The Trilobe Engine

Project Greensteam

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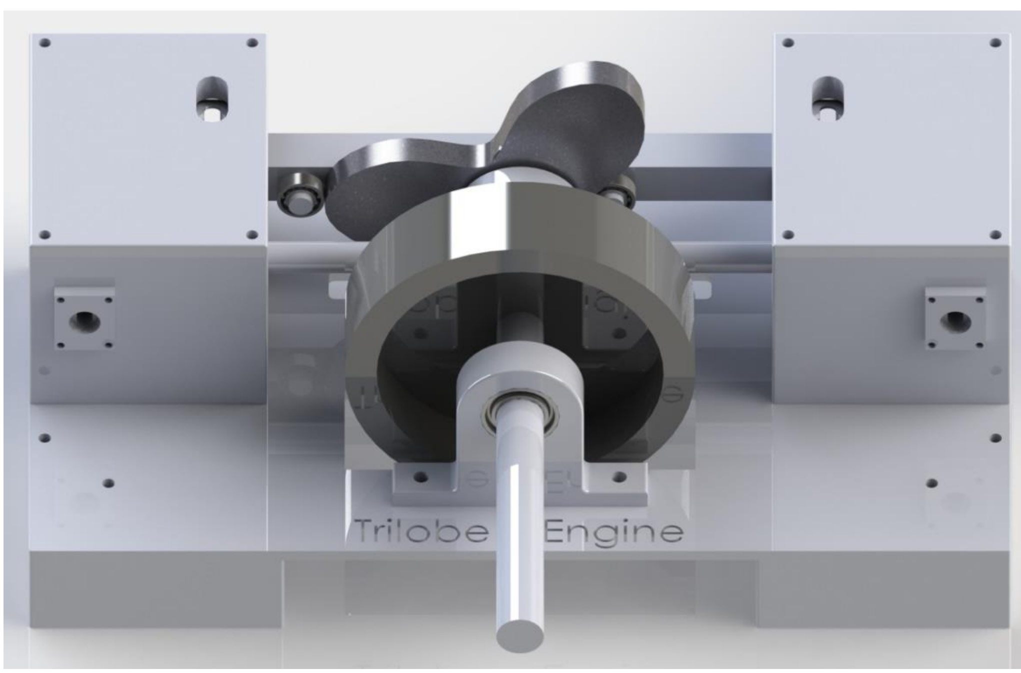
4/19/2020 – 8/31/2020



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Introduction

The Trilobe Engine

The Trilobe Engine designed for Project Greensteam is an external combustion steam engine that features an opposing two piston layout. The pistons are linked by a straight connecting rod and the translation of the pistons will be used to rotate a central “Trilobe” (or three lobed) cam. This Trilobe cam features peaks and troughs that correspond to Top Dead Center (TDC) and Bottom Dead Center (BDC) respectively. Steam is created outside of the piston chambers and will be fed into the engine with eccentric valves. The eccentric valves are activated by a second three lobed cam (not the Trilobe) that is rotated by the cam shaft. As steam enters the piston chamber, it forces the piston towards the Trilobe. This process provides two functions; it causes the Trilobe to rotate which will spin the cam shaft and connected flywheel thus generating engine power and it will cause the opposing piston to return its approach to TDC. As this engine has two pistons and operates as a two stroke, the engine will always be operating on one power stroke and one exhaust stroke.

Computer Design Model

The following is the first completed prototype model of the Trilobe Engine. The model was created using Solidworks and features a combination of parts and subassemblies.

