Bicilavadora
Final Report

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1 Background

1.1 Need

In developing countries, rural women are among the least privileged. Women are both essential to the family unit and integral to the economy, yet they rarely have equal opportunities for education, career development, or social status when compared to men.

One factor behind the inequality is the long list of responsibilities that traditionally fall to women. Not only do women perform agricultural duties and care for livestock alongside men, but women are also responsible for many domestic chores. Usually, new technology improves people's ef.cienc y, but women bene.t less from new technology for several reasons. First, women's duties are neglected by technological improvement efforts because domestic chores are often seen as cultural obligations for women so little effort is expended to diminish them. Second, foreign aid in the form of appropriate technologies is unevenly distributed because women are often considered less technically competent than men. Factors like these tend to prevent the development of improved technology for women's uncompensated, time-consuming, and laborious tasks.

Our team intends to directly address the plight faced by women by developing a pedal-powered washing machine. Our target community for a proof-of-concept design is Chimaltenango, Guatemala. We have found a strong local partner in a non-governmental organization called MayaPedal who currently produces and sells pedal-powered machines, or bicimáquinas. They produce pedal-powered grain grinders, blenders, and cement-tile shakers from unusable bicycle parts donated by partner organizations in the US, such as Bikes-not-Bombs. MayaPedal has been successful at introducing these pedal-powered technologies to men and women in nearby rural communities as laborsaving devices and as means of generating income.

The success of MayaPedal's bicimáquinasis proof that pedal power is effective and applicable to their community. Women's cooperatives that use MayaPedal's blender to make and sell fruit drinks or aloe shampoos in the market have actually requested a pedal-powered washing machine that would allow them to spend more time on pro.table tasks and less time doing chores. An average woman may do two to three loads per week for a family of about . ve children and her husband. It generally takes at least 8 hours of washing time, not including the extra time needed to walk to the public washing reservoir or hang up clothes to dry. Additionally, while washing clothes

by hand, women spend hours leaning over a concrete basin. Clothes are washed by laboriously scrubbing each section of cloth over a cement washboard with their hands immersed in detergents that are harmful to the skin.

A pedal-powered washing machine would allow women to wash clothes faster and with less strain. When asked what they would do with their free time, women said that they would try to generate income by making crafts or food to sell. Young daughters who help their mothers with domestic chores may also have the opportunity to concentrate more on their studies. Laundromat micro-enterprises may even arise if our washing machines are successful. Conditions vary in developing countries, but women in many regions are washing clothes manually while they could be doing more pro.table or rewarding work elsewhere.

2 Problem Statement

Women in Guatemala wash clothes manually, but the detergents are chemically harmful to their hands, and the motion of scrubbing is straining to the muscles. Our goal is to design an inexpensive and durable pedal-powered washing machine for use in rural areas to gently wash clothes. Due to cost constraints, the washing machine is to be shared among several families or can be used by a local entrepreneur to run a laundering service. The washing machine must be easy to build and maintain locally with local materials, easy to operate (minimal required steps), and easy to power by women or children. It must also be more comfortable to use than manual methods and culturally acceptable in Guatemala.

3 Design Speci.cations

The most important aspect in the design of the machine is its ability to perform as a device that eases the task of washing clothes. In order to be a viable solution in rural Guatemala, the machine should be able to deliver the same quality of washing without adding excessive overheads (in terms of water use, clothing wear, effort required to operate, etc.). Thus the design and operation of the machine should be .rmly grounded in the physics of clothes washing, with a special emphasis on the mechanical aspects (since water temperature and detergent composition are likely to vary).

The group also identi.ed a number of secondary goals with varying degrees of importance that could help make the machine more useful and thus more successful. The ability to spin-dry clothes would increase water economy by requiring fewer wash cycles, and could relieve the strenuous task of manually wringing the clothes before they are hung to dry. If the layout of the machine allowed the user to perform manual work (hand-craft, food preparation, etc.) while pedaling, we could further reduce the amount of time consumed by washing.

