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Department Of Mechanical Engineering.

M.Eng. Mechanical Engineering

Design of a Novel Product Using Waste Material

Jonathan Leary

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Supervisor: Dr S.R. Bradbury

Secondary Supervisor: Mr J.G. Heppell

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Summary

This project was carried out in conjunction with MayaPedal, an organisation based in Guatemala that convert old bicycles into useful machinery. These bicimáquinas (pedal powered machines) are designed to help local people become self sustainable in rural areas where electricity is not available and fuel is expensive. The purpose of this project was to design and build a bicycle powered water distribution pump. The Bicibomba Móvil (mobile bicycle pump) was conceived to transport water for a variety of purposes such as irrigation and domestic use. The main strength of the design is its mobility. A few simple steps transform a bicycle powered water pump into a fully functional bicycle that is also able to transport the pump. This makes the Bicibomba Móvil suitable for a many applications in a variety of different locations. The design reuses old bicycles that have been sent to MayaPedal by charitable organisations as well as taking an end-of-life electric pump and converting it to bicycle power. The few parts that do need to be manufactured can easily be made with the basic tools available in MayaPedal's workshop. The prototype was tested up to a 25m pumping elevation and generated a maximum flow rate of 40 l/min.

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1 AIMS AND OBJECTIVES

1.1 Aim

To develop a novel product that is manufactured from waste material.

1.2 Objectives

- To devise a concept for a novel product built from waste material.
- To research the potential sources for the chosen waste material to establish its availability and quality.
- To analyse the market and select the market segment/s that the product will be aimed at.
- To develop a basic design for the product taking into consideration the requirements of the potential customers from the chosen market segment/s.
- To improve the design by the building and testing of a prototype, use of market research, computer modelling and any other applicable methods.
- To take into consideration the cost, scale and methods used to manufacture the product and optimise the design accordingly.
- To consider how the product will be brought to the market place, for example, how it will be marketed and distributed.
- To produce a final design, taking into account all of the above factors that is ready to bring into the market place.

2 INITIAL IDEAS

2.1 Idea Generation

Initial research focussed on the different types of waste material produced by today's society and trying to find of a useful product that could be manufactured from them. A logical approach was used to break down each waste material into its core properties or parts, which could then be used to generate ideas for a product with those given properties. Some of the ideas generated using this technique are detailed overleaf:

- Glass Bottle → Translucent → Decorative Lamp
- Tetra Pack → Waterproof → Waterproof Panelling
- Refrigerator → Cooling Coils → Greenhouse Sprinkler System

However, none of the products were seen to be commercially viable in our society as they were of a significantly lower quality than their freshly manufactured counterparts. Although the idea of recycling is attractive to many consumers, they are unlikely to be willing to sacrifice the minimum standards of quality to which they have become accustomed, even if the product is slightly less expensive and from a sustainable source. Whilst many recycled products such as paper and glass have been successfully introduced to the market, their commercial success has largely been due to the extensive research and development that has gone into the recycling process to bring the finished product up to an acceptable quality. However, the situation in developing countries seems far more favourable. Here re-use of society's castaways is common: with old metal sheeting commonly used for roofing and discarded oil drums as make shift furnaces. Consequently, developing countries provide a much more attractive market as the cost of an item takes precedence over its quality. This makes a product made from waste material ideal.

2.2 Product Demand in Developing Countries

In order for a product to be successful, there must be a demand for it. These demands are driven by the wants and needs of consumers, with the wants only becoming relevant once the needs are satisfied. This means that consumer purchasing in developing countries is primarily driven by the consumers' daily needs. With reference to Maslow's Hierarchy of Needs (Figure

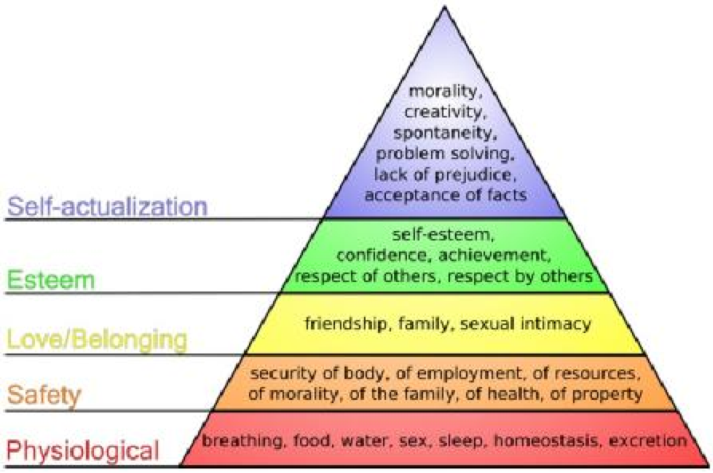


Figure 2.1 Maslow's Hierarchy of Needs[52]

2.1), the everyday lives of people in developing countries was dominated by attempting to satisfy basic survival needs such as shelter, food and water. A brainstorming exercise was conducted where each of these needs were isolated and potential solutions involving products made from waste material were generated, an example of which is shown in Figure 2.2.

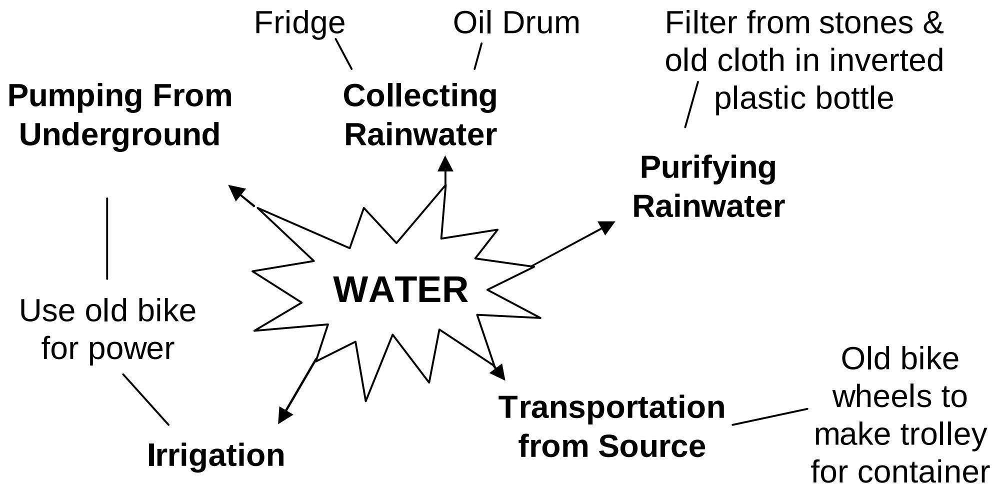


Figure 2.2 Brainstorming the basic needs of people in developing countries

2.3 Bicycles, MayaPedal and Bicimáquinas

As a result of the brainstorming exercise, it was evident that one specific waste product was particularly useful: the bicycle. It was especially practical means of supplying power for various processes in areas where electricity is not available. The concept of using bicycles as an alternative power supply for mechanical processes is not a new one. Some internet based research lead me to an organisation in Guatemala who convert old bicycles for mechanical applications in rural areas where electricity is not available. Since 1997 MayaPedal have been building pedal powered machines (bicimáquinas) to support small scale, self-sustainable projects and to help contribute to the conservation of the environment and health of the local economy. Figure 2.3 shows MayaPedal's bicycle powered blender being used to make pina-coladas at a local demonstration. The blender has also been used by a group of local women to produce organic shampoo from aloe plants they grow in their own homes. The sale of this shampoo helps support their families and fund their independently run municipal reforestation project. MayaPedal was set up by Pedal[25] of Vancouver, Canada, a voluntary organisation that repair and donate bikes for people in the city who need them. MayaPedal receive regular shipments of unwanted bicycles from Pedal and have also received bikes from other organisations such as Bikes Not Bombs[22] of Boston, USA. In 2001 MayaPedal became constituted under local control as Asociación Maya Pedal, helping to achieve one of the organisation's key goals of self-sustainability.

Figure 2.3 Blending Pina-coladas in MayaPedal's bicycle powered blender

2.4 Formation of the Partnership with MayaPedal

Initial contact with MayaPedal was made by email in order to determine the suitability of a collaborative project. A reply was received from Amilio, a Spanish speaking aerospace engineering student currently working for MayaPedal who has since been appointed as the organisation's Volunteer Co-ordinator. He seemed very enthusiastic about the prospect of a joint project. MayaPedal is a volunteer organisation and therefore are always keen to receive as much help as possible. However, he did stress that communication may become a problem as he is one of the few people currently working for the organisation who can speak English and that the internet connection is not very reliable. Consequently a concerted effort was made to obtain as much information as possible during the early stages of the project, in order to pre-empt any possible future communication issues.

2.5 Guatemala

MayaPedal is based in the town of San Andrés Itzapa, Guatemala (see Figure 2. and Figure 2.5). Guatemala is located in Central America and borders with El Salvador, Honduras, Belize and Mexico (see Figure 2.). Although Guatemala is a developing country, it is a country of many contrasts. Guatemalans are very aware of their more affluent North American neighbours, the influences of whom can be seen in the most unlikely of settings. For example, Amilio has often mentioned that is not can uncommon sight to see subsistence farmers who carry cell phones or families who live in mud brick houses, yet still watch television. The cell phone is likely to be an old American design and the television may even be black and white. It is this integration and re-use of technologies and designs from Guatemala's more affluent neighbours that have made the re-use of old bicycles a hugely successful venture. Although most of the population are not in danger of starvation, many Guatemalans are subsistence farmers and MayaPedal's machines are designed to help boost their income and help increase their quality of life. MayaPedal's bicimáquinas are designed to improve the everyday lives of local people by boosting the local economy, encouraging self-sustainability and reducing the amount of time spent on menial tasks.

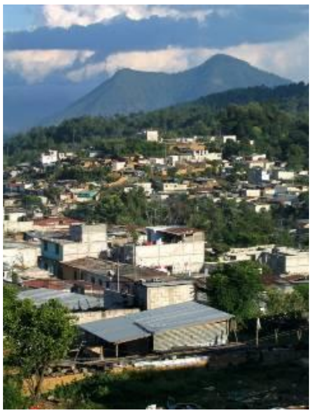


Figure 2.4 MayaPedal's home town of San Andrés Itzapa

Figure 2.5 MayaPedal's shop front

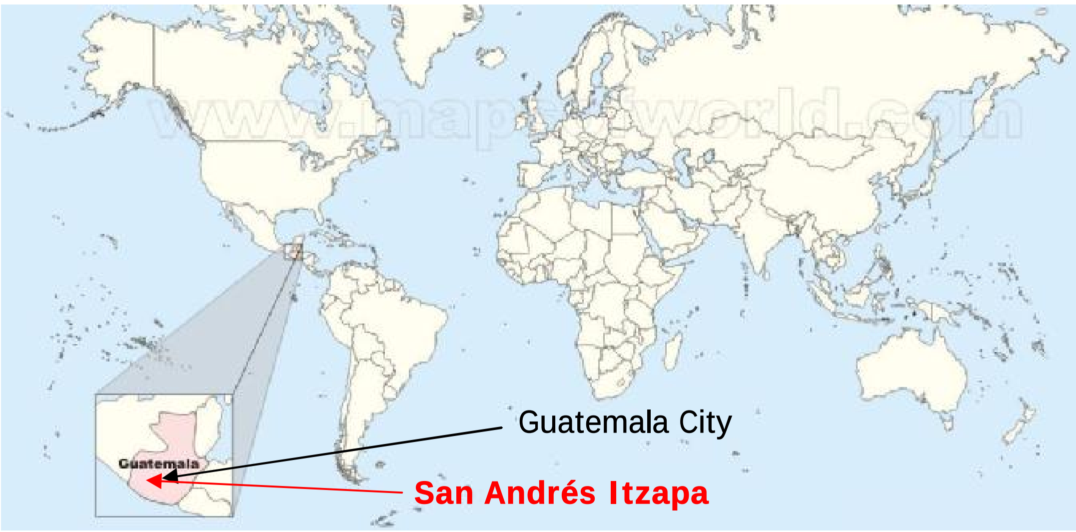


Figure 2.6 Global location of San Andrés Itzapa, Guatemala[54]

3 INITIAL PROJECT DEVELOPMENT

3.1 Available Projects

MayaPedal suggested four of their existing bicimáquinas that are in need of improvement and as such, their development could be suitable for this project.

3.1.1 Bicidescascadora de Nueces (Macadamia Nut-Sheller)

A number of Guatemalans grow macadamia nuts to sell, but lose out on a majority of the profit by selling whole nuts rather than going through the long and difficult process of de-shelling them. MayaPedal currently has a machine (Figure 3.1) that removes the husk of the nut, but the hard shell is more difficult to remove, especially since it is important to leave the nut whole. This machine would aid a group of very poor people.

Figure 3.1 Photograph of the Bicidescascadora de Nueces

3.1.2 Bicibomba (Water Pump)

Figure 3.2 and Figure 3.3 show the Bicibomba de Lazo (Bicycle Rope Pump) that MayaPedal have developed to pump water from a well up to 30 metres deep. However, most of the farmers in their region farm on very steep inclines. They would like to develop a pump that can move water greater distances uphill via pipes or hoses for irrigation and to supply water to houses. One farmer specifically requested a pump to transport water from a spring to his house (175m laterally, 75m up). They suggested that it might be possible to find a locally available ‘off-the-shelf’ electric pump and simply attach it to a pedal drive system (as they did for the de-grainer, coffee de-pulper and other machines).

Figure 3.2 Full view of the Bicibomba de Lazo

Figure 3.3 Close up of the Bicibomba de Lazo

3.1.3 Vibradora - Tejas de Microcreto (Micro-concrete Vibrator)

In order to produce good quality concrete roofing tiles the cement must be vibrated while wet to remove air bubbles from the material so that it sets properly. The roofing tiles shown in Figure 3.54 are attractive, durable and create better insulation than the corrugated metal roofs traditionally used in most of Guatemala. They are cheap to produce, meaning that the tiles have a great potential as the basis for a small business. MayaPedal currently has a working machine, but the man who uses it cannot make a profit from the tiles since with his current setup he needs three men to use the pedal vibrator - one to pedal, one to mix cement and one to move the moulds (see Figure 3.5). He has had to revert to using an electric machine that only requires two workers. The attachments for mounting the mould on the machine are also too difficult to use in mass production. Improving this machine will provide more income for the tile manufacturer (this is a small family run business) and make this source of income open to more people as well as making the cement tiles available to more communities.

Figure 3.4 Concrete tiled roof

Figure 3.5 Concrete tile mould

3.1.4 Bicilicuadora (Multi-purpose Blender)

MayaPedal have developed a pedal powered blender for use in a variety of applications to help boost the income of poorer families. They include the previously mentioned production of organic shampoo and selling of liquadas (blended fruit drinks) at festivals/football matches etc. The current design shown in Figure 3.76 and Figure 3.7 is only a static model and MayaPedal would like a design that was still rideable to allow the user to easily move location and act as a mobile street vendor, a profession that is very common in Guatemala. The design should include a space for a cooler (for fruit) and include the MayaPedal name on it to help raise awareness of the organisation.

Figure 3.6 The Bicilicuadora in use

Figure 3.7 Side view of the Bicilicuadora

3.2 Project Selection Process

A decision matrix was used to find the most suitable bicimáquina for further development in this project. The governing design criteria shown below were used to select the most suitable design:

A. The project must have enough technical content to be suitable for a final year project.
B. In order to be suitable for a mechanical engineering final year project, it must be relevant to the subject.
C. The project must be useful and of benefit to the local community.

D. The end product would be more useful if it could be used for a variety of task as opposed to a single function.
E. My personal technical knowledge is greater in some subjects than others, which would give me a greater understanding of that specific area, hopefully leading to a better final design.
F. It could be problematic if the raw materials required for testing were not readily available in the UK.
G. The better the scope for improving the current design, the more beneficial the project will be.

The binary dominance matrix shown in Table 3.1 was used to rank the design criteria in order of importance. The criteria were each judged against each other, with the more important criteria being given a 1 and the less important criteria being allocated a 0. The total score for each design criteria is added up at the end of each row. A value of 1 was assigned to all boxes on the leading diagonal so as to prevent any criteria from ending up with a total of zero (and consequently a weighting of zero). Each total was then divided by the sum of the totals to give the weighting for each criterion (the sum of which should be equal to one).

Criteria	A	B	C	D	E	F	G	Total	**Weighting**
A. Technical content	1	1	0	1	1	1	1	5	**0.250**
B. Relevance to mechanical engineering	0	1	0	1	1	1	1	4	**0.214**
C. Benefit to community	1	1	1	1	1	1	1	6	**0.179**
D. Multi-purpose	0	0	0	1	0	0	0	0	**0.143**
E. Relevant personal technical knowledge	0	0	0	1	1	1	1	3	**0.107**
F. Availability of raw materials for testing	0	0	0	1	0	1	0	1	**0.071**
G. Benefit from improving existing design	0	0	0	1	0	1	1	2	**0.036**
							Total	28	**1.000**

Table 3.1 Binary Dominance Matrix for ranking and weighting of design criteria

Finally, each concept was rated out of 100 according to how well it met each of the design criteria. These scores were then multiplied by the weighting for each criterion and totalled for each bicimáquina to give the overall percentage score shown overleaf in Table 3.2.

Criteria	Weighting	Bicimáquina Scoring Macadamia Nut Sheller	Water Pump	Micro-concrete Vibrator	Multi-purpose Blender
A. Technical content	0.250	80	**90**	80	60
B. Relevance to mechanical engineering	0.214	80	**100**	80	80
C. Benefit to community	0.179	80	**100**	70	60
D. Multi-purpose	0.143	30	**100**	30	60
E. Relevant personal technical knowledge	0.107	50	**70**	40	60
F. Availability of raw materials for testing	0.071	20	**70**	60	80
G. Benefit from improving existing design	0.036	60	**90**	80	70
	Total	64.6%	**91.8%**	65.4%	66.1%

Table 3.2 Decision matrix to select the most suitable project for further development

3.3 Project Choice

The water pump came out the clear winner, as it will require a sufficient level of technical analysis that is relevant to the area of study. I also have a good technical knowledge of pumps and pipeline systems. The new pump will allow farmers to irrigate their fields and increase their crop yield in areas where electricity is not available and fuel is too expensive. This will give the farmers more food for themselves and their families and help them become more self-sustainable. The pump will also allow people to transport water to their homes when previously this may have had to have been done by hand. Water is the only consumable raw material that I will require for testing, unlike the nut-sheller that would require unprocessed macadamia nuts which may prove difficult to find in the UK. There is also a clear benefit to improving the existing design as although it is excellent for extracting water from wells, it is not appropriate for irrigation or water transportation as it does not pressurise the water that it draws from the well.

4 DESIGN SPECIFICATION

4.1 Project Definition: Water Distribution Pump

Water-lifting devices fall into two main sub-categories depending on where the water is being lifted from:

- Groundwater – Rainfall seeps into the ground and collects in an underground reservoir. The upper limit of the reservoir is known as the water-table and can be just below the surface (as with a spring or oasis) or much deeper. The only way to get at this water is via a natural spring or to dig/drill down and use a water-lifting device to bring the water to the surface.
- Surface Water – Water from a lake, river or well may need to be transported to where it is required. Water-lifting devices can be used to make the water more accessible for purposes such as irrigation, drinking or bathing.

MayaPedal already have a working static water pump to retrieve groundwater (the Bicibomba de Lazo shown in Figure 3.2), however the water it provides simply dribbles out of the spout. The water then has to be taken to wherever it is needed – a time consuming and labour-intensive task. What they require is a device to transport the water so that it can be used for irrigation, bathing, drinking etc. Ideally there would be one machine that pumps the water up from the well and pressurises sufficiently to reach everywhere it is needed. However, as much of the Guatemalan farmland is very steep mountainous terrain, the vertical distances that the water will need to be pumped may exceed the limits of human performance. It is therefore concluded that bicycle powered water distribution pump will only be required to lift the water from the shallowest wells as its main function is to distribute the water across the surface.

4.2 Design Specification

A design specification was drawn up to ensure that the water distribution pump meets the requirements of MayaPedal and the Guatemalans who will use it.

Essential Features:

- Must be able to be built

Desirable Features:

- Should be easily transportable

using only the basic tools available to MayaPedal

- Must be pedal powered
- Must be cheap and easy to maintain by local people
- Must be hygienic if used for drinking water
- Must not require electricity or fuel
- Must be robust
- Must be easy to use
- Must be stable when in use
- Must be affordable

- Should have a flow-rate of at least 5 gpm (19 l/min)
- Should use standardised parts to reduce cost and allow easy maintenance
- Should be made entirely from bike parts
- Should be made entirely from recycled material
- Should be able to transport water up to 100m vertically
- Should only require one person to operate
- Should be self-priming
- Should be adaptable for many different situations
- Should pressurise the water for distribution
- Should be usable by men, women and children of varying sizes and fitness levels

5 EXISTING TECHNOLOGY

In order to be successful the bicycle powered water distribution pump must offer a significant advantage over the existing technology. The treadle and rope pumps are currently the most commonly used designs in Guatemala.

Figure 5.1 The MoneyMaker treadle pump[53]

5.1 Treadle Pump

The treadle pump uses a stair-stepping motion to draw water through a single or double pistoned body. Although not available in Guatemala, the MoneyMaker pump shown in Figure 5.1 is a good example of this technology. Over 45,000 pumps have been sold in Kenya, Tanzania and Mali. It has a maximum flow rate of 90 l/min and a can pump up to 13m vertically. However, it weighs over 20kg and consequently is difficult to transport. It is also expensive to manufacture, costing over $200(US) meaning that it must be governmentally subsidised to make it affordable

5.2 Rope Pump

The Chinese invented the concept for the rope pump with their chain and washer design over 1000 years ago. Over the years it has evolved with technological advances to create the modern rope pump shown in Figure 5.2. Evenly spaced washers are attached onto a long loop of rope to pull the water up through a pipe with a diameter just larger than the washers. Rope pumps are widely used throughout the world, particularly in Central America where 20,000 have been installed in Nicaragua alone since 1990[39]. They have been used to transport water up to 50 metres vertically and are generally used to retrieve groundwater from deep wells. MayaPedal's current Bicibomba de Lazo shown in Figure 3.3 is a bicycle powered adaptation of the rope pump used to retrieve water from a well. The rope pump provides a low-tech, low-cost option for water-lifting in developing countries and can easily be manufactured for under $70 (US) using locally available parts.

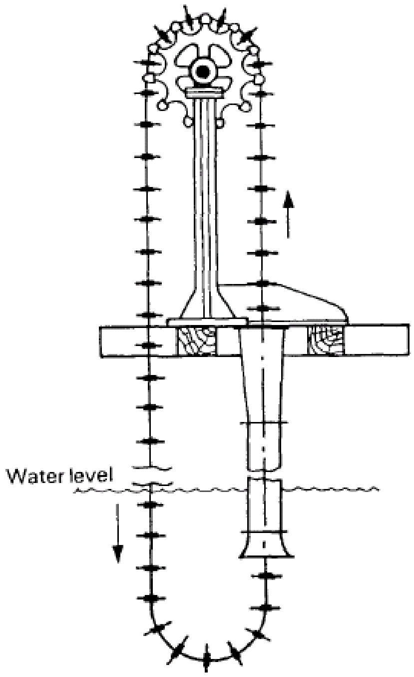


Figure 5.2 Schematic diagram of a Rope Pump[39]

6 CONCEPTUAL DESIGN IDEAS

6.1 Adaptation of Rope Pump for Surface Water Lifting

The Rope Pump is a robust, cheap and versatile pumping mechanism that has already been tried and tested. Figure 6.1 shows how it can easily be adapted to distribute water to a variety of sources using a bicycle by laying a PVC pipe along the ground and running the rope and washers through it. Although this would be acceptable for transporting the water to one place, it does not pressurise it for distribution at the receiving end. However, this problem can be easily solved by having the top of the pump slightly above where the water is required and connecting old drainpipes to the receiving end of the pump, allowing gravity to distribute the water.

