots were measured by a point of lift at every degree of rotation and can be seen in figures 6 and 7. In both cases this load was rounded up to be 350 lbs on the tip of the rocker and 550 lbs on the heel of

the rocker. This was a static determination of the loads in the rocker arms. This assumes the inertia loads which are not a maximum at the maximum lift point in the valve cycle would be negligible in comparison to the spring load. Calculation 1 shows the calculations for the force on the rocker arm due to the spring force. This was done by compressing the spring with a large screw and using a force scale to measure the force exerted. These points were then recorded in Tables 1 and 2. These tables were then plotted in Excel and linear regressions were done to find the spring constant  $k$ , figures 4 and 5 show these plots.

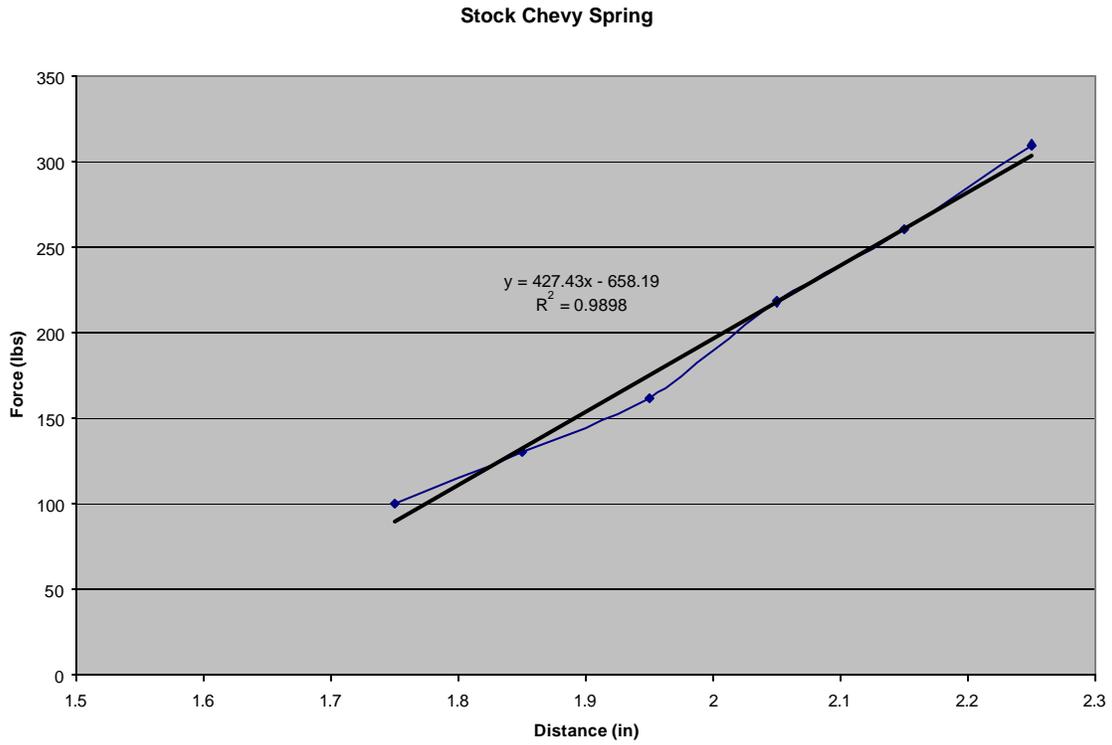
**Table 1** Stock Spring Rate Determination

Stock Spring	
Lift	Force (lbs)
1.75	100
1.85	130
1.95	162
2.05	218
2.15	260
2.25	310

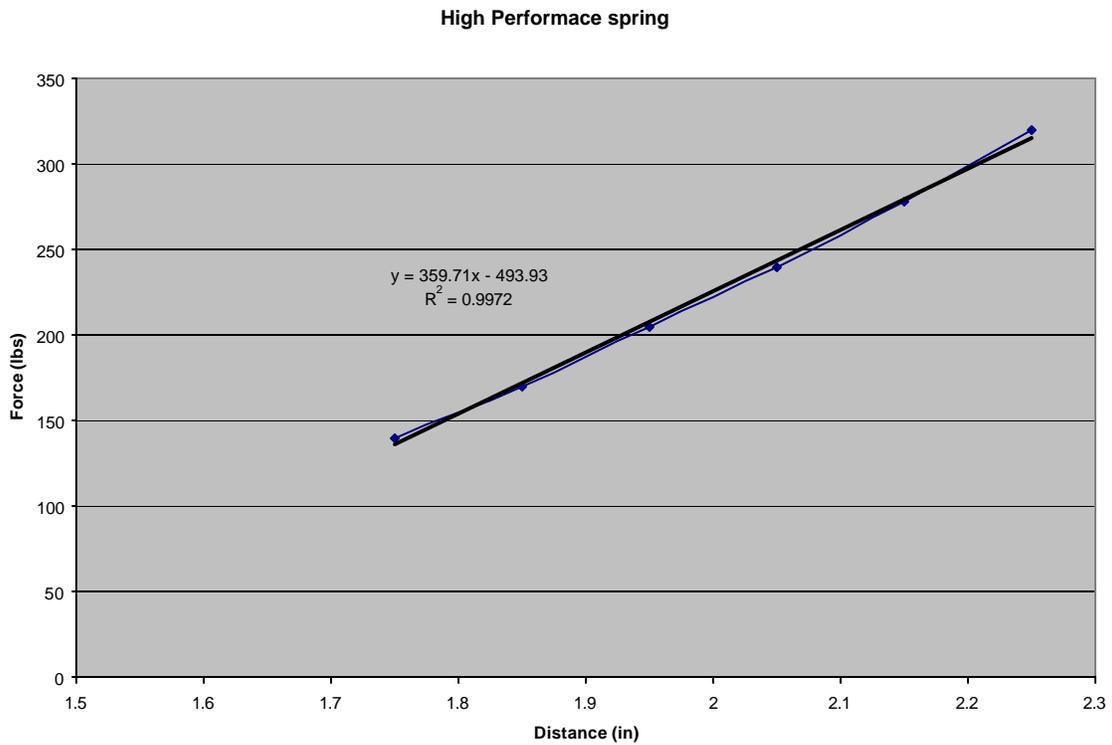
**Table 2** High Performance Spring Rate Determination