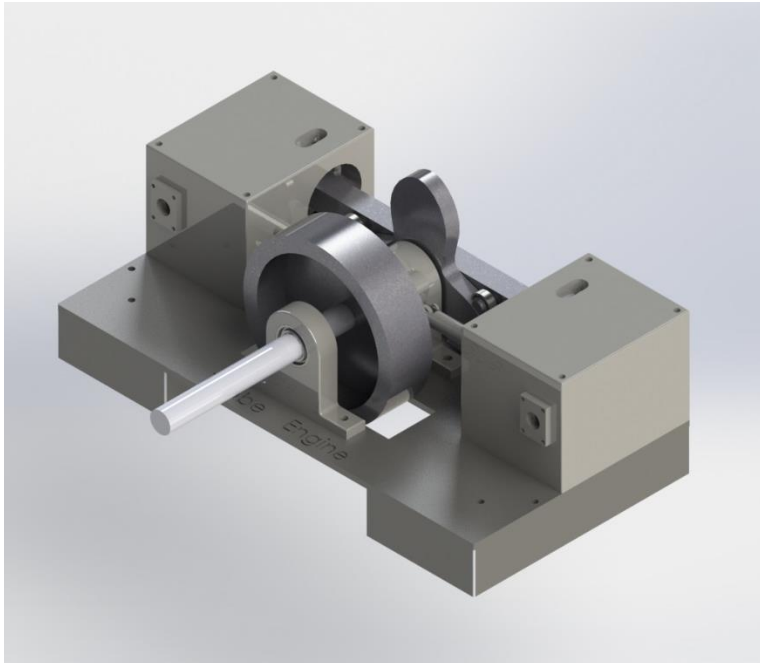

Figure 1: The Trilobe Engine Assembly

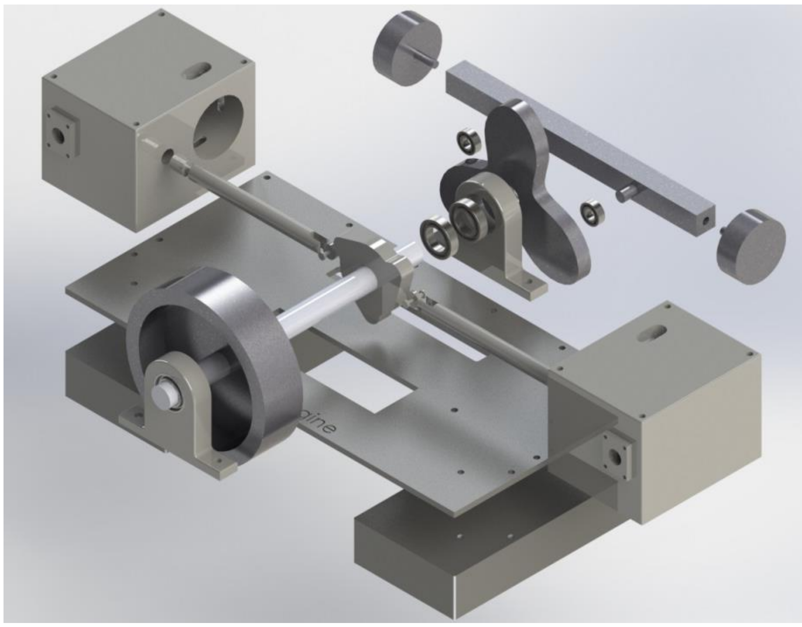

Figure 2: The Trilobe Engine Exploded View

Research Topics and Design Challenges

Two Stroke Engines

The Trilobe Engine features an opposed two stroke piston arrangement. For any piston based engine, a stroke is the complete motion of the piston from one end of the piston chamber to the other. In a piston engine, there are power strokes and exhaust strokes. Unlike the more commonly used four stroke engine which has one power stroke per four strokes, the two stroke engine is designed to accomplish a complete cycle of power generation in one stroke and the exhaust of spent fuel/ fumes in a second stroke. This means that the pistons will always be accomplishing power or exhaust in a stroke. Since the Trilobe engine has an opposed piston layout, one piston will always be on a power stroke while the other is on an exhaust stroke, meaning that the engine is generating power in every stroke.

The Trilobe engine is powered by steam which enters the piston chamber with the use of eccentric valves (see eccentric valves below for more) just after Top Dead Center (TDC) in the piston chamber. As steam enters the chamber, the piston will be forced downwards. This stroke which forces the piston towards the Trilobe is known as the power stroke. When the piston is nearing Bottom Dead Center (BDC) and the power stroke is concluding, the eccentric valve will stop letting steam into the piston chamber and the majority of the usable energy created by steam pressure will be gathered in the form of rotation of the Trilobe cam. This does not mean, however, that steam can now be added back into the piston chamber. In order to have another power stroke, the remaining steam pressure needs to be exhausted so that the piston can travel back to TDC. The piston chamber is exposed to three exhaust port openings when the piston reaches BDC in the piston chamber. The remaining pressure in the steam will allow it to exhaust naturally which will allow the piston to begin its return (or exhaust) stroke. This second stroke will not see the addition of new steam or the exhaust of more steam past the point where the exhaust ports are covered. The return of the piston to TDC will be aided by the addition of steam into the opposed piston which will force this piston to finish the exhaust stroke.

The Trilobe Cam

The Trilobe cam is a unique cam that has only been used in a handful of known engine designs or other applications. A typical cam is designed to turn rotational motion of the cam into linear motion with the use of a lobe protruding from the surface of the cam. The Trilobe cam is designed with three protruding lobes in order to accomplish multiple piston strokes per single rotation of the Trilobe. As pictured in the model, the Trilobe cam sits between the two pistons and makes contact with horizontally opposed bearings mounted perpendicular to the connecting rod. Unlike a typical cam which has one or a few lobes on a mostly circular cam, the Trilobe features both peaks and troughs equally spread around the cam. The addition of troughs to the cam means that the piston will have a gradual approach to TDC and BDC, allowing for a smoother power curve.

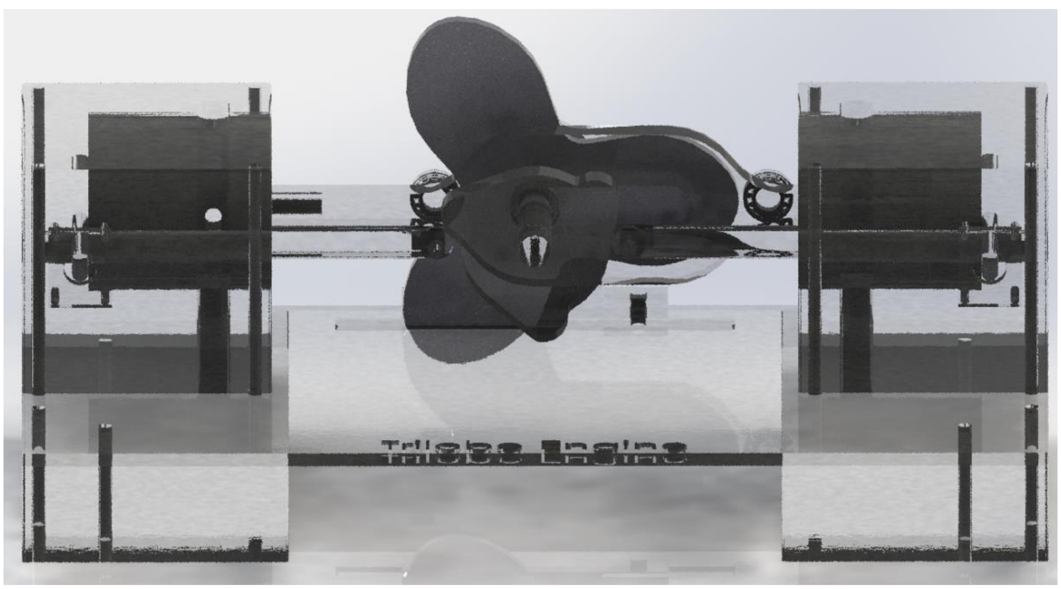

Figure 3: The Trilobe Cam in Assembly

The most important aspect of the Trilobe cam is that it controls how the power is delivered. While the cam is only receiving the rotational energy generated from the translation of the pistons when steam pressure is added to the piston chambers, the Trilobe cam curvature determines how smooth or sharp that power delivery will be. The curvature of the Trilobe cam has been the greatest design challenge not only of this cam but of the entire engine in general. Knowing that the distance between the two contact points of the Trilobe cam is fixed by the distance between the bearings on the connecting rod, the Trilobe becomes defined by the translation of that horizontal length. In order for the Trilobe to remain in contact with the bearings at all times, the horizontal line across the Trilobe must always be the same length. Now that this is known, it is important to note that the acceleration of the pistons back and forth also directly defines the shape of the Trilobe. If we want the pistons to accelerate quickly, we need to adjust the slope of the peaks to be steeper. If we want the power delivery to be more gradual, then we need to adjust the slope to be more gradual.