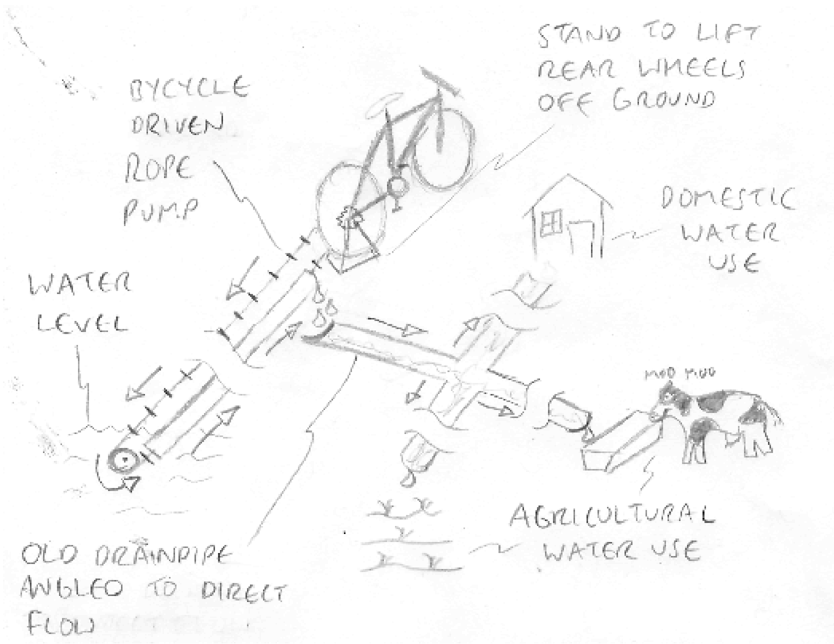


Figure 6.1 Sketch diagram of surface water rope pump design

6.2 End-of-life Electric Pump Conversion

Another option would be to take an end-of-life electric pump and simply adapt it for pedal power by connecting it to a rotating part of

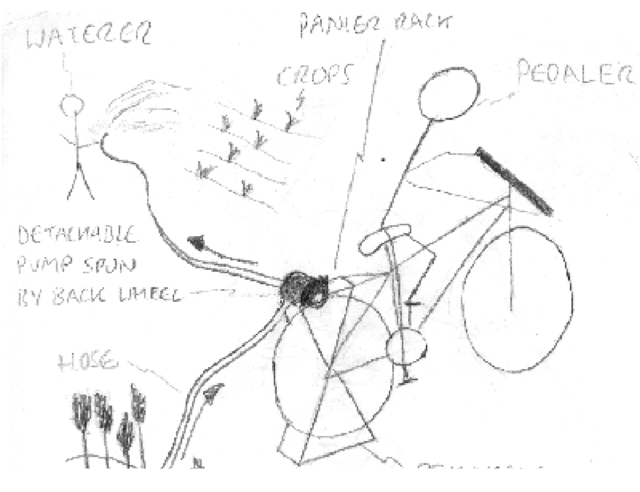


Figure 6.2 Sketch diagram of adapted end-of-life electric pump

the bicycle. Figure 6.2 shows how a standard bike could have a pump head from an end-of-life electric pump with a worn out electric motor attached onto the pannier rack at the back. With the rear wheels lifted off the ground using the aid of a stand, the back wheel could be used to drive the pump. An advantage of this design is that the bicycle could be kept virtually intact, meaning that it is still rideable and therefore the pump is mobile. A reservoir system using old bathtubs or oil drums could then be used to increase the distribution area as illustrated in Figure 6.3. This would enable water to be transported over much greater distances, using only one machine.

Figure 6.3 Schematic sketch diagram of bathtub reservoir system

SOURCE

6.3 Peristaltic Pump

A bicycle inner-tube could be used as flexible piping to create a peristaltic pump. Figure 6.4 shows how the wheel of the bike could have bumps welded onto it to so that when it is pressed against the water-filled inner tube and rotated, it would force the water in the direction of rotation. Although this

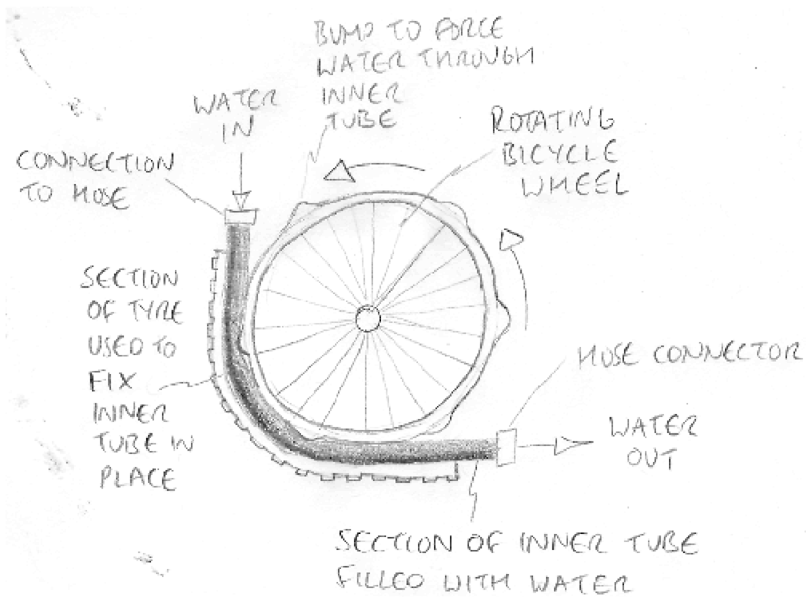


Figure 6.4 Sketch of peristaltic bicycle pump diagram

may not be a very practical option as the flow rate and head are likely to be too low to be useful, the design could be built entirely from old bicycle parts, so may be suitable for MayaPedal to use as a demonstration model to show what the organisation can do using only a simple bicycle.

6.4 Conceptual Design Selection Process

A decision matrix was use to evaluate the relative merit of each design using the criteria laid out in the design specification. Again, a binary dominance and decision matrix was used to select the most suitable concept for further development. Both are shown in APPENDIX 3 - Binary Dominance and Decision Matrices.

6.4.1 Conceptual Design Choice

The strengths of the peristaltic pump were that it was built entirely from recycled bicycle parts and as a consequence was also very cheap to manufacure. However, this also meant that it was not very durable and would most likely not be able to provide a high enough head or flow rate. The rope pump adaptation was the only design that was self-priming; it was mainly built from recycled parts and was able to provide a decent head and flow rate. Nevertheless, it was so big that it was not mobile or easily adaptable for different uses. It was less hygienic as it is open to the air and due to its size, would have been more complex to build.

The end-of-life electric pump conversion was clearly the strongest candidate. It uses standardised parts, making it durable and simple to build and maintain. The design is simple and easy to use and the fact that the bike is still rideable means that it can be moved around to wherever it is needed. It provides a good head and flow rate and can be built mainly from recycled parts by using end-of-life pumps and reconditioned bicycles. It is the most hygienic design, as the water is always enclosed within the pump or hose and therefore could be used to pump drinking water. The pump is not self-priming, however a foot valve could be placed on the suction hose so that it would only need to be primed once. Ideally the design should use an end-of-life electric pump, if a reliable source for these cannot be found then new pumps could easily be substituted to keep up with demand.

7 DESIGN DEVELOPMENT

7.1 Bicibomba Móvil (Mobile Bicycle Pump)

It seemed appropriate to name the design in the same style as the rest of MayaPedal's bicimáquinas. The name Bicibomba Móvil (Mobile Bicycle Pump) was chosen as it highlighted the main advantage of the design over MayaPedal's existing Bicibomba de Lazo (Bicycle Rope Pump): it can be moved around to pump at any location. Building a bicycle powered water pump is not a new idea: the machines shown in Figure 7.1 and Figure 7.2 as well as MayaPedal's own Bicibomba de Lazo are examples of pumps that have already been built. However, the mobility of the Bicibomba Móvil gives it a significant advantage over the existing technology as it greatly increases the potential water distribution area when used in conjunction with small reservoirs (see Figure 6.3). It also makes transportation of the pump far easier and leaves the bicycle intact so that it can still be used for personal transportation.

Figure 7.1 Bicycle powered water pump built by student of the University of Colorado, USA[32]

Figure 7.2 Bicycle powered water pump for watering the garden at C&C Hotel in Pattaya, Thailand[36]

7.2 Selection of Design Features

Taking the concept of a bicycle driving an adapted end-of-life electric motor up to the stage at which a working prototype can be built requires a number of decisions to be made on which design features to include. Binary dominance and decision matrices were used to ensure the correct selection was made at each point and ultimately end up with the optimum design. Full details of these can be found in APPENDIX 3 -

Binary Dominance and Decision Matrices. The decision tree shown in Figure 7.3 illustrates the interdependence of these decisions and consequently the order in which they must be made. An annotated diagram of a typical modern bicycle has been provided in APPENDIX 1 - Anatomy of the Modern Bicycle as a reference guide for the terminology used to describe bicycle components and sub-assemblies.

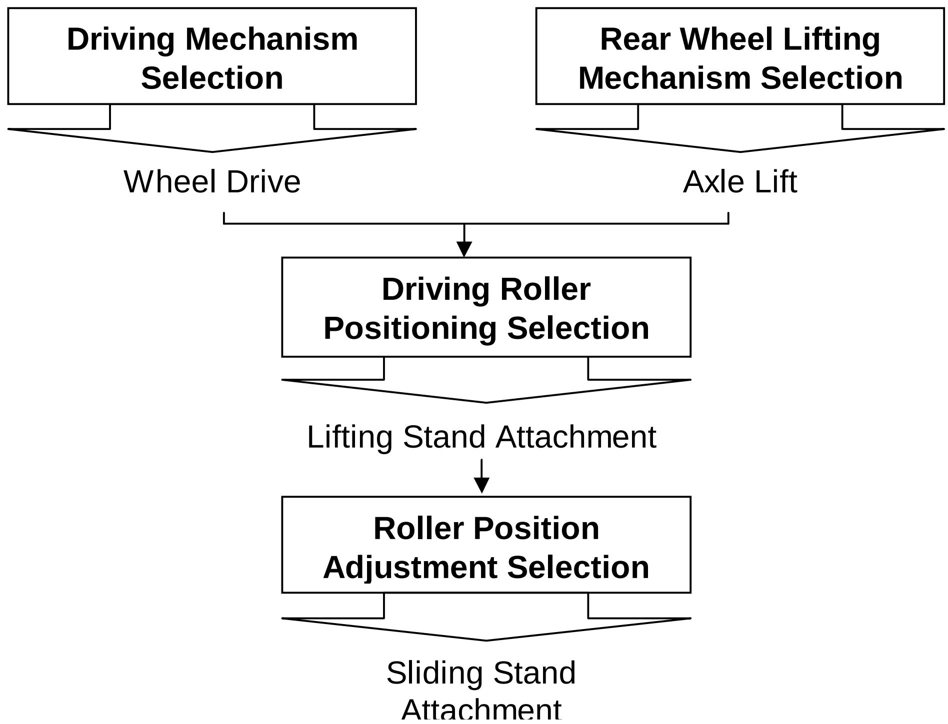


Figure 7.3 Decision tree for design feature selection showing the order of decision making and the outcomes of each stage

7.2.1 Driving Mechanism

The first decision that needed to be made was how to transfer the rotational energy from the bicycle to the pump. The sketches in Figure 7.4 show the various driving mechanisms that were considered.

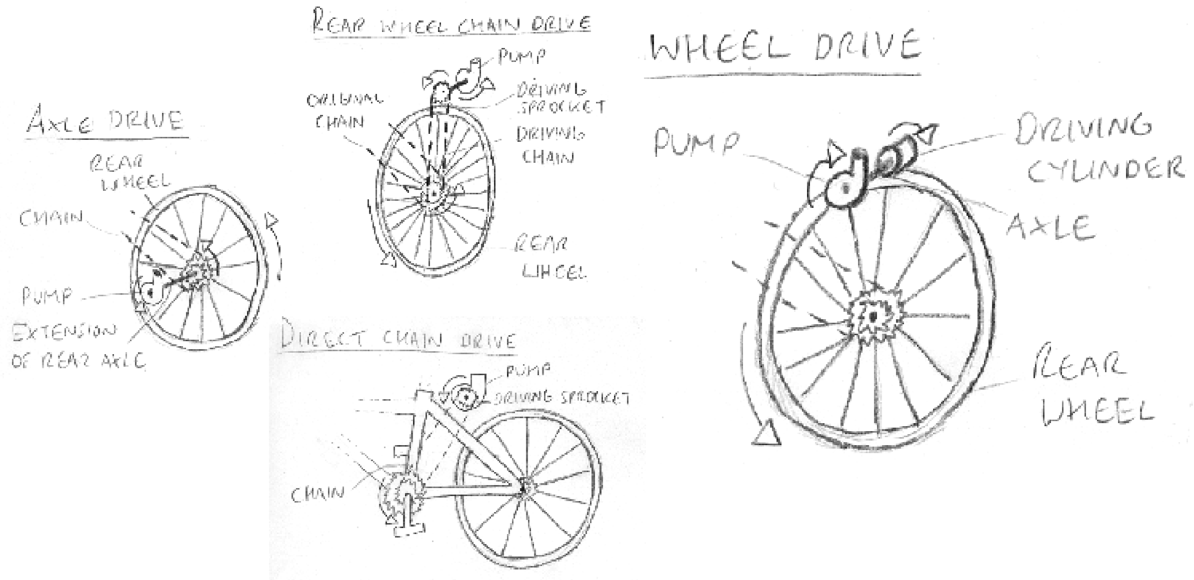
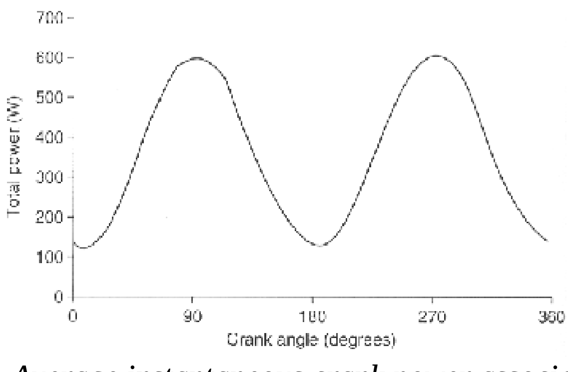


Figure 7.4 Sketch diagrams of the wheel drive and other possible driving mechanisms

The driving mechanisms were evaluated using the criteria shown below in Table 7.1:

Ease of use	People won't want to use a design that's fiddly and time-consuming to set up.
Weight	Lightweight designs are easier to use and transport.
Gear usage	If the existing bicycle gears form part of the drive-train then they can be utilised to optimise the pedalling cadence and pump speed.
Back wheel lifting	If the back wheel needs to be lifted off the ground then it will increase the complexity of the design.
Ease of manufacture	Complex mechanisms are difficult to make.
Ease of setup	The design should still be easily mobile and should take the least amount of time and effort to change between riding and pumping modes.
Cost	Complex designs are expensive to make.
Use of bicycle parts	Bicycle parts are obviously widely available at MayaPedal, so utilising them in the design will reduce the cost and mean that spares will be available.
Drive-train length	The shorter the drive-train, the less potential there is for energy loss between the peddler and the pump.
Power Regulation	As Figure 7.5 below shows, the power generated by a person on a bicycle fluctuates with the crank angle. The rear wheel can act as a crude flywheel in order to smooth the power flow from the peddler to the pump, thereby ensuring a more constant flow rate.  *Figure 7.5 Average instantaneous crank power associated with riding at 350W, 90rpm. Power is maximised when the cranks are near vertical*[1]

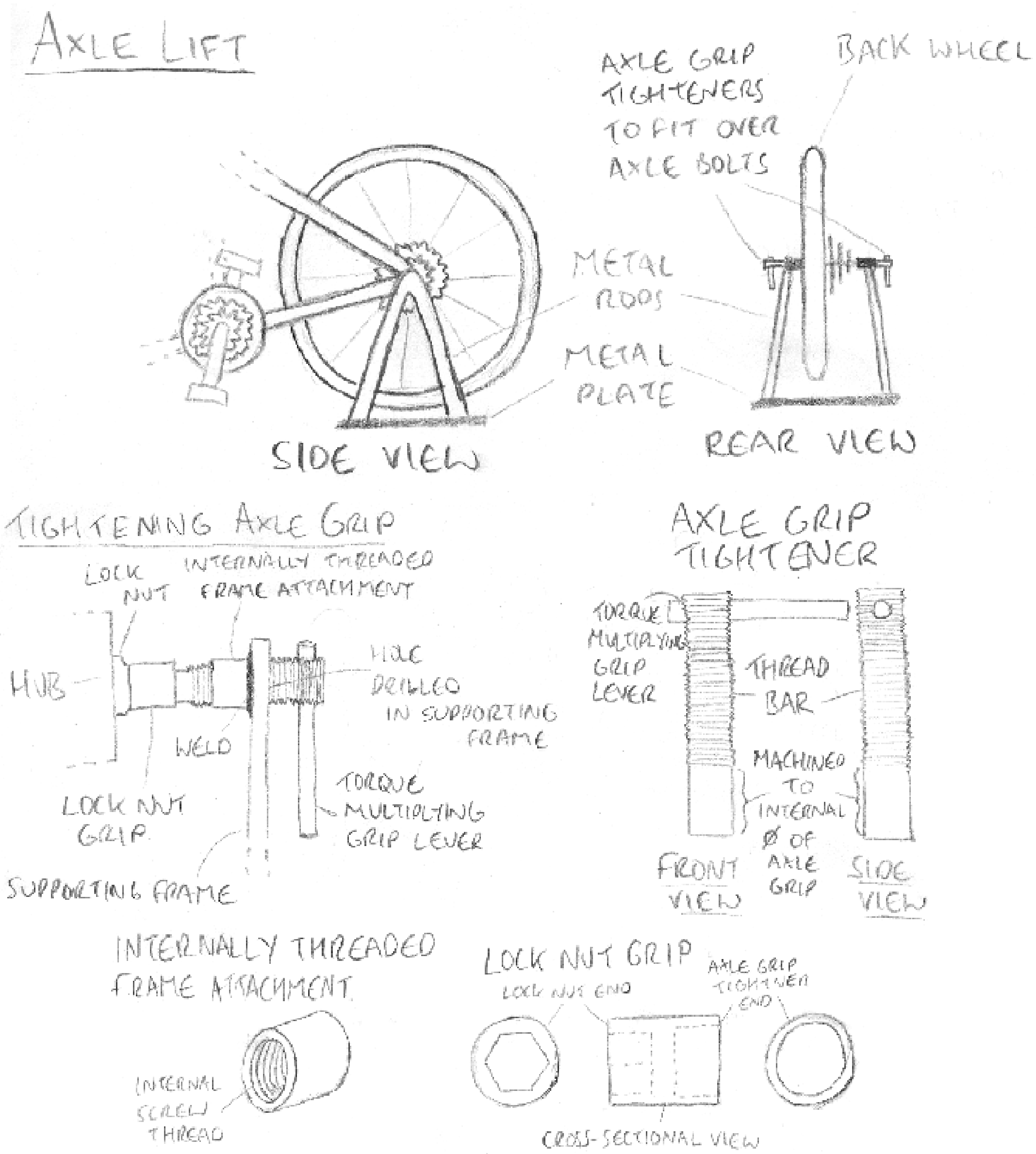
Adaptability	The design should be able to be used on as many different types of bicycle as possible.

Table 7.1 Design criteria for the selection of the driving mechanism

The wheel drive system was found to be the clear winner as it utilised the bicycle's existing gear system, was fairly simple to manufacture, setup and use, was adaptable to virtually any type of bicycle, and was the only design that utilised the rear wheel as a flywheel to smooth the power flow going into the pump.

7.2.2 Rear Wheel Lifting Mechanism

Figure 7.6 and Figure 7.7 show the two methods of lifting the rear wheel of the bicycle off the ground so that it is free to drive the pump.



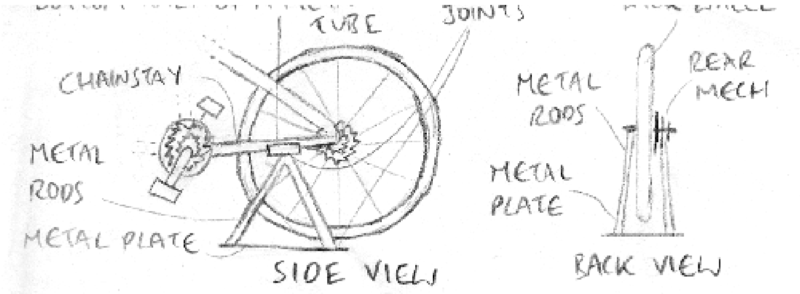


Figure 7.7 Sketch of the chainstay lift idea

The two designs were judged on the following criteria shown below in Table 7.2:

Ease of use	People won't want to use a design that's fiddly and time consuming.
Weight	Lightweight designs are easier to transport.
Adaptability	The design should be able to be used on as many different types of bicycle as possible.
Stability	The device should be stable, especially during pedalling.
Ease of manufacture	Complex mechanisms are difficult to make.
Ease of setup	The design should still be easily mobile and should take the least amount of time and effort to change between riding and pumping modes.
Cost	Complex designs are expensive to make.
Mobility	The design should be easily transportable between pumping sites.
Pedal interference	The closer things are to the pedals, the more likely they are to interfere with the rider during peddling.

Table 7.2 Design criteria for selection of rear wheel lifting mechanism

It was found that the axle lift was the more attractive option as it was more adaptable to bicycles of different shapes and sizes, was more stable, could easily be transported by flipping it upside down whilst still attached to the axles (see Section 7.8 later), and was less likely to interfere with pedalling.

7.2.3 Driving Roller Positioning Mechanism

The position of the driving roller is critical to achieving traction for effective power transfer and easy adjustment to different tyre types and sizes. The four options are sketched overleaf in Figure 7.8:

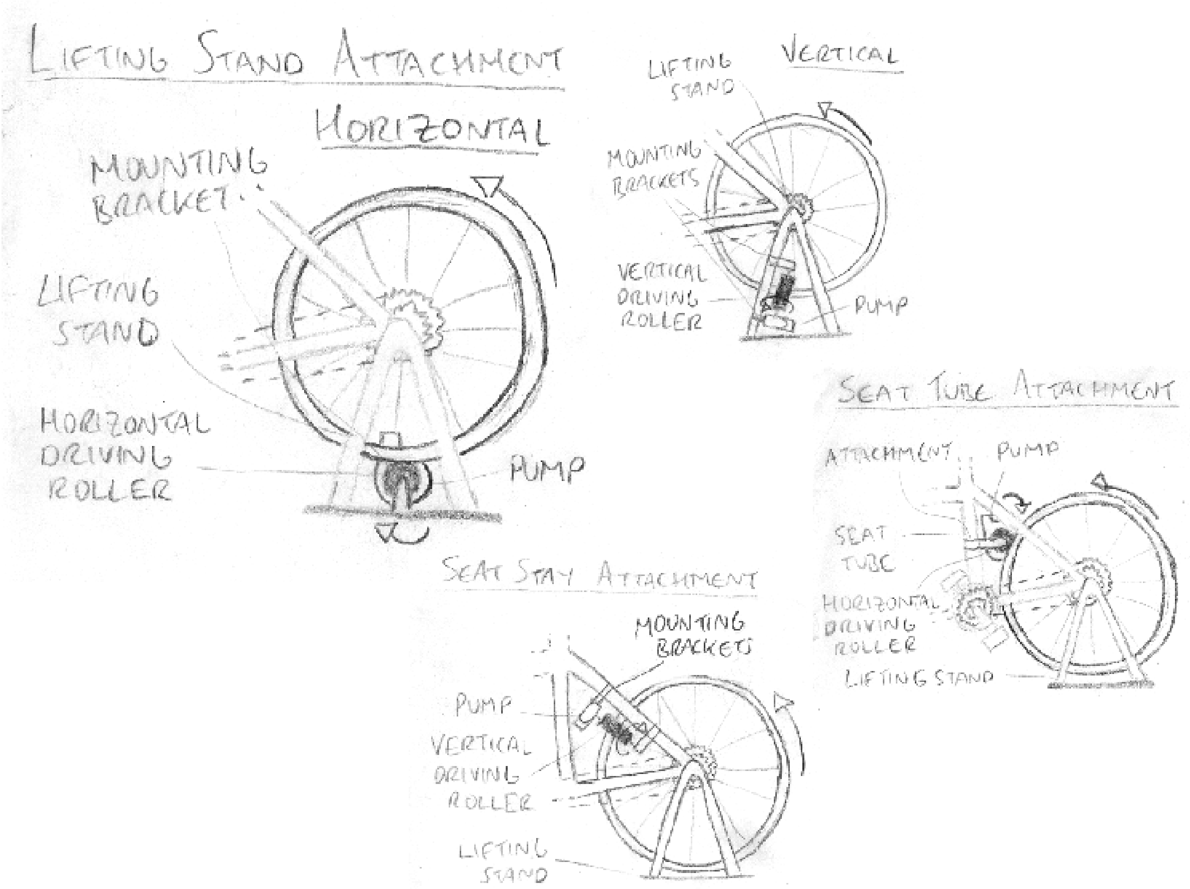


Figure 7.8 Sketches of the horizontal lifting stand attachment and various other positions for the driving roller

The four options were evaluated using the design criteria outlined in Table 7.3:

Ease of setup	Some of the designs require the removal of the mudguard and/or the attachment of parts on to the bicycle frame.
Proximity to Peddler	The closer the driving roller and pump are to the peddler the more likely they are to be knocked during peddling.
Wheel Size Adjustability	How well the design can cope with different sized wheels.
Tyre Type Adjustability	How well the design can accommodate the different tyre sizes, i.e. thin, smooth road tyres and knobbly, thick off-road tyres.
Extra Wheel Lift	Some designs require the rear wheel to be lifted further in order to fit the roller underneath the rear wheel. This will tip the bike more and make the seating position more awkward.
Traction	The amount of traction between the driving roller and the tyre will vary depending on how the driving roller is attached to the bike frame or stand. If there's not enough traction, the roller will slip and power will be lost.