A number of safety features should also to be included in order to mitigate the inherent safety issues involved in a chain-driven machine. If the machine was to be used in a home, insuring its portability of would allow it to be shared among families, transported close to a water source for operation, or used in households where space is limited.

Another set of speci.cations for load sizing, water usage and pricing, depend on the targeted

community. Since we are expecting the amount of laundry to vary between families, an initial size was selected based on existing washing machines, and designs allowing for easy re-sizing were preferred.

Design Specifications:

- **Cleaning**: Machine-washed clothes must be as clean as those hand-washed for 5 minutes [color]
- **Gentleness**: Must wear clothes at slower rate than hand-washing [hole/tear growth]
- **Capacity:** Minimum 5lb of clothes/load – should be easy to re-size.
- **Water**: Effective washing must occur in soft and hard water at temperatures from 70-120°F
- **Water usage**: Maximum 15L water / 1kg clothes
- **Active pedaling time for effective washing**: Maximum 20 minutes each for wash and rinse cycles
- **Total operation time**: Maximum 3 hours, including fetching water, .lling, washing, drain-ing, and cleaning machine
- **Power**: Maximum 100W (comfortable level of human-power output)
- **Cost**: Maximum $150 (comparable to cost of other MP machine)
- **Detergent cost**: Maximum $0.25 / load
- **Maintenance**: Maximum $25/year
- **Lifetime of structure**: 10 years, assuming daily use
- **Manufacturing capital cost**: $1500 (welder, metal cutter, shop tools)
- **Manufacturing location**: local (Maya Pedal)
- **Materials**: local (wood, weldable metals, oil drum, bike parts, etc.)
- **Dimensions**: [less than combined size of a bike and commercial washing machine]
- **Weight**: Maximum 30kg, or 45kg if it has wheels (1 woman can move it indoors so it cant be stolen or damaged).
- **Culturally acceptable**: Suitable appearance, user position and motion such that most Guatemalan women are willing to use the machine.

4 Design Alternatives

The team evaluated a number of mechanisms that could serve as the basis for the washing machine. Initial concepts were developed starting from the mechanical requirements of laundry washing, with inspiration drawn from existing and historical washing machines. Refer to the Appendix for diagrams of the design alternatives.

- **Vertical-Axis Agitator**: The usual washing machine found in American homes consists of two vertical-axis concentric tubs. The inner tub, which holds the clothes, has densely-spaced perforations which allow the water to run in and out easily. Soap an water are kept inside the outer tub during the was cycle. A central agitator alternating directions induces friction between the clothes to mechanically remove dirt and stains. For the spin cycle, water is emptied from the outer drum and the inner drum is spun to centrifugally extract water from the clothes.

- **Horizontal-Axis Tumbler**: Commonly used in European homes, this washer also uses two concentric tubs, however their revolution axis is horizontal. Instead of using an agitator, the horizontal washer utilizes .ns along the inner barrel that lift the clothes on the side of the drum, and let them fall back in the water on top of other clothes. Cycling the clothes through the water in this fashion eliminates the need for rapid changes in the direction of rotation of the agitator, which results in lower energy requirements. Since the drum is only .lled up to one third with water, the machine realizes a sizeable water economy.

- **Tilted-axis Tumbler**: A tub spinning at a inclined axis using a helical .n would perform the same kind of action, in a fashion similar to a cement mixer. The tilted design would allow for easier addition of water and clothes. No known commercial washers use this mechanism. Manufacturing of the helical .n proved to be problematic, and the other construction bene.ts we were hoping for in the tilted axis design did not end up materializing themselves. No conclusive cleaning experiments were performed using this design.

- **Crank-shaft piston**: Rather than using rotational motion to agitate the clothes, we were considering using a crack-shaft to convert the rotation of the pedals to vertical translation of a piston. There are several possibilities for the piston design. The clothes can be held in a container with holes that is plunged into and out of the water. The piston can also be a solid block pushing the clothes underneath it through the water. Two plates with holes could hold clothes between them as they plunge in and out of the water. We did not select this design because it seemed inef.cient to convert the rotation of the pedals into vertical motion since commercial washers operate on rotational motion already.

