PicoTurbine 250 Plans
Part 1: Blade Design

Instructions and Technical Notes

An easy to build and inexpensive Savonius blade design for use with the PicoTurbine 250 alternator.

BETA

This is an unproven design meant for experimentation only. This plan is intended for adults.

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CONTENTS

PART 1: Building Instructions

INTRODUCTION

The PicoTurbine-250 project is an ambitious research effort, with the goal of creating a set of plans for a 250 watt wind turbine that can be built for $1 per watt or less by a person of average mechanical skills in one to two days. These plans are for the blade design of the PicoTurbine-250 project. Two other documents will be a part of this set: Part 2 will give the alternator design, and Part 3 will present the design for a load controller that maintains optimal rotor loading.

The reason for this separation of plan documentation is that one could theoretically use a different blade design with the same alternator, or vice versa one could use a different alternator or generator with this blade design. For example, one could potentially use a surplus DC motor (used as a generator in this case) with this blade design, or one could design a Darrius style blade for the PicoTurbine-250 alternator. Please note, however, that precise matching must normally be ensured between blade specifications and alternator specifications.

Design Patent Information

This blade profile is loosely based on a profile documented in US Patent 5494407 by the inventor Alvin H. Benesh. There are differences between this profile and the one documented by Benesh. It is unclear whether this blade design infringes on Mr. Benesh's design. US patent law allows you to build a patented design for your own testing purposes, but you may not sell the resulting machine for commercial profit. For this reason, PicoTurbine.com only furnishes plans for the blade design, we do not furnish any finished parts, you must make them yourself and you must not sell them to others. If you wish to produce a commercial product based on this design, you must contact Mr. Benesh and negotiate appropriate license fees with him to do so. For his address, go to http://www.patents.ibm.com and search for the patent number above. Alternatively, you could modify the blade profile so that it implements a design that is not covered by any active patent. There are several expired patents for Savonius blade designs which are quite serviceable.

Modular Design

The design allows you to build blades in 4 foot [1.2m] tall segments. Multiple segments may be attached together to attain a larger swept area. The PicoTurbine-250 alternator will require 2 segments, resulting in a blade 8 feet [2.4 meters] tall and 2 feet [600mm] wide, with a corresponding swept area of 16 square feet (1.47 square meters).

You could decide to build more or fewer segments to suit the needs of generators other than the PicoTurbine-250 alternator, however there are practical considerations as the number of segments increase. See Part 2: Technical Notes for details.

CONSTRUCTION TIME

You should allow approximately 1 hour to build each segment, with some additional time to assemble all the segments into a single rotor. For assembly of four segments, allow approximately 1 hour. Thus, to build the entire blade set for a PicoTurbine-250, allow approximately 5 hours. Your actual building time may be more or less than this depending on how good your tools and skills are. For example, having built many test models, we can now build one segment in approximately 30 minutes. There is also some savings when building multiple segments in one sitting. For example, once you cut out one blade support you can use it to easily mark the wood for all the supports you need and cut them out at one time, the same goes for drilling holes and other tasks that must be repeated for each segment. This saves you time switching between tools, changing drill bits, etc.

BEFORE YOU BUILD THE BLADES

Step 1: Check Your Materials

The following materials are needed to build the PicoTurbine 250 blade set:

- An 8-foot by 4-foot piece of corrugated plastic cut into 8 sections two feet square. Corrugated plastic can be obtained from plastics supply houses or sometimes from sign supply or sign making companies. We use 2mm thick plastic, but that is usually hard to find. The most common is 4mm which will also work.
- An 8-foot long piece of pressure treated 4x1 wood, cut into 2 foot lengths.
- 24 angle brackets approximately 2 inches long (each side is 2 inches) and ¾ inch wide.
- A 10-foot section of 1.5 inch diameter PVC pipe. This must be cut into two sections each four feet long (there will be a couple of feet left over).
- A 10-foot piece of 1 inch diameter galvanized water pipe. This is available at any large hardware store or plumbing supply store.
- A 4-foot section of 1 inch black pipe and a floor stand (sometimes called a flange) for 1 inch pipe, and a "T" connector for a 1 inch pipe.
- Eight pipe clamps, 2 inches in diameter. These are metal strips with a screw that allows them to be tightened around a pipe.
- Approximately 100 screws. They should be about ¾ inch long and should have a rather large pan head. Number 8 screws are ideal.
- Approximately 100 washers of a size that fits the screws above.
- Four ¼ inch diameter bolts, 2 inches long.
- Approximately 10 inches of teflon tape, ½ inch in width or more. This item is optional if you have trouble finding it. We bought ours from Grainger (www.grainger.com).
- Approximately 25 feet of 3/8 inch plastic coated steel cable.
- A pulley rated at 100 pounds for a 3/8 inch cable.
- Four wire rope clamps.

The following tools are needed:

- An electric hand drill with a 2 inch wood cutting bore. Also, a ¼ inch metal cutting bit (such as a cobalt bit), and a 1/8 inch bit for drilling pilot holes in wood.
- A jigsaw, saber saw, coping saw, or some other saw capable of cutting curves in wood.
- A screw driver or screw driver attachment for the drill.

Step 2: IMPORTANT: Review Safety Rules

The PicoTurbine-250 blade set is not a dangerous project to build, but as with any construction project certain safety rules must be followed. Most of these rules are just plain common sense.