Table 7.3 Design criteria for selection of driving roller positioning mechanism

The horizontal lifting stand attachment proved to be the best option as it was easy to setup; out the way of pedalling; and gave acceptable traction to drive the pump.

7.2.4 Roller Position Adjustment Mechanism

In order to adapt to the different sizes and types of bicycle tyre, it is necessary to adjust the position of the driving roller. The illustrations shown below in Figure 7.89 and overleaf in Figure 7.10 show the various options considered. The potential designs were then rated according to their compliance with the criteria shown in Table 7.4:

Corrosion Potential	Designs with moving parts in contact with, or close to the ground are more likely to suffer from corrosion.
Ease of Setup	The design should be quick and easy to change from the riding mode to pumping mode.
Ease of Adjustment	The design should easily adjust to different tyre types and wheel sizes.
Adjustability	Some designs only allow for discrete adjustments of roller position, whilst others allow for a continuous range of roller positions.
Simplicity of design	The more parts the design has, then the more parts there are to go wrong.
Ease of manufacture	MayaPedal only have limited manufacturing capabilities.
Stability	The pump should be stable during operation.
Weight	Lightweight designs are easier to transport and handle.
Mobility	The design should be easy to transport between pumping points.

Table 7.4 Design criteria for selection of roller position adjustment mechanism

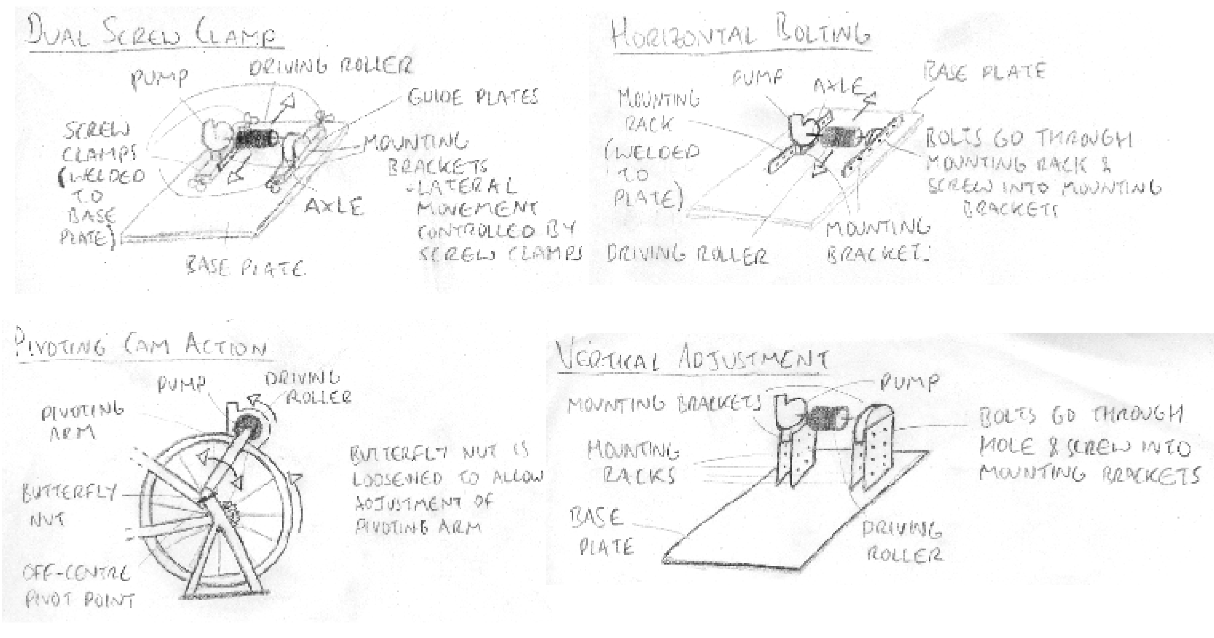


Figure 7.9 Sketch of various ways to adjust the position of the driving roller to accommodate different tyre shapes and sizes

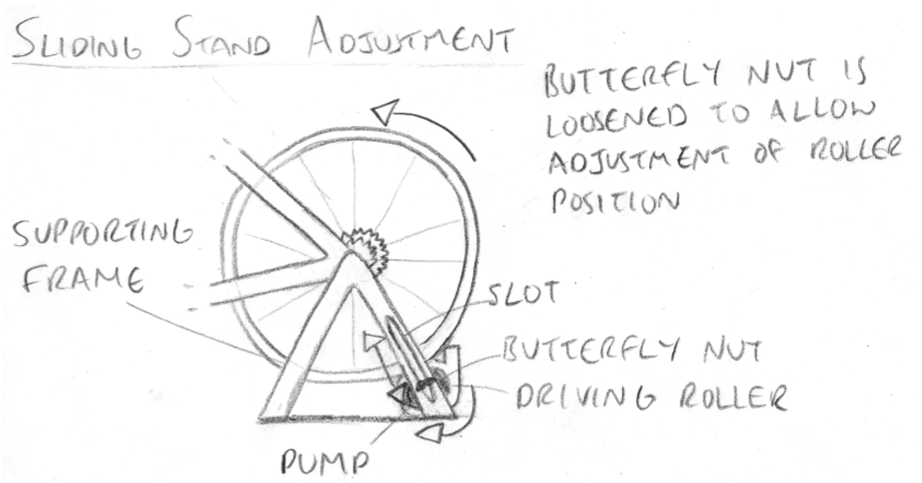


Figure 7.10 Sketch of the sliding stand adjustment design

Both the sliding stand adjustment and the pivoting cam action design came out very favourably, with scores of 73% and 69% respectively. The pivoting cam action design was seen to be less at risk from corrosion (as it is further away from the pump and the ground), it was also easier to set up and adjust to different tyre sizes. However, the sliding stand adjustment was chosen because it was a simpler design with fewer parts, meaning that it was lighter and easier to make. It was also slightly more mobile as the pivoting cam may have interfered with the chain when the stand was inverted for transportation. One of the major deciding factors was the instability of the pump in the pivoting cam design. It would be difficult to keep the pump level over the whole range of tyre sizes without adding in extra complexity. Instability may also occur during operation due to the difference in weights of the two sides of the pump.

7.3 Pump Selection

7.3.1 Background information

The most suitable type of pump for this application was found to be a centrifugal pump. Its compact size, simplicity of design, relatively low cost, light weight and widespread availability of pumps and spare parts make it ideal for use in this project. Centrifugal pumps are a well established technology and consequently their performance is well understood. The performance of a centrifugal pump is governed by the impeller diameter, rotational speed, input power and the output piping system. The pump affinity laws give the relationship between head, flow rate, input power, rotational speed and impeller diameter for centrifugal pumps. Equations 7.1, 7.2 and 7.3 below show the pump affinity laws for a pump of constant impeller diameter[2]:

$$\frac{Q_1}{Q_2} = \frac{w_1}{w_2} \tag{7.1}$$

$$\frac{H_1}{H_2} = \left(\frac{w_1}{w_2}\right)^2 \tag{7.2}$$

$$\frac{P_1}{P_2} = \left(\frac{w_1}{w_2}\right)^3 \tag{7.3}$$

Q	= flow rate	(l/min)
H	= head	(m)
P	= power	(W)
ω	= rotational speed	(rpm)

7.3.2 Matching Human Capability to Pump Performance

Electrically powered pump heads are designed to work optimally at the specific input power that is normally provided by the pump's electric motor. It is therefore important to find a pump with a rated electrical power that matches as closely as possible with the power that a person can realistically generate on a bicycle. Figure 7.11 overleaf shows how the power generated by people of varying fitness levels drops as the duration of exercise increases. It is estimated that the Bicibomba Móvil will be used for around 20-30 minutes for each pumping session. Reading from Figure 7.11, healthy men can expect to generate around 250 Watts when peddling for this period of time. The design specification states that the Bicibomba Móvil should be able to be used by men, women and children of varying sizes and fitness levels. Also taking into account the fact that the average Guatemalan is significantly smaller than the average European, the average power generated by the average user of the Bicibomba Móvil is likely to be significantly lower than this.

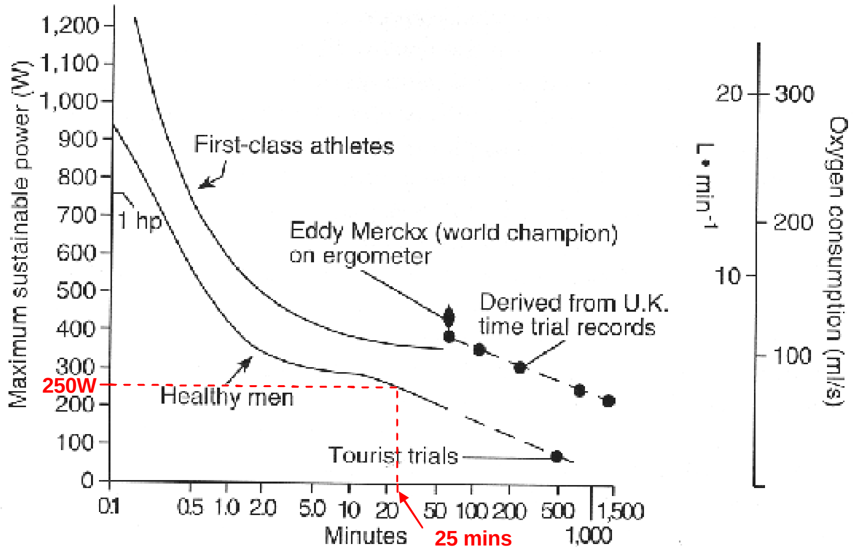


Figure 7.11 Power versus duration of exercise for various athletes[1]

7.3.3 Acquiring a Suitable Pump

It was decided that using a new pump would be appropriate for the first prototype as this would allow the most suitable pump to be selected. Acquiring a used pump, whose performance may not be as well matched to the design could cause unnecessary complications. On a visit to the hardware store in nearby Chimaltenango, Amilio photographed the small centrifugal electric water pumps available for sale, in particular the specification plates on the top of the pumps. Figure 7.13 overleaf shows one such pump and photographs of the others can be found in APPENDIX 4 – Guatemalan Pump Photographs. The maximum heads (H_{max}) ranged from 16-50m; maximum flow rate (Q_{max}) from 35-70 l/min; and maximum input powers (P_{max}) from 185.5-800W. Unfortunately none of these pumps are available in the UK, so a pump of similar specification was sought. The Clarke TAM105 pump shown in Figure 7.12 was found to be ideal as it was widely commercially available, relatively cheap and its rated input power of 330 Watts is closest to the human input power estimated previously. Table 7.5 shows the pump performance data given in the Clarke TAM105 operating manual.

Input Power	Operating Speed	Max. Head	Max. Suction Lift	Max. Flow Rate	Weight
330W	2800rpm	35m	7m	40 l/min	7.2kg

Table 7.5 Specification for Clarke TAM105 pump

Figure 7.12 The Clarke TAM105 electric water pump[46]

Figure 7.13 Sample photograph of the centrifugal water pumps available locally in Guatemala (H_{max}=50m; Q_{max}=45 l/min; P_{max}=800W)

Because a pump performance curve detailing the flow rates achieved by the pump across its range of operating heads was not available in the pump's operating manual, the following model based on standard centrifugal pumps[2] was used to estimate it:

$$H = H_{max} - \frac{H_{max}}{Q_{max}^{\ 2}} Q^2 \qquad 7.4$$

H	= static head	(m)
H_{max}	= static head at zero flow rate (shutoff head)	(m)
Q	= flow rate	(l/min)
Q_{max}	= maximum flow rate	(l/min)

The result is shown below in Figure 7.14:

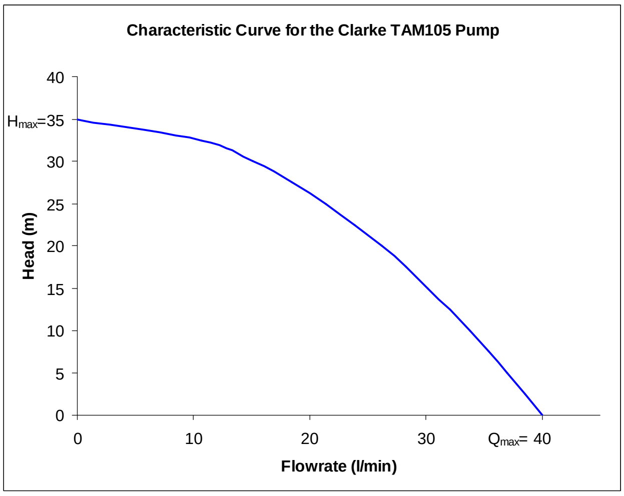


Figure 7.14 Estimated characteristic curve for the Clarke TAM105 pump

7.3.4 Dismantling the Pump

After dismantling the pump, a reverse engineering exercise was conducted to find out the function of each part and establish whether it would be suitable for use in the bicycle powered water pump. A CAD model was created to aid in visualisation of the different parts and how they fit together. As shown in Figure 7.15 below, it was found that most of the original parts could be utilised. The end casing, fan, screw rods and electric motor were no longer required. The armature of the electric motor that formed part of the shaft was found to be ideal as a driving roller to transfer rotational energy from the back wheel of the bicycle via a friction drive. A gear train analysis was conducted (see Section 7.5 - Gear Train Analysis) to calculate whether the pump would still run at the correct rotational speed without modification to the size of the armature/driving roller. All other parts were utilised and retained their original function.

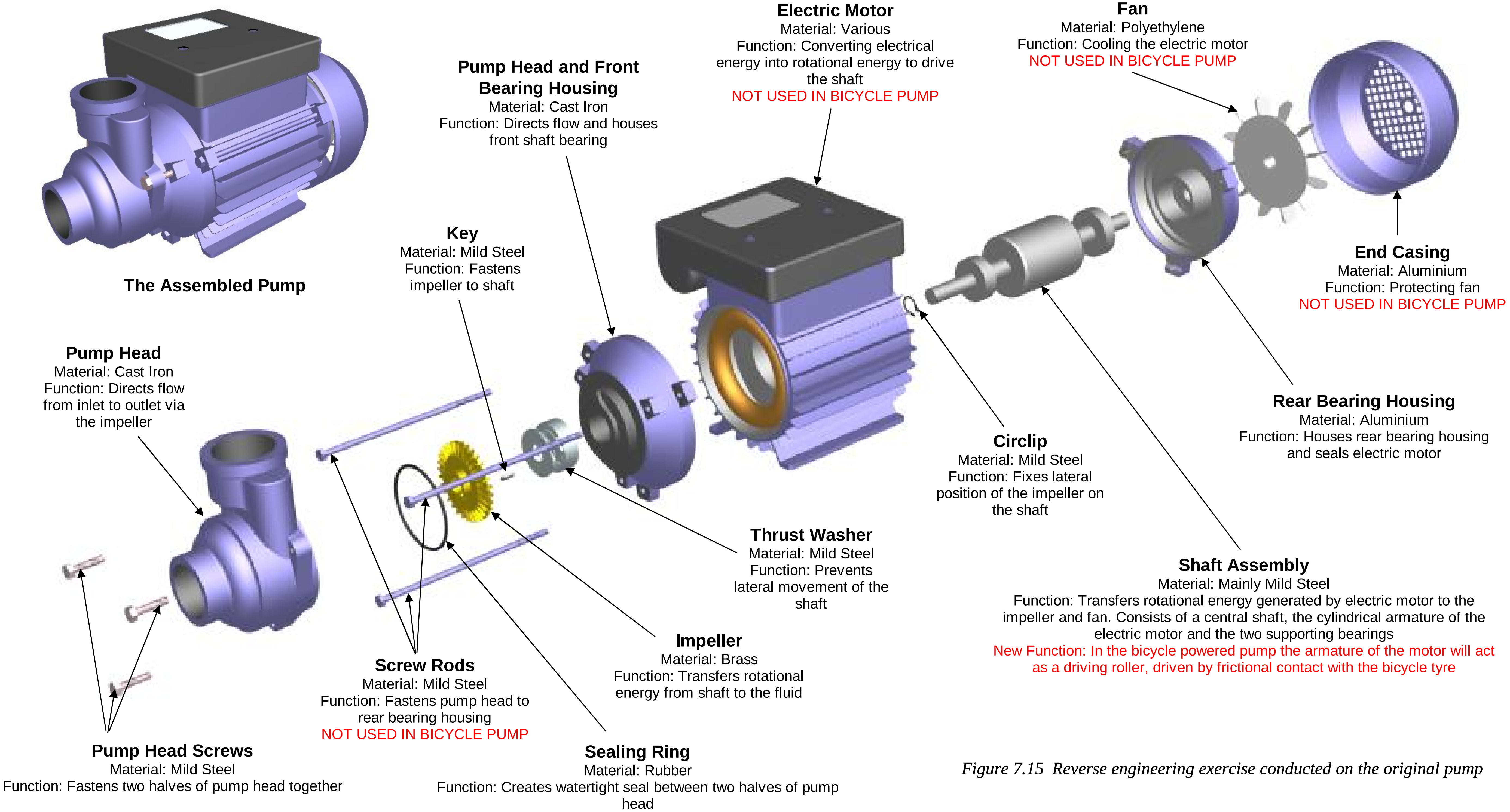
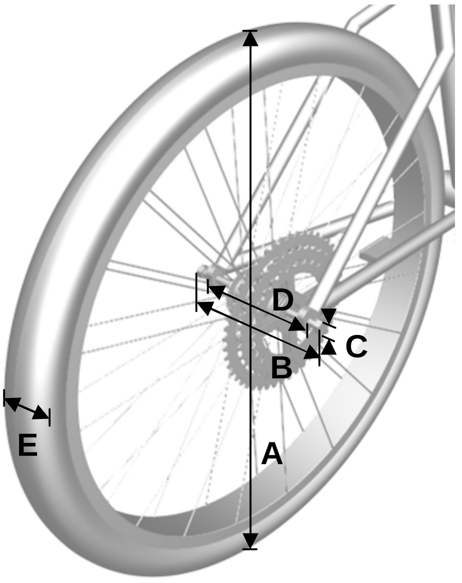


Figure 7.15 Reverse engineering exercise conducted on the original pump

7.4 Obtaining a Test Bicycle

The Shimano 18-speed Mach 15 mountain bike shown in Figure 7.16 was obtained without charge through the free online trading website for unwanted items, vSkips[11]. The following geometric measurements shown in Figure 7.17 were taken for use in dimensioning the Bicibomba Móvil. As the Bicibomba Móvil has been designed to accommodate as many different sizes as possible, the table also shows the range of these measurements for standard sizes of bicycles. The annotated diagram of a bicycle in APPENDIX 1 - Anatomy of the Modern Bicycle has been provided as a reference for the correct naming of bicycle components.

Figure 7.16 The Shimano 18-speed Mach 15 mountain bike



	Shimano Mach 15	Standard Dimensional Range
A. Tyre Diameter	614mm	462-716mm[48]
B. Rear Axle Length	179mm	Approx. 135-190mm[6]
C. Rear Axle Lock Nut Size	15mm	15mm[6]
D. Rear Dropout Spacing	134mm	Approx. 100-150mm[6]
E. Tyre Width	49mm	18-57mm[48]

Figure 7.17 Useful measurements from the test bicycle and the range of standard bicycle dimensions with CAD illustration

7.5 Gear Train Analysis

7.5.1 Gear Ratios and Operating Speed

The performance of a pump is directly related to the speed at which the impeller spins. The Clarke TAM105 pump has a rated operating speed of 2800rpm. In order to obtain maximum performance, the bicycle powered pump should run as close to this speed as possible. It has been proposed that the armature of the motor, which has a diameter of 46.5mm, should be used as a driving roller for the pump. It is possible to calculate whether this will drive the pump at the right speed by analysing the gear train. Using a friction drive on the rear tyre means that the gear train has 4 sections, the bicycle's front chain rings (1), rear sprockets (2) and rear wheel (3) and the pump's driving roller (4):

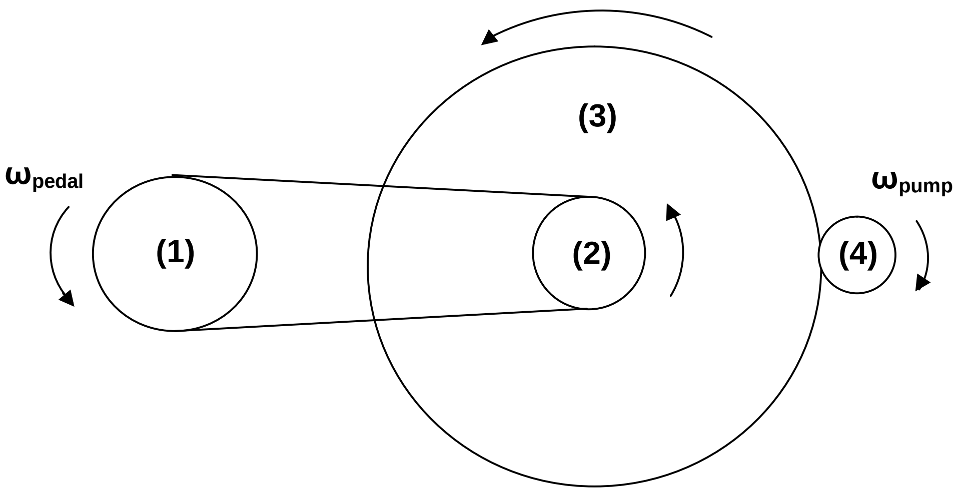


Figure 7.18 Gear train schematic

The gear train can be described using the following formula:

$$\frac{w_{pump}}{w_{pedal}} = \frac{n_{chainring}}{n_{s\,procket}} \times \frac{f_{wheel}}{f_{roller}} \qquad 7.5$$

w_{pedal}	= peddling cadence	(rpm)
w_{pump}	= pump operating speed	(rpm)
$n_{chainring}$	= number of teeth on front chain ring	
$n_{s\,procket}$	= number of teeth on rear sprocket	
f_{wheel}	= rear wheel diameter	(mm)
f_{roller}	= pump driving roller diameter	(mm)

The test bicycle has a tyre diameter of 614mm and the armature of the electric motor that will be used as the pump driving roller has a diameter of 46.5mm. A number of sources have suggested that 80rpm is the optimum cadence for comfortable pedalling[1][3][6][49]. As the bicycle uses a variable gearing system, a number of different gear ratios are possible for the first section (1-2) of the gear train. Table 7.6 shows the range of gear ratios available on a typical 18-speed bicycle.

		Number of Teeth on Rear Sprocket					
		28	24	21	19	16	14
Number of Teeth on Front Chain ring	48	1.714	2.000	2.286	2.526	3.000	3.429
	38	1.357	1.583	1.810	2.000	2.375	2.714
	28	1.000	1.167	1.333	1.474	1.750	2.000

Table 7.6 Typical gear ratio range for an 18-speed bicycle

Rearranging Equation

7.5 it is possible to find the optimum gear ratio for the bicycle in order to operate the pump at its design speed:

$$\text{Optimum bicycle gear ratio} = \frac{n_{chainring}}{n_{s\ procket}} = \frac{w_{pump}}{w_{pedal}} \times \frac{f_{roller}}{f_{wheel}} = \frac{2800rpm}{80rpm} \times \frac{46.5mm}{614mm} = 2.65$$

The gear ratio of 2.65 is clearly well within the range of a normal bicycle, as shown in Table 7.6. Consequently, the armature of the motor will make an ideal driving roller for the pump.