HP Spring	
Lift	Force (lbs)
1.75	140
1.85	170
1.95	205
2.05	240
2.15	278
2.25	320

**Figure 4** Stock Chevy Spring Rate



**Figure 5** High Performance Spring Rate



**Calculation 1 Spring Load Calculations**

.35 inches of cam lift

1.6 rocker ratio

Stock Valve train: 100 pounds of seat pressure on valve, 427 pounds per inch spring rate

$$.35'' * 1.6 = .56'' \text{ of valve lift}$$

$$F_{\text{Tip}} = 100 \text{ lbs} + .56'' * 427$$

$$F_{\text{Tip}} = 339 \text{ lbs}$$

$$F_{\text{Heal}} = 339 \text{ lbs} * 1.6 = 543 \text{ lbs}$$

Race Valve train: 140 pounds of seat pressure on valve, 360 pounds per inch spring rate

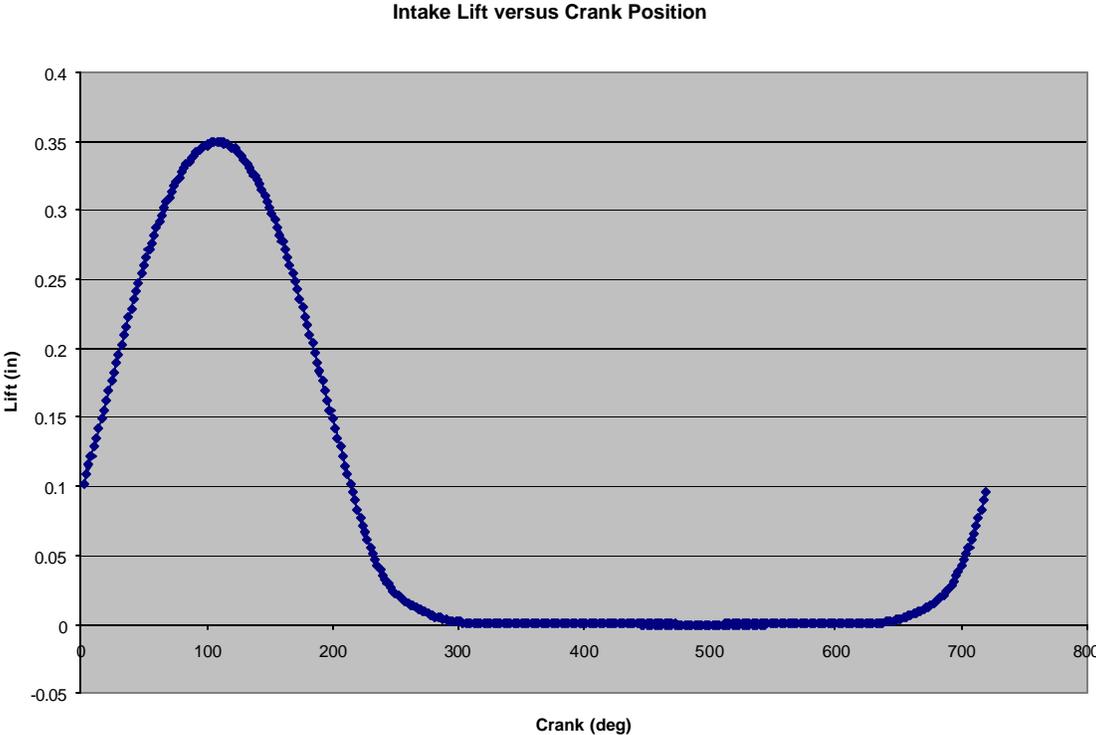
$$.35'' * 1.6 = .56'' \text{ of valve lift}$$

