THE SHARP HAWT-KITE CONCEPT
A Hybrid of a Solid-Wing Kite, a Horizontal Axis Wind Turbine, and Ram-Air Turbines based on using T-Rule Centrifugal-Spring Passive Pitch-Control for each Blade/Wing/Kite

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This paper is about a simple experiment I did a long time ago that might lead to something important if additional experiments are done.

As far as I can tell, the conventional wisdom in wind energy is that a few categories of devices are competing with each other to determine which will become dominant in which niche market (on-land, on-water, in the jet streams, etc.) over the long term. Energy kites and tower based wind turbines are regarded as in competition with each other. My opinion is that we are still in the early stages of innovation and so we are likely to see a blending or blurring of those categories. This paper discusses one such potential blending as an example of what I mean. I believe that there are still a great many wind energy conversion devices that have yet to be invented and/or tested.

Way back in 1978 when I was first experimenting with passive pitch-control for vertical axis wind turbines (VAWT), I did a quick and dirty experiment to see if I could achieve passive pitch-control for a single blade, extended on a string, and flying in a vertical orbit, as if it were the tip of a blade of a horizontal axis wind turbine (HAWT). The experiment worked. But a lot more experimenting was required for further development, so I went back to developing what later became the Sharp Cycloturbine and the Bird Windmill, both vertical axis windmill/wind turbines with passive pitch-control.

That single blade on a string functioned as a new kind of kite, which I now call a “Sharp HAWT-Kite”. (Inventing is my art form, so I like to “sign” my work.) I would like to do the necessary experiments, but I need to focus on building more Sharp Cycloturbine models when my arthritis allows me to do so. So I wish to share the HAWT-Kite concept in the hope that some open minded inventors will eventually explore it further.

It might become commercially successful because it has the potential to greatly lower the cost of horizontal axis wind turbines (HAWT) and airborne wind energy systems (AWES). It could be ground mounted on a tower, or it could be airborne using a lifting/buoyant kite. It might even fly as an autogiro energy kite. It could potentially sweep an enormous area of wind at high speed, using multiple blades (wings, kites), and it might be substantially simpler, cheaper, and more powerful than the Makani energy kite system. It could reduce tether drag because the main tether would remain relatively stationary, and that in turn could reduce fatigue of the electrical wires that were part of the primary tether.

For my original “quick and dirty” experiment, I used a piece of folded paper for the blade skin. The paper was card-stock paper which is thicker and stiffer than printer paper. When folded, it forms a symmetrical, streamlined profile, albeit with a relatively sharp leading edge. The span of the blade was 11”, the same as the longest dimension of the paper. As I recall, the chord length was 3”. I used clear tape or staples to join the trailing edges of the paper. I placed a ¼” diameter wooden dowel inside of the leading edge of the blade. Near the outer tip of the blade, I pierced the leading edge of the blade with a thin rod of stiff music wire. The music wire passed through a hole in the dowel and extended chord-wise out the trailing edge of the blade. When I secured the music wire in place (glue), that made the blade, the dowel, and the music wire into a solid unit. The music wire extended about 3 or 4 inches ahead of the blade. The blade looked a bit like an unbalanced "T".

At the leading end of the stiff music wire, I attached a streamlined lead sinker. The weight wasn't critical for the initial experiment because I had no idea what it should be, so I didn't bother to weigh it. It was probably around a half ounce to an ounce. I could have used a steel washer instead, mounted perpendicular to the blade. The wood dowel extended a bit out of the bottom of the blade skin, and I drilled a hole in it for tying a string to the dowel. The string was just ordinary household twine, about 5' long. I probably also tied or glued the bottom of the blade skin to the dowel to prevent any flexing.

In order to fly the blade like the blade of a HAWT, I used a length of thick dowel 3 or 4 feet long to act as the horizontal rotor shaft. At one end, I drilled a hole through the diameter of the thick dowel and inserted a thinner dowel that was about 1' long. So the thinner dowel stuck out at a right angle to the thicker dowel, like an "L" shape. That arrangement enable the blade to transmit torque to the horizontal shaft. I pinned the thinner dowel so that it couldn't slip out of the thick dowel. I drilled a hole in the outward end of that thinner dowel so I could tie the string to it. And finally I assembled the parts.