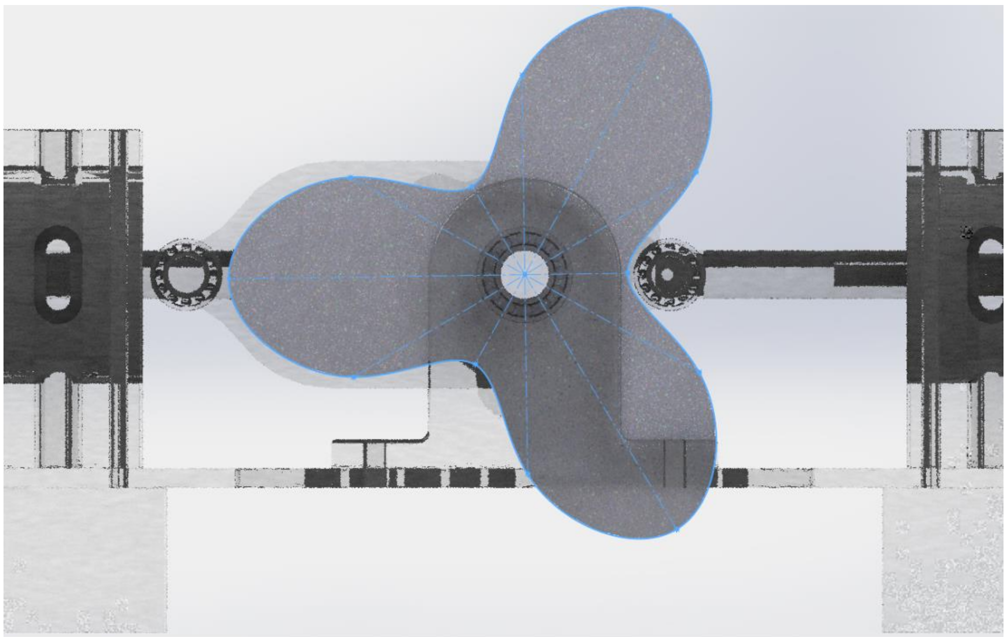

Figure 4: Trilobe Cam Sketch Using the Understanding of the Horizontal Length (Dotted Lines Highlighted in Blue)

The Flywheel

One of the main concerns with the Trilobe cam is the point where the bearing reaches BDC. At this point, the bearing has the potential to get stuck in rotation, thus stopping the cam's rotation. Some alternatives to the Trilobe's symmetrical and gradual curved shape have the potential to solve this (described below), but the more common solution to this problem is the addition of a flywheel. The flywheel is mounted to the cam shaft and acts as a way to store the rotational energy created by the Trilobe. While the added momentum of the flywheel does not remove the problem that the Trilobe has, it at the very least makes it harder for the engine to stall.

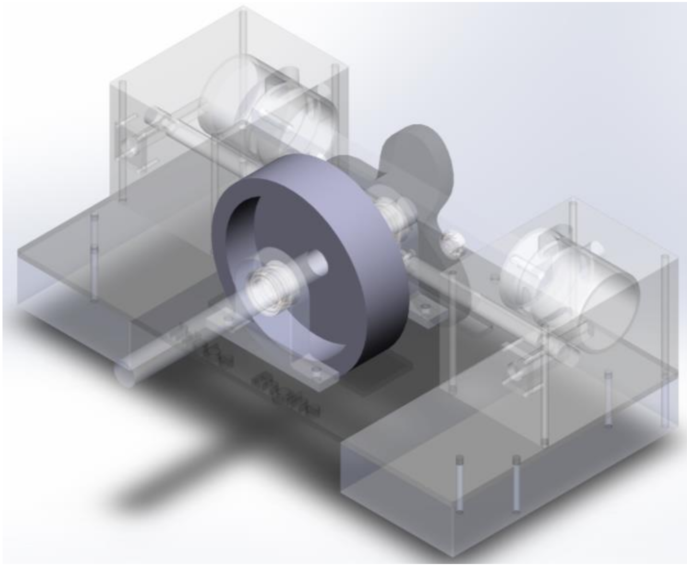

Figure 5: The Flywheel

Other "Tri" Cams

After many tests, models and simulations, the current version of the Trilobe proved to be the best shape for this engine. However, there have been some unique alternative design theories that, with further testing, may prove to be better alternatives.

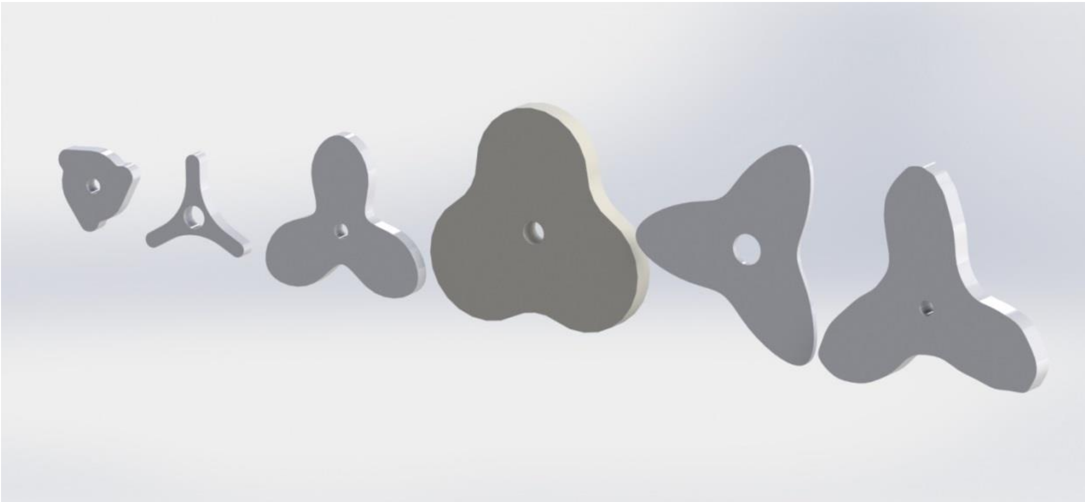

Figure 6: Various Tri Shapes That Were Modeled and Tested

The Tristar

The main design philosophy of the Trilobe discussed above is centered around a smooth power curve, but what if the cam was designed to act more like an on off switch? This design became known as the "Tristar" (pictured below). The main design constraint for the Tristar is that the displacement of the piston stroke remains the same as the Trilobe: one inch from TDC to BDC. Instead of complex curvature like that used in the Trilobe, the Tristar is designed around three lines. These lines are used to define the maximum distance from the center of the cam.