- **Pressurized Bubbler**: A rather new concept is pressurizing air and bubbling it forcefully through the clothes. This may lift the dirt off the clothes without requiring them to be scrubbed against one another. Heated water has also been shown to increase cleaning ef-.cienc y. Since this idea is not common in commercial washers, we thought it would be too risky to base our prototype on it without having a good understanding of the cleaning mechanism or how to implement it with cheap, available, easy-to-maintain components.

5 Final Design Choice/ Description of Prototype

Our .nal design resembles a commercially available horizontal axis washer. The inner drum which holds the clothes is currently constructed by modifying a plastic utility tub. Tubs like these are widely available in Guatemala, but could easily be substituted for other types of buckets, perforated sheet metal or mesh, depending on availability. The inner drum is perforated, so that spinning the drum will extract water from the garments. There are also three triangular .ns inside the inner drum that agitate the clothes during the wash cycle.

The main structure of the machine consists of a simple tube frame. The frame can be built by modifying an existing bicycle frame. The inner drum is mounted on one side of a pedal shaft. Rotational force turns the drum via a drive gear attached to the opposite side of the pedal shaft. A bicycle chain connects the gear at the drum to a set of pedals mounted on the Bicilavadora frame. The pedals are mounted close to the ground so that the operator can pedal the machine while seated in a regular chair.

There is an outer barrel that surrounds the inner drum and contains all the water. In our current design, the outer barrel is constructed using a common plastic oil drum. The operator loads and unloads clothing from the inner drum through a cutout on the side of the outer barrel. The operator drains the soapy water and rinse water by opening a drain value at the bottom of the barrel.

A convenient feature of the Bicilavadora is the optional table mounted above the structure. The operator can use her hands to do manual work like weaving while pedaling the machine. Women in Chimaltenango expressed interest in this particular feature.

5.1 Analysis

5.1.1 Gearing

The machine uses a regular mountain bicycle transmission which can provide gear ratios between 1:1 and 3.5:1. The user is expected to turn the pedals of the machine at about 60 rpm for the wash cycle, and a higher 80 rpm during the dry cycle, where the lack of resistance from water makes pedaling easier (continuous pedaling is not necessary in this case).

With a inner drum diameter of 19in, at a 1:1 gear ratio, pedaling at 60rpm results in a centripetal acceleration on the clothing of about 0.87 g, which results in ef.cient clothing tumbling. For the spin cycle, the user would switch to the highest available gear, and a pedal speed of 80 rpm results in an acceleration of 18.5 g. This has been shown to extract 50% of the water from wet cotton clothing (remaining water weight in clothing is approximately 90% of the dry fabric weight - comparable to commercial vertical axis washing machines).

5.1.2 Water usage

The diameter of the outer tub is 23 inches, and depth 22 inches. Our machine is not optimally ef.cient in terms of water use, since the plastic construction of the inner drum required larger clearance between the two tubs in order to prevent contact during the spin cycle. The front of the

outer drum also extends considerably past the front of the inner drum to provide easy access for clothes.

With approximately 1/3 of the capacity of the outer drum .lled with water, the machine requires about 10 gallons of water. Total water usage for one load of laundry adds up to approximately 20 gallons, half of which is used for the wash cycle, while the other half is used for the .rst rinse cycle. The water from the second rinse cycle, containing just soap, can be reused for washing the next laundry load. We expect that clever design would allow for sizeable reduction in the water requirement in the next prototype.

5.1.3 Cost

The majority of the cost of the initial prototype is found in the price of the outer barrel and bicycle parts. A metal or plastic 55gal barrel retails for $80-$100 new in the US. We are expecting however that almost all machines would be constructed from re-used barrels, such that the cost would not be prohibitive.