I tested that very crude HAWT-Kite at the top of a steep hill in San Francisco where the wind blew at about 10 mph most afternoons during the summer. I held the long dowel horizontal above my head and swung the blade in vertical circles to get it started. The blade was downwind of my body. It quickly began to propel itself. It rotated the long dowel I was holding loosely. It produced some useful torque, but not much, because the blade was small and had a low aspect ratio. The orbit diameter of the blade was about 12'. The blade speed seemed to be about twice the speed of the wind, which seemed appropriate for such a crude blade. A good quality blade with a high aspect ratio probably would have moved at 5 or 6 times the speed of the wind, but that would have been too dangerous for a first experiment. Anyway, that part of the experiment was a success. The blade functioned as a new kind of kite and also as a new kind of horizontal axis windmill. So it was a hybrid of a kite and a windmill, a HAWT-Kite.

But when the angle of the wind changed, the orbit of the blade became unstable. It didn't remain in a plane perpendicular to the horizontal dowel shaft. So I had to stop the blade for fear that it might hit me. That happened repeatedly. The next experiment would have been to test ways to keep the orbit stable relative to the horizontal rotor shaft so that the HAWT-Kite could orient to the wind like a normal HAWT rotor that yaws. One way to do that might be to add additional triangulating cords between the shaft and the blade. And if those experiments proved successful, then it should eventually be possible to add more blades and mount the rotor on a tower and a yaw bearing, or fly the whole rotor using a lifting kite.

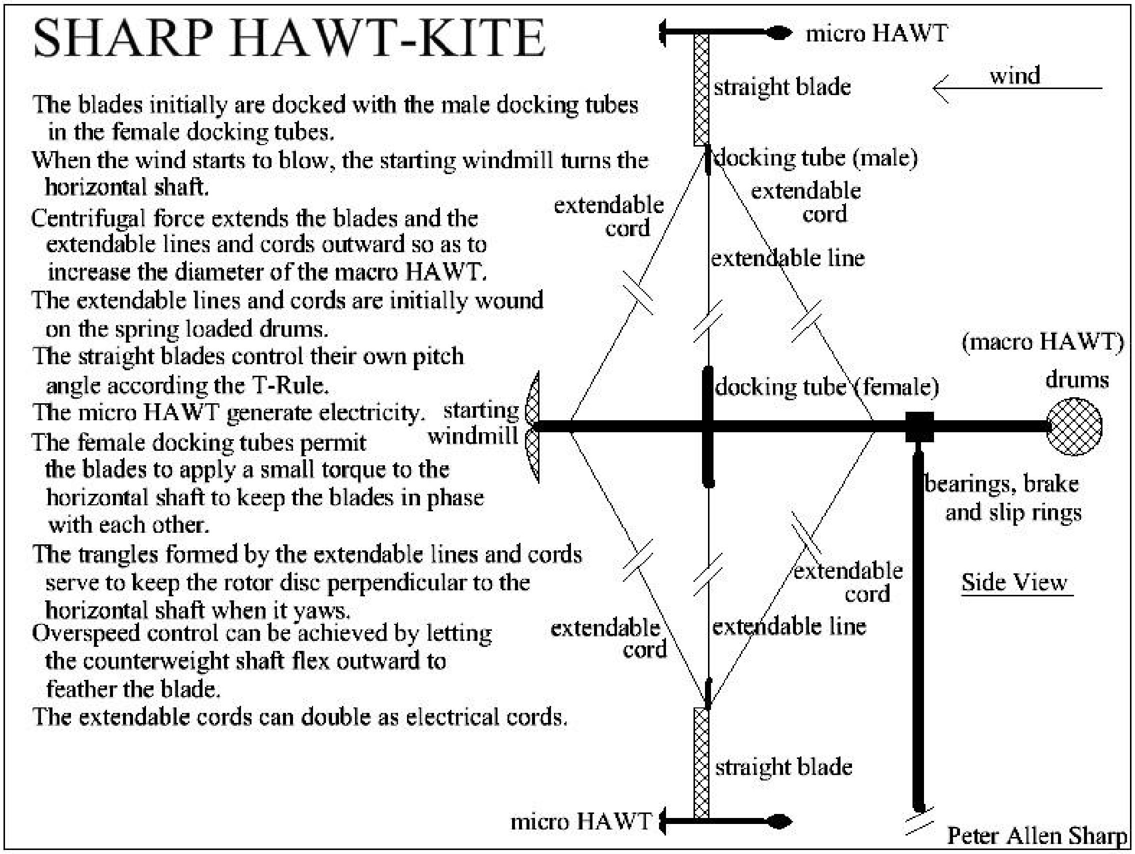
The blade controlled its own pitch angle automatically using a centrifugal spring. The centrifugal spring kept the blade from stalling or feathering. The principle I used is called a "T-Rule" centrifugal spring. If a string is tied to the bottom of a wood, metal, or plastic "T" shape, and then the "T" is swung in a circle (vertical or horizontal), the top bar of the "T" will lie flat in its plane of rotation. It does so because, in that position, the mass of the top bar is farthest from the axis of rotation (your hand holding the string). Centrifugal force (actually centripetal force) pulls on the "T" and tries to pull it as far as possible from its axis of rotation. That creates the centrifugal spring.