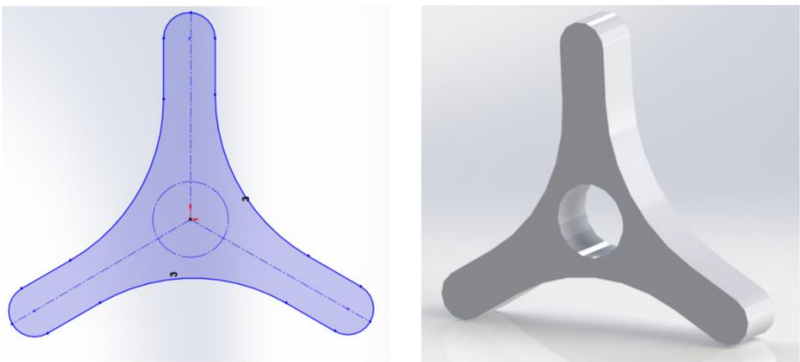

Figure 7: The Tristar Based on the Three Line Sketch

After establishing this constraint, curvature was then added to the peaks and troughs to give the bearings a curve to roll on and to give the Tristar a more realistic shape. While the curvature of the Trilobe was more deliberately designed for the bearings used, the trough curvature in the Tristar is used to add more thickness to the cam near the hole for the cam shaft. The Tristar is a promising alternative to the Trilobe cam. The main area of concern for this cam is around the bearings not always remaining in contact with the Tristar. This is because the horizontal distance across the Tristar is not the same throughout the cam's rotation. This increases the risk for reverse rotation and until this can be solved or proven to be an unnecessary concern, the Trilobe remains the preferred design.

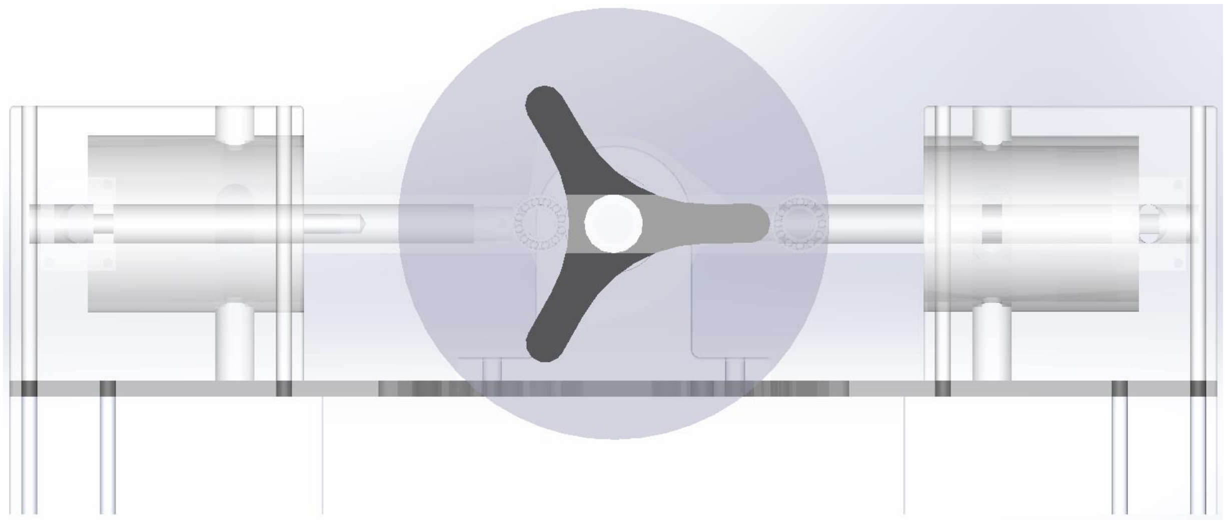

Figure 8: The Tristar Cam and the Associated Connecting Rod with Bearings at their Closest Distance.

The Asymmetrical Trilobe

The next Trilobe to discuss is a modified version of the current Trilobe that attempts to solve an issue with its curvature. The concern is over the engine getting “stuck” in its rotation at Bottom Dead Center due to the bearing not being able to move out of the trough in the Trilobe. One potential solution for this is an asymmetrical Trilobe. The design is made with the understanding that the Trilobe will be rotating in a specified direction (clockwise or counter clockwise) and can be shaped in a way that the force provided by the bearings will benefit from. This remains a design concern with the current Trilobe and the asymmetrical design could be a good replacement for it, but the best curvature has proven difficult to calculate. A rough curvature based on an existing model lead to the model shown below, but this design is rough and will not work as a final version of the cam. The other concern with this design is over whether both bearings can remain in contact with the Trilobe throughout the rotation. The only way for the bearings to both remain in contact with the cam is if the horizontal distance across the cam remains the same throughout the rotation. An asymmetrical cam may not allow for this distance to be equal all the way around the cam, but this also needs to be researched further before final conclusions can be drawn.