A new bicycle of suf.cient quality for the purpose of this machine can be bought for about $40 in Cambridge, MA, but the team found bicycles in Chimaltenango, Guatemala to be considerably more expensive. However, like other Maya Pedal machines, the Bicilavadora does not require sacri.cing a useful bicycle, and can be constructed from a bicycle which is no longer useful in a transportation role. The drive train, which is the main part of the bicycle used in our design, is usually much more resilient and remains functional after the frame, fork or wheels of the bicycle have exceeded their lifetime.

Taking all these factors into account, the maximum component price for the Bicilavadora is estimated to be around $160, but expected to be considerably less if the outer drum and bicycle parts can be acquired used. The manufacturing cost can has not been determined since an optimum assembling sequence has not been identi.ed.

5.2 Ease of Use

Our Bicilavadora will be easy to use by younger and older women. After loading the machine, washing requires three cycles. Between each cycle, the drum spins quickly to draw the water out of the clothing, as it drains out of the drum. In the .rst cycle, water and detergent are added to the drum. The operator pedals the machine for roughly 25 minutes, spins, and drains the water. The next two cycles are rinse cycles. In each rinse cycle, the operator pours clean water into the machine, pedals for 10 minutes, spins, drains the drum. After the last rinse cycle, the operator spins the clothes dry and saves the slightly soapy water for the next wash cycle.

Our research into existing washers and our earlier prototypes indicate that the power required for washing and spinning is relatively low. We demonstrated that it is not dif.cult to spin a perforated plastic drum up to extraction speeds with clothes inside. For these experiments, we used a geared transmission from a bicycle.

Both younger and older women can generate enough power for the wash and spin cycles. We estimate this power to be 50-75 watts. While familiarity with pedaling in general and the machine in particular will reduce the effort expended by the user, no prior experience will be necessary for

its operation. The ability to change gearing ratios will allow some level of tuning to individual users and also allow for shorter wash times with more power input or conversely less strenuous operation if the user can pedal for a longer amount of time.

5.3 Justification

- **Efficient** : It is much more ef.cient to wash clothes using the Bicilavadora than to use the manual washing tanks. The Bicilavadora washes and dries many clothes concurrently whereas each item must be washed individually in the wash tank.

  The Bicilavadora also requires less energy when compared to vertical axis washing machines. The horizontal axis of rotation in the Bicilavadora uses less power because it rotates continuously without changing directions. The operator does not need to combat the momentum and drag forces of a barrel full of water.

  The Bicilavadora is also more comfortable to use than the washing tanks. The operator does not need to lean over the washing tank and submerge her hands in the soapy water. Instead, the operator sits on the Bicilavadora's seat and pedals most of the time. She only needs get up to load the machine, change the water and unload the machine. This leaves her hands free to work on making crafts and keeps them out of the harmful detergent.

- **Affordable**: The target buyer for our Bicilavadora is an entire community in contrast to a single family. A natural location to install a Bicilavadora is at the public washing stations. The women already use the washing stations and they will be able to share the washing machine among the entire community (See Appendix). With a common washing machine, an individual family will not need spend a large sum of money for a home washing machine. Those who would not normally be able to afford such a device would be able to use one for free or for a small fee.

  A Bicilavadora is also inexpensive to operate because the user does not need to pay for power. This is especially important in places like Chimaltenango, where electricity is extremely expensive.

  MayaPedal receives its bicycle parts as donations, we have minimized the use of other materials like angle iron and wood to reduce the cost to the end customer.

- **Easy to Build and Maintain**: Unlike any of the other alternatives, the Bicilavadora uses locally available materials or recycled bicycle parts. It can be produced in any area that has prevalent bicycle technology and things like plastic buckets. Since the parts are widely available, the Bicilavadora can serve as a basis for local entrepreneurs to start micro-enterprises which would stimulate the local economy.

  Another advantage of using locally available parts is that the Bicilavadora is easy to repair. It is mechanically simple enough that any bicycle repair shop would be able to service the pedal-drive.