In my experiment, the blade's center of mass was located at roughly the leading edge of the blade due to the counterweight out in front of the blade. As a result, the blade's center of pressure (typically assumed to be at the quarter-chord point) was aft of its center of mass. That causes the blade to try to orient toward its apparent wind. With respect to its distribution of mass, the blade was similar to a "T".

When I swirled the blade around in the wind, it tried to face directly into its apparent wind. As a result, two forces acted on the blade. The centrifugal force tried to keep the blade lying flat in its plane of rotation. The apparent wind force (the vector addition of the blade's relative wind and the true wind) tried to make the blade face directly into its apparent wind. The two forces, centrifugal and aerodynamic, opposed each other. So they reached a compromise, a balance point. That balance point was the pitch angle of the blade.

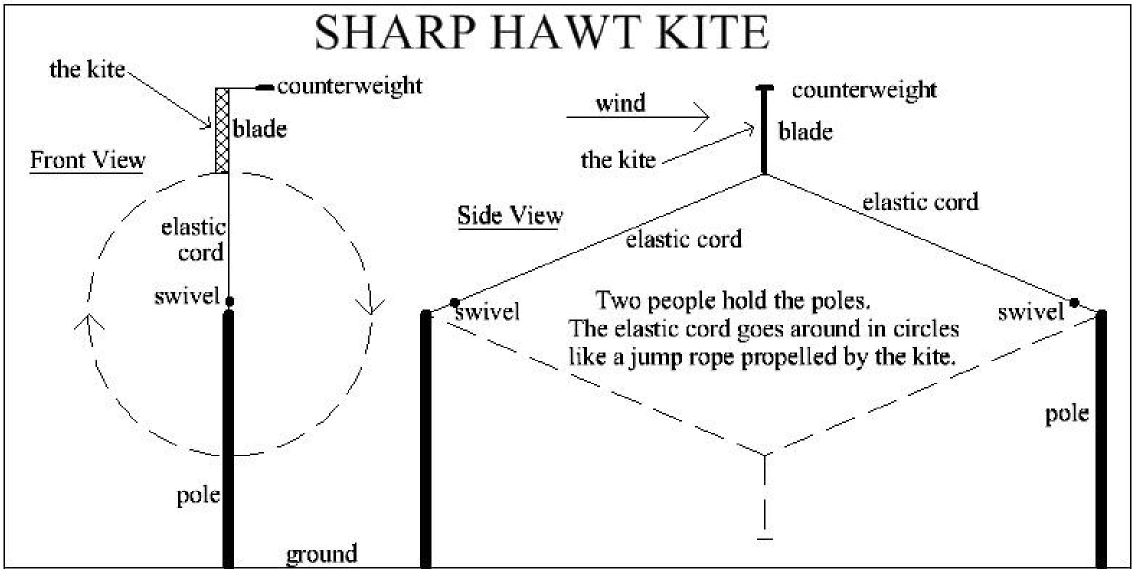
The pitch angle of a HAWT blade determines the blade's angle of attack relative to the blade's apparent wind. The paper blade could maintain an angle of attack to its apparent wind that was below its stall angle and above its feathering angle. It could create lift and thrust just like a normal HAWT blade. Actually, the paper blade functioned like a HAWT blade with active pitch control, only better, because the paper blade could instantly adjust its pitch angle to adjust to local changes in the velocity of its apparent wind.