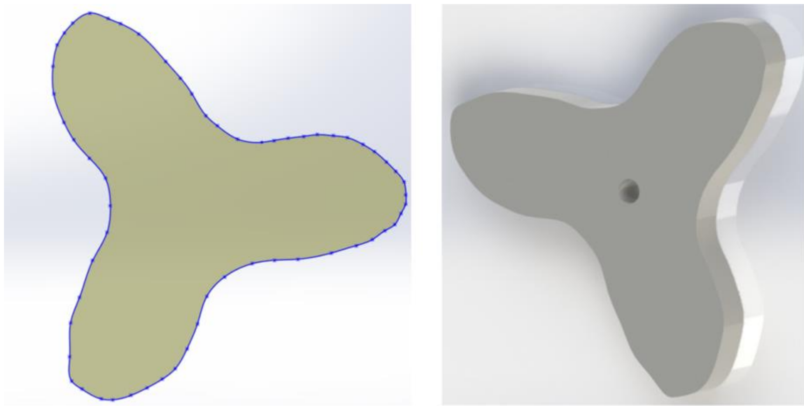

Figure 9: Asymmetrical Trilobe

The Circular Trilobe

The remaining designs have been less promising than the Tristar but cannot go without mention. The Trilobe pictured below is designed around a completely circular curvature. The shape is designed using 6 circles; 3 for the peaks and 3 for the troughs. While this shape has a smoother curve, the peaks are far more curved than desired. Because the curvature is more gradual than the currently used Trilobe, the only way to get a displacement of one inch would be to make a much larger version of this cam.

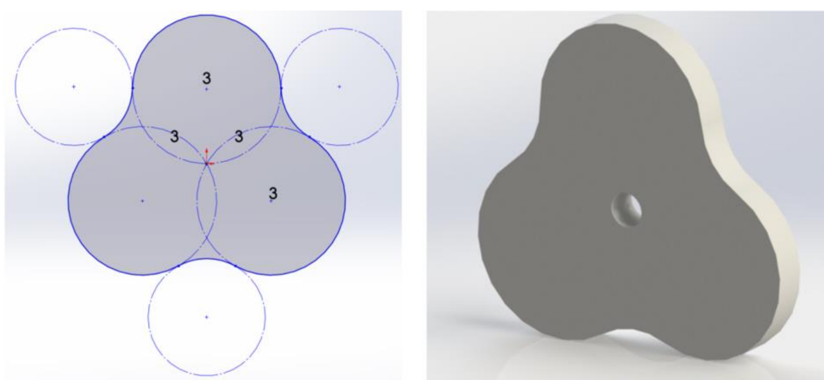

Figure 10: The Trilobe Cam Based Completely on Circular Curvature

Original Trilobe Curvature Model

The next Trilobe to discuss is an early version of the existing Trilobe, but the method for creating the curvature was less refined. The peaks and troughs were designed the same way as they are with the current Trilobe, but in order to make the width of the lobes controllable three more constraining lines were added. These are equal length and are placed halfway between the center point and the peaks of the lobes. This resulted in a shape that is similar but not as precise as the currently used Trilobe.

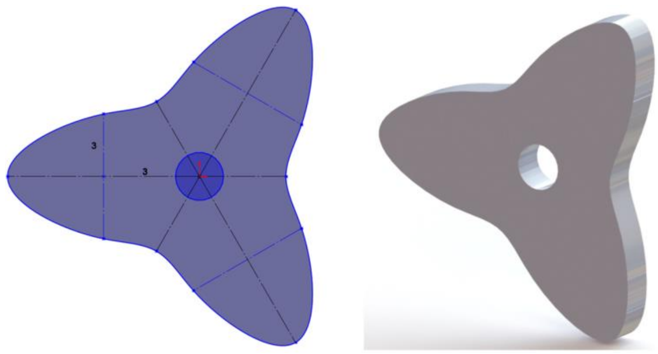

Figure 11: An Early Version of the Trilobe

Eccentric Valves

The eccentric valves are the valves that allow steam to enter the piston chamber at the precise time that it is needed. As mentioned above, steam is combusted externally. This steam will need to travel through a tube from where it is boiled to where it is turned into power in the engine. Once it reaches the engine, it needs to be precisely input into the piston chambers so that it can be used most effectively. This will be paired with the downward stroke of each piston (the stroke where the piston is travelling from TDC to BDC).

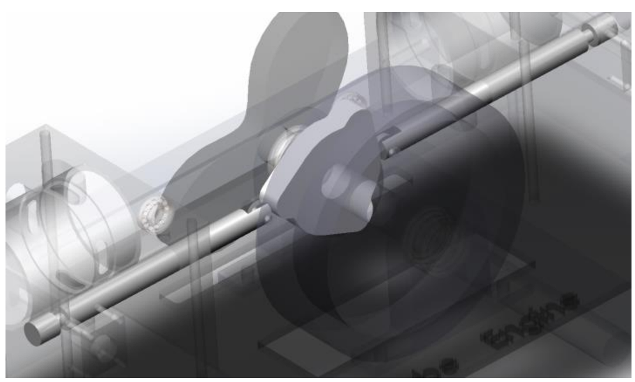

Figure 12: The Three Lobed Cam and the Eccentric Valves

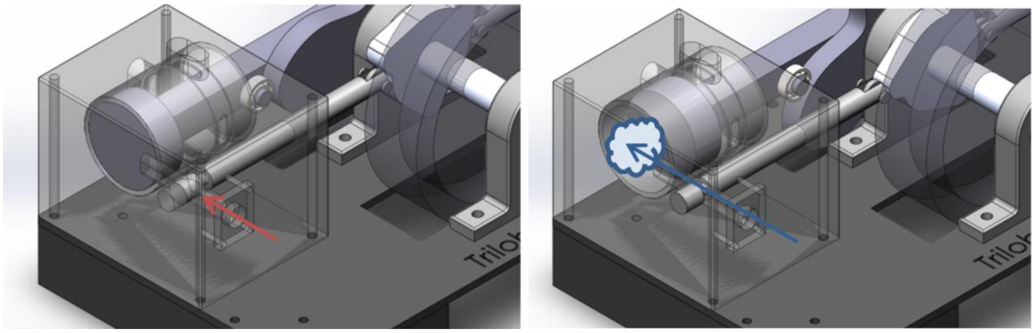

Figure 13: The Eccentric Valve is Closed (Left). The Eccentric Valve is Open and Steam Enters into the Piston Chamber (Right)

The valve is mechanical and operates on a three lobed cam that is similar to the Trilobe. However, unlike the Trilobe cam with its gradual and symmetrical peaks and troughs, the eccentric valves only need to open the valve for a short burst of steam. This means that the eccentric valve cam features abrupt peaks gradual curvature instead of troughs. The eccentric valve that is paired with the Trilobe engine is unique as it has to open three times per revolution of the Trilobe rather than the expected once per 360 degree rotation. This is accomplished by having a cam with three lobes that are placed at an even spacing around the cam.