- **This project is experimental in nature. There may be unknown risks associated with building this project, this list of risks does not purport to be complete. This project is intended only for adults who are willing to experiment.**

- **The tree-mount described in this project is undesirable from a number of standpoints. The tree may suffer damage or be killed, so do not mount this project on any tree you are not willing to put at risk. Be certain to have a good footing and use a stable ladder when attaching parts. Pole mounting is preferred.**

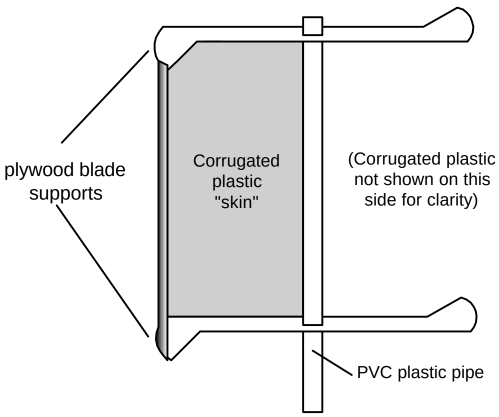
- **The pole mount described in this document is experimental in nature and has not undergone extensive testing. Construct it according to the rule: "build it so it can never fall down, and place it expecting that it absolutely will fall down." Place this structure in an area where it will not damage property if it falls, and away from areas frequented by people or animals. If you are unsure of whether you are building the structure securely enough, consult a local engineer.**

- ♦ **Follow all manufacturer safety guidelines when working with power tools or other tools. Appropriate eye protection and footwear should be used. Avoid loose jewelry. If any recommendations in this document conflict with manufacturer recommendations, follow the manufacturer recommendations instead.**

BUILDING THE BLADES

BUILDING A BLADE SEGMENT

A blade segment consists of a piece of 1.5” PVC pipe with two wooden blade supports which support a corrugated plastic “skin”. See the diagram below.



Step 1: Building the Blade Supports

Cut out the three templates given at the end of this document. Tape them together such that sides marked “A” match up, and sides marked “B” match up as shown in the final page of templates.

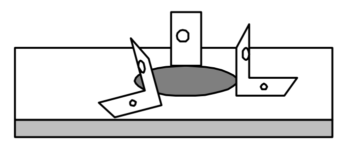
Using the template you taped together, mark a piece of 3/4” plywood. Cut out the shape using a coping saw, scroll saw, jig saw, or other saw capable of cutting curves in wood.

Drill a hole 2 inches in diameter in the center of the blade support. Repeat this process to construct a total of 4 identical blade supports.

Step 2: Attaching Blade Supports to PVC Pipe

On each blade support, attach three angle brackets as shown in the diagram. Use ¾” wood screws.

Now, place a pipe clamp over the 3 angle brackets, and slip the whole assembly onto the PVC pipe. Tighten the screw on the pipe clamp. Attach the four supports so that there is precisely 2 feet between the outer edges of each pair of two supports.



Step 3: Attaching the Plastic “Skin”

Take a piece of 2 foot square corrugated plastic. Going with the “grain” of the corrugations, make a 1” wide bend along the length of the plastic. A yardstick or other piece of wood will help you make a straight bend. Make additional such bends at 1” intervals for approximately a six inch area.

If you are using 4mm thick corrugated plastic (which is much more commonly available than the 2mm we use) then you may need to score through one side of the plastic. To do this, place a piece of wood to be used as a guide down the length of the plastic (in the same direction as the corrugations), and score through only the top surface of the plastic, do not score all the way through. This will allow you to easily negotiate the curved blade, but will result in some loss of strength of the material.

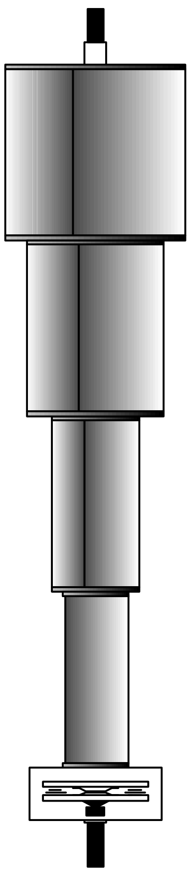
Starting at the tip of the curved portion of the blade, drill 1/8” pilot holes in the plywood blade supports. Space these pilot holes about 2” apart. Do this on each side of the supports, as indicated in the figure below.

Starting again at the tip of the curved portion of the blade support, attach the corrugated plastic using a screw and washer. The washer is needed to help distribute the pressure over a wider area of plastic helping to avoid breakage. It is best to put first one screw on the top support, then one screw on the bottom support. Adjust the spacing between the blade supports if necessary using the pipe clamps. Continue until the plastic is secured along the length of both blade supports, then repeat for the other side of the blade. Finally, repeat this entire process for the lower pair of blade supports.

MOUNTING SEGMENTS

One or more segments may be mounted on a 1” (inner diameter) pipe. Simply place the PVC pipe of each segment over the 1” pipe. Make sure that each segment is oriented the same way, i.e. so that they will all spin in the same direction. Segments may be attached to each other simply by using screws through an adjacent pair of blade supports. Drill pilot holes to make it easier.

In order to smooth out torque and enhance startup from any wind direction, it is desirable to offset each segment as shown in the figure below. In fact, it is desirable to offset each section of a single segment. Our preferred spacing would be a 30 degree angle between each subsection, making the bottom-most subsection a right-angle with respect to the top-most subsection.