That means that a HAWT-Kite blade has the potential to capture more energy than usual. It might be especially good at capturing the energy in wind gusts. The energy in wind gusts can be as much as 30% to 40% of the energy in the wind. A wind turbine's ability to capture the energy in wind gusts is not the same as it coefficient of performance (Cp), which is typically measured in a steady wind. A wind turbine that was especially good at capturing the energy in wind gusts could potentially capture a lot more energy annually than another wind turbine that had a higher Cp.



The blade had a "zero" pitch angle, meaning that if it were orbiting when no wind was blowing (using auxiliary power, such as my hand), the blade would lie flat in its plane of rotation. It might be desirable to give the blade an initial bias pitch angle, either upwind or downwind. That could be done, for example, by bending the counterweight arm a bit in the downwind direction to cause the blade to have a preset pitch-angle that was facing a few degrees upwind. The counterweight would try to lie in the plane of rotation, so it would act like a lever that would force the blade to pitch a few degrees to windward.

In the above drawing, I show the blades turned sideways in order to show how they are configured. They would normally lie approximately in the plane of rotation when operating. Let me stress that this design has not yet been tested to see if the plane of the rotor can stay perpendicular to the horizontal shaft, so the sketch is a proposal for a test.



Start kite by twirling it in circles. Once moving, it will produce its own thrust. The kite controls its own pitch angle. The principle of pitch control is called the "T-Rule".
Centrifugal force tries to keep the blade aligned with its plane of rotation. The wind tries to make the blade face directly into its apparent wind. The two forces reach a balance which is the pitch angle of the blade.
The kite functions as the tip of a horizontal axis wind turbine (HAWT) blade.
If a rotating shaft were placed between the two poles, the kite could be used to rotate the shaft.
One or more additional blades could be added to balance the original blade.
Since most of the power generated by a HAWT is produced by the tip of the blades, why bother with the rest of the blade?
Peter Allen Sharp

Some power generating kites, such as the Makani solid wing kite, use small, high speed HAWT mounted on the wing. The wing/kite flies in circles or figure 8's and forces the small HAWTs through the air. The small HAWTs are then called an "aerodynamic transmission", or a "ram air turbine" ("RAT"). That concept was used originally to provide emergency backup electricity for airplanes. It can be over 80% efficient (according to an old, Russian research paper translated by NASA).