7.5.2 Tyre-roller Contact Friction

In order for smooth operation and maximum power transfer to occur, the roller must not slip as it is driven by the tyre. The inflation pressure of the tyres and their grip pattern both significantly alter the contact friction between the two components, making analytical modelling inappropriate. Preliminary testing will be carried out on the prototype after construction to determine whether the roller is slipping. If this is the case then the contact friction could be increased by applying grip tape to the roller or coating it with gritted paint.

7.6 CAD Modelling

The CAD model of the prototype and bicycle shown in Figure 7.19-Figure 7.25 was created to help visualise the design, both as individual parts and to show the interaction between the assembled components.

7.6.1 3D Visualisations

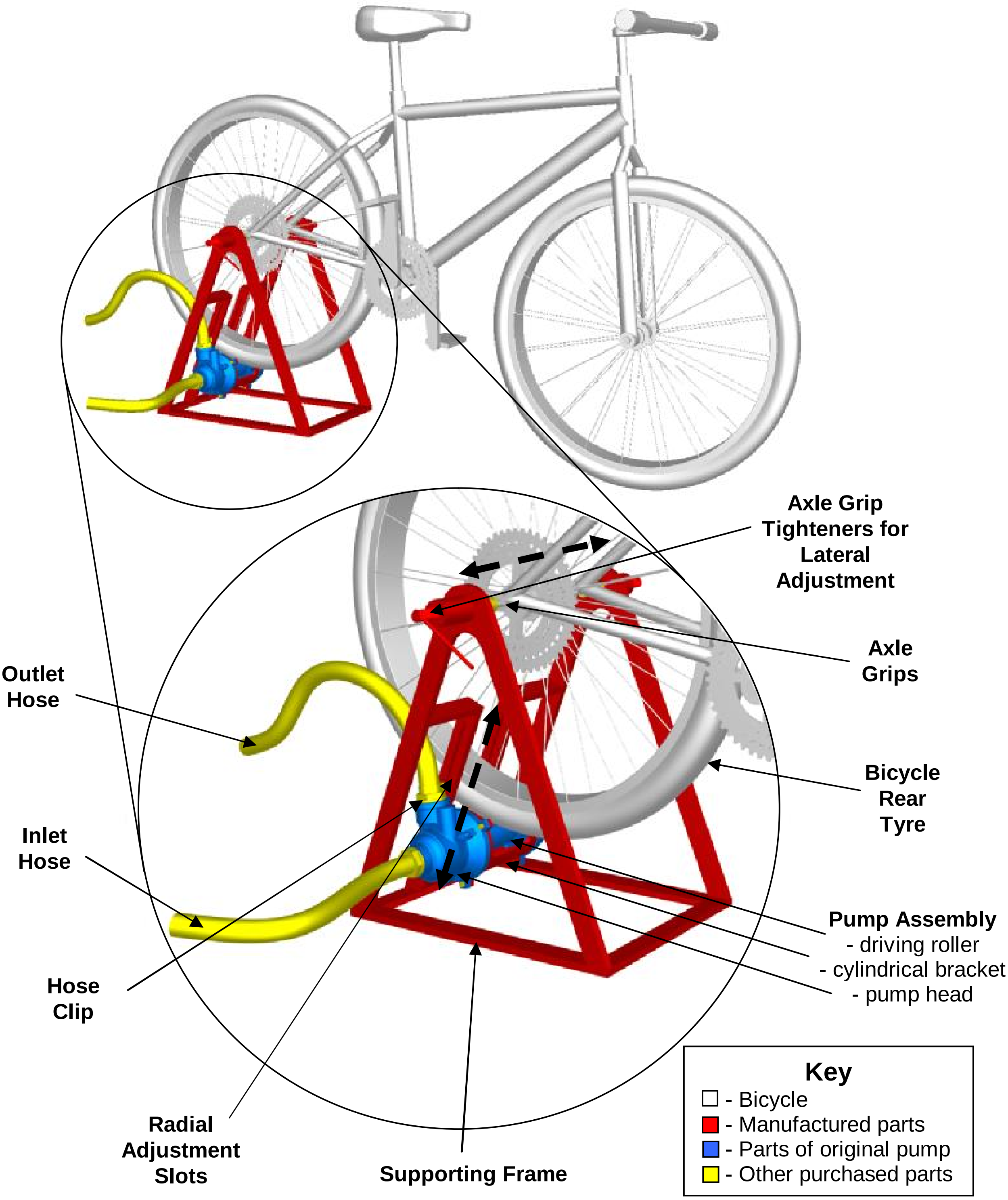


Figure 7.19 Annotated CAD illustration of the prototype and bicycle in use

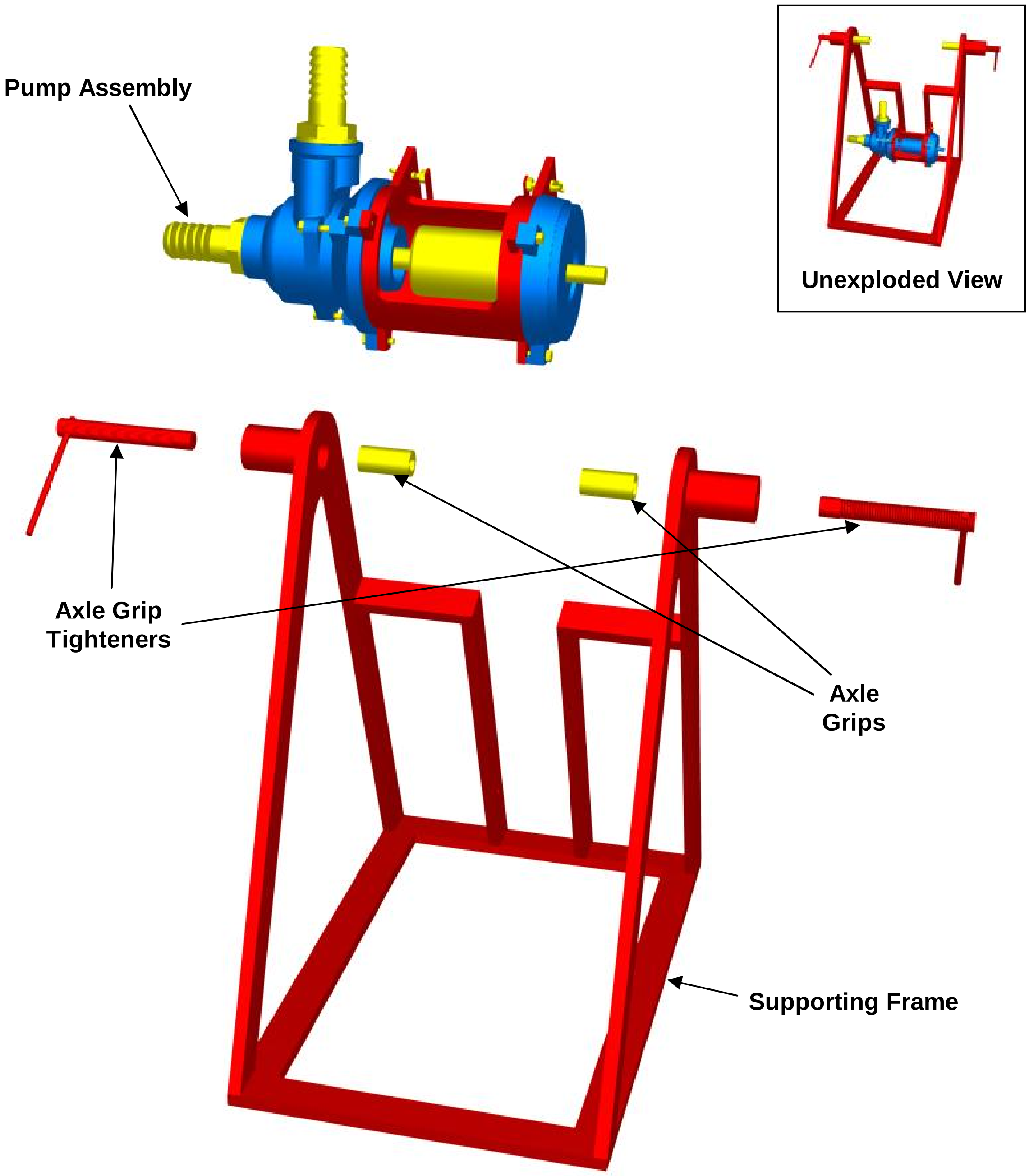


Figure 7.20 Annotated CAD illustration of the exploded frame and pump assembly

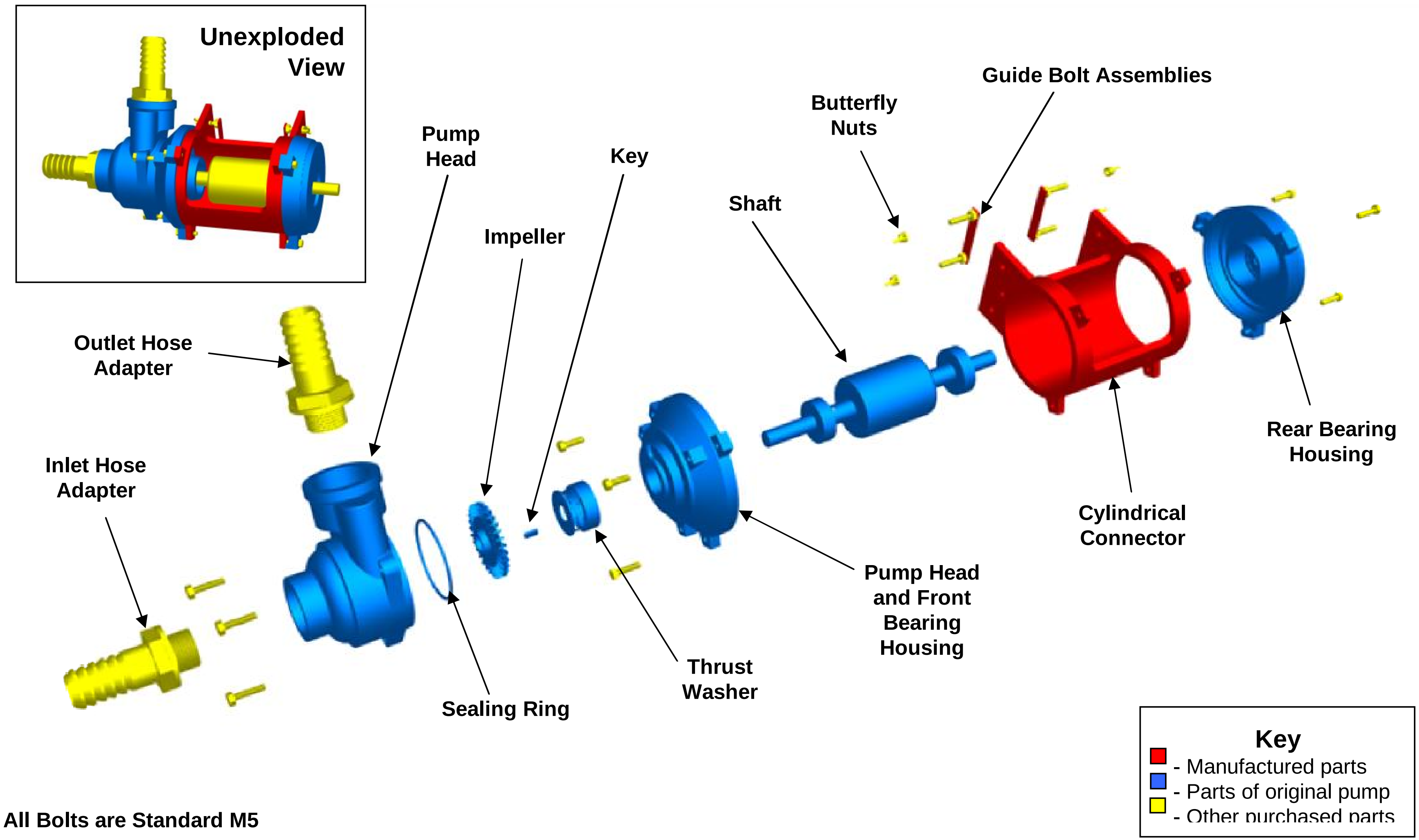


Figure 7.21 Annotated CAD model of the exploded pump assembly

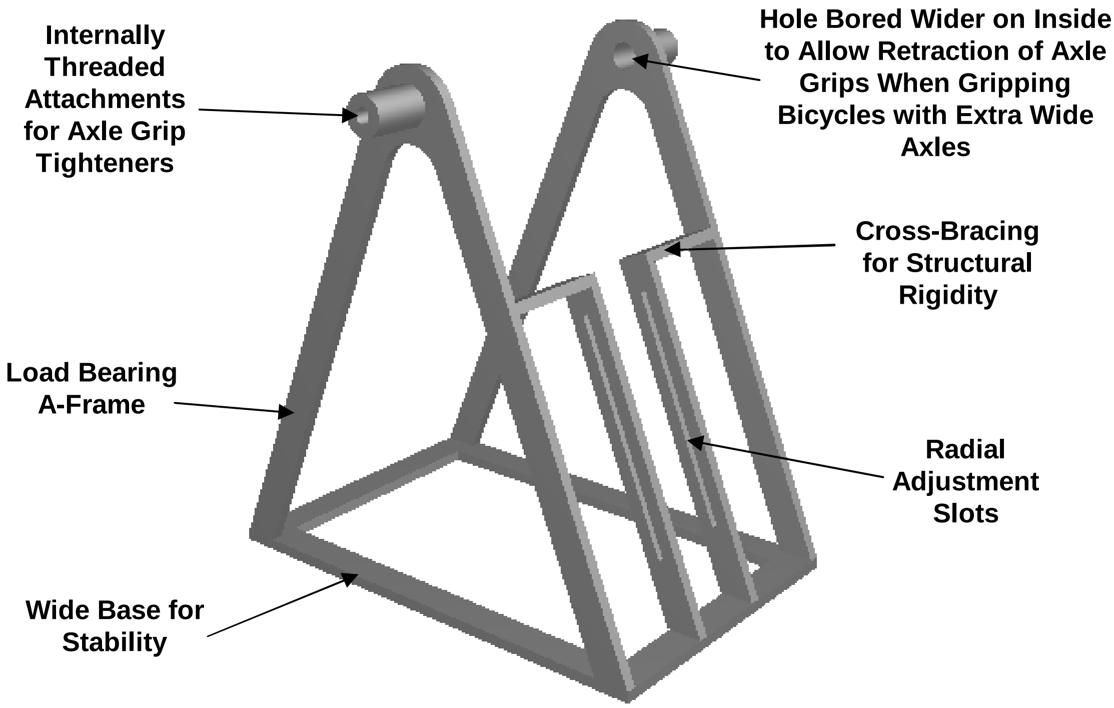


Figure 7.22   Annotated CAD model of the supporting frame

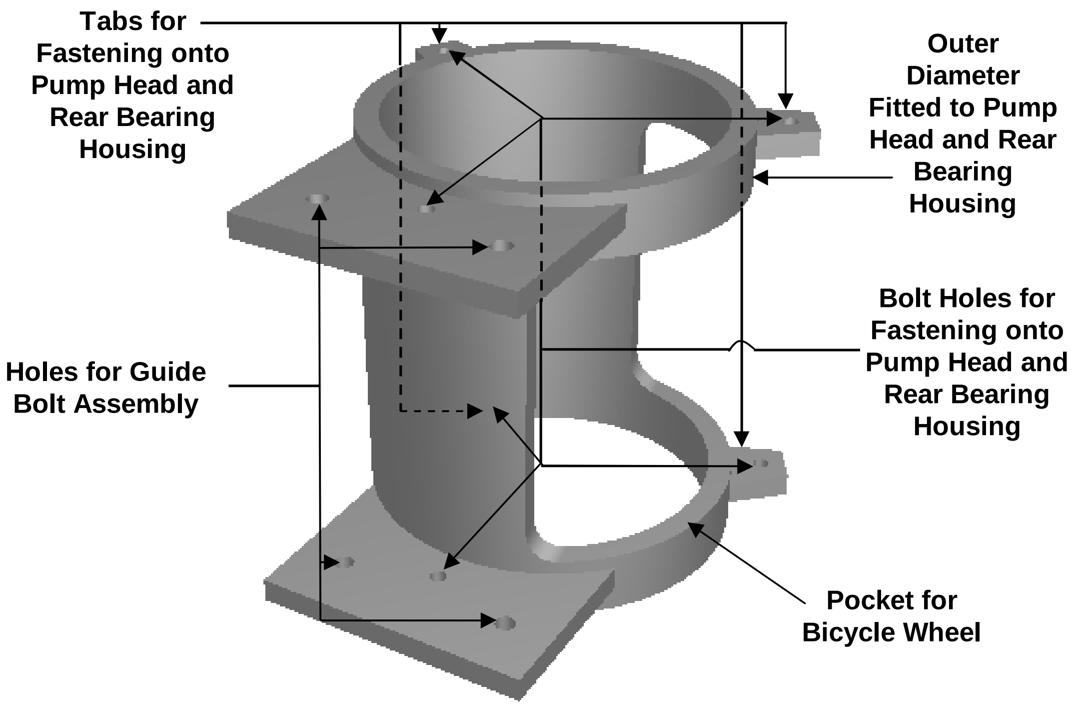


Figure 7.23 Annotated CAD model of the cylindrical bracket

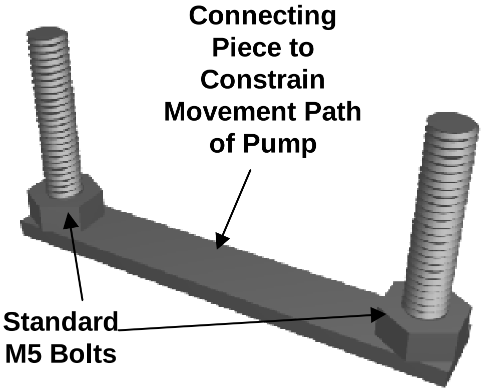


Figure 7.24 Annotated CAD model of the guide bolt assembly

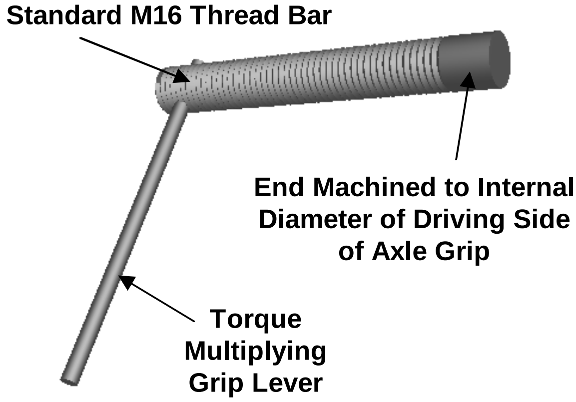


Figure 7.25 Annotated CAD model of the axle grip tightener

7.6.2 Engineering Drawings

Engineering drawings from which the prototype was to be constructed were created from the CAD models. The complete drawings can be found in APPENDIX 2 – Engineering Drawings.

7.7 Failure Analysis

The following areas of the design were identified as those most likely to undergo failure under normal loading conditions:

- Buckling of the supporting frame due to the weight of the bicycle and peddler or due to lateral instability during mounting of the bicycle or peddling on an uneven slope.
- Failure of the axle grips due to the shear force and bending moment induced by the weight of the bicycle and rider.
- Fatigue of the bearings under the contact force of the bicycle's rear wheel.

7.7.1 Frame Stability

As illustrated previously in Figure 7.22, the supporting frame was designed to have a wide base for stability and cross-bracing to improve the structural rigidity of the part under lateral loading. Due to the difficulty in predicting and the complex nature of the loading that the frame is likely to undergo during mounting and dismounting of the bicycle, it was considered impractical to create a Finite Element model of the component under load. Instead, preliminary strength testing of the prototype will be conducted before it is considered safe for testing.

7.7.2 Axle Grip Deflection Analysis

The deflection of the axle grips is critically important, as if it is too large, then the bicycle's rear tyre will exert an undesirably large force on the pump's driving roller. The axle grips were redesigned to be as short as possible without limiting the size range of bicycle hubs that could fit between them. This minimised the deflection of the part by reducing the bending moment induced by the weight of the bicycle and rider. The axle grip tightener was modelled as a cantilever beam with a fixed end support and the maximum deflection was found to be very small (just over 1mm). Full details can be found in APPENDIX 6 – Supporting Calculations.

7.7.3 Bearing Fatigue Analysis

The pump's bearings will have been designed to cope with the torque-inducing tangential load exerted by the armature of the motor and the impeller, as well as a small axial load from the thrust washer. However, the only radial force they would have incurred would have been from the self weight of the shaft, bearings and armature. Converting the pump to bicycle power means that a significantly larger radial force will be exerted on the armature of the motor, as a specified contact force is required to maintain traction between the tyre and driving roller/armature. An analysis of the increased loading was performed and it was found that the existing bearings were not in danger of failure. Refer to APPENDIX 6 – Supporting Calculations for further information.

7.8 Process Flow Diagram

Figure 7.26 illustrates the steps required to go from transportation mode (bicycle fully rideable and Bicibomba Móvil stored on back of bicycle) to pumping mode (Bicibomba Móvil fully set up and ready to pump). The process is repeated in reverse when pumping has finished and the Bicibomba Móvil is required to return to transportation mode.

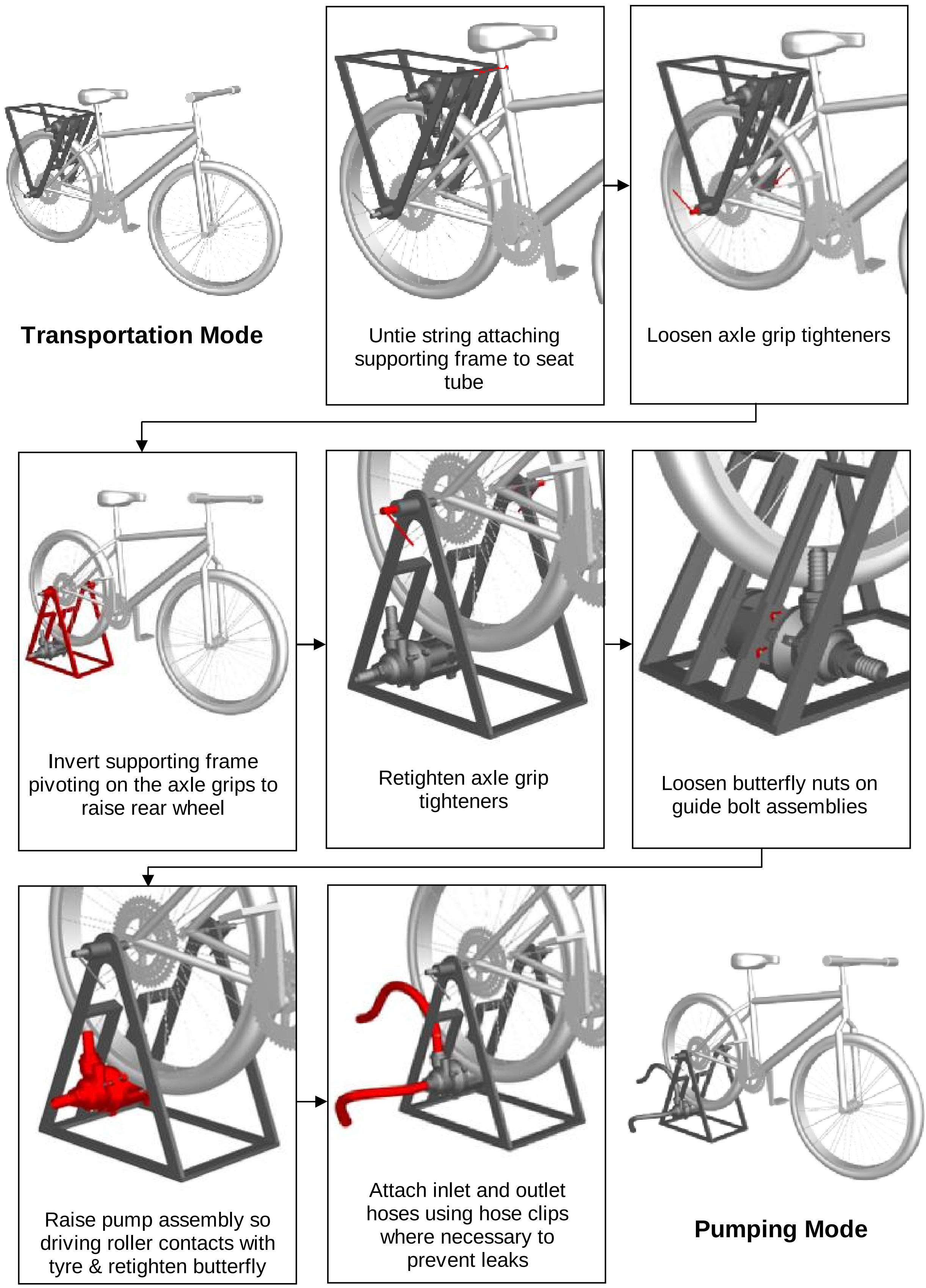


Figure 7.26 Process flow diagram showing the steps needed to go from transportation mode to pumping mode

8 BUILDING THE PROTOTYPE

Using the engineering drawings produced from the CAD model, the prototype was constructed in the Department of Mechanical Engineering's Student Workshop. All parts built in the workshop were constructed from mild steel. The purchased 15mm sockets that act as axle grips were made from chrome-vanadium steel. The prototype was designed to use 10x30mm strips for all its flat parts for ease of ordering and reduced cost.