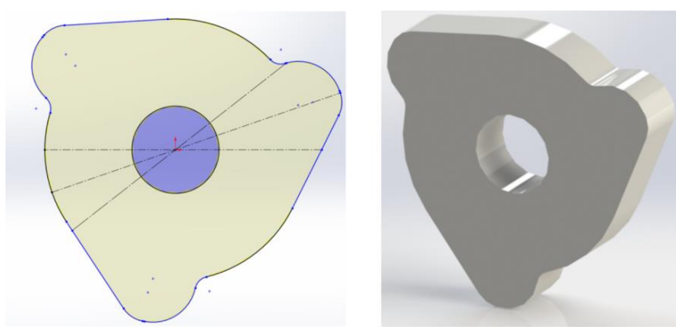

Figure 14: The Eccentric Valve Cam

Connecting Rod

Transferring the linear momentum from the piston movement to the Trilobe has been an area of difficulty with this engine design. In all referenced existing Trilobe engines, the connection between the connecting rod and the Trilobe is in line with the connecting rod. However, this leaves a point at every peak or trough where the Trilobe could stall in rotation. Essentially, the bearing on the connecting rod has the potential to get stuck at BDC on the Trilobe. One potential solution was to move the position of the bearings vertically off of the connecting rod so that the point of contact is not directly in line with the trough of the Trilobe. Though this design concept was a promising solution, simulations revealed a new problem where the bearings were now getting in the way of the Trilobe's rotation. The initial push by the bearing on the Trilobe removed the stall problem, but as the connecting rod began its return stroke it collided with the Trilobe thus reversing its rotation.

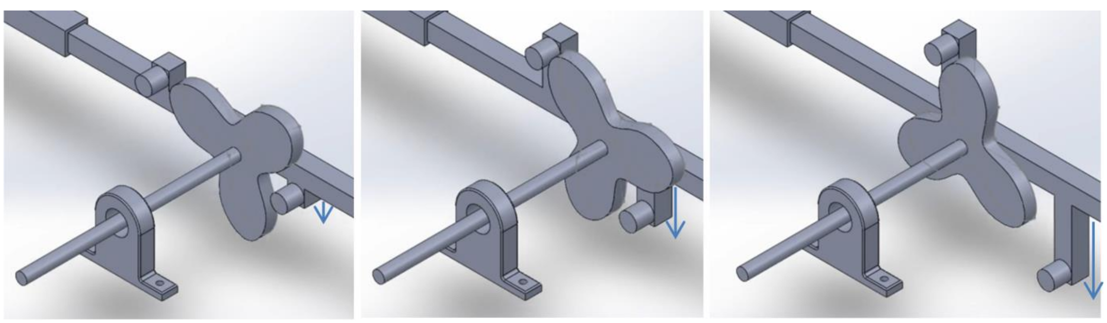

Figure 15: Examples of Various Connecting Rods Simulated. Note the Length of the Extension Off of the Connecting Rod (Blue Arrows)

From the simulations done, it was clear that the concern over the bearings coming into contact with the rotating Trilobe was justified and that the best solution was to leave the contact points in line with the connecting rod (shown below).

It is important to also discuss the horizontal displacement off of the Trilobe. When the design process started, it was assumed that the best position was for both bearings to remain in contact with the Trilobe on both sides throughout the rotation. However, the only bearing that needs to be in contact with the Trilobe is the one on the power stroke. The results from the simulations done indicated that the best position for the bearings is as close to the Trilobe as possible as any gap increased the risk of the Trilobe being forced to spin the wrong way. This is the position used in the current state of the models.

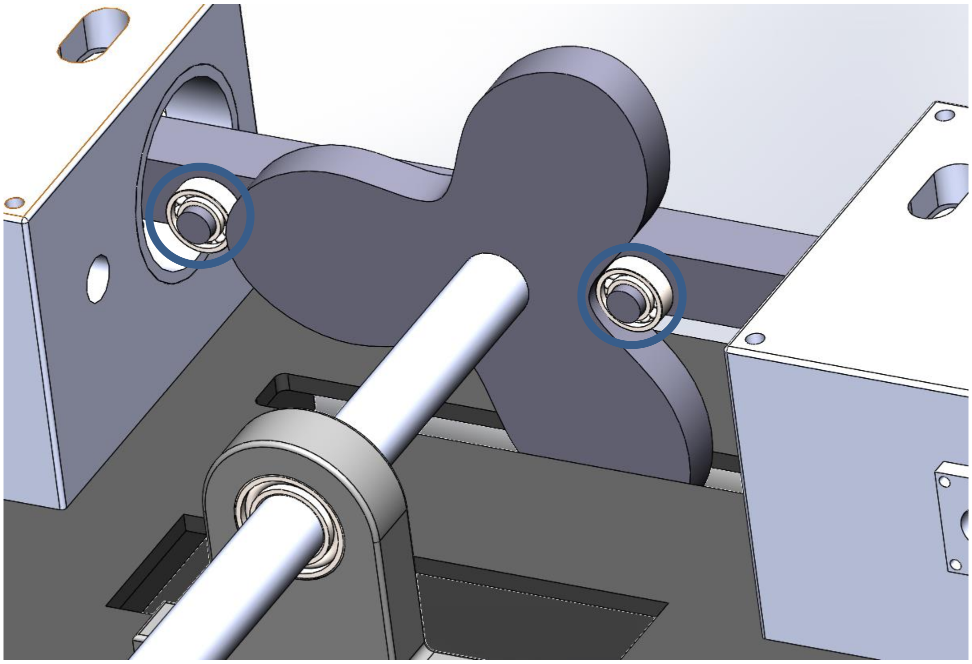

Figure 16: Final Positions of the Bearings in Line with the Connecting Rod (Circled in Blue)

Conclusion

Though some of the parts are relatively complicated to design, the Trilobe Engine promises good performance with simple, low cost part construction. This will be highly beneficial for project Greensteam as it will likely be at a low cost to prototype and then apply in real world applications. The future modification of the Trilobe cam will likely need to happen in a trial and error testing scenario where the effects of the curvature on power delivery can be viewed in a real world setting. Though both steam and the Trilobe have not seen much real world application in recent years, Greensteam and the Trilobe Engine seek to be a catalyst for innovation to the engine designs that have become commonplace in modern society.