If you have access to Teflon tape, it is desirable to clean the outer surface of the 1” pipe and apply several rings of tape. The tape should be oriented such that the rotation of the blades will tend to wrap it tighter rather than to rub against the outer edge of the tape and cause it to unwrap. Several rings of tape should be placed near the top and the bottom sections of PVC pipe, where the most friction occurs.

After applying the tape, if any, you should thoroughly oil or grease the 1” pipe. This results in quite low friction between the PVC and the pipe, whether or not you are using the Teflon tape.

The bottom bearing, on which the weight of the blade set rests, will be the PicoTurbine-250 alternator. If you wish to test out the blades before constructing the alternator, you may use a piece of metal or large washer, greased, to rest the bottom of the PVC pipe upon. Although this will have significant friction compared to the ball bearings of the alternator, we have done weather testing in this way and have found the blades will turn quite nicely with this simple bearing except in the lowest of winds. If you have a ball bearing of the proper size, or could make it the proper size using wooden inserts, this would make for a better bearing for weather testing.

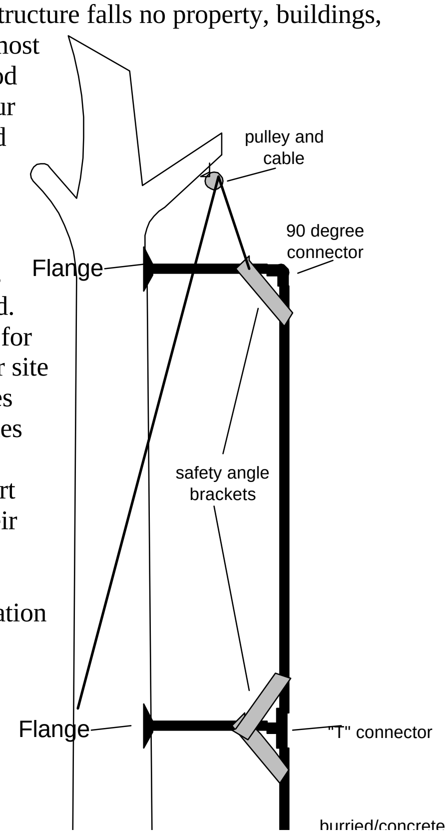
MOUNTING THE BLADES OUTDOORS

There are several different ways to suspend the pole. The ideas presented here are to be considered only suggestions, none of them has sufficient testing to insure they are safe and effective. Always follow the adage: “mount your wind turbine in a way that it cannot possible fall; and place the turbine expecting that it absolutely will fall.” Be sure that a setting is selected that is clear from areas that people or livestock regularly traverse, and that if the structure falls no property, buildings, electric wires, etc., will be damaged. Mounting is probably the most dangerous part of wind turbine deployment. Be sure to use a good sturdy ladder with good footings on the ground. Always plot your moves carefully to avoid falling. Never attempt this in high wind conditions or during bad weather. Use common sense.

Tree Mount

For our initial testing we used tree mounts. We should point out that tree mounts have many disadvantages, among which is the possible death of the tree involved. In our case the convenience of this type of mount outweighed the disadvantages for initial testing, however we are testing out pole mounts for actual production. Our site has many 40 foot tall oak trees, which make reasonably good mounts. These trees are about 1 foot wide at the base of the trunk and so are quite sturdy. The branches on oak trees start quite high, about 20 feet, making for a clear section that makes mounting easy. Other types of tree will not work as well due to branches that start lower. Evergreen trees such as spruce would be completely unsuitable due to their shape.

The figure below shows how we use a tree mount for testing. A simple configuration using standard pipe parts is easily constructed. To prevent the pipe parts from



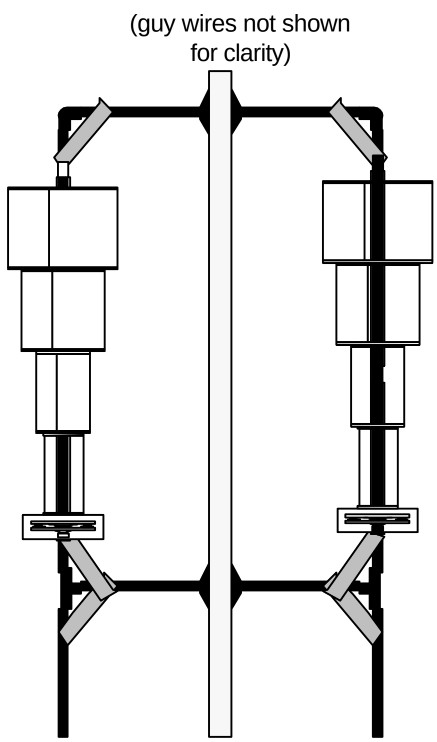
unscrewing themselves (a problem we had with early prototypes), we drill a ¼” hole near the connectors on the pipes and use bolts to affix a small section of angle iron. To hoist up the pipe and provide added safety, we used plastic coated steel cable and a pulley. We leave the steel cable and pulley attached to the tree for easy lowering if ever necessary, and for added safety in case the mountings come loose. The bottom of the steel cable is attached to nails driven in the trunk near the base.

We secured the top section of pipe first by nailing the pipe flange to the tree and screwing in the four foot section and 90 degree angle fitting, securing with the angle iron discussed above. The blade section can then be inserted from the bottom, along with any washer or steel disk used as a temporary bearing. Then, the “T” connector is attached and a second four foot section is affixed to the tree, along with another safety bracket made from angle iron. If desired, another section of pipe can be placed on the lower section of the “T” and buried in the ground. A permanent footing of concrete would be suggested for a permanent installation. In our temporary testing stations we often just use several cinder blocks or large rocks to stabilize the bottom pole, but that would not be desirable for a permanent installation.