8.1 Construction Method

Table 8.1 below details the construction method used to build the bicycle powered water pump. It also shows the tools required and time taken to build each part. Since MayaPedal's workshop consists of hand tools, a few vices, a bench grinder, an arc welder, a chop saw and a drill press, significant modifications will need to be made to the design before it can be manufactured in Guatemala. The frame and cylindrical connectors pose a significant problem as they require the use of milling equipment, a lathe and boring tools – none of which are available to MayaPedal without an expensive and time consuming trip to the machine shop in the next town. Suggested design modifications are shown later in the Section 11.1- Future Design Improvements.

Part	Construction Time	Tools Required	Construction Method
Frame	12 hours	- Milling Equipment - Welding Equipment - Drill - Drill Bits - Boring Tool - Tap - Lathe - Saw - Vice	1. Cut lengths of 30x10mm steel plate 2. Machine angles on bottom ends and round off top ends of A-frame 3. Weld two halves of A-frames together 4. Turn outer diameter of axle grip guides to 35mm 5. Drill and tap M16 threaded hole through axle grip guides 6. Bore Ø25mm hole 30mm into axle grip guide 7. Drill Ø25mm hole in centre of A-frame 8. Mill 5mm guide slots 9. Weld remaining joints
Cylindrical Connector	42 hours	- Milling Equipment - Welding Equipment - Drill - Drill Bits - Boring Tool - Tap - Lathe - Wooden	1. Cut solid cylindrical piece to length 2. Turn cylindrical piece to outer Ø 94mm 3. Bore cylindrical piece to inner Ø 82mm 4. Build wooden end caps to hold cylindrical piece 5. Mark on and mill pocket at 10º from horizontal with wooden end caps in place 6. Cut out straight edges of locking tabs and slot guides 7. Drill and tap (where necessary) the locking tabs and slot guides

		End Caps - Saw - Vice	8. Use boring tool to cut a 47mm internal radius into the locking tabs so that they fit the external diameter of the cylindrical piece 9. Weld locking tabs and slot guides onto cylindrical piece
Axle Grip Tighteners	2 hours	- Saw - Vice - Drill - Drill Bits - Hammer	1. Cut M16 thread bar to length 2. Turn end of thread bar to fit into driving side of the 15mm socket axle grips 3. Drill hole for torque lever 4. Cut bar for torque lever to length 5. Install torque lever and flatten ends with a hammer to prevent it falling off
Guide Bolt Assembly	1 hour	- Welding Equipment - Saw - Vice	1. Cut connecting plate to size 2. Weld bolts to connecting plates
Assembly	1 hour	- Allen Key - Hammer - Vice	1. Screw axle grip tighteners into frame and fit axle grips 2. Reassemble pump with cylindrical connector in place of the electric motor 3. Fit guide bolt assembly through slot in frame and fix in place with butterfly nuts
Painting	1 hour	- Paintbrush - Anti-rust Paint	1. Paint all manufactured components with anti-rust paint and allow to dry

Table 8.1 Construction method for the bicycle powered water distribution pump

9 TESTING THE PROTOTYPE

9.1 Functional Testing

9.1.1 Deflection Testing

Figure 9.1 shows how the bicycle was locked into the supporting frame using the axle grips, but without the pump assembly in place, as failure of the axle grip tighteners would cause the weight of the bicycle and peddler to suddenly drop onto the pump. As the peddler gradually mounted the bicycle, the deflection at the axle grips was observed. The observed deflection was negligible, which agrees with the predicted value of just over 1mm. The supporting frame was also found to be structurally sound.

Figure 9.1 Photograph showing the negligible deflection of the axle grips when under full loading

9.1.2 Wheel Clearance

As Figure 9.2 shows, there is a clearance of approximately 10mm between either side of the tyre and the frame. However, the tyre was initially contacting with the cylindrical connector. The pump assembly was tilted slightly towards the tyre to avoid this problem. After this minor modification, a clearance of around 10mm was obtained between the cylindrical connector and the tyre.

Figure 9.2 Photograph showing the clearance around the tyre

9.1.3 Hose Clearance

Figure 9.3 Photograph showing the outlet hose constriction

Figure 9.4 Photograph showing the modification to the outlet hose

The photograph in Figure 9.4 demonstrates how tilting the pump assembly caused the outlet hose was to become constricted by part of the supporting frame. The temporary solution demonstrated in Figure 9.4 was to reroute the outlet hose over the left axle grip and use a curved piece of metal to ensure that this did not create any kinks in the hose. A more permanent solution is given in Section 11.1.2 - Redesign of Supporting Frame.

9.1.4 Mobility Testing

The process detailed above in Figure 9.5 was executed first in reverse to go from pumping mode to transportation mode, then back to pumping mode. It was found to take around one minute to switch form one mode to the other. The mudguard presented a slight problem, but could easily be tucked under the pump assembly. The bicycle was ridden around whilst in transportation mode with little change to the normal handling of the bicycle.

Figure 9.5 Riding the bicycle in transportation mode

9.1.5 General Operational Testing

During pumping the Bicibomba Móvil was found to be slightly wobbly, but stable due to the supporting stand's wide base. The tilting of the frame due to the lifting of the rear wheel did not hinder mounting and dismounting of the bicycle or make the peddling position uncomfortable. The only part that interfered with peddling was the curved piece of metal that was used to guide the outlet hose, but as it is only a temporary feature, this will not be an issue in the final design. The tyre-roller contact provided enough traction without the need to increase the surface roughness of the roller as discussed earlier (see Section 7.5.2 - Tyre-roller Contact Friction). Preliminary performance testing was conducted to give an initial estimate

Figure 9.6 The Bicibomba Móvil in operation

of the pump's performance so that suitable testing procedures and apparatus could be determined. Figure 9.7 and Figure 9. show the experimental set-up for the preliminary testing. It was found that at zero pumping elevation (virtually zero head), that a 20 litre bucket could easily be filled in under 30 seconds – a flow rate of over 40 l/min. The pump was easily able to cope when a crane was used to winch up the hose around 4m.

Figure 9.7 Winching up the hose to test the pump with a 4m head

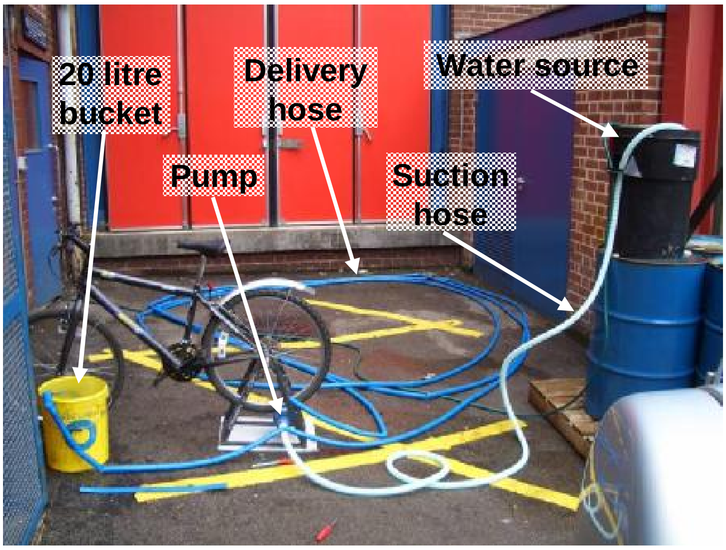


Figure 9.8 Testing the pump's flow rate with zero pumping elevation

9.2 Performance Testing

9.2.1 Aim

To test the performance of the pump over various loading conditions.

9.2.2 Prediction

As shown previously in Table 7.5, the Clarke TAM105 pump is able to produce a maximum head of 35m and a maximum flow rate of 40 l/min when operating with 330W of input power and running at 2800rpm. From the flow rate obtained during the preliminary experiment it is reasonable to assume that the pump will perform similarly after it is adapted to bicycle power.

9.2.3 Apparatus

Figure 9. shows the experimental set up used to measure the performance of the Bicibomba Móvil.

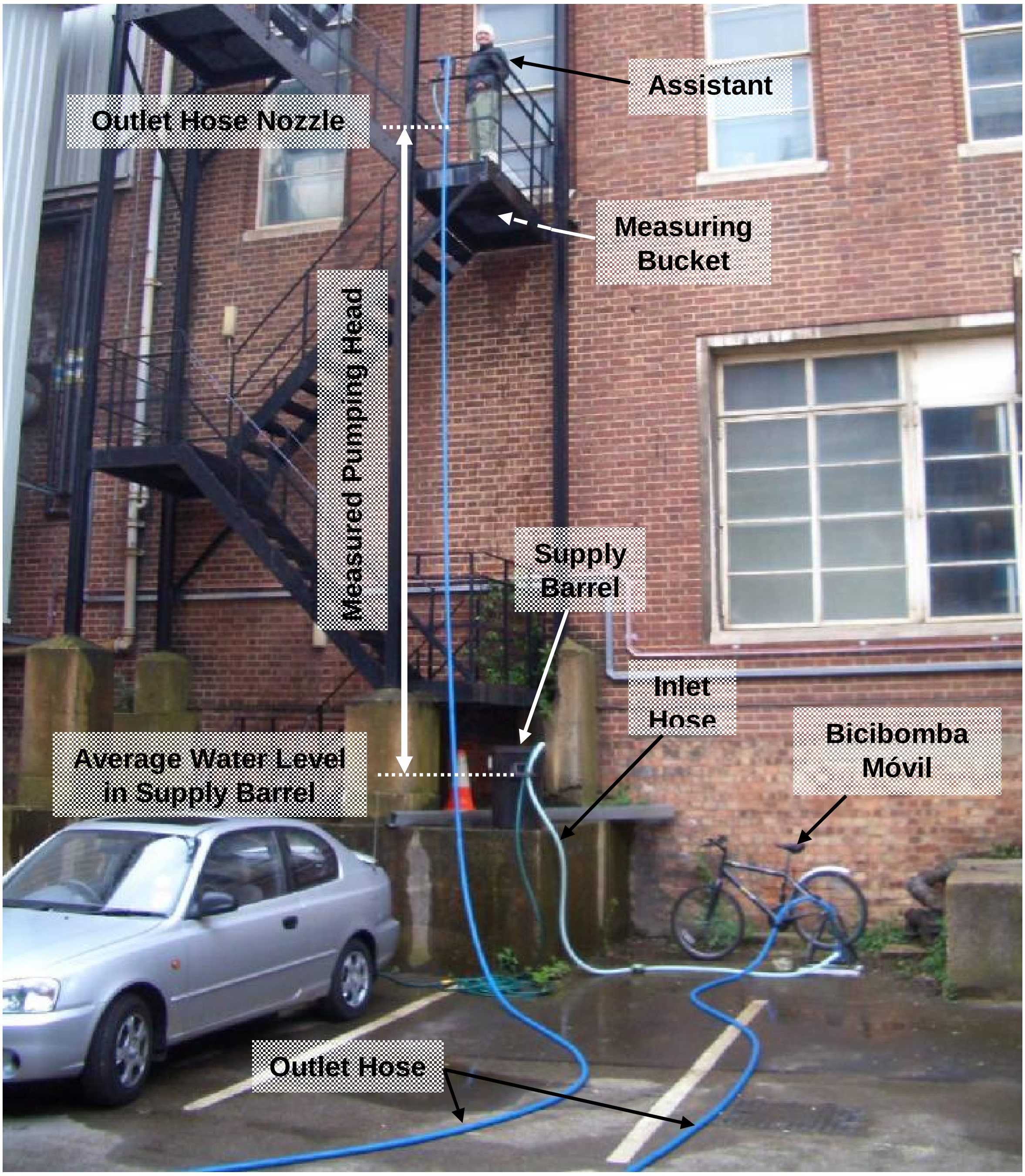


Figure 9.9 Experimental set up for performance testing of the Bicibomba Móvil

The following equipment was needed to conduct the testing:

- Stopwatch
- Bicibomba Móvil and bicycle
- 5m suction hose with foot valve to prevent backflow into the supply barrel
- 30m delivery hose
- Water supply barrel
- Hose and hose adapter to fill supply barrel with water from tap
- Ruler to measure depth of water in measuring bucket
- Measuring (delivery) bucket

9.2.4 Method

All peddling should be done with the same power input as far as possible in order to ensure reliability of results.

1. Fill supply barrel with water and place above ground level to gravity feed pump.
2. Set up Bicibomba Móvil in pumping mode as detailed in previously in Figure 7.26.
3. Fit foot valve onto inlet hose and submerge at the bottom of the supply barrel.
4. Remove kinks from outlet hose to ensure flow is not restricted.
5. Place measuring bucket on the ground next to assistant (This is pumping to a head of -1m as the measured pumping head is the difference in elevation between the free surface of the water in the supply barrel and the outlet hose nozzle).
6. Begin peddling at a constant rate and when flow becomes steady, put outlet hose nozzle over the measuring bucket and start the stopwatch.
7. After 30 seconds remove the outlet hose nozzle from over the measuring bucket and stop peddling.
8. Measure and record the depth of water in the measuring bucket to calculate the flow rate and then empty it.
9. Repeat steps twice 6-8 for reliability.
10. Repeat steps 6-9 with the other peddler.
11. Raise measuring bucket onto first testing level, as shown in Figure 9. overleaf (This is pumping to a head of 3.5-1=2.5m).
12. Repeat steps 6-10.

13. Continue repeating steps 6-10 until the top testing level has been reached or the peddlers cannot provide enough power to lift the water to the required height, whichever comes first.

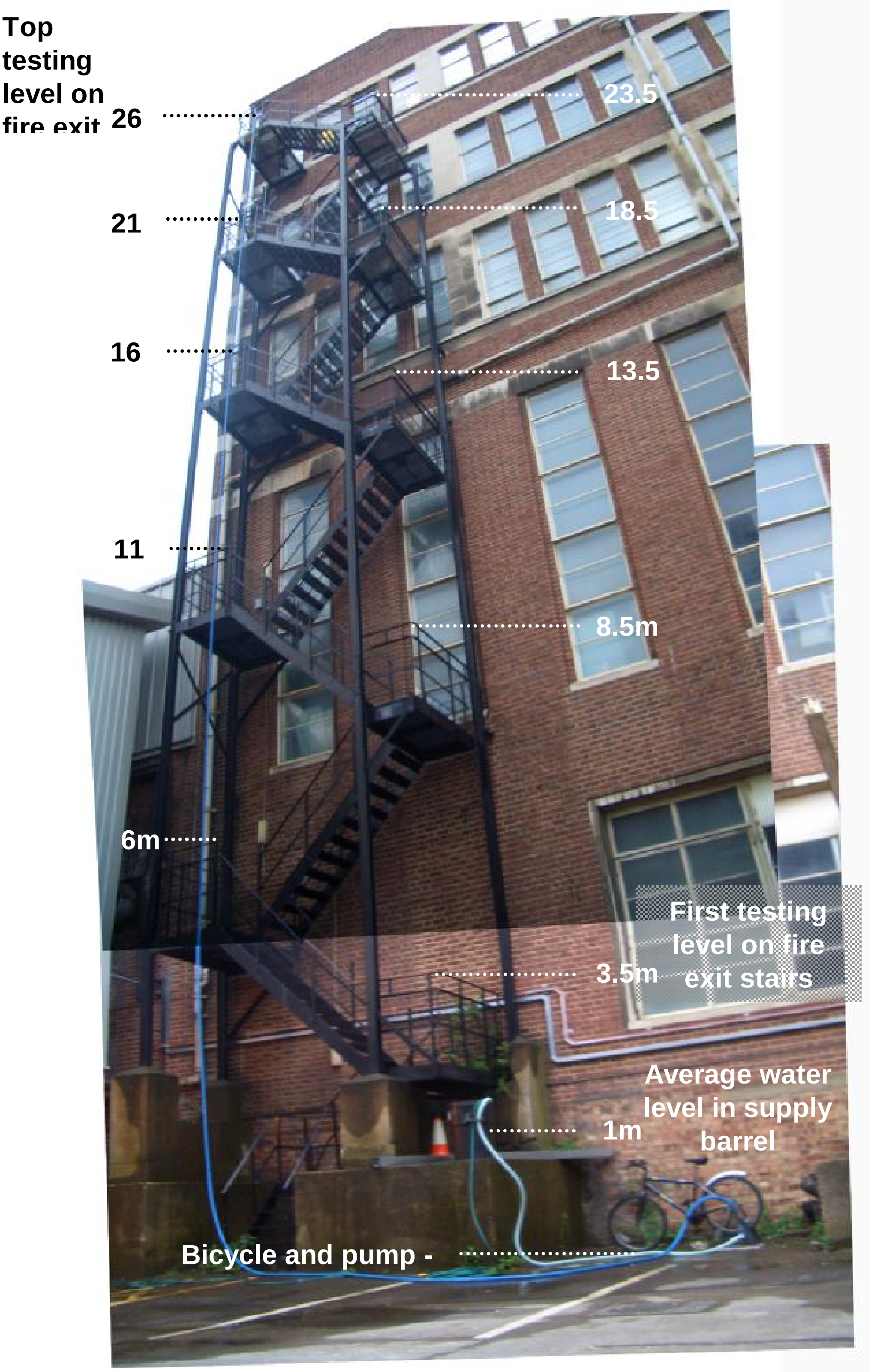


Figure 9.10 Photograph of the testing set up showing heights above ground level

10 RESULTS

Figure 10.1 shows that the male peddler was able to pump to the maximum testing head (25m) with a flow rate of around 4 l/min. However, the female peddler was less powerful and could only reach 12.5m. At ground level, the male and female peddlers generated flow rates of around 40 and 30 l/min respectively. At a moderate pumping elevation (10m) the peddlers achieved flow rates of around 25 and 10 l/min respectively. The pump affinity laws detailed in Equations 7.1, 7.2 and 7.3 were used to generate the predicted pump performance curves for the pump with 100, 200 and 300W input power.

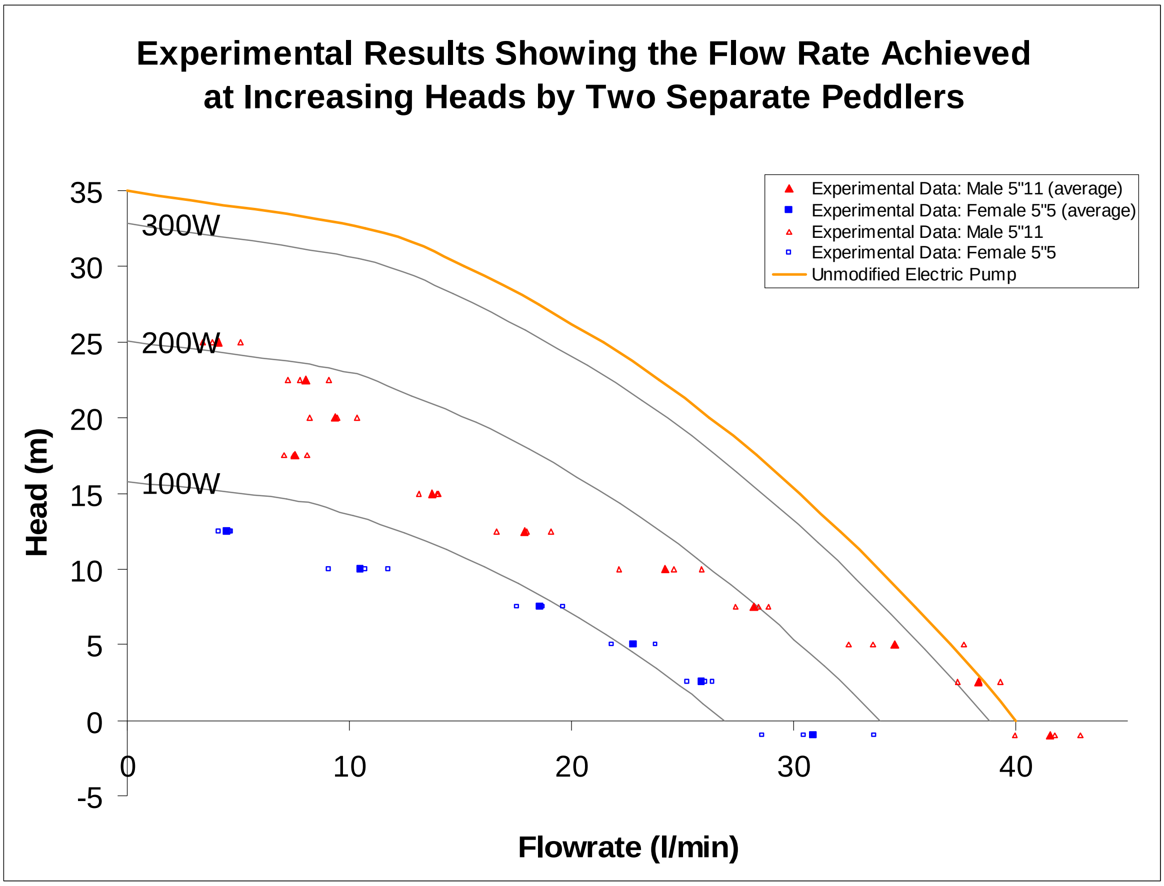


Figure 10.1 Plot of the flow rates measured at various pumping head

10.1.1 Conclusion

The achievable pumping head and flow rate are directly related to the input power, as shown by the pump affinity laws detailed in Equations 7.1, 7.2 and 7.3. Therefore the performance of the pump will vary depending on who is peddling and how much effort they are putting in. Figure 10.1 shows that the male peddler was generating between 120 and 350W and the female between 80 and 200W. The results differ significantly from the prediction that performance would be similar to the unmodified pump. This is largely due to the effect of fatigue – the first few results show a much higher level of input power, but as the testing went on the peddlers became tired and were unable to generate the same power levels. The large difference in flow rates at identical pumping heads illustrates how difficult it was to keep a constant input power level. The marked power increase in the male peddler's results at pumping heads of 20, 22.5 and 25m occurred because a certain power level was required just to get the water to that height, even with no flow rate. Even though the peddler had been getting tired, a little extra power was mustered for the last few elevations.

10.1.2 Evaluation

The main difficulty in the experiment was keeping the power level constant. Fatigue had a major influence as the testing went on, but as the large spread of even the first few results show (-1m head), it is virtually impossible to peddle with constant power. There were also some issues with constrictions in the delivery hose. Although an effort was made to straighten the hose at each change of elevation, it was difficult to eliminate all of the kinks from the hose. There was a slight leak where the output hose was fastened onto the hose adapter, even though two hose clips were used and tightened as much as possible. However, it was only small and so was unlikely to significantly affect the performance of the pump. It was difficult to measure the pumping head accurately as the free surface of the water in the supply barrel was constantly changing. This could have caused an error of ±0.5m in the measurement of the pumping head. The resistance of the hose was not taken into account. Human error in timing, measurement of the water depth in the measuring bucket and keeping the outlet hose nozzle at the correct height could all also have contributed to errors in the measurements.