$$F_{\text{Tip}} = 140 \text{ lbs} + .56'' * 360$$

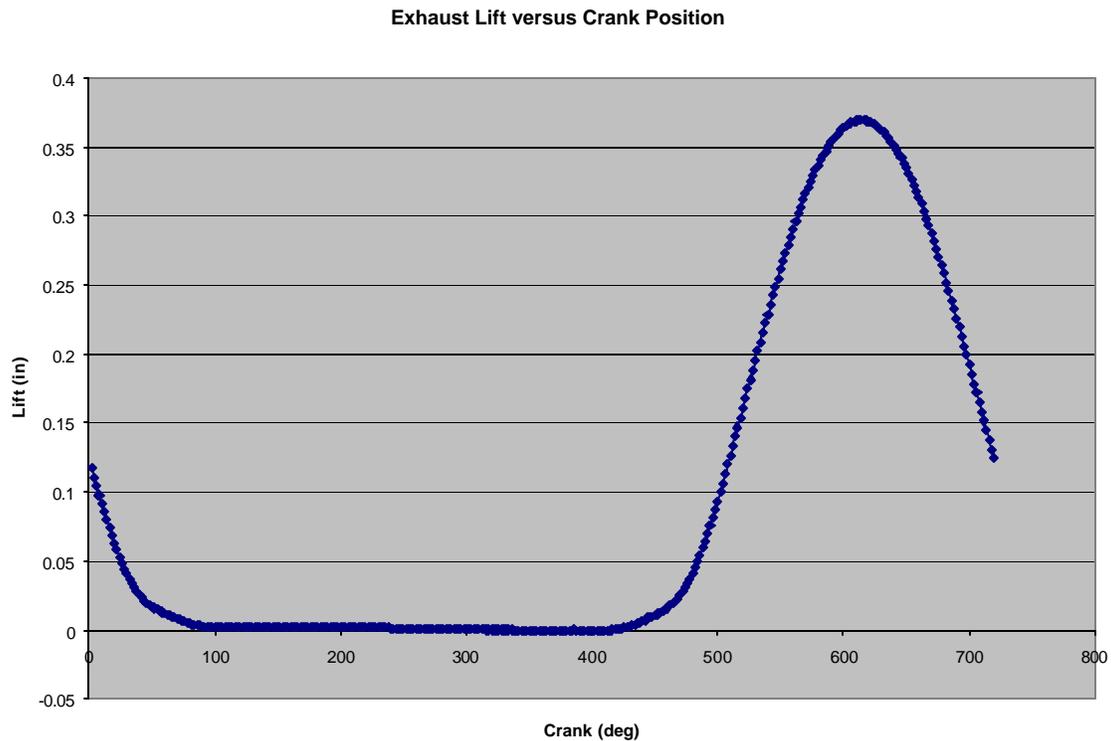
$$F_{\text{Tip}} = 341 \text{ lbs}$$

$$F_{\text{Heal}} = 341 \text{ lbs} * 1.6 = 546 \text{ lbs}$$

**Figure 6 Intake Lift versus Crank Position**



**Figure 7** Exhaust Lift versus Crank Position



*Loading in Model:*

The loads applied to the stock rocker arm are not easy to apply because of the tolerances associated with designing a stamped steel part. This part has no exact loading surface associated with it because the end of the valve is allowed to translate along the tip of the rocker arm and does not load any specific point. Since it becomes difficult to apply this load to the rocker arm an assumed contact area was determined from the geometry of the end of a valve and was assumed to be circular. This geometry was then modeled by extruding a small round cylinder from the face that would represent where the end of the valve would contact the rocker. The load was then applied through this extrusion and should accurately represent the loading of the tip of the stock rocker arm. The heel of the stock rocker was loaded simply by applying a load over the face where the pushrod would contact. This face is designed to contact the pushrod relatively evenly over a convex smooth surface in order to reduce stress concentrations; for this reason an applied force over the convex area is reasonable. These loadings represent accurately the true loading of the rocker arm and will yield a reasonable model.

The loads applied to the roller rocker are significantly easier to apply because they are applied through bearing surfaces. The load at the tip of the roller rocker is applied through a small roller; this is where the roller rocker gets its name from. This was applied to the model as a bearing load on the surfaces where the roller contacts. The load at the heel of the roller rocker is transmitted to the aluminum through a small hardened steel convex disk that protects the softer aluminum. Since this disk takes any of the harshness from the pushrod, the force on the body of the roller rocker can simply be a force applied to the convex hemispherical indentation. These loads are accurate and represent the real life loading of the roller rocker so they too will yield an accurate model.

### *Constraints:*

The constraints on the rocker arms are a little more difficult to specify because for the stock rocker arm there is no single pivot point. The pivot is determined by a small hemispherical disk that is pinned on to the stud that supports the rocker arm. This is what allows the rocker to pivot about the dished area in the bottom of the stamping. Since this dished area is what supports all of the force the model was constrained such that this dished surface of the rocker arm was not allowed to move. This is a reasonable approximation except that when the valve is under full lift one side of the dishing will be taking more of the load than the other side.

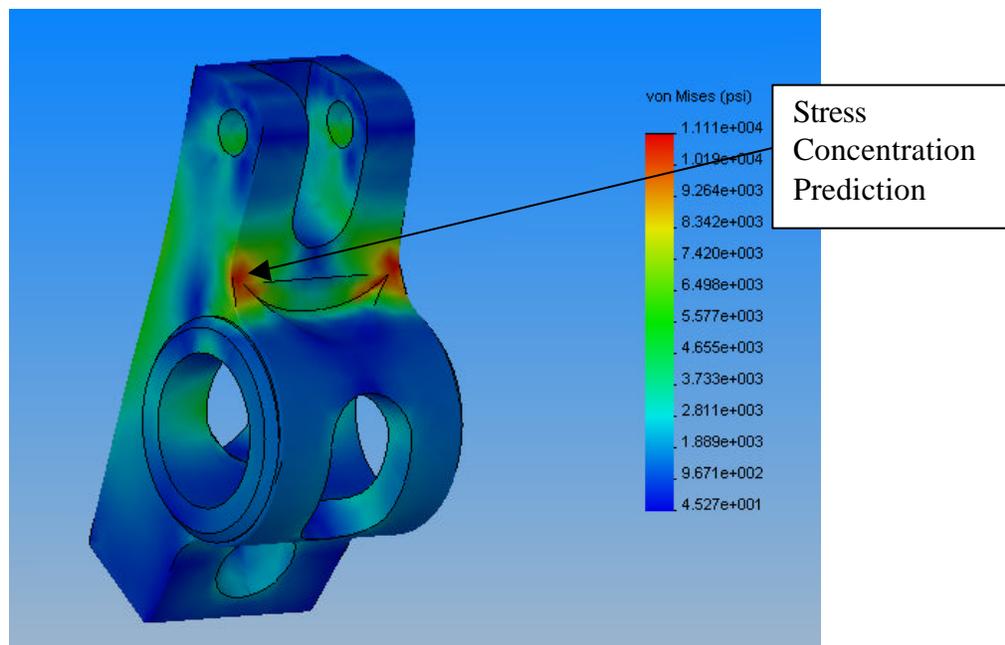
The constraints for the roller rocker are easier to understand and apply to the model because they are done through bearing pivots. The rocker is constrained by a bolt through the pivot shaft which supports the rocker body by two roller bearings. Since these bearings and shaft are not part of our study they were not included in the FEA and the body of the rocker arm was supported at the location of the bearings by a cylindrical surface that represents the bearings. This is an accurate constraint for the part and the model should lead to an accurate model.

### **FE Results:**

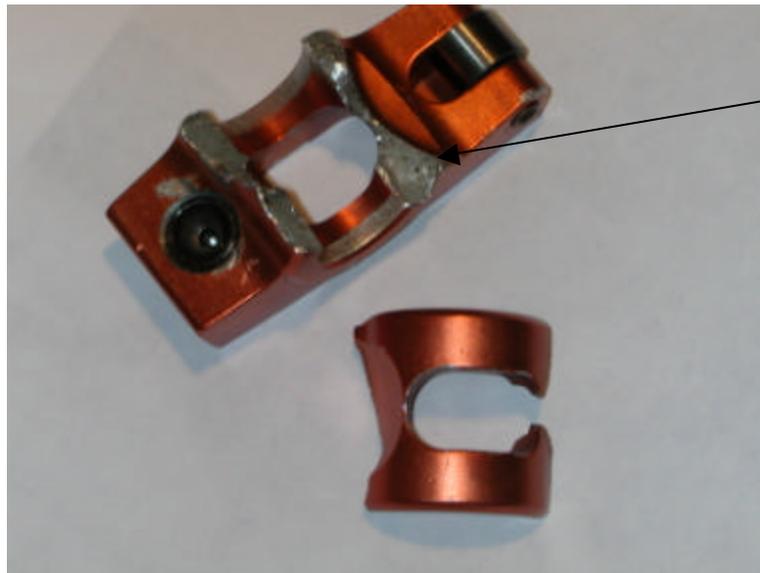
Once the finite element analysis was completed, the data was collected, and the two rockers were compared. In both designs there are stress concentration areas; both had a major one in the neck of the rocker. The stock rocker had a fairly smooth distribution of stress through