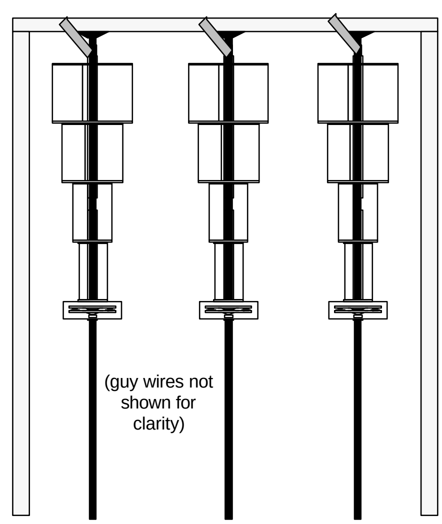
Sometimes the pole will not be straight as mounted above because the tree trunk narrows or curves slightly as it gets higher. We have found that there is little measurable effect on performance if the pole is not perfectly straight. As long as the top is within a few inches of vertical when compared to the bottom it should be ok. You could use longer or shorter sections of pipe for the upper or lower supports to adjust if necessary, or build out the top or bottom flange from the tree by placing a piece of wood board between the flange and the tree.

Pole Mount

A pole can be used in place of a tree for a much more desirable mounting structure. We are experimenting with 4x4 inch poles 14 feet long. Such poles must be sunk several feet into the ground and guyed with wire. It would be possible to put 2 turbines on a single pole as shown in the figure below, as long as you are in an area with a “prevailing wind” this will not hurt performance significantly. Position the two turbines such that they do not block each other during a typical “prevailing wind”.



Another type of multi-turbine installation that could take advantage of a prevailing wind direction would be a line of turbines supported by a horizontal wooden beam. This beam could either be suspended by other beams or pipe poles in concrete footings, or could be suspended from two trees (if you are willing to risk losing two trees). In this case the flanges could be connected directly to the mail axle pipe without the cross-bar piece. The angle bracket to prevent unscrewing of the flange would be connected from the axle pipe to the top beam in this case. Once again, guy wires would be needed to ensure stability in high winds.



In most cases, it is possible to do maintenance near the ground. This is because the alternator is at the bottom already, so all electrical connections and the most complex part of the turbine are already near the ground. If the blades ever need to be taken down, it is possible to simply disconnect the lower safety angle brackets, unscrew the lower horizontal support pipe from the flange, unscrew the “T” connector, remove the bolts holding the alternator stator to the pole, and then simply lower the whole structure down from the pipe. There is rarely a need to go back up a ladder because of this ability to remove the turbine from ground level. The only regular maintenance that would require a ladder would be to grease the entire pipe, and even that could often be done simply by using a oil rag on a pole.

PART 2: Technical Notes

INTRODUCTION

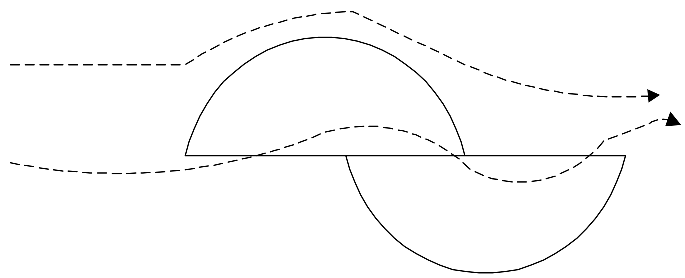
This section explains some technical points about the blade design described, and discusses some possible modifications and other auxiliary material.

SAVONIUS BLADE THEORY

The Savonius blade design was invented by S. I. Savonius in the 1920s. The idea behind the blade design is twofold:

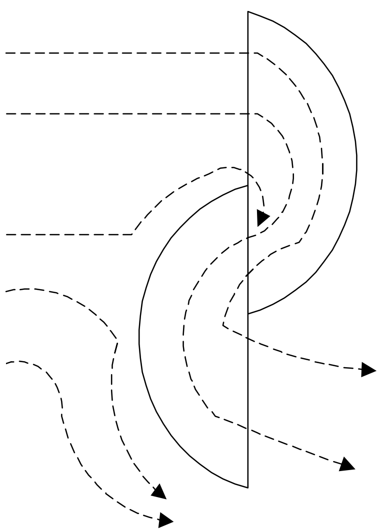
1. Produce torque by both lift and drag by using a semi-airfoil shape,
2. Allow air to flow through a cavity connecting the two blade halves, resulting in decreased turbulence and friction.

The traditional Savonius design, called the "split barrel", can literally be made by cutting a 55 gallon drum in half. From the top it looks like this:



With the wind coming from the left side of the page, this shape assumes a simple air foil-like configuration, causing some lift to aid the rotation of the turbine. It is also this effect that allows the turbine to start up even if it has this profile from a dead stop. However, torque is minimal in this position relative to the wind.

When the blades are oriented 90 degrees from this position, the blade profile acts in a purely "drag" fashion as shown here. The open cup at the top makes the blade spin clockwise. There is drag opposing this movement from the back of the lower cup, but because of the shape there is a net torque clockwise. The fact that the two cups are connected by an open area in the center allows the air to pass through and reduces turbulence, which robs any wind rotor of power.