Illustrations

The following section is dedicated to the design process that was used to create the existing model of the engine. Many of the early designs did not make it past the sketch phase, but should be mentioned as a way to acknowledge the ideas that would not work for the Trilobe engine. The more relevant designs will hopefully also offer a simplified visual to aid in understanding the basic functions of the engine.

Early Sketches

The following figure describes four key points in the engine's rotation. These key times were used to create the constraining lines used in the current version of the Trilobe (see Figure 4).

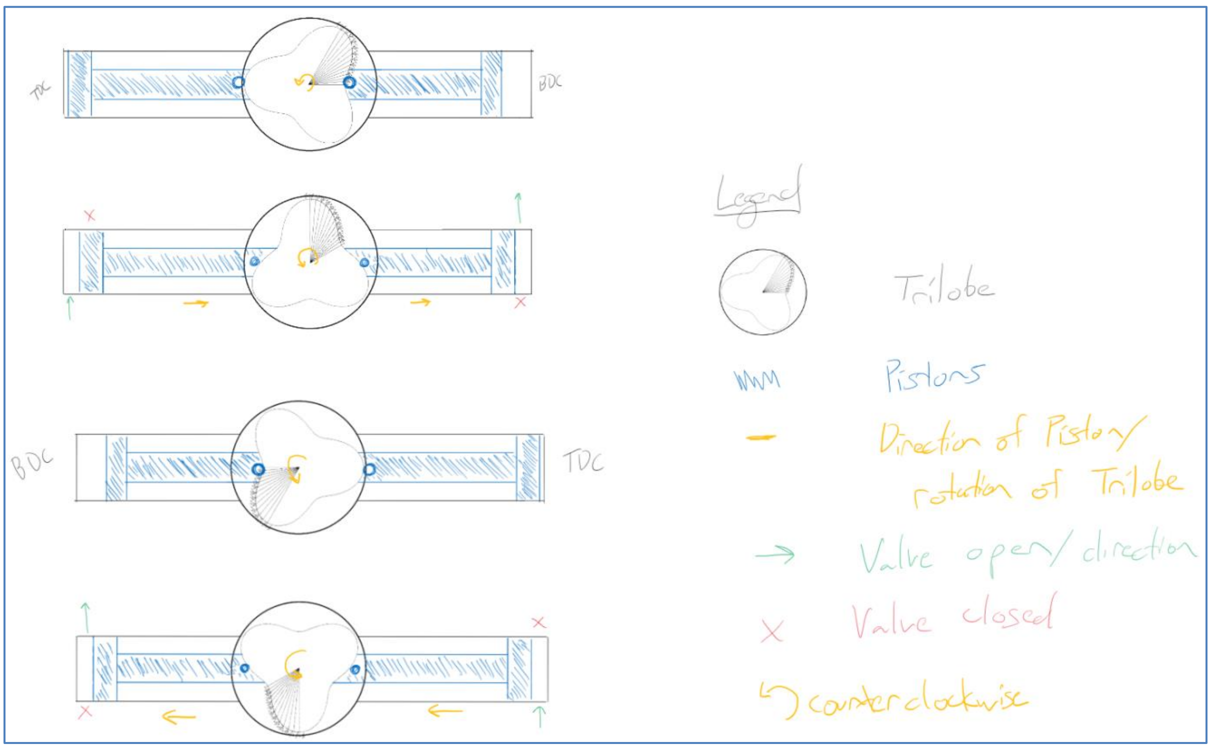

Figure 17: 4 Frames of the Full 360 Degree Motion of the Trilobe Engine

The figure below was used to visualize the impact that the curvature of the Trilobe makes on the engine displacement. As seen below, the thinner Trilobe (yellow) allows for a greater engine displacement than the more gradually curved cam (outlined in black) with the same cam size.

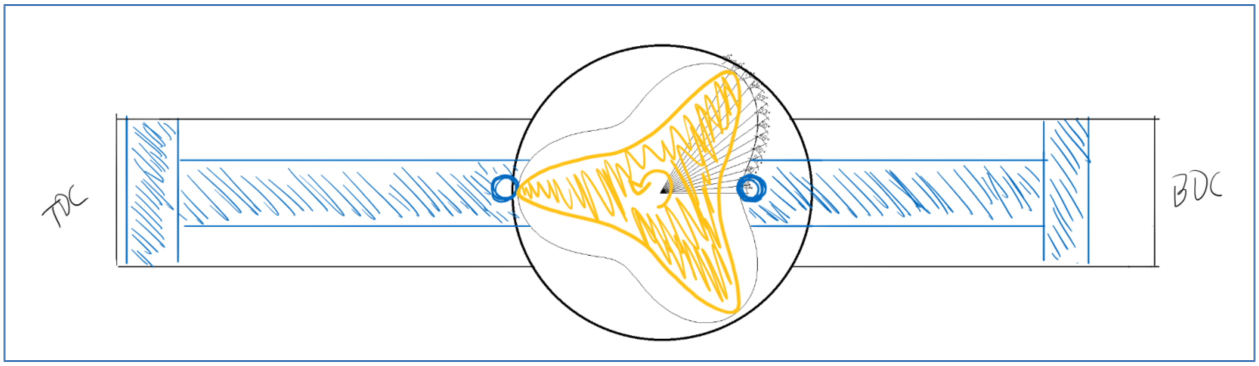

Figure 18: Understanding the Significance of the Cam's Curvature

Outdated Concept Sketches

This section shows designs that were not used in the current version of the engine due to concerns over whether it would function properly.