out the stamping because there are no sharp transitions. On the other hand, the roller rocker contains two locations on the bottom side of the neck of the rocker right in front of the pivot point, which had stress concentrations. The reason for this is the cut away on the in front of the pivot appears to have been made in order to make room for a larger diameter valve spring and retainer. The currently used valve springs that were obtained for study in this project did not interfere with this surface if it was not machined. The engine builder that gave us the roller rocker also gave us a broken rocker as an example of what could happen. After examining it we have seen that the stress concentration in the roller rocker is exactly where the roller rocker broke and shows that our model is indeed an accurate one. See figure 8 and 9 to see the predicted stress and where the rocker actually broke.

**Figure 8** Modeling Stress in Roller Rocker



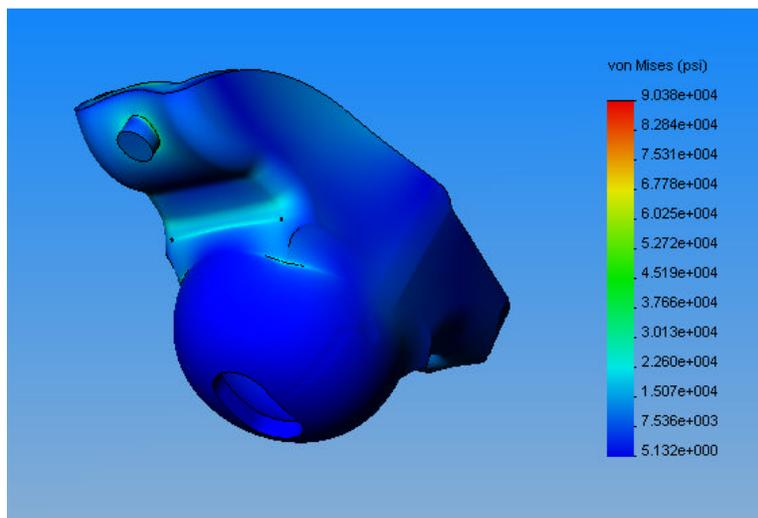
**Figure 9** Broken Roller Rocker Confirming Stress Concentration



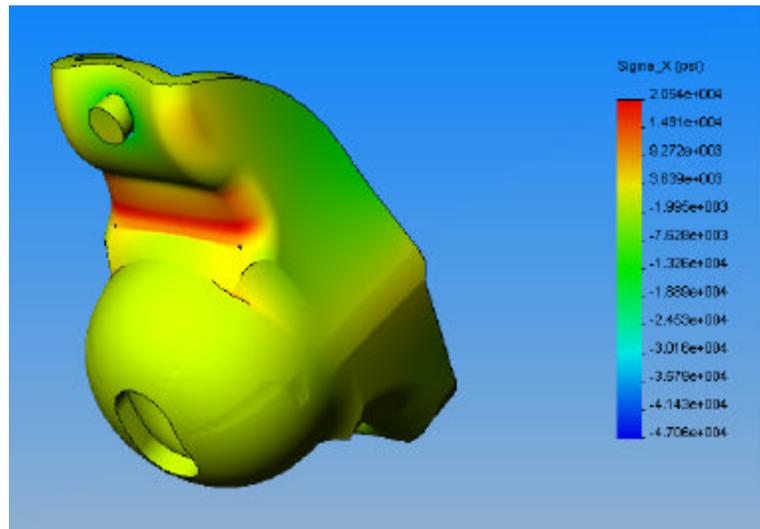
Fracture at  
Stress  
Concentration

There are many outputs given by Cosmos Works that describe the stresses, strains, deformations, and many other important factors. Since every design desires a different output to look at different things going on in each model a series of figures was inserted into this report to show some of the capabilities of the model. Some examples are shown in figured 10 through 13 for the stock rocker and were also done for the roller rocker but are not shown.

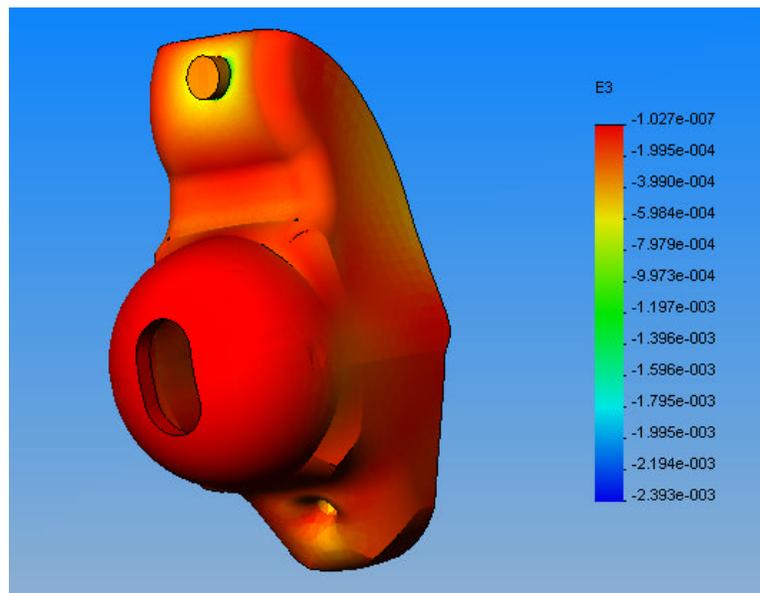
**Figure 10** Stock Rocker Von Mises Stress