Barrel Savonius Efficiency

The degree to which the two cups are offset from each other can be varied, both horizontally and vertically. In 1974 , Sandia National Laboratories (www.sandia.gov) published an extensive study of this shaped rotor called *Wind Tunnel Performance Data for Two- and Three-Bucket Savonius Rotors* (you can search for this document on their web site, search for the terms "Savonius" and "bucket"). They found that an optimally loaded Savonius rotor was about 24 percent efficient, and this optimal loading happened when the rotor tip speed ratio (TSR) was approximately 0.80. In other words, the very end of the rotor must be travelling at about 80 percent of the wind speed to achieve this maximum efficiency. At tip speeds both above and below this speed, the rotor performs more poorly.

By way of comparison, modern horizontal axis wind turbine blades typically have an efficiency (Cp is the technical nomenclature) of approximately 30 to 40 percent. The maximum possible efficiency, derived by the fluid dynamics scientist A. Betz and known as the *Betz Limit*, is about 59 percent. It is physically impossible for any wind capturing device to exceed this limit of efficiency.

Benesh Profile Savonius Blade

Many patents have sought to improve on the barrel design. If you search at www.patents.ibm.com for the term "Savonius" you will find many. In 1996 Alvin Benesh patented his design for a Savonius rotor (US Patent number 5494407). Although he does not say so in the patent, this design obviously seeks to improve the lift part of the Savonius blade by making the shape closer to a true air foil. Another advantage of this design, which is mentioned in the patent, is that the long, flat area of the blade is very easy to construct from low cost materials. Benesh claimed that his tests showed this blade profile has a Cp of 0.37, which compares well with some of the best horizontal blade designs. We do not know of any independent confirmation that the Benesh blade profile actually can achieve a Cp of 0.37, and frankly we have our doubts based on theoretical grounds. Our own tests are not yet complete, and will in any case not be definitive since we lack funding for the sophisticated equipment required to perform a conclusive test. However, we do feel, based on preliminary results, that the Benesh blade profile achieves a Cp somewhat better than that reported for simple barrel style blades. Our current estimate is 0.28 when optimally loaded.

Aspect Ratio and Alternator Considerations

Another result of the Sandia Labs tests was that for a Savonius to be practical, it must have a high *aspect ratio*. In layman's terms, it should be tall and skinny instead of short and fat. In the PicoTurbine-250 project we use a 4 to 1 aspect ratio, since the blade structure is 8 feet tall and 2 feet wide. The reason you need a high aspect ratio has to do with the tip speed of the Savonius rotor. Recall that the tip speed will be somewhat less than the speed of the wind, about 80 percent. So, in a 10 meter/second wind (about 22 MPH) the PicoTurbine-250 blade will be turning, under load, at about 300 RPM. If we had made the blades twice as wide, it would only be turning at 150 RPM at the same wind speed. Note that the power available would be the same, just the ratio of rotational speed to torque would be different (power is torque times rotational speed). However, in order to extract that power, we must use an alternator, and the alternator cares very much what the rotational speed is. Doubling the speed of an alternator increases the power output by a factor of four for the same material costs. We can make an alternator that produces an arbitrary amount of power at any speed, but it will cost more (require more magnets, more coils) at a lower RPM.

You might ask, "why not increase the aspect ratio still further to take advantage of this effect?" Well, we cannot play this game forever! The skinnier you make the blade, the taller you must also make them to derive the same amount of power. At some point, it becomes impractical to keep making the blades taller and taller. Also, at some point the blades are so skinny that there is not enough torque for the rotor to overcome startup friction and inertia.

We feel we have chosen a good compromise in the PicoTurbine-250 design. The two foot wide blade also has the advantage that the plastic covering turns out to be an even divisor of the most commonly available size for corrugated plastic sheets, and the entire blade structure requires exactly one such sheet (4 feet by 8 feet).

ALTERNATIVE CONSTRUCTION IDEAS

We chose these materials after months of investigation, in which we tried many different materials. But, there are always choices to be made, and we will discuss some of them here.

Corrugated Plastic Characteristics

The best characteristics of the corrugated plastic material we decided on are:

- Low cost, a 4x8 foot sheet only costs about $15.
- Lightweight, a whole sheet only weighs a few pounds.
- Safe, no sharp edges.
- Easy to work with. Can be cut with ordinary razor blade.
- High strength. This material is actually used to make packing containers that hold hundreds of pounds of materials.
- Very quiet. Even in high winds this material gives off almost no sound that can be heard beyond a few dozen paces.
- Easy to obtain. This material is widely used for signs and can be found world wide in sign stores or plastics supply companies.
- Recyclable, at the end of its operating life the material can be recycled.

The only drawback we are aware of is that the material is not UV tolerant. According to the manufacturer, when used as a sign material it will start to degrade in two to three years. We have been weather testing pieces of plastic for about five months now, and we have seen no deterioration yet. However, we have not had extreme cold temperatures of winter yet, so only time will answer the question of how long it will last in a windmill application.

Also, we would like to point out that just because the material does not last more than 3 years in a signage application does not necessarily rule out that it will last longer in our application. While the material will be under much more stress when used as a wind turbine blade material, the judgement of whether it is still usable is quite different from a plastic outdoor sign! In fact, the manufacturer may have meant that color fading and minor imperfections would start to occur in two to three years. In a wind turbine application such considerations are not important. The only important thing is whether it holds together. We believe some patching could be done to extend the life the material as well. A little duct tape might repair minor defects that arise over the years and extend the life significantly.