11 DESIGN EVALUATION

The performance of the Bicibomba Móvil is directly related to the power of the peddler. With reference to the Design Specification in Section 4.2, the male peddler was able to provide the desired 19 l/min flow rate at pumping elevations up to 10m. Pumping to over 25m was also possible, but at a reduced flow rate. The Bicibomba Móvil uses standardised pump parts, so should be cheap and easy to maintain by locals. It is hygienic so can be used for drinking water. It is pedal powered so does not require electricity or fuel. It is robust, stable when in use and only requires one person to operate. It pressurises the water for distribution allowing connection to existing piping networks. However, its main advantage over existing designs is its mobility. This means that it is highly adaptable to different situations and, with the aid of the small reservoir distribution system shown in Figure 6.3, can distribute water over much larger distances that conventional pumps. The pump is not self-priming, but the foot valve on the inlet hose means that it only needs to be primed once. Because the design allows virtually any size bicycle to be used, men, women and children of varying sizes and fitness levels can use the machine. The Bicibomba Móvil has been designed to use one of MayaPedal's recycled bicycles, an end-of-life electric pump and old bathtubs for small intermediary reservoirs to increase the distribution area. Unfortunately, the parts that do need to be manufactured, in particular the frame and the cylindrical connector, are difficult and time consuming to make and require tools that MayaPedal do not have (see Section 8 - Building the Prototype). Future design improvements are listed in the following section that address this problem and the other smaller issues that have arisen during the building and testing of the prototype.

11.1 Future Design Improvements

11.1.1 Redesign of Cylindrical Connector

As previously discussed in Section 8 - Building the Prototype, the cylindrical connector was by far the most time consuming part to make and required the use of milling equipment and a boring tool – both of which MayaPedal do not have. In order to simplify the manufacture of this part, the design shown below in Figure 11.1 uses flat plates as opposed to a bored cylinder with a pocket cut into it. The redesigned part requires only a saw, vice, drill, drill bits and welding equipment – all of which are available to MayaPedal. It also solves a number of other smaller issues with the part: because of its shape, the cylindrical connector collected dirt from the bicycle tyre, so the redesigned part has an open bottom to prevent this. It also prevents corrosion of the bearing casing by acting as a splashguard.

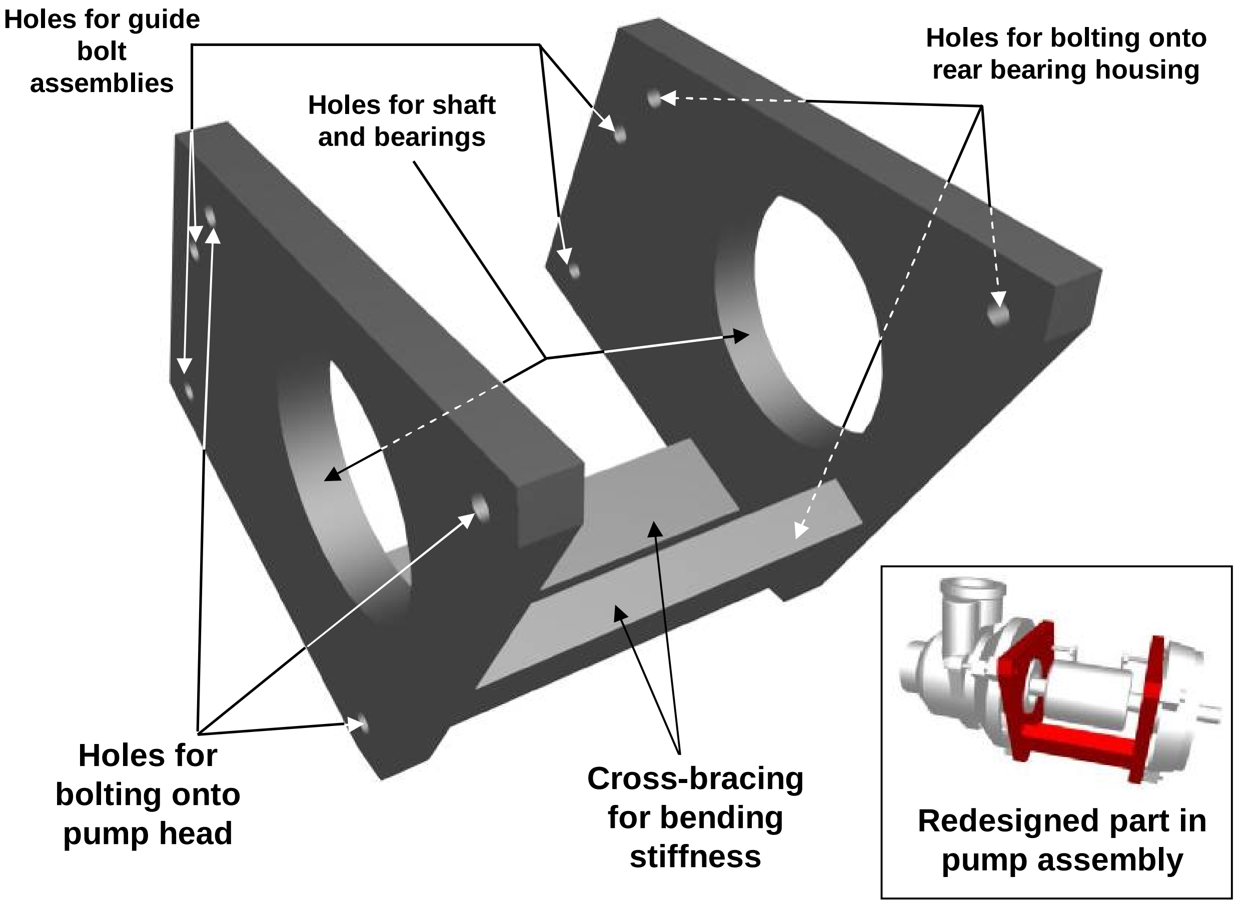


Figure 11.1 Annotated CAD diagram of the redesigned part

11.1.2 Redesign of Supporting Frame

The supporting frame also required the use of the same tools that were unavailable to MayaPedal. Figure 11.2 shows how the part was redesigned to address this issue and other minor problems such as the constriction of the outlet hose (see Figure 9.4). As some dimensions were not critical (such as the outer diameter of and the internal bore depth of the axle grip attachments), stock sizes could be used instead of machining to size or drill bits used in place of boring tools.

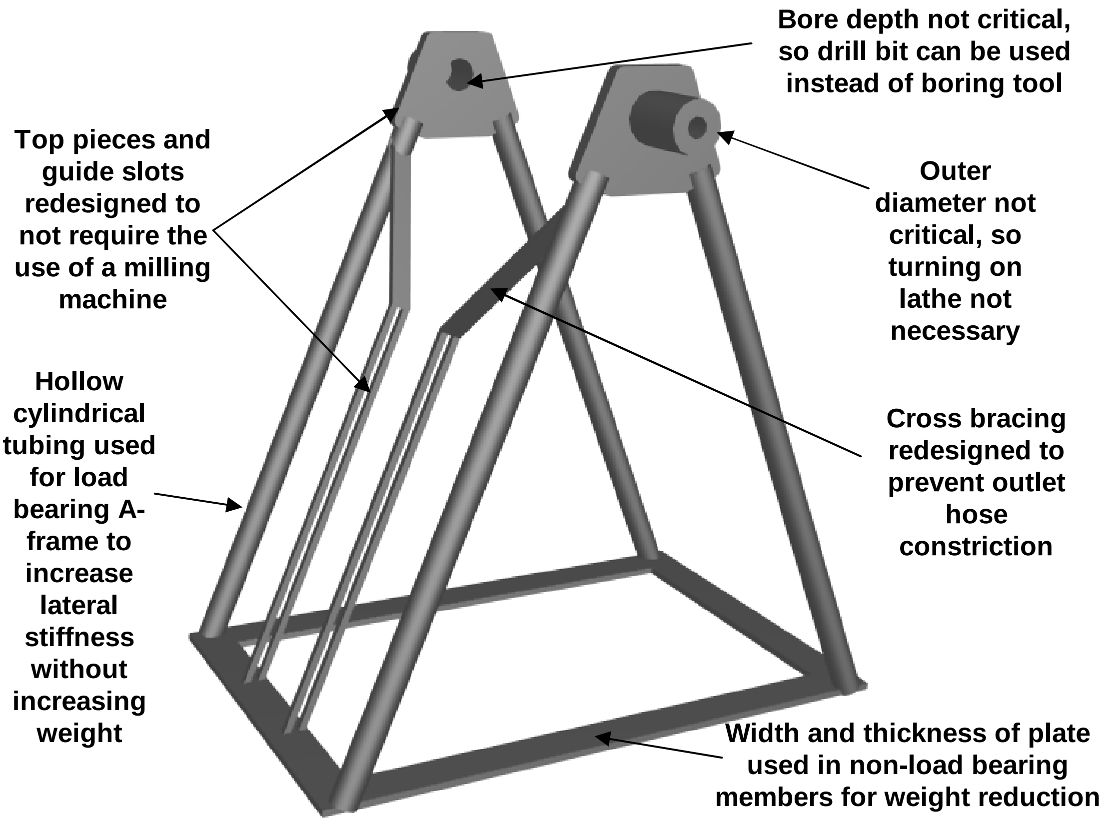


Figure 11.2 Annotated CAD drawing of the redesigned supporting frame

11.1.3 Hose Storage

No provision for storage of the hose was made in the original prototype. It was assumed that during transportation the peddler would wrap the hose around their body or carry it separately. One such solution problem would be to add a pair of detachable spikes to the bottom of the supporting frame. Figure 11.3 overleaf shows that when the Bicibomba Móvil is in transportation mode, the spikes would act as points to coil the hose around so that it can be stored in a similar way to a pannier rack. As the Bicibomba Móvil is likely to be used in muddy areas, Figure 11.3 shows how the spikes can improve the stability of the design when operated on softer ground. The spikes would of course be detachable for use on harder ground.

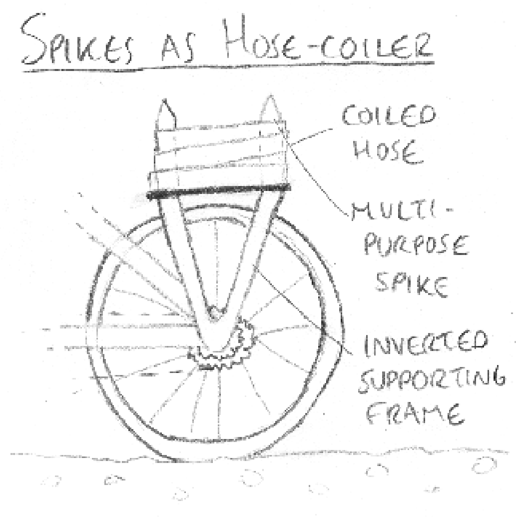


Figure 11.3 Multipurpose spikes in transportation mode

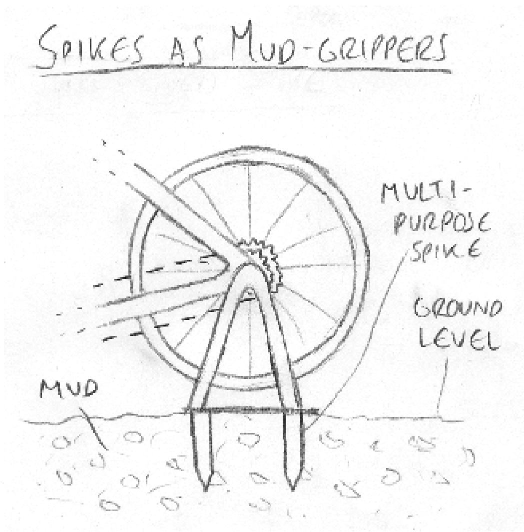


Figure 11.4 Multipurpose spikes in pumping mode

12 THE NEXT STAGE

As a continuation of this project I have received funding from Engineers Without Borders and the Margaret Enid Wilson and William Frederick Wilson Memorial Fund to travel to Guatemala for 2-3 months. The sponsorship application that I submitted is attached in the APPENDIX 5 – Sponsorship Application for Travel to Guatemala. I intend to work at MayaPedal as a volunteer, with the aim of developing the Bicibomba Móvil into a successful product that can be used in the local community and ultimately on a wider scale. Through the building of further prototypes, field testing and with the help of MayaPedal's extensive bicimáquina building knowledge, I hope to share and improve the technology that I have developed in this project.

13 CONCLUSION

The aim of the project was to design a novel product from waste material. Although not constructed entirely from waste material, the Bicibomba Móvil uses recycled bicycles that MayaPedal have acquired and is designed to reuse end-of-life electric pumps with burnt out motors that would otherwise be scrapped. With reference to the objectives of the project, a concept and prototype for a bicycle powered water pump based was designed, built and evaluated. The design was specifically developed for use in rural Guatemala, but the technology could easily be used in any developing country or area without electricity. The Bicibomba Móvil was able to pump over 25m vertically and achieved flow rates above 40 l/min. Its main advantage over existing technology is its mobility which means that it is suitable for a variety of applications such as irrigation, agricultural, light industrial and domestic water transportation. With the suggested design modifications mentioned previously, I should be able to create a refined Bicibomba Móvil in Guatemala that can be used as a viable alternative to transporting water by hand, using expensive and polluting diesel pumps or forcing a community to become reliant on an electricity supply company.

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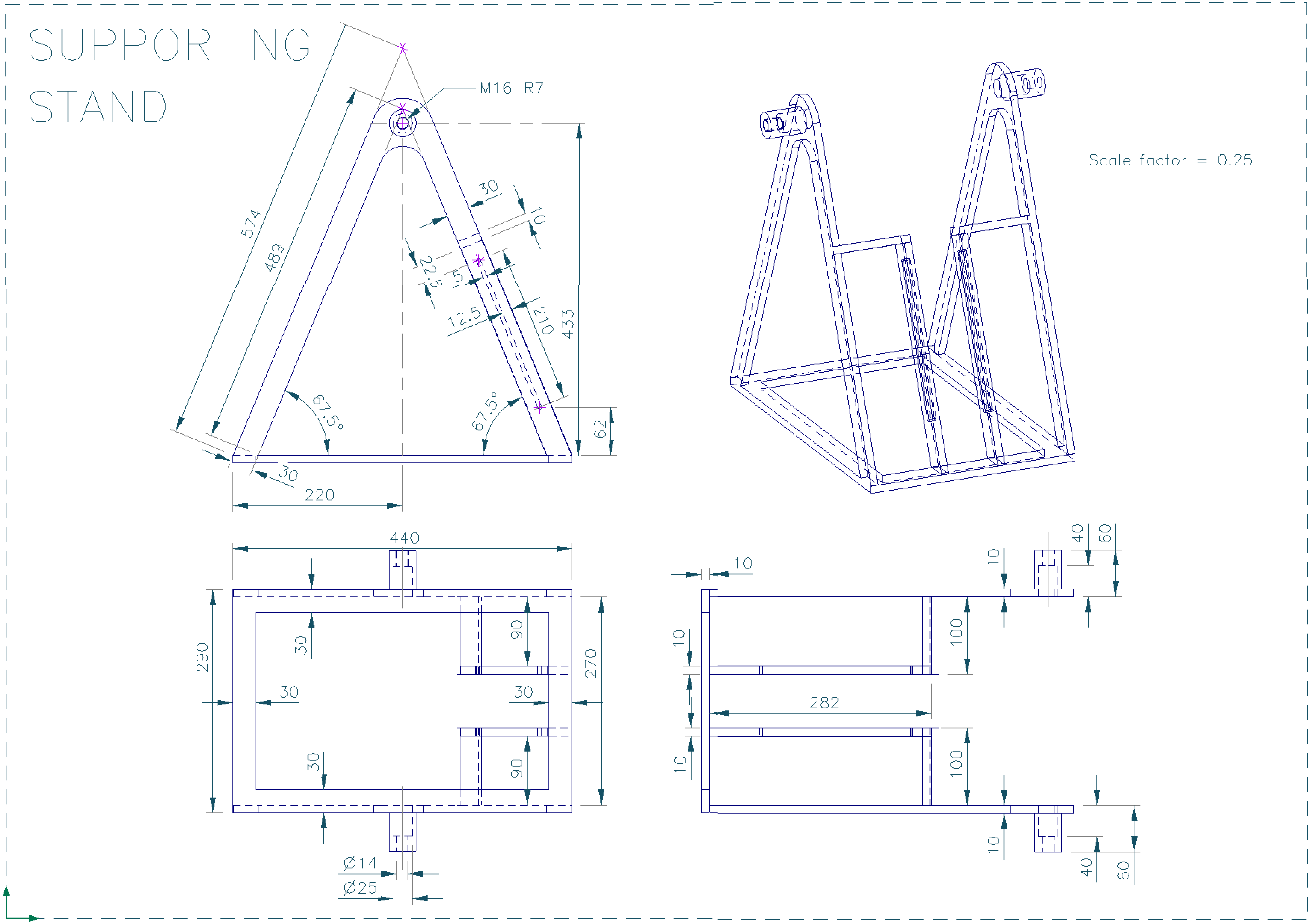
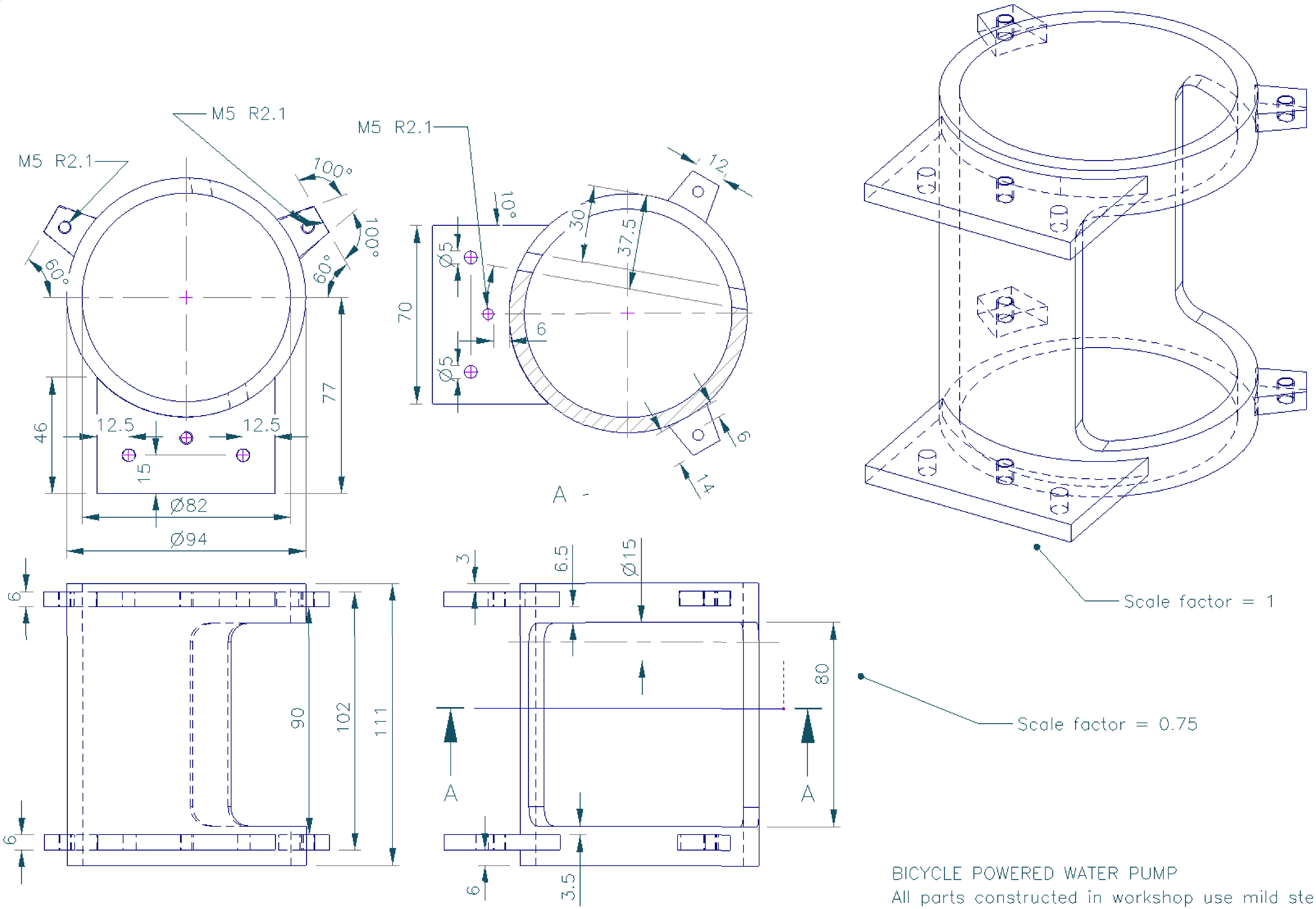
APPENDIX 1 - ANATOMY OF THE MODERN BICYCLE

Image Courtesy of Sidwells, C - Bike Repair Manual, Dorling Kindersley, London, 2004[6]

APPENDIX 2 – ENGINEERING DRAWINGS

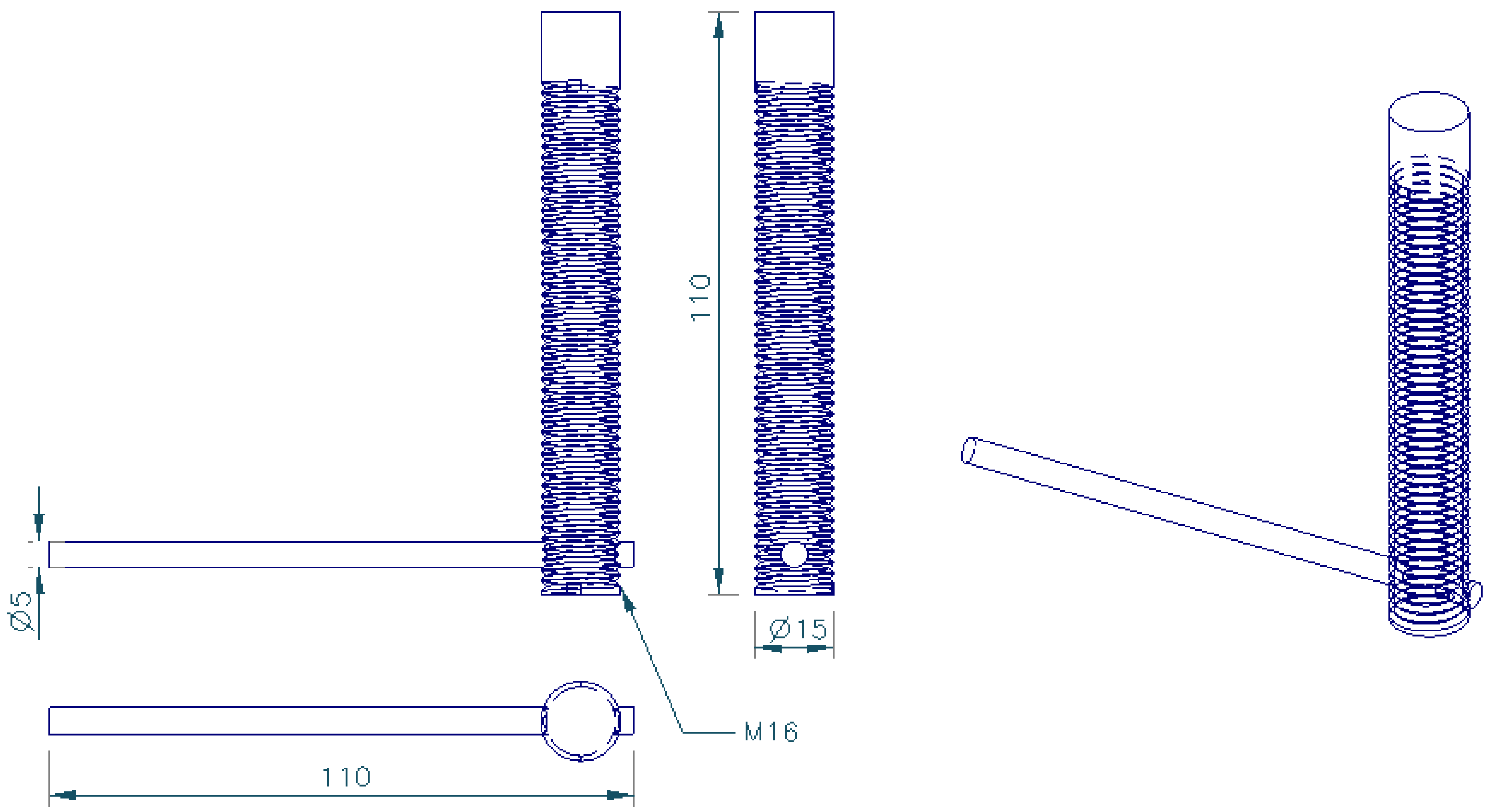


Cylindrical Stabiliser



BICYCLE POWERED WATER PUMP
All parts constructed in workshop use mild steel
Jon Leary – mea04jl@sheffield.ac.uk