6 Critique of Prototype

- **Inner Barrel Instability**: The inner barrel was cantilevered from a rotating shaft supported in a bicycle bottom bracket. Since the plastic was so .e xible, the inner barrel distorts quite a bit during rotation and needs a large clearance within the outer barrel to avoid collisions. Frequent use would probably lead to fatigue failure of the bucket, shaft, or bearing.

- **Vibration**: Our structure of our initial prototype was made primarily out of wooden planks bolted to each other and the frame because we wanted it to be easy to disassemble for design changes, and light for portability. However, using removable fasteners increases the assembly time and leaves possibilities for tampering since the machine is used in public spaces. Also having a light-weight structural frame makes it dif.cult to prevent vibrations during the spin-dry cycle when clothes may gain a centripetal acceleration of up to 20G. We had been putting removable 50lb weights on the structure to allow it to remain portable, but the .nal design should have the weight incorporated into its structure so it will not be misused.

7 Next Step

7.1 Next Generation Prototype

- **Double Supported Inner Barrel**: The inner barrel will be supported at both ends .x ed to a rotating shaft. Since the .rst prototype had one open end to allow for side-loading, alternative loading mechanisms must be designed. One option is to have a trap door in both the inner and outer barrels. Another is to make one of the support for the inner barrel movable so that the inner barrel can still be opened and accessed from the side.

- **Welded steel structure**: To reduce the assembly time and prevent others from tampering with it in public areas, the structure will be made out of welded angle iron. Welding .xtures may be designed to make it easier to weld several structures with proper alignment of components. The welded structure will add to the weight of the machine, making it inherently less likely to vibrate. The steel structure may also be cemented into the ground to ensure stability and security of the machine from theft.

- **Different Materials for Outer Barrel** We are considering using a steel oil drum so it can be welded directly to the structure. Welded attachment points would not require any bolt holes that need to be sealed. The oil drum may also be shortened by cutting off the end, and welding on a steel lid. Steel would also be more rigid than the plastic drum we used for the initial prototype, so it would be easier to align the barrels and avoid collisions during rotation.

  We are also considering using a cement basin that has the structure incorporated into it. This would make the machine much easier to manufacture because most of the machine would be a single intact piece.

- **Steering Column or Industrial Bearings**: Since MayaPedal does not currently have a use for the steering columns they receive, it would nice to incorporate it into the washing machine design so the component would not go to waste.

  Industrial bearings are also available in Guatemala. If we .nd that bicycle bearings are not suitable to support the load, we may use industrial bearings with greater tolerances and load capacities.

- **Extend Barrels Axially**: We are assuming that extending the barrel axially will not greatly increase the effort that must be exerted to rotate the barrel. Having longer barrels would increase the capacity of the machine and the amount of clothes that may be washed at one time. There are possibilities for dividing the outer barrel so that there are two compartments, which would allow for washing to occur on one side and rinsing to occur on the other with the same shaft rotating two separate inner barrels.

- **Faucet Drain Spout**: To maximize the ease of use, we will use a faucet spout rather than a rubber stopper so the out.o w of water can be better controlled. Leakage may be less of a concern if there was a .x ed spout rather than a removable stopper which could be easily lost or may not .t properly after repeated use.

8 Implementation Plan & Timeline

Going forward, we must complete our .rst prototype of the Bicilavadora and work out the technical challenges. After we have a working prototype, we intend to travel to Chimaltenango and build a prototype with the locally available parts. With this second prototype, we will run a small trial period with one of the local women's groups. We will collect their feedback and revise our design. We will then run a larger scale trial period and place a Bicilavadora at the public washing station. Depending on the feedback from this trial period, we may need to revise the design again.

To transfer the technology to MayaPedal, we will write a production manual that contains fabrication techniques and an operating manual. MayaPedal will be able to continue constructing Bicilavadora for their home community after we depart. For a detailed account of our time-line, see Table 1.

If our work with MayaPedal is successful, we will try to distribute the Bicilavadora pedal powered technology to other places in Central America and Africa where other groups have expressed a strong interest in pedal-power technology. To ensure that these sites have the infrastructure to produce bicimáquinas, we will implement the training program and distribute the production manuals through Bikes Not Bombs, a Boston-based organization that donates used bicycles to developing nations.