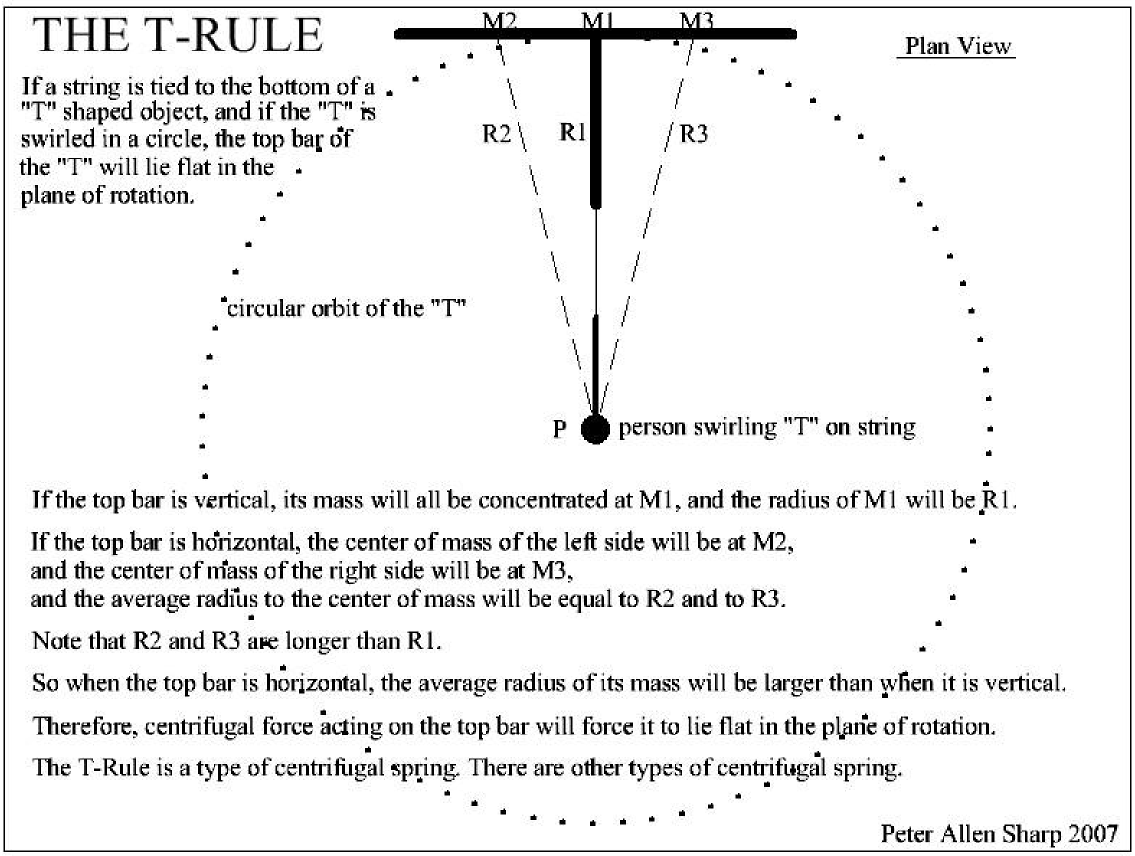
The counterweight used for the HAWT-Kite blade could be the generator of a RAT. A HAWT-Kite could use 2, 3, or many more blades, and each of them could carry a RAT. The advantage of doing so would be to replace the conventional gearbox and large, relatively low rpm generator of a HAWT with small, high rpm, RATs. They would be noisy due to their very high tip speed ratio relative to the true wind (25 to 36). So that problem would need to be resolved, perhaps by adding a ring around the blade tips of a RAT rotor to suppress vortex shedding, and by increasing its solidity ratio to lower the rpm.

The cost saving could be quite large. HAWT-Kite blades should be a lot cheaper than conventional HAWT blades because they would be only about 1/3 the normal length, or less, and they would require no twist and no taper. If RATs are used on the blades, the rpm of the large rotor does not matter; only the tip speed ratio matters.

In order to launch the kite blades, the cords to the blades could be extendable. The cords could unwind from a spring-loaded drum. And to keep the blades in a plane perpendicular to the wind, additional extendable cords could be added between the horizontal shaft and the blade. The first sketch shows what a HAWT-Kite might look like. If the rotor could function in that manner, it might also be able to fly in autogiro mode.

The second drawing shows a way to do experiments in a simplified manner to explore the pitch control of the blade. This simplified device might also be used as a wind pump in places where the wind is from one direction most of the time. The poles could be flexible, with one guy wire each to hold them apart. Pull cords would extend from the tips of the poles, and extend sideways to the pump, or to a rocking, upside-down-V-tower above the pump. Some automatic way to start the blade would need to be devised.

To help understand the T-Rule, which is the basis for the passive, centrifugal-spring pitch-control, see the third sketch.



For a given tip speed ratio and rotor diameter, the centrifugal force and the aerodynamic forces acting on the blade increase and decrease at the same general rate: by the square of the blade's speed (ground speed and air speed, respectively). That is why the pitch-control can be accurate over a wide range of tip speed ratios. At lower tip speed ratios, the blade pitches more because the aerodynamic pitching force is relatively stronger than the centrifugal anti-pitching force. That increase in pitching compensates for the larger angle of the apparent wind at lower tip speed ratios. So the blade doesn't stall or feather. That simple device can achieve complex pitch control.