AXLE GRIP TIGHTENER



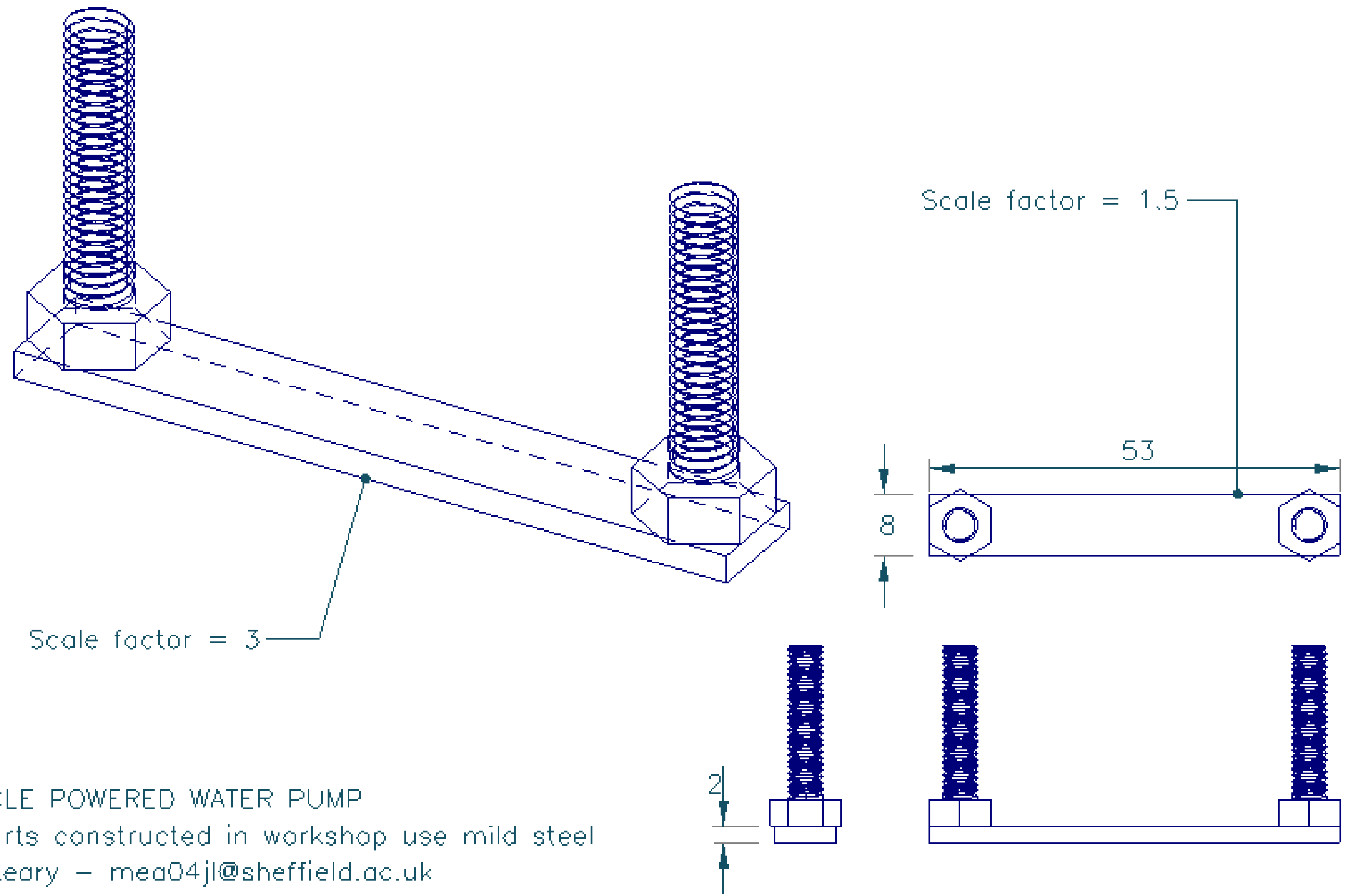
BICYCLE POWERED WATER PUMP

All parts constructed in workshop use mild steel

Jon Leary – mea04jl@sheffield.ac.uk

Scale factor = 1

GUIDE BOLT ASSEMBLY



BICYCLE POWERED WATER PUMP

All parts constructed in workshop use mild steel

Jon Leary – mea04jl@sheffield.ac.uk

APPENDIX 3 - BINARY DOMINANCE AND DECISION MATRICES

A3.1 Conceptual Design Selection

Criteria	A	B	C	D	E	F	G	H	I	J	K	L	M	N	Total	Weighting
A. Simplicity of construction	1	0	0	1	0	0	1	0	1	1	0	0	1	1	7	**0.067**
B. Simplicity of maintenance	1	1	0	1	0	0	0	0	1	1	0	0	1	1	7	**0.067**
C. Cost	1	1	1	1	0	1	1	1	1	1	1	1	1	1	13	**0.124**
D. Durability	0	0	0	1	0	1	0	0	1	1	0	0	1	1	6	**0.057**
E. Ease of use	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14	**0.133**
F. Self-priming	1	1	0	0	0	1	0	0	1	1	0	0	1	1	7	**0.067**
G. Mobility	0	1	0	1	0	1	1	1	1	1	1	0	1	1	10	**0.095**
H. Flow-rate	1	1	0	1	0	1	0	1	1	1	1	0	1	1	10	**0.095**
I. Constructed solely from bicycle parts?	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2	**0.019**
J. Constructed solely from recycled parts?	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	**0.010**
K. Maximum head	1	1	0	1	0	1	0	0	1	1	1	0	1	1	9	**0.086**
L. Adaptability	1	1	0	1	0	1	1	1	1	1	1	1	1	1	12	**0.114**
M. Hygiene	0	0	0	0	0	0	0	0	1	1	0	0	1	1	4	**0.038**
N. Stability	0	0	0	0	0	0	0	0	1	1	0	0	0	1	3	**0.029**
														Total	105	**1**

Binary Dominance Matrix for allocation of weighting of the design criteria

	Weighting	Conceptual Scoring Rope Pump Adaptation	**Standard Electric Pump Adaptation**	Peristaltic Pump
A. Simplicity of construction	0.067	30	**90**	60
B. Simplicity of maintenance	0.067	60	**90**	40
C. Cost	0.124	60	**40**	90
D. Durability	0.057	50	**90**	10
E. Ease of use	0.133	50	**80**	70
F. Self-priming	0.067	100	**0**	0
G. Mobility	0.095	10	**90**	50
H. Flow-rate	0.095	80	**80**	20
I. Constructed solely from bicycle parts?	0.019	40	**50**	100
J. Constructed solely from recycled parts?	0.010	90	**70**	100
K. Maximum head	0.086	90	**70**	20
L. Adaptability	0.114	30	**90**	70
M. Hygiene	0.038	40	**90**	60
N. Stability	0.029	80	**60**	80
	Total	54.76%	**72.00%**	51.52%

Decision matrix to select the most suitable conceptual design for further development

A3.2 Driving Mechanism Selection

Design Criteria	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	Total	**Weighting**
A. Ease of use	1	1	1	1	0	0	0	1	0	1	0	6	**0.091**
B. Weight	0	1	0	1	0	0	0	0	1	0	0	3	**0.045**
C. Gear usage	0	1	1	1	0	0	1	1	1	0	0	6	**0.091**
D. Back wheel lifting	0	0	0	1	0	0	0	0	0	0	0	1	**0.015**
E. Ease of manufacture	1	1	1	1	1	0	1	1	1	1	0	9	**0.136**
F. Ease of setup	1	1	1	1	1	1	1	1	1	1	0	10	**0.152**
G. Cost	1	1	0	1	0	0	1	0	0	0	0	4	**0.061**
H. Use of bicycle parts	0	1	0	1	0	0	1	1	1	0	0	5	**0.076**
I. Drive-train length	1	0	0	1	0	0	1	0	1	0	0	4	**0.061**
J. Power regulation	0	1	1	1	0	0	1	1	1	1	0	7	**0.106**
K. Adaptability	1	1	1	1	1	1	1	1	1	1	1	11	**0.167**
											Total	66	1.000

Binary Dominance Matrix for allocation of weighting of the design criteria

Design Criteria	Weighting	Conceptual Scoring Axle Drive	**Wheel Drive**	Rear Wheel Chain Drive	Direct Chain Drive
A. Ease of use	0.091	80	**80**	80	70
B. Weight	0.045	50	**50**	60	90
C. Gear usage	0.091	100	**100**	60	30
D. Back wheel lifting	0.015	0	**0**	0	100
E. Ease of manufacture	0.136	70	**70**	50	60
F. Ease of setup	0.152	80	**80**	50	50
G. Cost	0.061	90	**70**	80	80
H. Use of bicycle parts	0.076	40	**60**	90	80
I. Drive-train length	0.061	80	**40**	50	80
J. Power Regulation	0.106	0	**100**	0	0
K. Adaptability	0.167	10	**90**	70	90
	Total	55.30%	77.12%	56.21%	61.21%

Decision matrix to select the most suitable driving mechanism

A3.3 Rear Wheel Lifting Mechanism

Design Criteria	A.	B.	C.	D.	E.	F.	G.	H.	I.	Total	**Weighting**

A. Ease of use	1	1	0	0	1	0	1	0	1	5	**0.111**
B. Weight	0	1	0	0	0	0	0	0	0	1	**0.022**
C. Adaptability	1	1	1	1	1	1	1	0	1	8	**0.178**
D. Stability	1	1	0	1	0	0	1	0	1	5	**0.111**
E. Ease of manufacture	0	1	0	1	1	0	1	0	1	5	**0.111**
F. Ease of setup	1	1	0	1	1	1	1	0	1	7	**0.156**
G. Cost	0	1	0	0	0	0	1	0	1	3	**0.067**
H. Mobility	1	1	1	1	1	1	1	1	1	9	**0.200**
I. Pedal interference	0	1	0	0	0	0	0	0	1	2	**0.044**
									Total	45	**1.000**

Binary Dominance Matrix for allocation of weighting of the design criteria

Design Criteria	Weighting	Conceptual Scoring **Axle Lift**	Chain stay Lift
A. Ease of use	0.111	70	90
B. Weight	0.022	80	90
C. Adaptability	0.178	80	50
D. Stability	0.111	90	40
E. Ease of manufacture	0.111	60	80
F. Ease of set-up	0.156	60	80
G. Cost	0.067	60	70
H. Mobility	0.200	100	40
I. Pedal interference	0.044	80	50
	Total	**77.33%**	61.56%

Decision matrix to select the most suitable mechanism for lifting the bicycle's rear wheel

A3.4 Driving Roller Placement Selection

Criteria	A.	B.	C.	D.	E.	F.	Total	**Weighting**
A. Ease of setup	1	0	1	1	1	0	4	**0.190**
B. Proximity to peddler	1	1	1	1	1	1	6	**0.286**
C. Wheel size adjustability	0	0	1	1	1	0	3	**0.143**
D. Tyre type adjustability	0	0	0	1	1	0	2	**0.095**
E. Extra wheel lift	0	0	0	0	1	0	1	**0.048**
F. Traction	1	0	1	1	1	1	5	**0.238**
						Total	21	**1.000**

Binary Dominance Matrix for allocation of weighting of the design criteria

Criteria	Weighting	Conceptual Scoring Seat Tube	**Lifting Stand Horizontal**	Lifting Stand Vertical	Seat Stay
A. Ease of setup	0.190	30	**80**	60	20
B. Proximity to peddler	0.286	20	**80**	70	30

C. Wheel size adjustability	0.143	90	**50**	90	90
D. Tyre type adjustability	0.095	90	**80**	90	90
E. Extra wheel lift	0.048	100	**50**	50	100
F. Traction	0.238	90	**90**	50	40
	Total	59.05%	**76.67%**	67.14%	48.10%

Decision matrix to select the most suitable conceptual design for further development

A3.5 Roller Position Adjustment Selection

Criteria	A.	B.	C.	D.	E.	F.	G.	H.	I.	Total	**Weighting**
A. Corrosion Potential	1	1	1	1	1	1	1	1	1	9	**0.200**
B. Ease of Setup	0	1	1	0	1	1	0	1	0	5	**0.111**
C. Ease of Adjustment	0	0	1	0	0	0	0	1	0	2	**0.044**
D. Adjustability	0	1	1	1	1	1	0	1	0	6	**0.133**
E. Simplicity of design	0	0	1	0	1	1	0	1	0	4	**0.089**
F. Ease of manufacture	0	0	1	0	0	1	0	1	0	3	**0.067**
G. Stability	0	1	1	1	1	1	1	1	0	7	**0.156**
H. Weight	0	0	0	0	0	0	0	1	0	1	**0.022**
I. Mobility	0	1	1	1	1	1	1	1	1	8	**0.178**
									Total	45	1.000

Binary Dominance Matrix for allocation of weighting of the design criteria

Criteria	Weighting	Conceptual Scoring Horizontal Bolting	Screw Clamp	Vertical Bolting	**Sliding Stand Adjustment**	Pivoting Cam Action
A. Corrosion Potential	0.200	10	0	50	50	80
B. Ease of Setup	0.111	50	40	50	70	90
C. Ease of Adjustment	0.044	70	60	70	80	90
D. Adjustability	0.133	0	100	0	100	100
E. Simplicity of design	0.089	90	50	70	80	50
F. Ease of manufacture	0.067	90	40	70	70	50
G. Stability	0.156	100	100	90	80	40
H. Weight	0.022	90	70	70	60	50
I. Mobility	0.178	60	50	70	70	60
	Total	52.89%	53.56%	57.56%	**72.67%**	69.11%

Decision matrix to select the optimum roller position adjustment mechanism

APPENDIX 4 – GUATEMALAN PUMP PHOTOGRAPHS


DAB
KPS 30/16 M
MADE IN ITALY


TRUPER
Bomba centrífuga
de 1/4 HP
Electric water pump
TRUPER®
Voltaje: 120 V~
Frecuencia: 60Hz
Corriente: 3.5A
Flujo de salida: 70 l/min
Altura maxima: 16 m
Frecuencia de rotación: 3450 min-1
Marca: Truper
Modelo: BOAC-1/4
NOM · ANCE
CONT: 1 PIEZA
Importador: TRUPER HERRAMIENTAS, S.A. de C.V. Parque Industrial No.1, Jilotepec, C.P. 54240, Estado de Mexico, México. Tel.: 01(761) 782-91-00, Hecho en China. Fax: 01(761) 782-91-70, R.F.C.: THE-791105-HP2. www.truper.com
Ultima actualización: diciembre 2004
LEA Y SIGA TODAS LAS INSTRUCCIONES DE SEGURIDAD Y OPERACIÓN ANTES DE USAR ESTA BOMBA.
5a. Avenida 1-45, Zona 2 Chimaltenango
Telefax: 839-4805 o mensajes al
SKYTEL 3600000 Pin 4980456


CORONA

APPENDIX 5 – SPONSORSHIP APPLICATION FOR TRAVEL TO GUATEMALA

Application for the Margaret Enid Wilson and William Frederick Wilson Memorial Fund

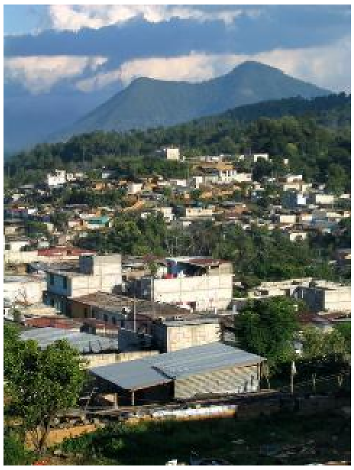
Title of Project

Development of a Bicycle-powered Water Distribution Pump for use in Rural Guatemala

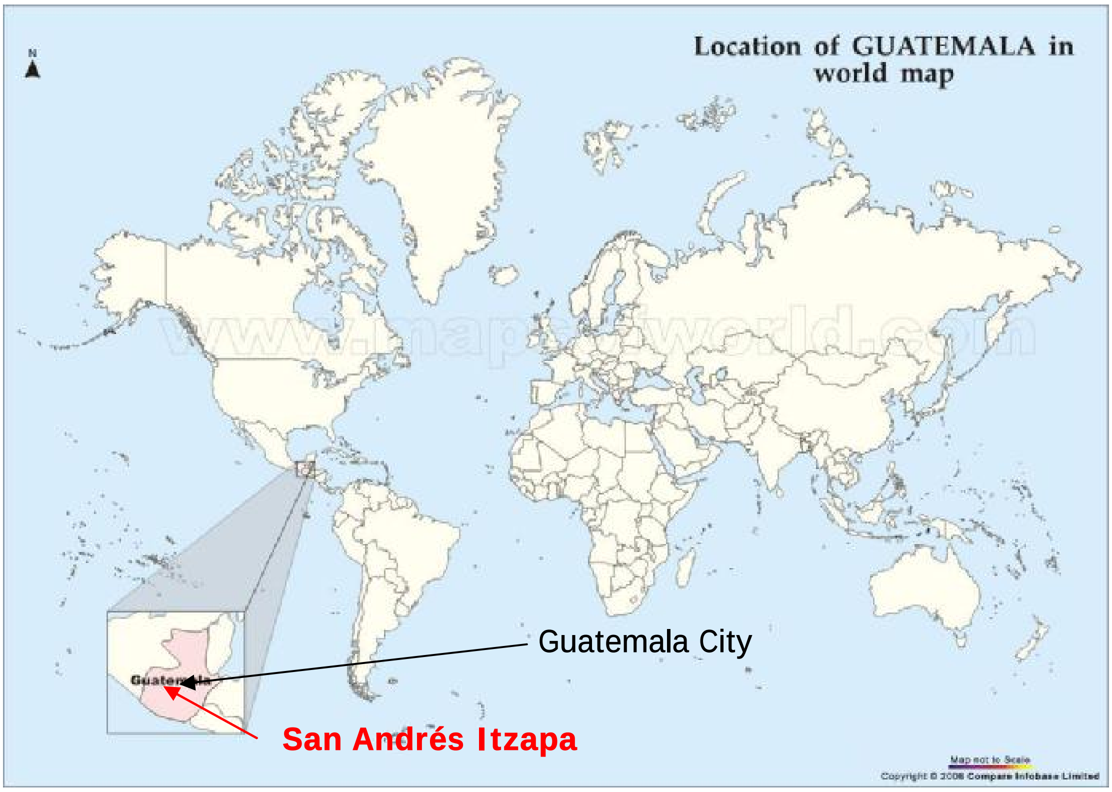
Location of Project

San Andrés Itzapa, Chimaltenango, Guatemala

MayaPedal's Shop Front in San Andrés Itzapa



The View over San Andrés Itzapa



Target Group(s) / Beneficiaries

Guatemalan subsistence farmers, local small businesses and rural family groups.

Aims and Objectives

Specifically, I intend to build and distribute the bicycle-powered water distribution pump that I have designed in partnership with MayaPedal for my final year project. More generally, I am planning to work as a volunteer at MayaPedal in San Andrés Itzapa. MayaPedal aim to design, build and distribute pedal-powered machines (bicimáquinas) constructed from recycled bicycles. The machines are designed to meet the necessities of local communities by contributing to the local economy and improving the productivity and health of rural families with the aim of helping them become self-sustainable without damaging the environment. They aspire to share the experiences of the organisation through community-based environmental education, and printing articles about the benefits of pedal-powered technology. They actively seek to establish alliances with national and international groups that have similar goals and that have the capacity to transfer pedal-powered technology to other areas of the world. To summarise, MayaPedal aim to produce, promote and commercialise bicycle machines and the products made with them, with the ultimate purpose of being a self-sustainable organisation, and to help associated groups also achieve this goal. I respect these values and would like to contribute further to the organisation by working with them in San Andrés Itzapa.

About MayaPedal

MayaPedal is a non-governmental organization located in San Andrés Itzapa, Chimaltenango, Guatemala. Founded in 1997, in partnership with a group of Canadians from the organization PEDAL, they became constituted under local control as Asociación Maya Pedal in 2001 to work towards a vision for sustainable development in Guatemala. They recycle used bicycles to build pedal-powered machines, bicimáquinas, which support and help facilitate the work of small-scale, self-sustainable projects. Through this work they hope to contribute to the conservation of the environment, the health of the Guatemalan people and the productivity of the local economy. The pictures overleaf show a couple of the bicimáquinas MayaPedal have successfully produced and distributed.

The organisation's mission statement is: "To support the basic family economy, through the design and distribution of bicycle machines, providing an efficient alternative for the rural development of Guatemala. To be a non-governmental organization that promotes the use of bicycle machines through programs, projects, partnerships, activities, and actions, also promoting the use of alternative transportation using bicycles and tricycles."

The Bicycle-Powered Well Pump

The Bicycle-Powered Macadamia Nut-Sheller

MayaPedal receive container shipments of old bikes from other charitable organisations such as Working Bikes, Chicago, USA and Peace Corps, Guatemala. Organisations such as Canadian International Development Agency and GAIA Project, Sierra Club, BC Chapter have supported them by sending a number of international interns to work voluntarily at MayaPedal. PEDAL, the organisation from Vancouver, Canada that helped to get MayaPedal off the ground as well as Bikes Not Bombs, Boston, USA have both contributed enormously to the project by sending funding, materials, skilled volunteers and containers of old bicycles.

Why is the Project Needed?

MayaPedal already have a working bicycle-powered well-pump, but after the water has been extracted, it still needs to be distributed for agricultural, domestic or small scale commercial processes. A lot of time and effort goes into water transportation, especially considering that the local terrain is highly mountainous. Currently much time is spent carrying water from place to place by hand, or if larger quantities are required and funds are available, then expensive petrol or electric pumps are used.

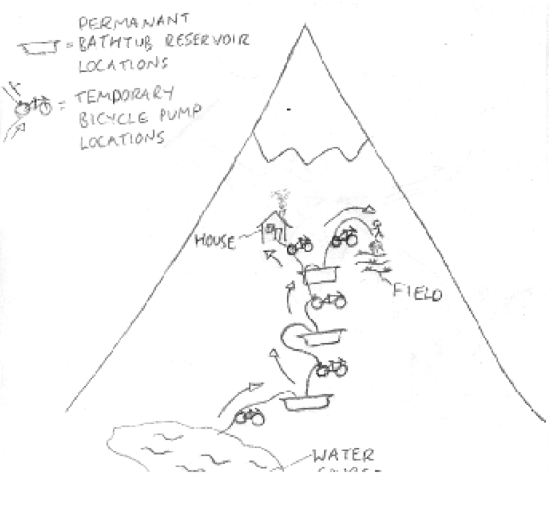
The pump will save time for people that currently transport their water by hand, as well as allowing them to transport greater volumes of water, increasing their productivity and freeing up their time for other things. For people currently using electric or petrol powered pumps, it will not only save them the fuel costs, but also provides a practical and environmentally friendly alternative, making their operations more sustainable.

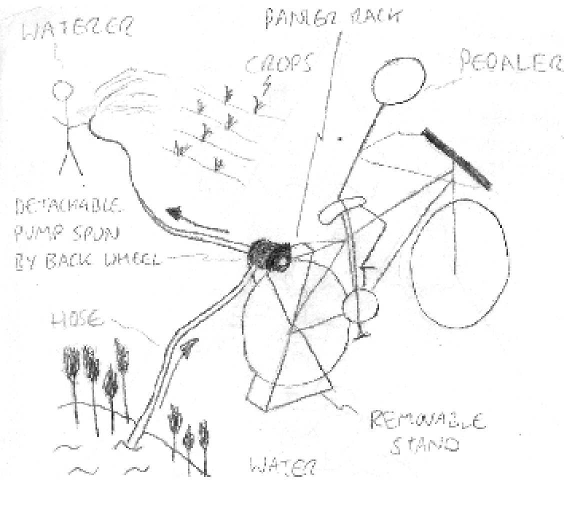
Many rural Guatemalans are struggling to meet the basic needs of both themselves and their families without resorting to environmentally damaging methods such as the use of dangerous pesticides or petrol powered generators to provide electricity in remote areas. The use of bicimáquinas have given people a realistic way to meet their needs by making use of simple machinery that we take for granted in the modern world, but ordinarily cannot be used in areas where electricity is not available.