8.1 Challenges

One of the main challenges we face in introducing the pedal-powered washing machine is cost. The machine must be inexpensive and easy to build if it will be adopted into the community. We

Date	Stage Completed
	Initial Prototype
5-27-05	Complete First Prototype
6-03-05	Write documentation for .rst prototype
	First Trial
6-09-05	Depart for Guatemala
6-17-05	Build second prototype using local parts
6-20-05	Install prototype in women's cooperative
7-01-05	Get feedback during .rst trial
7-04-05	Find incompatibilities
7-04-05	Revise Design
	Second Trial
7-08-05	Build three new prototypes
7-08-05	Hire an instructor from .rst trial to demonstrate washer at washing station
7-10-05	Install prototype in public washing station
7-12-05	Install prototypes in more cooperatives
7-29-05	Get feedback during second trial
8-01-05	Revise Design
	Technology Transfer
8-05-05	Write a fabrication manual
8-07-05	Write a user manual
8-11-05	Teach a technician to build the Bicilavadora

Table 1: Time table for Bicilavadora trials. Dates are deadlines.

recognized this need and designed the machine from the start with low cost in mind. The machine will only contain parts that are readily available in Guatemala. This eliminates the need to order or import components just for the washing machine. The machine also uses bicycle parts for all the precision parts. These parts are very inexpensive because MayaPedal has a surplus of unused bicycle parts.

Another challenge we may face is acceptance into the community. The pedal-powered washing machine is quite different from the community's current method of washing clothes; the community may be reluctant to try the new machine. To help encourage the adoption of the washing machine, we will run multiple trials with local women so we can adjust the design to meet their needs. We will run the trial periods with groups like the women's cooperative who are already familiar with pedal powered machines; they have already proved they are willing to try new technologies. If women in the cooperative accept and use the machines, then they will serve as spokes-people for the new machine in their local community. Their support will greatly increase the credibility of the machine so that local people will be willing to try it.

Image removed for copyright reasons.
Guatemalan women washing clothes, by Miguel Cruz.
Source: http://travel.u.nu/photo-gt_15.php

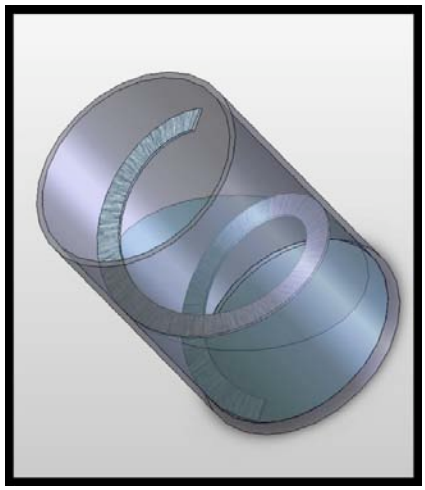

Fig. 2. Tilted-axis washer.

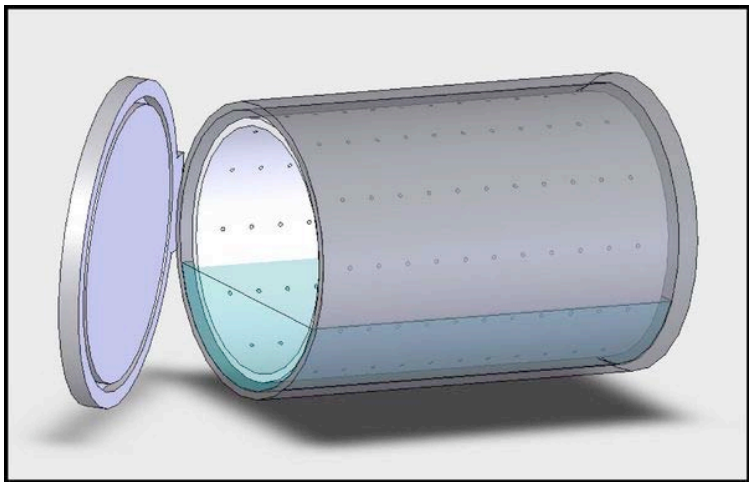

Fig. 3. Horizontal-axis washer.