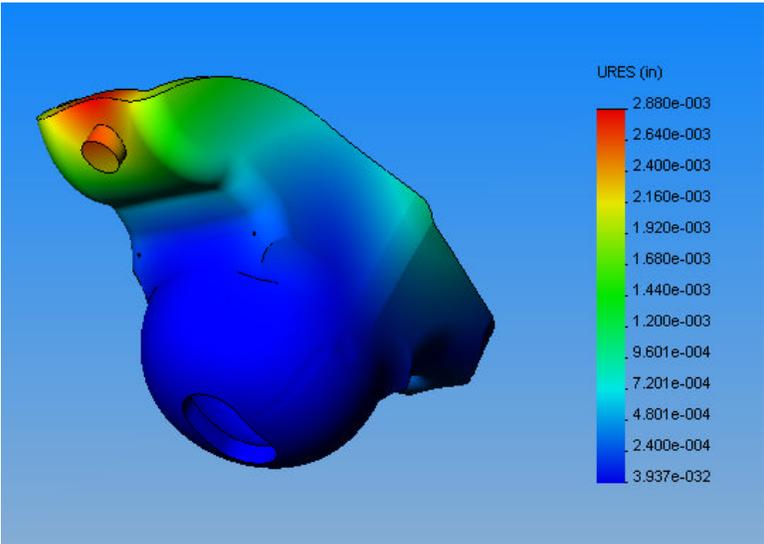
**Figure 11** Stock Rocker X-direction Stress



**Figure 12** Stock Rocker Strain Energy Direction 3

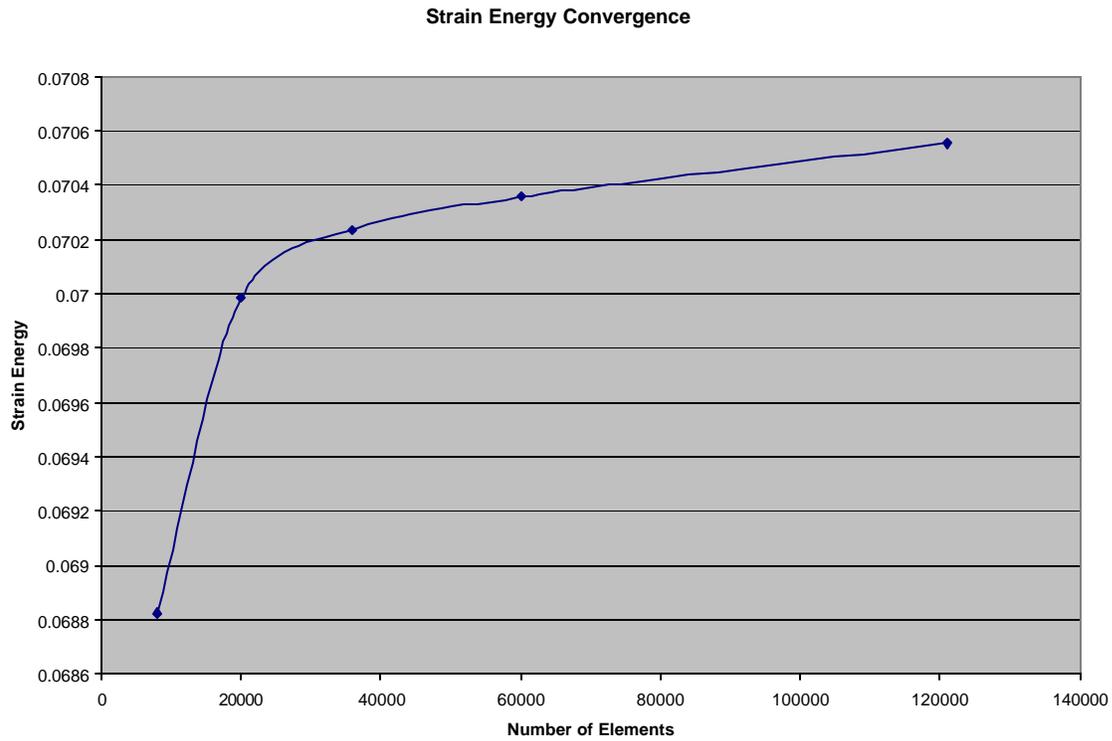


**Figure 13** Stock Rocker Displacement

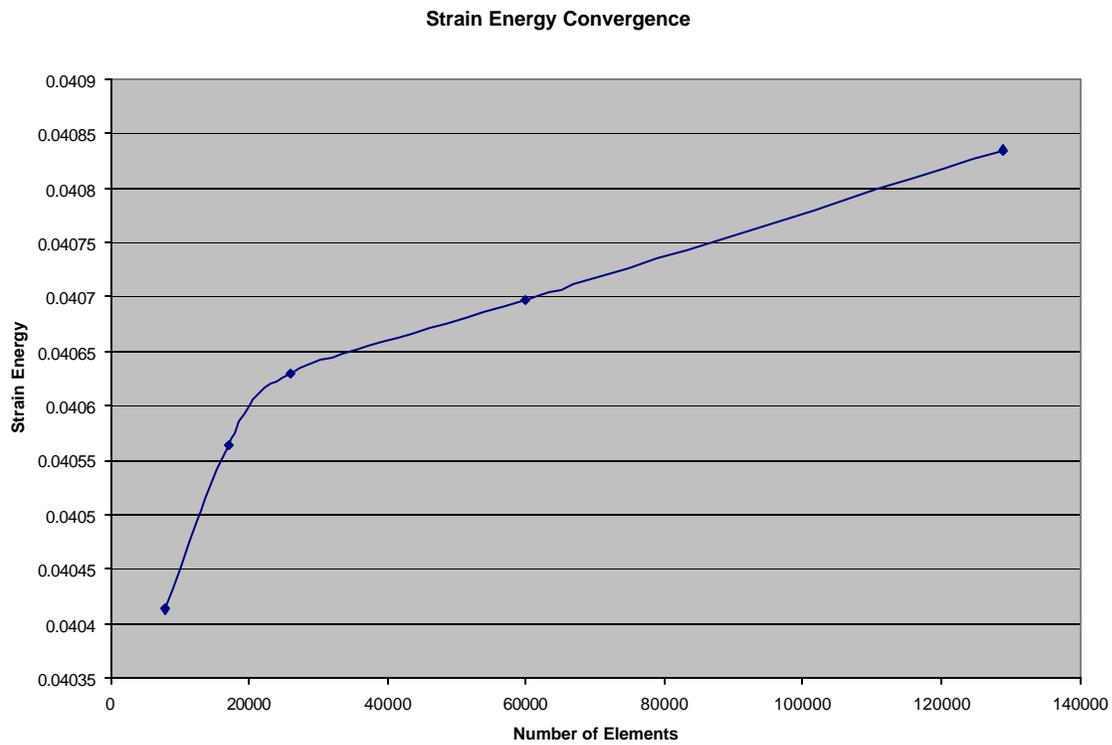


To prove that the model was indeed an accurate one, the total strain energy was plotted versus resolution. The figures show that the total strain energy converges logarithmically as the resolution of the model is increased. This is a good check to show that the models are indeed accurate representations of the loading on the model. This has been shown for each model in figures 14 and 15.