The Project So Far

The brief for my final year project was to develop a novel product from waste material. This gave a huge scope for possible topics. After some initial research I came across MayaPedal's web site. I contacted them regarding the suitability of undertaking my final year project in partnership with them. I received a reply from Amilio and we discussed the suitability of various projects and agreed on the bicycle-powered water distribution pump.

The proposed design consists of an adapted cheap electric pump that can be temporarily attached to and driven by the rear wheel of the bicycle. This way, the bicycle remains rideable and the pump uses standardised parts that are cheap and easy to replace. A system of small reservoirs made from old bathtubs or oil drums may be used to increase the distribution area. The diagrams below show the conceptual ideas . I





Initial Timeline of Activities

Project start date: Early September 2008

Project end date: Late October 2008

I intend to work as a volunteer at MayaPedal, primarily to help with the building, field testing, distribution and general further development of the bicycle-powered water distribution pump that I have been designing in partnership with MayaPedal for my final year project (see below). In addition to this I will also be helping out with more general work within the organisation, including:

- Assembling bicycles for sale and other bike shop related tasks
- Building pedal-powered technology: cutting, grinding, welding, assembling, painting, testing
- Assisting in the production of manuals for each bicimáquina: drawing, writing, layout
- Delivering bicimáquinas/bicycles to communities; unloading, greeting, demonstrating machinery, roadside truck repair
- Assisting community projects; gardening, carpentry, animal husbandry
- Keeping the base house clean and comfortable

The list below gives a rough idea of the order of the intended work to be carried out:

- First few days: arriving in Guatemala and travelling to San Andrés Itzapa. Meeting the MayaPedal team and getting to know them, the organisation, the culture, the bicimáquinas and the tools and processes used in the workshop.
- First week: Building, testing and improving my bicycle-powered water distribution pump.
- Second week: Initial distribution of the bicycle-powered water distribution pump to the first users. Evaluation of its performance and collection of feedback on its usefulness and areas for improvement.
- Third week: Improvement of the design and adaptation for specific needs such as domestic vs. agricultural uses.

- Fourth week: More widespread distribution of the bicycle-powered water distribution pump. General maintenance of first run designs.
- Second month: Further development and distribution of the bicycle-powered water distribution pump. More general work for the organisation, as detailed above.

Health and Safety

The following health and safety issues have been taken into consideration:

- The rainy season in Guatemala runs from June to November which could cause landslides, leading to major disruption.
- Earthquakes are also common and there are four active volcanoes in Guatemala, but the risk of eruption is relatively low.
- The home office reports that there is a low risk of terrorism since the end of the civil war in 1996, but that violent crime is relatively high. They suggest avoiding travelling on local busses, going out late at night alone, avoiding displaying items of value and not to resist in the event of a robbery.
- There is a risk of contracting tetanus; hepatitis A, typhoid, rabies, hepatitis B, tuberculosis, diphtheria and cholera. I am already vaccinated against all of these diseases other than cholera, which can be done for free at the University Health Service. Malaria is also prevalent, so after consultation with a medical professional I will most likely be taking anti-malarials.
- As I will be using both hand and power tools to build and repair bicimáquinas, care must be taken to ensure that I have been properly trained with the equipment that I am not familiar with and initially to work under supervision.

Proposed Budget

- Return flight to Guatemala City: £500 (http://www.cheapflights.co.uk/flights/Guatemala-City/London-Area/)
- Transportation from Guatemala City to San Andrés Itzapa and back by bus: <$US10 (£6) (estimate from The Lonely Planet Guide to Guatemala by John Noble, Susan Forsyth)
- Approximate living costs for 7 weeks:

- Food and personal expenses: ~$US25 (£13) per week (estimate by Amilio Aviles - Volunteer Coordinator for MayaPedal)
- Housing in San Andres Itzapa: provided by MayaPedal (from MayaPedal website)
- Transportation for project related activities: provided by MayaPedal (from MayaPedal website)

Total = (£13 per week)x(7 weeks) = £91

- All required bicycles, parts and tools provided by MayaPedal.
- Travel insurance: £60 (STA Travel Budget Plan for 2 months)
- Visa: not required for UK citizens
- Vaccinations: Cholera – free from University Health Service if required
  Anti-malarials - £60 based on an 8 week course of Choloroquine and Proguanil (from GalaxoSmithKline factsheet)

Total cost for 7 week trip = £500 + £6 + £91 + £60 + £60 = £717

Amount requested: £717 or portion thereof

Other Funding

I am also currently applying for both the Laverick-Webster-Hewitt Travelling Fellowship and a project bursary from Engineers Without Borders (EWB). The bursary scheme provides funding for member-initiated non EWB-UK learning opportunities, research projects and volunteer placements which contribute to the personal development of their members and benefit partner development organisations. I have written similar applications to this one, asking for full or partial funding. Ideally, I would be able to obtain one third of the full amount from the Laverick-Webster-Hewitt Travelling Fellowship, EWB and the Margaret Enid Wilson and William Frederick Wilson Memorial Fund.

About Me

I am a fourth year Mechanical Engineering Student here at the University of Sheffield. I am a keen traveller, having travelled to many parts of Europe, North America, India and Kenya. I spent my third year on exchange at the University of

Alberta, Canada and greatly enjoyed the challenges and rewards of living in another country. I've really enjoyed working with MayaPedal so far on my final year project. It's very rewarding knowing that the end result will hopefully help improve peoples' daily lives and help communities become more sustainable. Amilio has told me that he has learnt a huge amount during his time working at MayaPedal. I think it is a unique opportunity for me to learn about practical engineering in a developing country and that it will be highly fulfilling for me to follow the project through right from the conceptual design to seeing the difference it makes when people use the finished machine. I also hope to improve my Spanish, which at the moment is only very basic, both before I travel to Guatemala and whilst I'm there.

Contact Details

MayaPedal:

- Asociación Maya Pedal
  Cantón San Antonio
  San Andrés Itzapa,
  Chimaltenango
  Guatemala, C.A.
- www.mayapedal.org
- Tel: (+502)7849-4671
- Amilio has been my point of contact with MayaPedal and has contributed greatly to the initial design work for the bicycle-powered water distribution pump. He is also the volunteer co-ordinator for the organisation.
  Email: Amilio Aviles - volunteer@mayapedal.org or astromilio@hotmail.com

My Contact Details:

- Full Name: Jonathan Leary
- Address (until the end of June 2008): Flat A, 106 Whitham Road,
  Broomhill,
  Sheffeild, S10 2SQ
- Tel: 07942 580161

- Email: jonnylsemail@gmail.com

My final year project supervisors at The University of Sheffield:

- Mr G J Heppell, Senior Teaching Fellow

  Tel: (0114) 222 7750

  Email: g.heppell@sheffield.ac.uk
- Dr S R Bradbury, Lecturer

  Tel: (0114) 222 7731

  Email: s.r.bradbury@sheffield.ac.uk

APPENDIX 6 – SUPPORTING CALCULATIONS

A6.1 Axle Grip Deflection Analysis

Aim

To calculate the maximum deflection of the axle grips.

Assumptions

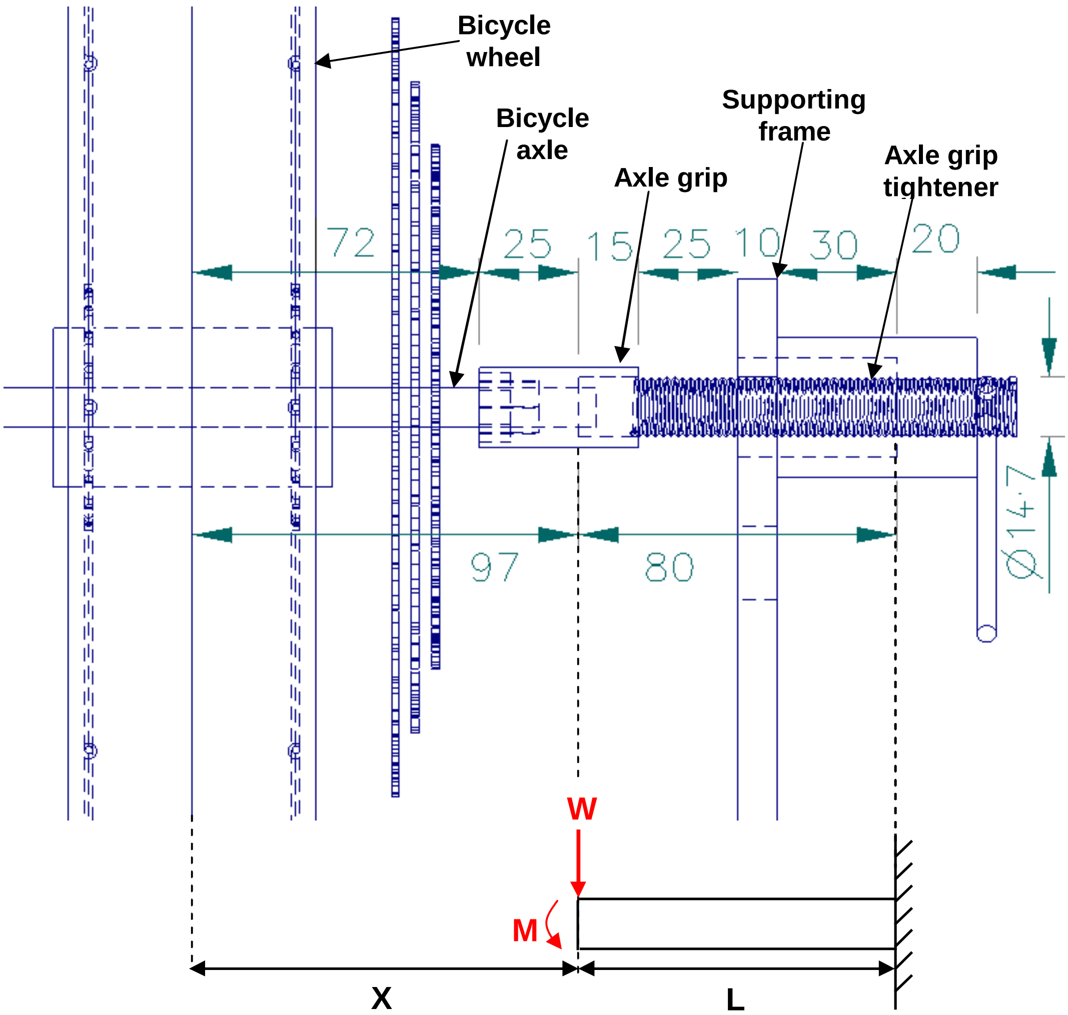
- The supporting frame provides a rigid support for the axle grip tightener.
- The deflection within the axle grip itself is negligible.
- The diameter of the thread bar can be approximated to its pitch diameter, i.e. M16 thread→14.7mm.
- The weight of the rider and bicycle is evenly distributed between the left and right axle grips

Method

Figure A6.1.1 overleaf shows how the axle grip tightener was modelled as a cantilever beam with a fixed end at the supporting frame and a moment and point load exerted at the free end.

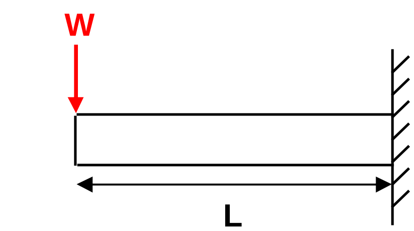
The point load, W, represents the weight of the peddler and the bicycle. In the worst case scenario, the weight of the heaviest peddler, m_pg, on the heaviest bicycle, m_bg will be entirely over the rear wheels. The weight, $g(m_b+m_p)$, has been assumed to be evenly distributed over the two axle grips, meaning that a force of $\frac{1}{2}g(m_b+m_p)$ is exerted on each one. However, due to the effect of a suddenly applied loading occurring as the rider mounts the bicycle, the loading force should be doubled[8]. Therefore: $W=g(m_b+m_p)=9.81m/s^2*(20kg+100kg)=1177.2N$

The moment, M, exerted by the force, W, acting at a distance, x, from the free end of the axle grip tightener has magnitude: $M=WX=1177.2N*97*10^{-3}m=114.2Nm$

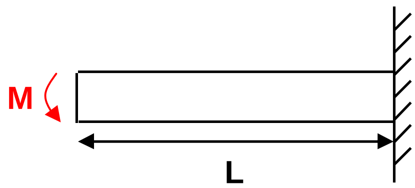


The maximum deflections, δ_{max}, of fixed end cantilever beams bent about principal axes with point loads, W, and moments, M, applied at the free end are as follows[9]:

$$d_{max} = \frac{ML^2}{2EI}$$

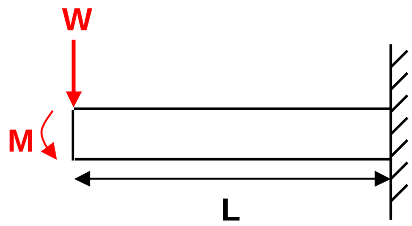


$$d_{max} = \frac{WL^3}{3EI}$$



Therefore the maximum deflection of the fixed end cantilever beam with both a point load, W, and a moment, M, applied at the free end is given by summation of the two previous results:

$$d_{\max} = \frac{ML^2}{2EI} + \frac{WL^3}{3EI}$$



The axle grip tightener is manufactured from mild steel, which has a Young's Modulus, E, of 207GPa. It has a circular cross-section of radius, r, of 7.35mm, giving it a second moment of area:

$$I = \frac{pr^4}{4} = \frac{px(7.35x10^{-3})^4}{4} = 2.292x10^{-9}m^4$$

Therefore, the deflection of the free end of the axle grips is given by the following formula:

$$d_{axlegrip} = \frac{ML^2}{2EI} + \frac{WL^3}{3EI} = \frac{114.2\times(80\times10^{-3})^2}{2\times207\times10^9\times2.292\times10^{-9}} + \frac{1177.2\times(80\times10^{-3})^3}{3\times207\times10^9\times2.292\times10^{-9}}$$

$$= 1.194\times10^{-3}m \approx 1mm$$

Conclusion

The deflection of the axle grips is just over 1mm.

A6.2 Bearing Fatigue Analysis

Aim

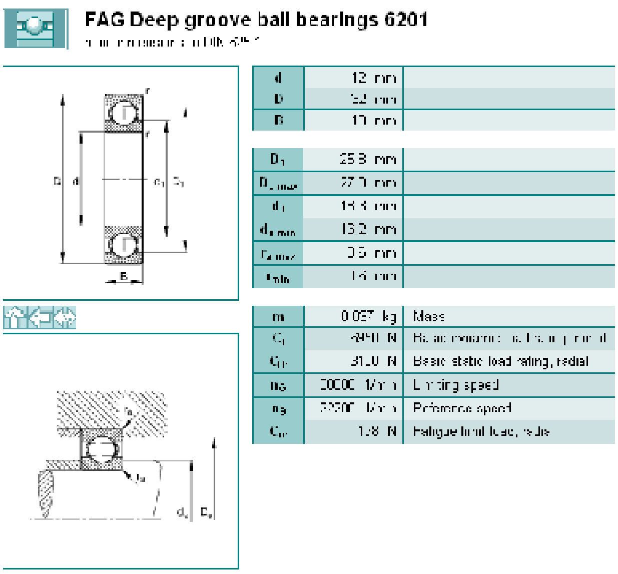
To establish whether the bearings are able to withstand the increased loading associated with converting the pump to bicycle power.

Assumptions

- The force of the water in the pump head is evenly distributed across the impeller.
- The self weight of the shaft, bearings and armature is negligible in comparison with the contact force between the armature/driving roller and the bicycle tyre
- The contact force between the bicycle tyre and the armature/driving roller does not exceed 100N
- The axial force exerted on the impeller by the thrust washer does not exceed 20N
- The axial loading from the thrust washer is taken entirely by Bearing B

Method

Upon disassembly the Clarke TAM105 pump was found to contain two single row deep groove radial ball bearings of similar specification to those shown in Figures A6.2.1 and A6.2.2.



FigureA6.2. Specification of Bearing A[56]

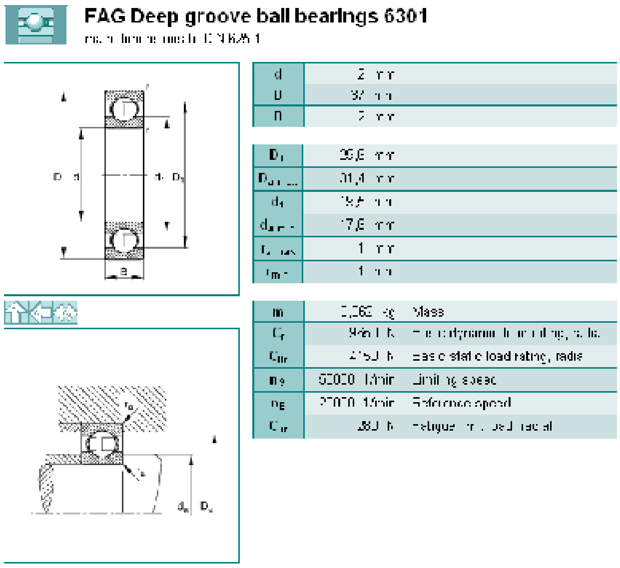


Figure A6.2.2 Specification of Bearing B[56]

Figure A6.2.3 below shows the dimensions of the shaft assembly, with specific reference to the locations of Bearings A and B.

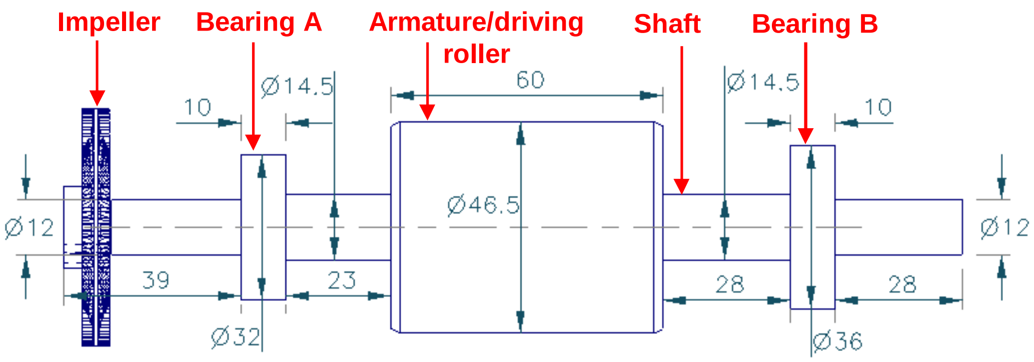


Figure A6.2.3 Fully dimensioned CAD drawing of the impeller, shaft, bearings and armature

Figure A6.2.4 shows the radial and axial forces on the assembly that are relevant to the analysis.

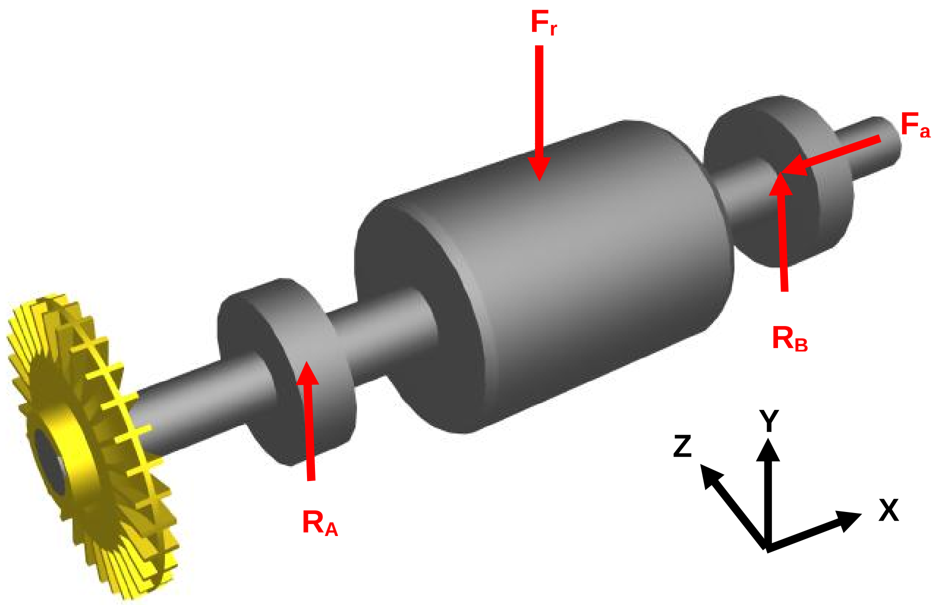


Figure A6.2.5 CAD illustration of the shaft assembly showing the relevant radial and axial forces

The free body diagram in Figure A6.2.6 isolates the forces acting on the shaft in the x-y plane.

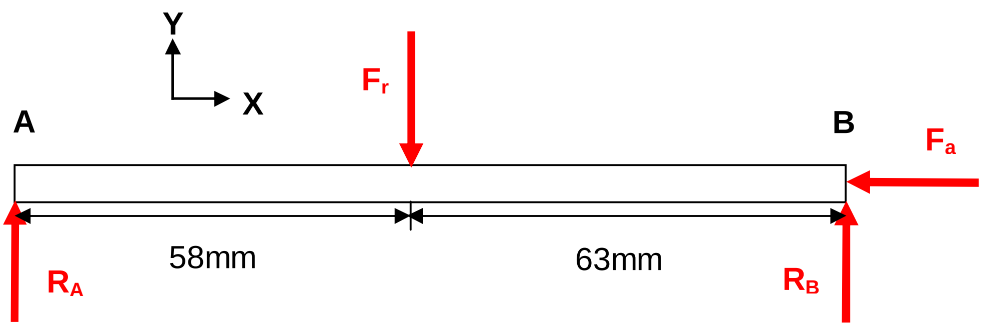


Figure A6.2.6 Free body diagram of the shaft

The reactions at the bearings are calculated using static force and moment balances:

$$\Sigma F \uparrow : Fr = R_A + R_B$$

$$\Sigma M_B (CW) : R_A (58 + 63) - F_r \times 63 = 0$$

$$F_r = 100N \rightarrow R_A = 52.07N,\ R_B = 47.93N$$

The basic radial dynamic load rating, C_r, is the catalogue rating load that will give a life of 1 million revolutions of the inner race and is given for the bearings shown in

Figures A6.2.1 and A6.2.2. Using the following equation[10], the expected life, L (millions of revolutions), of the bearings can be calculated:

$$L = \left(\frac{C_r}{R} \right)^a$$

Where R is the radial loading at the bearing and for ball bearings, a=3[10].

Bearing A

C_r=6950N, R_A=52.07N → L=2377889.563 million revolutions

The applied loading is so far below the bearings rated loading that Bearing A will have a virtually infinite life.

Bearing B

For the case of combined radial and thrust loading, the American Bearing Manufacturers Association (ABMA)[55] recommend using an equivalent radial force, R_{eq}, that would cause the same amount of wear as both loads combined. The equivalent radial force can be found using the following equation[10]:

$$R_{eq} = XVR + YF_a$$

Where V is the rotation factor and is equal to 1 for bearings with a rotating inner ring[10]. The radial factor, X, and thrust factor, Y, are determined from the ratio of the axial force, F_a, to the basic static load rating, C_0. Figure A6.2.2 shows that for Bearing B, C_0 = 4150N. Consequently F_a/ C_0 = 20/4150 = 0.00482. For single row bearings, this gives corresponding X and Y values of 0.56 and 2.86 respectively[10]. Using these values, R_{eq} can now be calculated:

$$R_{eq} = 0.56 \times 1 \times 52.07 + 2.86 \times 20 = 86.35N$$

The equivalent radial force can now be used to calculate the life of Bearing B:

C_r=9650N, R_{eq}=86.35N → $L = \left(\frac{C_r}{R_{eq}} \right)^a = \left(\frac{9650}{86.35} \right)^3 = 1395709$ million revolutions

Again, the loading on Bearing B is so far below its rated capacity that the bearing will have a virtually infinite life.

Conclusion

Both bearings can easily take the increased loading associated with converting the pump to bicycle power.