In any case, we do not feel a $15 replacement cost once every few years is a major problem. Using an electric screw driver, the blade coverings could be replaced in about one hour. This would be quite within a normal maintenance requirement of most commercial wind turbines in terms of both time and money.

Other Possible Blade Coverings

Other possible blade coverings include:

- Sheet metal. We rejected aluminum flashing material after testing it last winter. It was found to be very noisy in high winds. It also suffered from small fatigue cracks after only a few months, and we feel it would be quite shredded in a year or two. It is also rather sharp and presents cutting hazards. It is possible that a heavier grade of aluminum sheet metal would work properly, but it would be unlikely to be as lightweight and easy to work with as the corrugated plastic.
- Sail cloth. We rejected these materials based on price. There are many different grades and types, but all the ones we looked at were between five to twenty times more expensive than the plastic. We never tried to see how they worked, however, and sail cloth might be fine to use if you have a source of used or surplus material.
- Tyvek. This material is used to wrap houses and even to make lab coats. We tried it, and it shredded to pieces in the first 40 MPH wind storm. A heavier grade might work better, though. It was also rather noisy, sounding like large sheets of paper being rattled. We did not pursue investigating other grades of the material.
- Other sheet plastics. There are more grades and types of sheet plastic than we can mention here. It is quite possible that a much better material is out there. In terms of price and availability, though, the corrugated plastic is hard to beat. Every other plastic material we looked at was more expensive for the same strength and size characteristics, or would be very hard for people to find locally.
- Fiberglass. This was both more expensive, and also heavier, than the plastic material. But if you care to make things using fiberglass it would probably make a very nice blade set. It is commonly used for horizontal axis wind turbine blades. It would probably last more or less forever at the slow speeds of a Savonius.

HIGH WIND AREA MODIFICATIONS

We are testing our designs in Northern New Jersey, USA. We are in a class 3 wind zone, rather average. If you are in a much windier place, such as a class 4 or 5 wind zone, you might consider beefing up the blades to handle the larger amount of wind. Here are some ideas we have had, but have not tested. We would enjoy hearing other ideas, or hearing whether these ideas were useful.

It is important to note that these reinforcement ideas add expense to the wind turbine, and also add weight and extra inertia that detracts from startup. If you are in a high wind area then neither of these caveats are of much concern—if you have a lot of wind you need a stronger machine, and the added cost is made up by the fact that you will be getting a greater amount of energy out of the machine. In a high wind area the extra inertia of a heavier blades is also not as much of a concern, since presumably there is plenty of wind on most days for start up purposes.

Reinforced Plastic Edge

The place where the plastic meets the wood, held in place by screws, is under a good deal of stress in high winds. It is possible that over time the screws will eventually pull through the plastic. This top edge could be reinforced by placing a three-quarter inch strip of metal along the length of the plastic, and punching holes in this metal for the screws to be inserted through. Such strips can be found in hardware stores, they are used in plumbing for hanging pipes in basements, and already have holes in them in some cases. They are often made from copper which will not rust. This strip would help distribute the pressure from the screws along a wider area and would also offer some weather protection and UV protection to this crucial area of the plastic covering.

Another area of concern at the wood/plastic interface is that the screws will pull out of the plywood. If a good grade of plywood is used and pilot holes are drilled for each screw the hold should be good. But, over time as the wood wears out the screws may start to pull through. Small angle brackets could be placed once every few screws to combat this. The angle brackets could be screwed in both on the edge where the plastic is, and also on the top of the blade support, through the plywood rather than edgewise. This would be most important at the curved area of plastic, and less so on the flat area that is under less stress. So, you could put several brackets on the curved portion, then space them out more along the flat section, perhaps only having two or three along the entire flat area.