**Figure 14** Stock Rocker Strain Energy Convergence



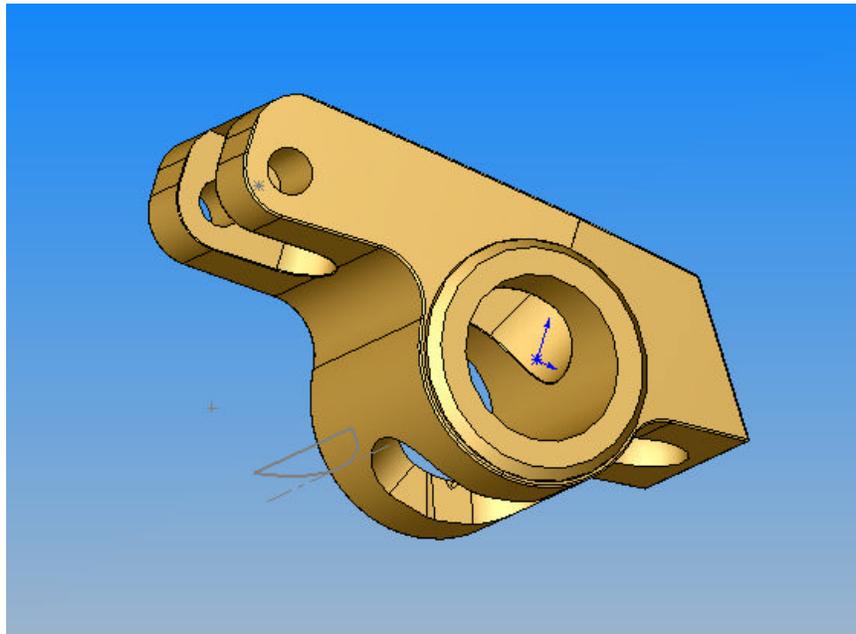
**Figure 15** Roller Rocker Strain Energy Convergence



## Recommendations and Optimizing:

With the results of the stock and roller rocker completed the next step was to analyze the roller rockers with the goal of optimizing the part. Since there is a large stress concentration in the roller rocker this cut will be eliminated and the neck of the rocker arm will be smoothed out. After the stress concentration is eliminated the most important thing to be optimized on the rocker is to reduce the rotational inertia. This can be done by taking as much mass away from the parts farthest from the center of rotation. Since there are sections at the tip and heel of the rocker that do not contain much stress they can be eliminated. An example of the quickly optimized rocker can be seen in figure 16, there are more areas or methods to optimize the rocker.

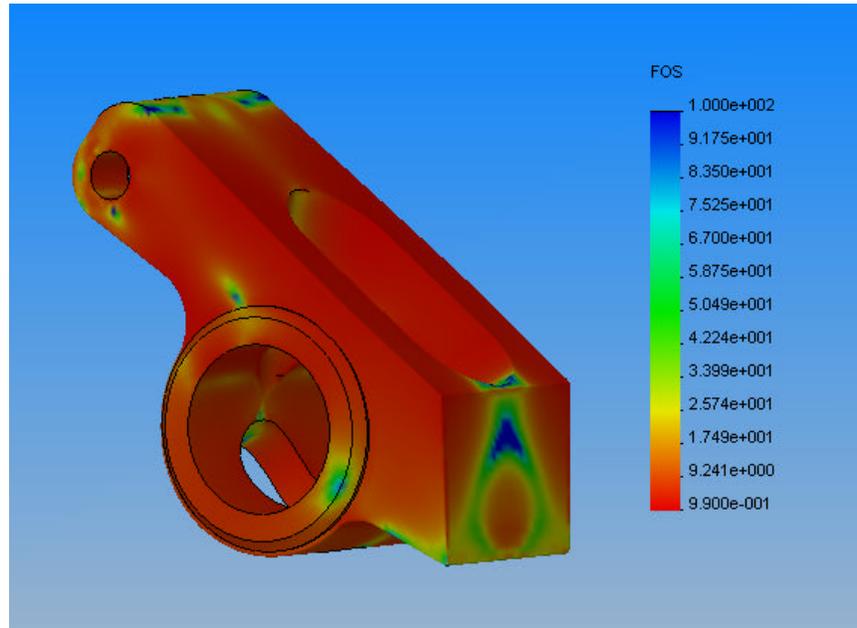
**Figure 16** Optimized Rocker Arm



Since the absolute optimum rocker would have a factor of safety of 1 throughout, this was taken into consideration for the part. Figure 17 shows that the factor of safety through out

the part is just less than 1 with a conservative ultimate stress. This should lead to a much better rocker design that would perform better in a race motor.