The designs shown in the two pictures below are showing a 90 degree angle "V" shape version of the Trilobe engine. This design was not used because it would have more complicated components like the connecting rod which would need to be in two pieces. It was also discovered that if the pistons were to be offset by an entire cycle (one at TDC while the other is at BDC), the engine would need to be 60 degrees rather than 90 degrees. This is due to the way that the Trilobe is designed.

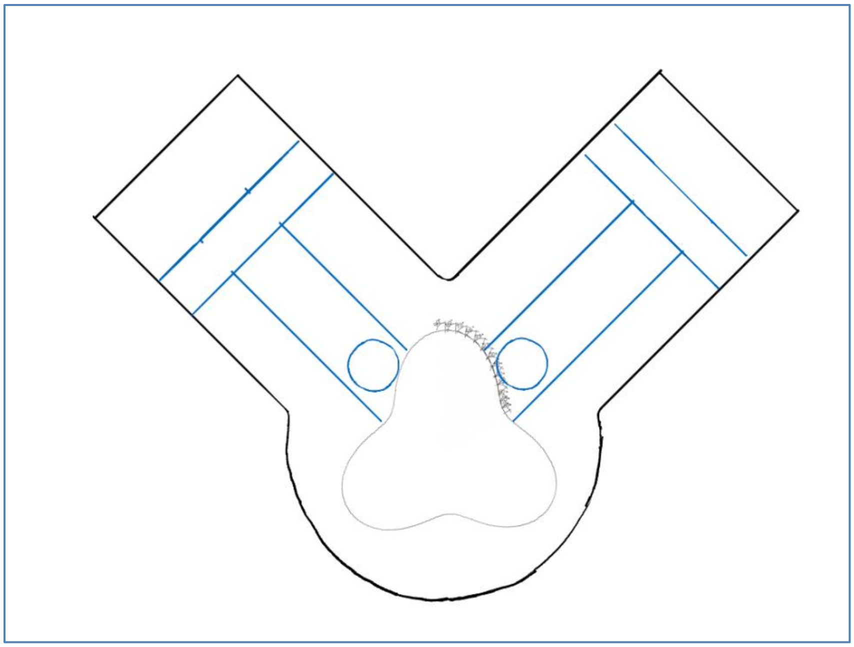

Figure 19: A 90 Degree Version of the Piston Arrangement.

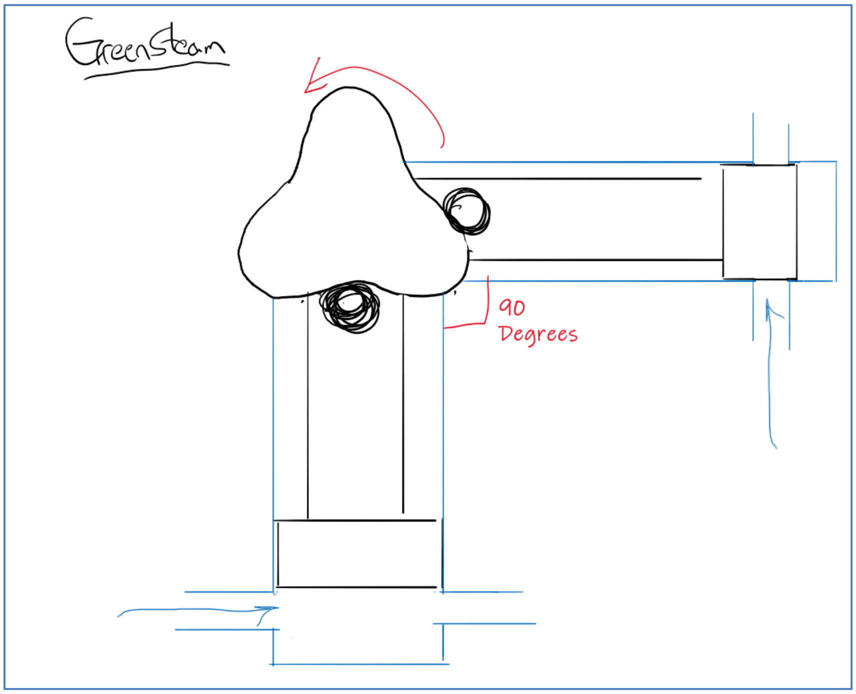

Figure 20: Another Drawing of the 90 Degree Layout

The figure shown below is an early sketch of the asymmetrical Trilobe described in this document. This design was retired early on over concerns about its complex curvature, but has since been looked into as a possible alternative to the current version of the Trilobe.

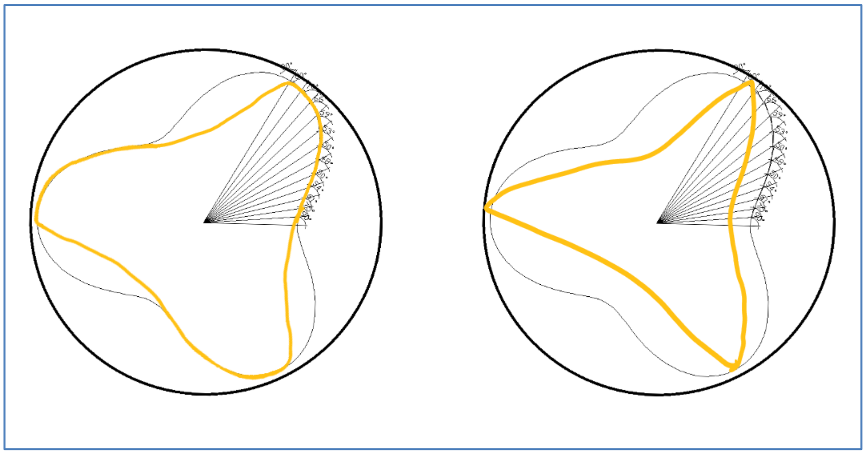

Figure 21: Concepts for the Asymmetrical Trilobe