There can be a counterweight aft of the blade as well -- as long as the blade's center of pressure remains aft of its center of mass. And a counterweight could be added at the inward end of the blade. Moving a counterweight away from the blade will increase the leverage of the counterweight to resist pitching, and will increase the angle of attack.

A simple way to achieve overspeed control would be to let the counterweight arm in front of the blade bend radially outward (in the plane of rotation), thus causing the center of mass of the blade to move back toward the center of pressure, which would feather the blade. The tip speed ratio of a Sharp HAWT-Kite should be about the same as a conventional HAWT.

Another instance where I make use of the T-Rule is on the single, vertical blade of the Bird Windmill which is suspended by elastic cords above it and below it. I place the counterweight at the mid-span of the V-blade. The counterweight tries to remain in its horizontal plane of rotation. The effect is to dampen the fore and aft oscillations of the vertical blade tips when hit by a gust of wind. A different kind of centrifugal spring is used to control the blade pitch. It's called a "bowstring centrifugal spring". The Sharp Cycloturbine uses a third type of centrifugal spring to control the pitch of its blades individually. It's called a "centrifugal pendulum spring". (The Bird Windmill and the Sharp Cycloturbine are not variations of the Darrieus rotor; they are more fundamental.)

I also invented a toy whip-stick V-wing glider that uses a T-Rule centrifugal spring for pitch control. It can fly in a large-diameter, horizontal orbit (easily over 30 feet) even though the blade span is only about 1 foot. It flies at about 30 mph, and can be made to climb and descend by changing its plane of rotation manually. It has no tail or horizontal stabilizers because centrifugal force maintains the wing's angle of attack. I call it a "Whip Wing". The Whip Wing could also be classified as a windless kite. If I slow the Whip Wing down too much, thus reducing the centrifugal force too much, it does a nose dive because the counterweight out in front of the vertex of the V-wing makes the blade nose-heavy.

The counterweight is ahead of the mid-span of the V-blade (the vertex of the V). The whip-string attaches to the inward blade-tip at its leading edge. The counterweight, due to centrifugal force, tries to rise up to the plane of rotation defined approximately by the whip-string, and that gives the blade a positive angle of attack to create upward lift. The same V-blade used for a Bird Windmill can be used for the Whip Wing glider/kite. But in the windmill mode (horizontal or vertical orbit), the Bird blade employs a different kind of centrifugal spring for pitch control. (A Bird blade with a vertical orbit is called a "Sharp Cyclo-Kite" because it can fly above and upwind of its anchor points [the tops of two poles spaced widely apart] under its own power.)

If there were a wind blowing vertically downward on the horizontal orbit of the Whip Wing, that wind would propel it without the need for manual power. Similarly, if the orbit of the Whip Wing were vertical, a normal wind could propel it -- like the blade of a HAWT. Consequently, the Whip Wing glider/kite would demonstrate that bending the counterweight arm of a HAWT-Kite in the downwind direction would force the blade to assume a preset pitch angle toward the upwind direction. In other words, a V-blade in a vertical orbit -- with its counterweight in front of the vertex of the V-blade -- will function the same as a straight blade with its counterweight arm bent a few degrees in the downwind direction. That indicates that a Whip Wing, if flown in a vertical orbit (with the V pointing downwind), could function as a HAWT-Kite with a pre-set pitch bias in the windward direction. I have yet to do that experiment, but I expect it to work as predicted by theory. (The tip speed ratio may be limited by the preset pitch angle to windward.)

It is also possible to construct a multi-blade vertical axis wind turbine that uses blades that extend outwards while supported by long cords connected to the normal horizontal, blade support arms mounted on the vertical shaft. So the vertical blades extend outwards on tethers and therefore function as kites. The blades could support RATs. I may explain that technology in another article.

Centrifugal pitch-control may play an important role in future AWES because it could simplify kite control in some cases, it could lower costs, and it could be more reliable than computerized control.