**Figure 17** Optimized Rocker Arm Showing Factor of Safety



## Conclusion:

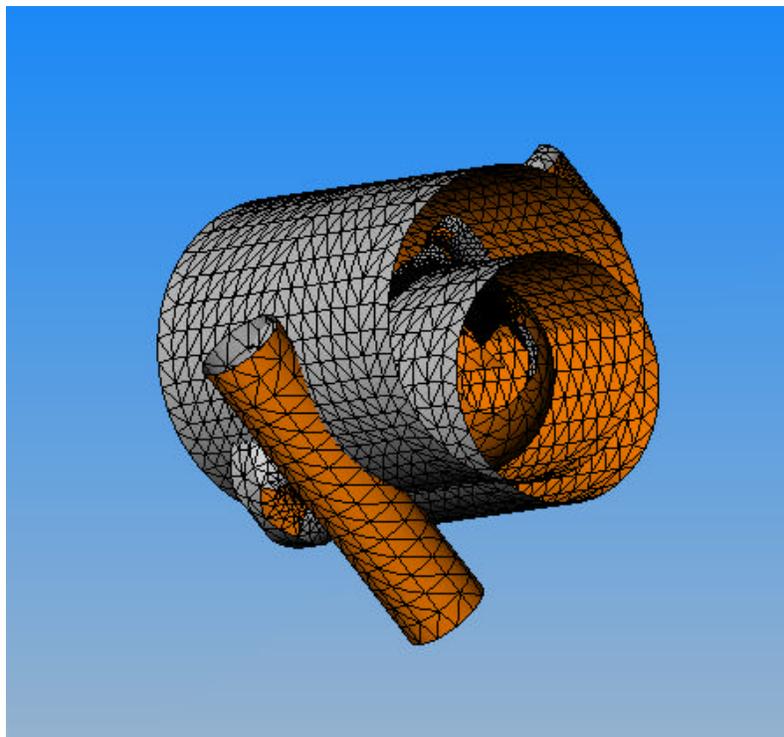
It is difficult to make comparisons between a stock Chevy small block stamped steel rocker and a high performance aluminum roller rocker because they are vastly different. Each accomplished its own task either by being cheap and reliable or making high performance engines possible. This report did not focus on pointing out all of the differences but rather on showing how the parts could be modeled and that the models were likely accurate. The plots show some of the examples of what Cosmos is capable of outputting and that these plots can be used to optimize a part.

The roller rocker that was studied had some room for improvement. The optimizing of this part was easy in theory but took a few iterations in practice to get it right. The goal was to make a part that would survive the loads while reducing the rotational inertia because this inertia will cause valve float and larger dynamic loads on all the valve train parts. There are indeed

further optimizations that could be done or different methods of changing the shape of the roller rocker but the purpose of the project was not solely to optimize the roller rocker but to only prove that it was possible using the models we created.

For entertainment purposes only Figure 18 has been included to show what can happen when the wrong inputs are put into Cosmos Works FEA software. Whoops.

**Figure 18** Thin Feature Mesh Generation Mistake



Appendix A  
List of References

## References

Daryl L. Logan. A First Course in the Finite Element Method. 3<sup>rd</sup> edition, Copyright 2002.

Solid Works 2003, Cosmos 2003, Help and Tutorial Files

<http://www.howstuffworks.com/>. How Pushrods Engines Work, Copyright 2003.

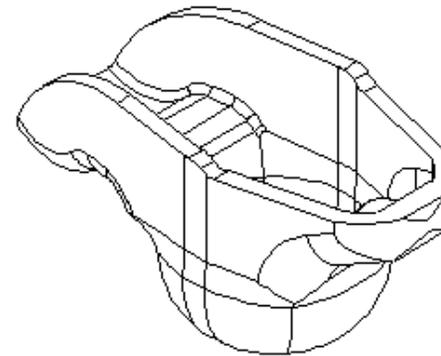
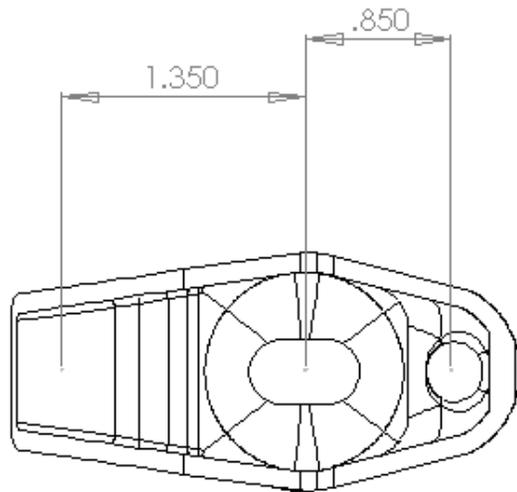
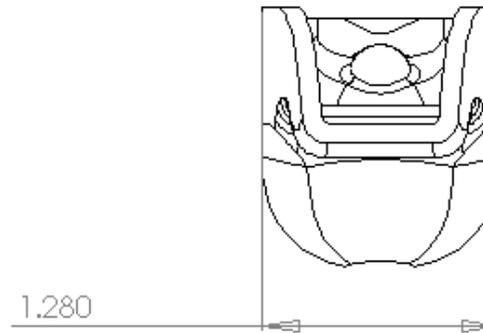
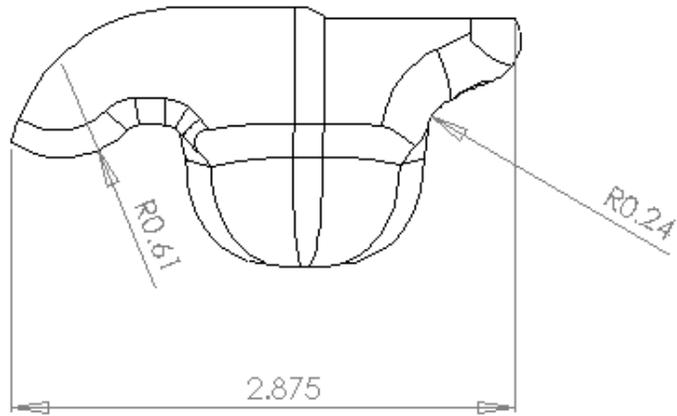
<http://www.drerracing.com/> DRE Racing, Shaft Rocker Arm Information, Copyright 2003.

<http://www.re-racing.com/> R&E Racing, Race Rocker Arm Information, Copyright 2003.