Fig. 4. Bubbler.

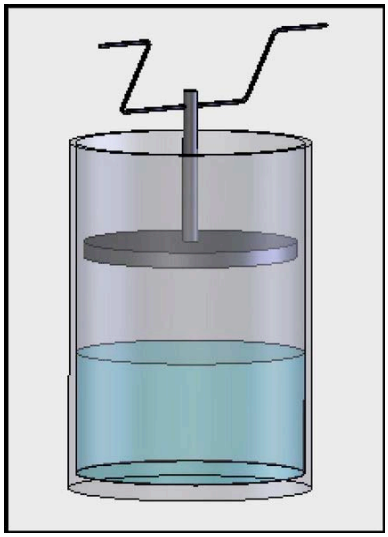

Fig. 5. Crank-shaft piston.

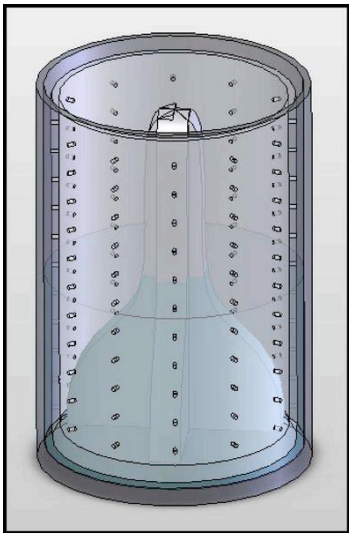

Fig. 6. Vertical-axis washer.

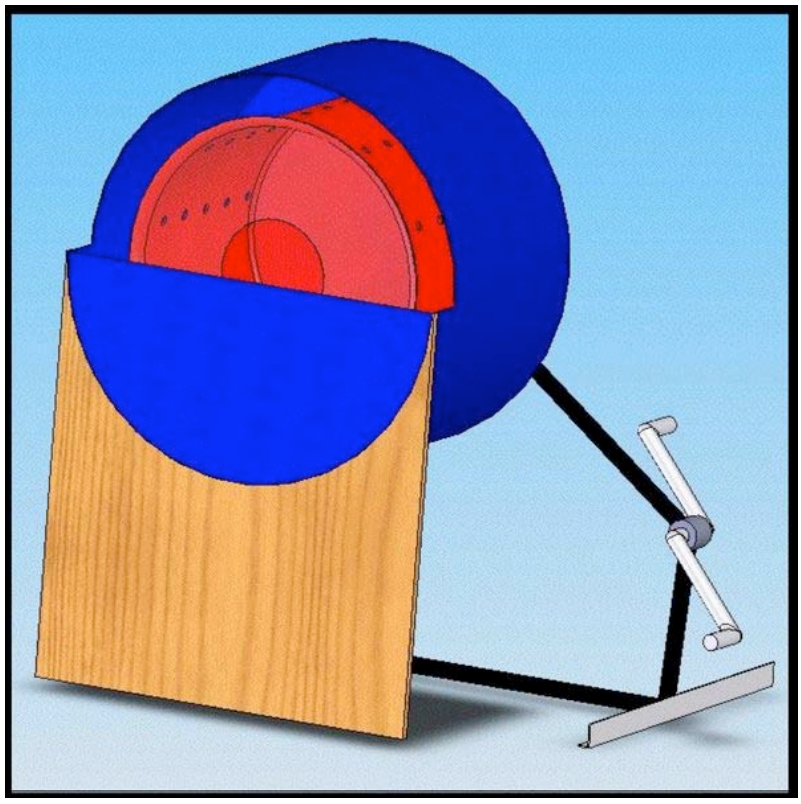

Fig. 7. CAD model of prototype.

Fig. 8. Front view of prototype.

Fig. 9. Side view of prototype.

Fig. 10. Back view of prototype.