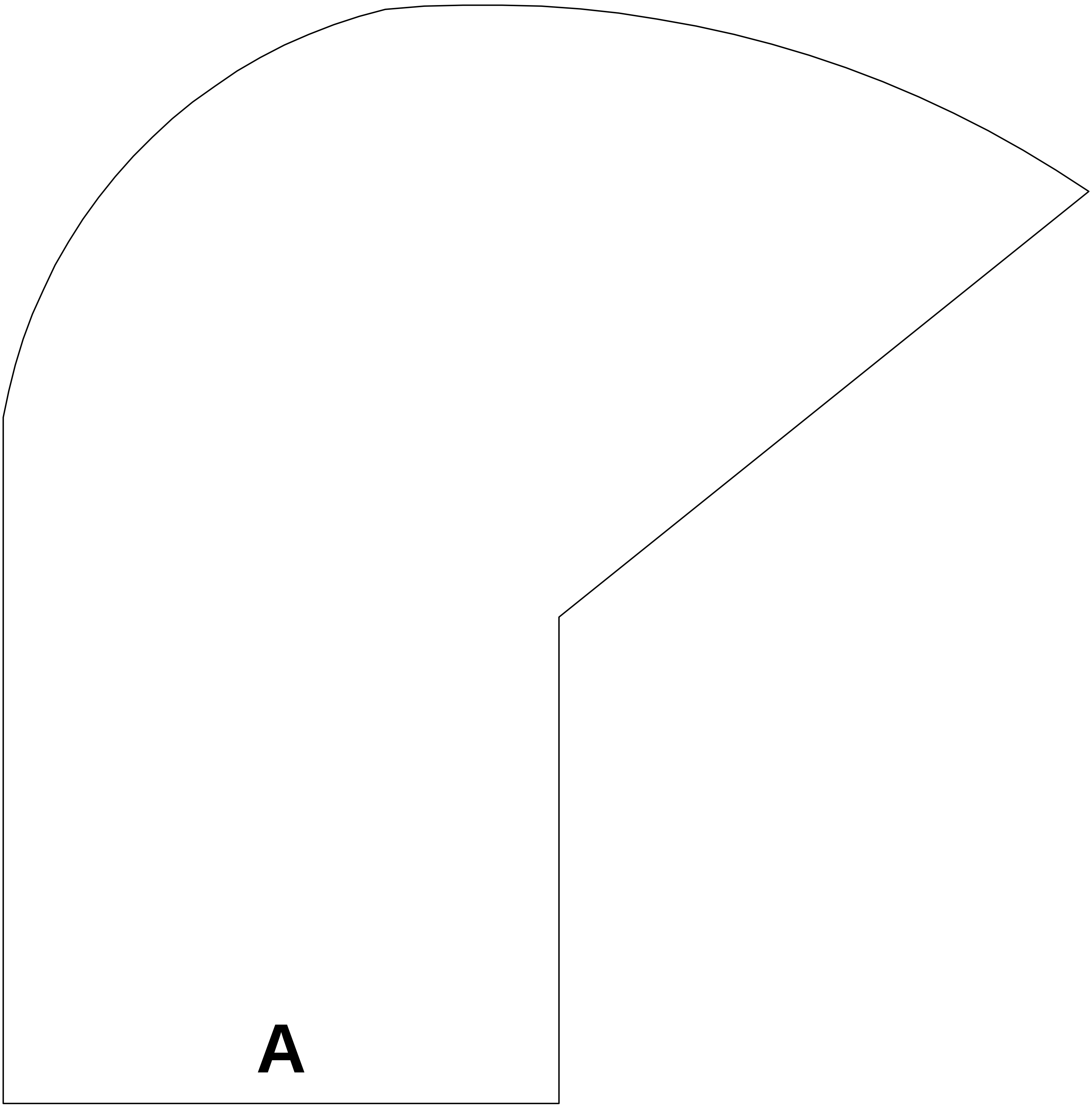
The leading and trailing edges of the plastic could also be reinforced in a number of ways. A simple piece of duct tape or some other weatherproof tape would help shield this part from weather and give it more strength. Another idea would be to thread a heavy wire through the corrugation along this edge and attach the wire to the top and bottom of the blade supports with a screw. This would serve to reinforce the entire length of the leading edge, which faces the heaviest stream of wind.