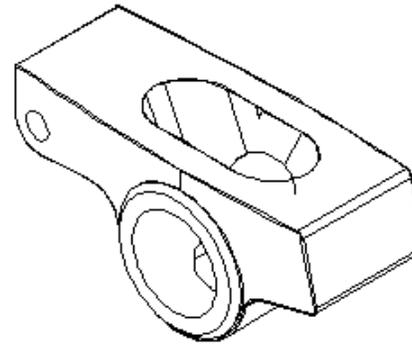
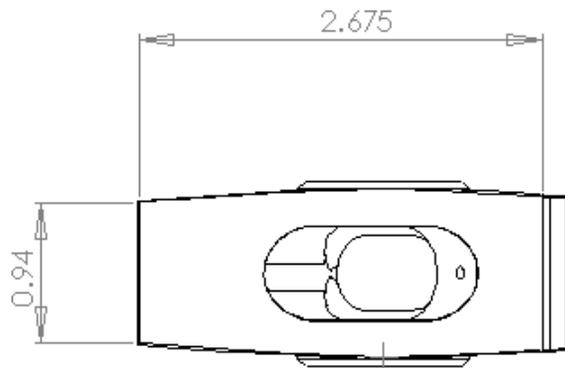
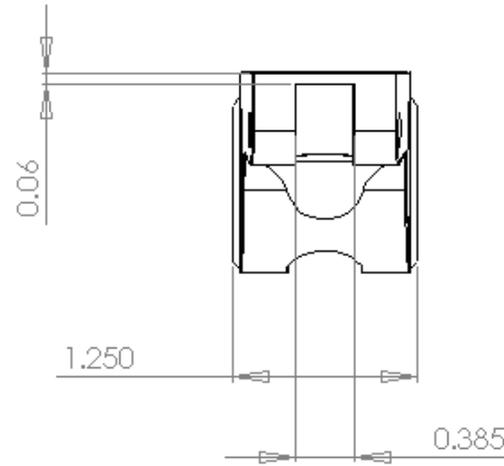
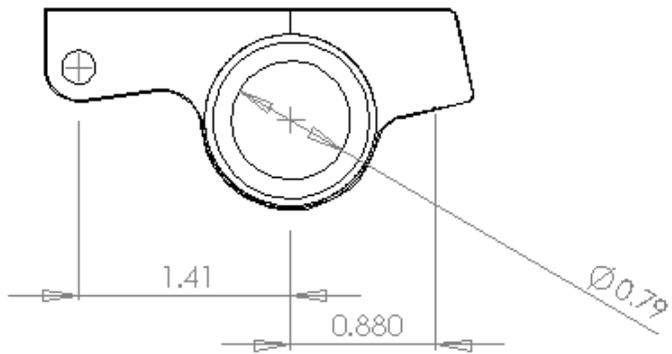
Bill Sansone, Charlie Hough. B & C Machine, Engine Builders, Copyright 2003

Joseph Edward Shigley. Mechanical Engineering Design. 5<sup>th</sup> Edition, Copyright 2001

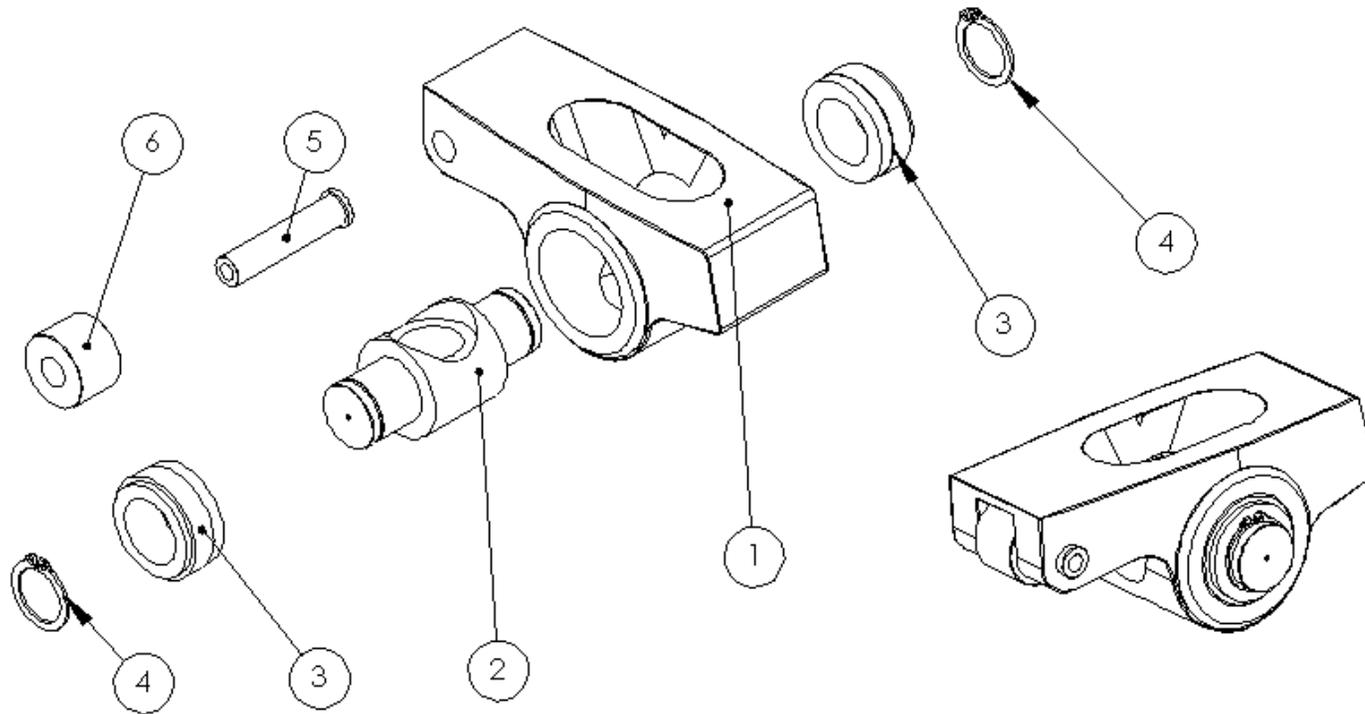
Appendix B  
Design Details and Figures



Stamped Steel Thickness: 0.125 in		
SIZE	<b>A</b> Stock Rocker	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



Material: 2024 Billet Aluminum		
SIZE	<b>A</b> Roller Rocker	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



ITEM NO.	QTY.	PART NO.	DESCRIPTION
1	1	Roller Rocker	Machined Alum.
2	1	Needle Bearing Housing	Steel
3	2	Bearing Cap	Steel
4	2	Snap Ring	Steel
5	1	Rollerpin	Steel
6	1	Spring Roller	Steel

SIZE	<b>A</b>	Roller Rocker Exploded View	
		SCALE 1:1	WEIGHT: SHEET 1 OF 1