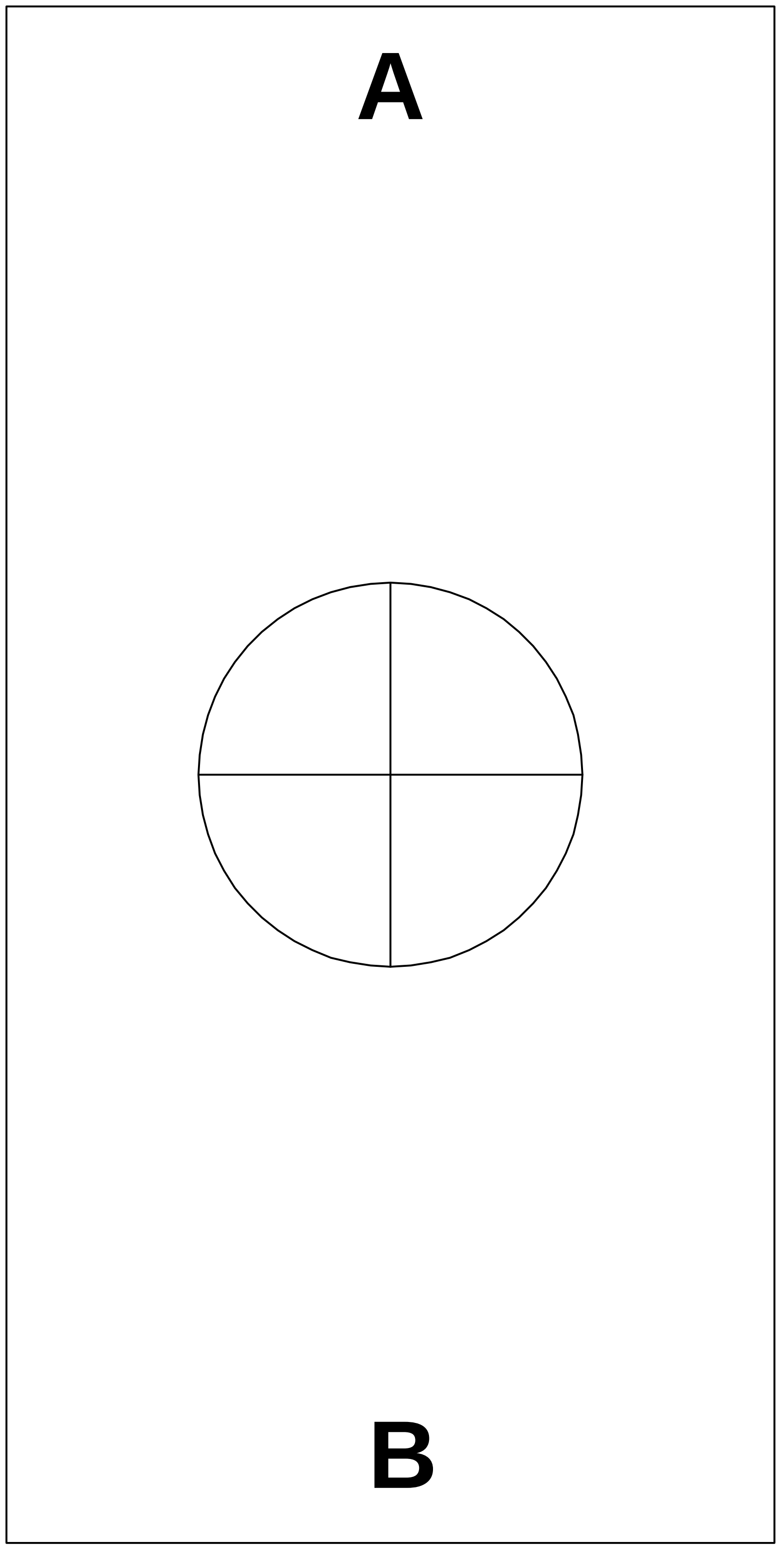
Reinforced Blade Support

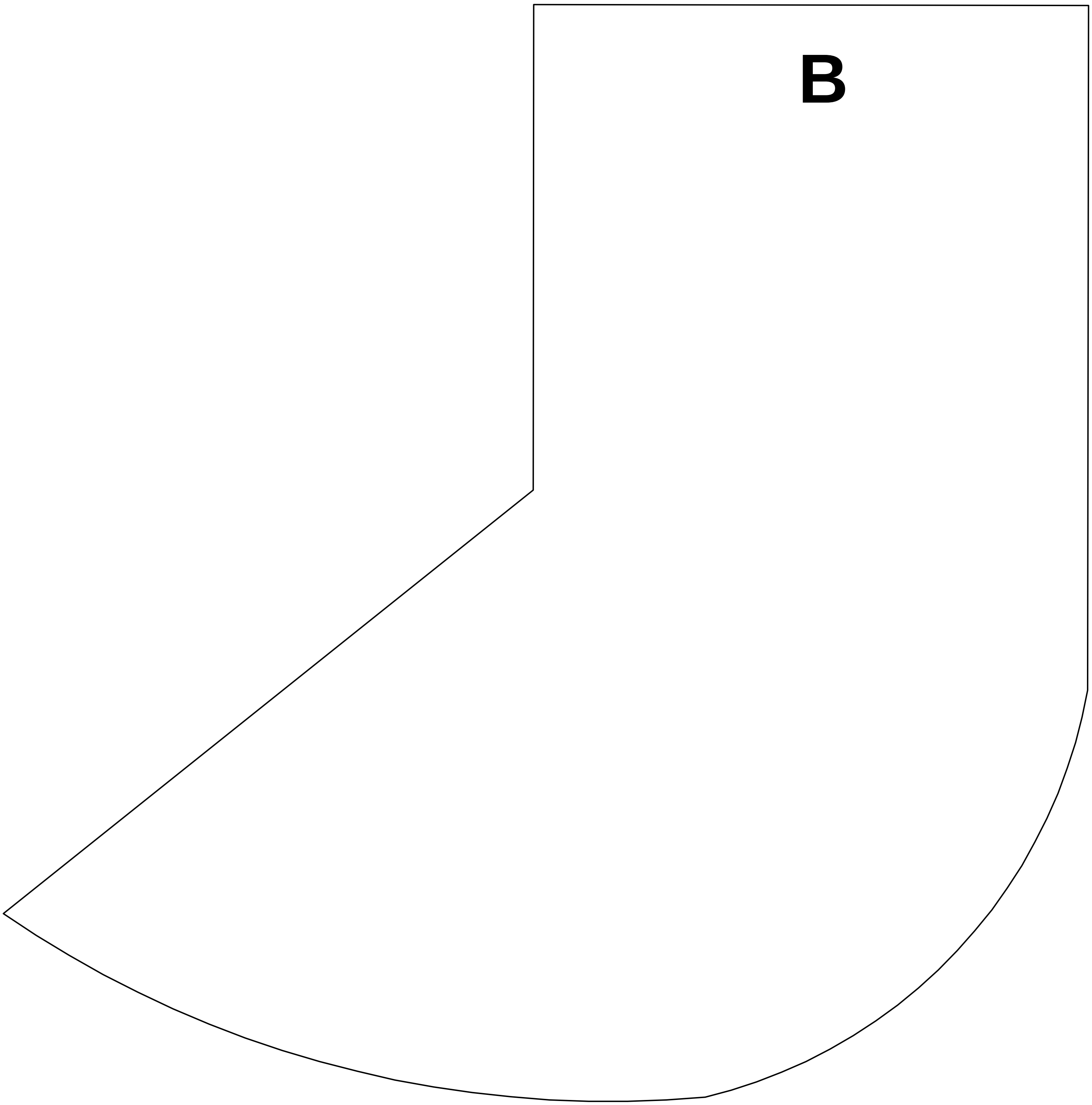
The blade support can be made from 1” thick wood instead of plywood. There is a lot of waste in this case because you must use a 12” wide board and much of it will end up being cut away. Another idea is to just reinforce the central section by running a piece of 1x4” wood underneath the plywood, stopping when you get to the curved sections. This can be affixed using about a dozen screws, put in from the plywood side with pilot holes.

Doubling up the pipe clamps by using two per blade support would give an extra bit of hold to the blades against consistently strong winds. Longer angle braces might be needed in this case to accommodate the two clamps.

TEMPLATES




A
B


B

The templates are to be cut out and assembled like this using tape: