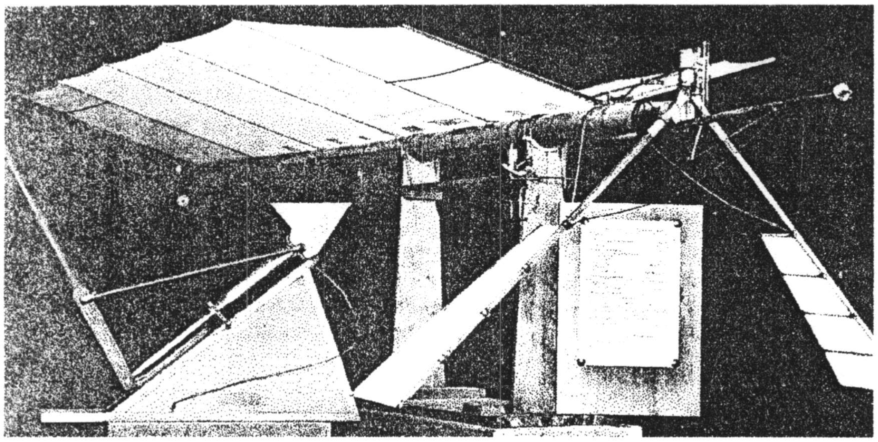
SUMMER 1999

# Flapping Wings

THE ORNITHOPTER SOCIETY NEWSLETTER



## Lawrence Hargrave (1850-1915)

*by Reuben Hoggett*

"If there be one man more than another who deserves to succeed in flying through the air," wrote Octave Chanute in his classic *Progress in Flying Machines*, "that man is Mr. Lawrence Hargrave of Sydney, New South Wales." Hargrave perfected the box kite and demonstrated the tremendous lift and stability of what was basically a biplane configuration. More than a decade later aviation design was still dominated by Hargrave's box-kite formula. Hargrave provided considerable input into the Wright brother's Kitty Hawk. He was also the inventor of the radial (rotary) engine.

Hargrave's constructions included 20 India-rubber-powered flying machines designed and built; over 100 kites and gliders and soaring machines designed and tested; 42 engines of various types designed; 36 engines (reciprocating, vibrating, radial, rotary, turbine, and pure jet; operated by compressed air, steam, gun powder, and petrol) designed and built between 1888 and 1911; design of 16 engine-powered flying machines, 8 of which were man carrying; and 13 engine-powered flying machines that he designed and built.

Throughout his aviation experimentation, he concluded that natural (i.e. flapping) flight was the path to follow for manned heavier than air flight. For a while he experimented with a variety of engines, including steam and gunpowder. The internal combustion engines of the time proved too heavy and unreliable. Ironically, it was due to his lack of propeller development, despite being advised by peers to use more proven designs, that he concluded that flapping wings were more promising and hence failed to achieve the goal of manned flight.

## New Additions to Web Site

The Flapping Flight Web Site, www.catskill.net/evolution/flight, has some new content you'll want to check out. There is a new video clip staring Albert Kempf's Truefly electric RC ornithopter. You'll see the psychedelic toucan rise and maneuver with full audio. Also notice the new plans, which include the rubber-powered biplane on page 7, and PH Spencer's Orniplane, which was the first RC ornithopter. Tony Baker donated server space for the videos.

Best of all, in the Resources section of the web site, there is a neat little program you can use to try out different flapping mechanism geometries before building.

### Ornithopter Society Membership Info

**To join the Ornithopter Society or renew your membership:** Dues in the USA are $12 per year. Dues outside the USA are $17 US per year. Checks are payable to:

***Industrial Evolution***
***PO Box 376***
***Arkville NY 12406 USA***

**Newsletter:** Nathan Chronister, editor of *Flapping Wings*, invites you to submit material for the newsletter. Send items to Nathan Chronister at the address above, or E mail your articles to evolution@catskill.net.

**OS on the web:**
www.catskill.net/evolution/flight

With his interest in sailing and boats, Hargrave's frequent, long voyages implanted in his mind the idea of harnessing the power of the waves for ship propulsion. He built a boat and suspended flat paddles beneath the water from long arms installed amidships on each side. With the boat anchored in a fresh south-easterly breeze the action of waves on the paddles propelled it forward until it was over the anchor. Then it fell off, and dropped in the trough of the sea until the anchor brought it head to wind again.

On 30 June 1882 Hargrave set down his "trochoided plane theory" based on these experiments. ["Trochoidal motion" refers to the path mapped out by a point on the circumference of a circle when rolled.]

1. The use of a plane revolving normal to a trochoid to generate reaction in a contrary direction to that of the propagation of waves by that revolving plane.

2. The adaptation of the said reaction to the motive power, first by the alteration of the length of the waves propagated by lengthening or shortening of that portion which I call the connecting rod; or second, by the alteration of the height of the waves propagated by the lengthening or shortening of that portion which I call the crank.

3. The use of this reaction for propelling ships, boats, vessels, balloons, or flying machines.

4. The use of a plane revolving normal to a prolate cycloid for the same purposes.

Development of this theory had two consequences. It led him directly into aeronautics and its philosophy hamstrung his aeronautical work throughout his life.

Hargrave now began to apply his trochoidal principle to air flows. He built an experimental wind-wave mill consisting of two flat plates with a combined area of 0.66 square feet, and found that a conventional windmill required five square feet to do an equivalent amount of work. He asked the English periodical Knowledge to publish the results so that: "my independent work may become public property and not liable to seizure by the first patent-hunting pirate who might see one of my models at work. If that end is attained by giving the principle and methods of application publicity it will, I trust, lead to others with more time and means at their disposal, thoroughly investigating a matter that cannot but interest all who inquire into the hidden mysteries of nature and science."

Hargrave was now investigating the movement of animals, particularly snakes and fish, and he believed their progress dependent on a wave-like motion. He considered the dorsal fin of the fish its main propelling medium. He found that a diamond fastened to a snake's belly scratched circles when the snake was liberated on a sheet of glass.

Hargrave built a series of models operated by clockwork to demonstrate various trochoidal motions -- small wooden boats with flat paddles, and snakes of wood and sheet tin segmented and supported on tiny metal wheels. Some still preserved testify to Hargrave's excellent craftsmanship.

About 1882 two important books he read confirmed some theories and persuaded him to amend others and turn to the examination of bird flight and aeronautics. They were Animal Locomotion, by the Scottish professor J. Bell Pettigrew, and Animal Mechanism by Etienne-Jules Marey, a French anatomist and chronophotographer. Pettigrew claimed that quadrupeds walk, fishes swim, and insects, birds, and bats fly by a figure-of-eight movement. Marey described the figure-of-eight movement of a bird's wingtip which in effect acted something like an airscrew. Pettigrew's conclusions clinched Hargrave's interest in flight: "It will be evident that a remarkable analogy exists between walking, swimming, and flying. It will further appear that the movements of the tail of the fish and the wing of the insect, the bat, and the bird can be readily imitated and reproduced. These facts ought to inspire the pioneer of an aerial navigation with confidence. The land and water have been already successfully subjugated. The realms of the air alone are unvanquished. These, however, are so vast and so important a highway for the nations that science and civilization equally demand their occupation. The history of artificial progression endorses the belief that the fields ethereal will one day be traversed by a machine designed by human ingenuity and constructed by human skill."

In order to construct a successful flying machine it is not necessary to reproduce the filmy wing of the insect, the silken pinion of the bat, or the complicated and highly differentiated wing of the bird, where every feather may be said to have a peculiar function assigned to it; neither is it necessary to reproduce the intricacy of that machinery by which the pinion of the bat, insect, and bird is moved: all that is required is to distinguish the properties, form , extent, and manner of application of the several flying surfaces, a task attempted, however imperfectly executed, in animal locomotion.

In July 1883 Hargrave revised his opinion that a snake's movement is circular. He wrote: "I now believe the figure described is more like a figure-of-eight and that the effect of this action on the water is a tendency to throw two series vortices backwards, the left-hand series revolving in a contrary direction to the right."

Undoubtedly this conclusion first gave him the idea for flapping flight, simply by turning the (snake's) plane of movement from the horizontal to the vertical. Hargrave said: "The trochoidal action of fins, muscle, and legs seemed so plain I could not help but theorize of the motion of wings in flight; I say theorize, simply because I do not have a flying machine to show you, but the chain of evidence seems so complete that I have no doubt it will soon be accomplished without the air of a screw or gas-bag."

One of the models he displayed had a pair of oar-shaped wings hung at the outer-end of an eight-foot rod which formed a rotating radius centered by a vertical support. A music-box spring supplied power to flap the wings. Seven and a half flaps took them round the circle, demonstrating that mechanical wings could supply forward motion. It was a copy of a model Marey had made, except that Marey's power came from a hand-operated air pump.

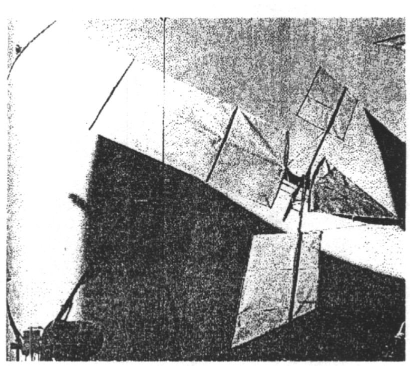
On the last day of 1884, Hargrave's great breakthrough came with a model which accomplished his first free flight. It weighed one ounce and was driven by flappers, two stretched rubber bands giving torsional stress to the wings.

Hargrave had postulated that, because of gravity, the orbits of wave particles were elliptical rather than circular, as they were in water. The flappers, operating as bird wings do, threw one wave and the body plane flexed to throw another compensating wave which dampened the vertical movement that the thrust of flappers produced. The rubber bands that powered his first machines were stretched from aft forward; he reversed this so that as the rubber contracted, the centre of gravity also moved forward, reducing the angle of attack to lessen air resistance, compensating for the reduction of power. (The angle of attack is the angle the mainplane makes with the forward horizon.)

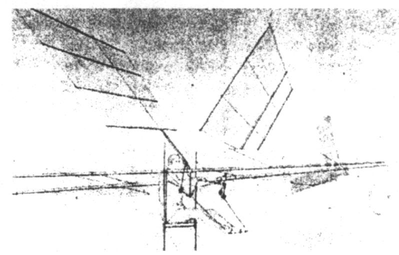
He then made a prediction quite remarkable in 1884: "In the larger machines this would have to be done by making the area of the tail surface variable for ascending or descending, and tilting one corner up or down for turning to either side. It is perhaps premature to speak of alighting before we ascend at all; but we may take a lesson from the birds and observe how they turn around and feel the wind when coming to the ground, the same way as a yacht picks up her moorings."

He continued to improve his construction using the power stored in rubber under tension. An interesting model, powered by 16 rubber bands, flew 110 feet. Hargrave had developed an arrangement consisting of small ivory pulleys over which cords ran from the ends of rubber bands to 2 toggles with centers riveted to the two steel cranks that moved the flappers. He progressively increased the number of rubber bands to 48, fabricating a hollow main spar with glued joints in order to obtain the necessary strength without a weight overload.

In November, he successfully built two more of these, Numbers Five and Six. The latter is fortunately still preserved, and it flew 120 feet through still air at a speed he reckoned at 14.6 mph.



In 1886, he was thinking about manned flight. From a drawing titled "Probable development of the trochoided plane flying machine", it had the supporting surface ahead of the flappers and was equipped with a tricycle undercarriage. The pilot crank-operated the flappers.

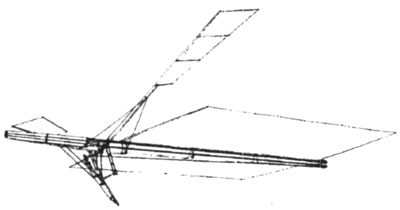


To determine the weight, area of supporting surface, and power necessary for the flight of a full-sized machine he built a test rig consisting of a tower-like structure on wheels.

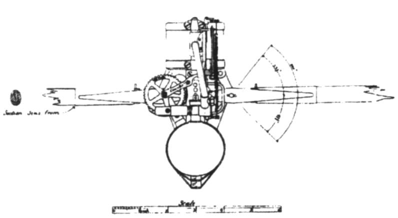
He calculated that a powerful athlete could create a thrust of 23 lb for a short time. With an area of supporting surface of 100 square feet, a weight of 225 lb, and an angle of attack of 5 degrees, a speed of 122 mph would be required to support the machine without allowing for the drag of the operator. This indicated that his proposed man-powered flying machine was impracticable. Some additional power would be required.

Throughout 1887 he worked to perfect his India-rubber-powered flying machines, doing away with the forward plane supporting surface and increasing power until one machine achieved a flight of 300 feet. This machine, with a supporting surface of twenty-two square feet, weighed only 2 lb. The last machine in this year generated an energy output of 470 ft lb.

Two Hargrave inventions had insisted in the improved results. The first tested rubber bands for power output, pulleys for friction and strain, and cords for strength, demonstrating that weight savings could be made. The second tested the comparative efficiency of various forms of flapper. With it, Hargrave could determine the relationship of the thrust to the length of the connecting rod, and of crankshaft revolutions to speed, and find the most efficient location of the flapper lever's juncture with the leading edge of the flapper.

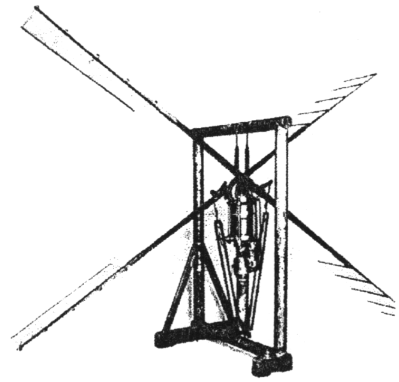


He designed a new lightweight engine of still another principle to power his third flying machine, a simple reciprocating engine that would move the flappers up and down, obtaining thrust by the twisting of the shaft thus eliminating the weight of the heavy cranks.



After two months at the drawing-board he began his thirty-fourth engine in March 1907, a two-cylinder opposed two-stroke, and again it was designed to drive flappers. It incorporated two vapor pumps to act as a supercharger in the same way as on his thirty-second.

Hargrave then evolved his thirty-fifth engine, the "concertina, or spring engine". Once again designed to operate flappers. The basic idea was that on the explosion stroke its single cylinder would extend four powerful springs, which would then apply equal pressure on the flappers for the return stroke.



After a short illness, Lawrence Hargrave died on 6 July 1915.

Most of the collection, sent to Germany, was bombed during WW2. Of the 176 models sent, only 25 in whole or in part were saved. These were returned to Australia in 1960. There is a model in the Smithsonian Air and Space Museum in Washington.

**References:**

Moolman, Valerie. *The Road To Kitty Hawk.* Virginia: Time-Life Books, 1980, p 95.

Shaw, W Hudson, and Olaf Ruhen. *Lawrence Hargrave: Explorer, Inventor & Aviation Experimenter.* Stanmore, New South Wales: Cassell Australia Limited, 1977.

# Ornithopter Society CD-ROM

*by Tony Baker*

It has been over 21 years since the last public update to the flapping flight movement. Peter Hainings, *The Compleat Birdman*, 1978, to my knowledge, was the last publication of flapping flight achievements.

What has happened since?

Nathan Chronister's Flapping Flight Web Site and the Ornithopter Society are now the backbone of the flapping flight movement. I say movement because flapping flight is becoming ever closer as this technology is increasing in the quest of manned flapping flight. To increase this movement, we must reach out and tell others of what we are doing. The general public would be interested in the recent developments of the OS members.

There is a market, but we must build it ourselves. If we advertize the OS, the general public will inquire. This is the first step of building a market for the ornithopter. Without a market it will be difficult for the ornithopter to exist.

To help build public interest, as Natural Flight Company, I have offered to sponsor the production of a multimedia CD for the OS.

The OSCD will have an opening video of Nathan (the OS spokesman) introducing the Ornithopter Society and offering an invitation to join. Then the CD will go to a navigation page or directory. From there, to the entire web site and videos of recent achievements. I hope to have some music also.

Anyone that has something to share or update about the subject can summit it. The due date is the first week in January 2000. The release date is next spring. So be included, get your material together, and help support the OSCD.

Natural Flight is sponsoring the creation of the OSCD without a profit. All I ask is for my expenses after the CD sells. After expenses, all monies will go back into advertising for the OSCD.

Due to the complexity of this task, I ask that all materials be submitted in electronic media. I will accept other forms, but I would have to contract it out for a reasonable fee to have it converted into digital media. Electronic media include: E mail, PC100 zip disk, floppy, and CD (IBM). I would reserve the right to edit as necessary.

This is how we can get the word out nationally:

To those that have a concept or have something to sell and would like to advertize, you may do so on this CD. In lieu of payment for your concept or item for sale, you may take out an ad in a national magazine (one of your choice) advertising the CD for as long as you feel necessary. I would suggest at least one year. Remember you are advertizing for yourself and for OS. This would help give the CD support that will lead to a market for the ornithopter.

Don't miss out on becoming a piece of documented history in this millennium OSCD. It will become a collector's item someday, as is *The Compleat Birdman*.

I am looking forward to the creation of this OSCD. I believe the OSCD will be a boost to the quest of achieving manned flapping flight.

*Some people think the end of the world is coming this millennium! I think flapping flight is coming, and it will be the preferred way of travel.*

— *Tony Baker*

*Step outside today, at the end of the Twentieth Century, and look up; ninety nine times out of a hundred, the only thing you'll see flying, will be flying with flapping wings.*

— *Jim Theis*

# What's Wrong

## (and Right) with Rubber Power?

*by Nathan Chronister*

In the 1870s, India rubber achieved quick success as the main power source for ornithopters. Initially used in an awkward stretched configuration by Jobert in 1871, he and others soon learned to use a twisted rubber motor just like the ones we use today. Still use today. Except for a few successful ornithopters using other power sources, including one internal-combustion-powered ornithopter flown by Gustav Trouvé in 1870 prior to any rubber-powered flight, most flapping flight today is still powered, if not by muscle, then by rubber bands.

Part of our fascination with rubber power must lie in its simplicity. We who build ornithopters like to experiment with new design ideas. New wing designs, new flapping mechanisms, new devices. It is annoyingly slow to build a whole, complex, engine-powered ornithopter for each new experiment. Rubber power is quick. I should add that engine-powered ornithopters are so complex that they often fail altogether, either because of mechanical problems, too much weight, or too much creativity in wing design resulting in a new idea that should have been tried on a rubber flapper first.

One of the main reasons rubber power is so easy, and one of its main advantages, is that a rubber motor can crank out a huge amount of torque without recourse to gear reduction. They're good at exerting a large force slowly. High-RPM motors used in model airplanes can't do that.

Another advantage of rubber motors is that they can release their energy in a very short amount of time, unlike other motive devices. Think about it this way: If you stretch a rubber band between your fingers and release it, all the stored energy is immediately used to propel the rubber band across the room. In an ornithopter, the speed of unwinding the motor is limited only by the load presented by the wings. (The load increases as the flapping rate increases, so there is a balance between motor toque and wing resistance.) A short, fat motor can provide an incredible amount of power because it can unwind quickly against a considerable load.

Now let's look at some of the disadvantages of rubber motors. Obviously they become less practical with larger aircraft. I don't know that rubber motors store any less energy for their weight when scaled up, but certainly it becomes more apparent that they really don't store much energy to begin with. Steve Morris sent me a video of a huge rubber-powered airplane that flew powered less than a minute despite the huge mass of elastic in its belly.

Let's see how rubber motors stack up to the competition. In the 5 April 1997 issue, *New Scientist* published an article on "Palmtop Planes" that gave energy densities for some common ornithopter storage media. Petrol, the article says, holds 13.1 watt hours per gram. (There are 745.7 watts in one horsepower.) Lithium batteries hold only 0.3 watt hours per gram, and nicad batteries score a paltry 0.03 watt hours per gram. (Before you run out and buy a bunch of expensive lithium cells for your flapper projects, be aware that the *power* output of nicads exceeds that of lithium cells, though lithiums last longer.) Drawing on an older source, Octave Chanute's *Progress in Flying Machines*, I found out that rubber holds 600 foot pounds of energy per pound of rubber. That's only 0.0005 watt hours per gram!

Given this disparity, it's amazing that rubber-powered ornithopters can fly at all. Certainly it's due to their unique ability to release all their energy in a few seconds that rubber motors can power many of the heavier models such as Tim Bird, which needs about a watt of power to haul its sorry 20-gram mass through the air.

Several years ago, I calculated the power requirement for Tim Bird in level flight. To do this, first I measured the amount of torque exerted by the motor. You can measure this directly, by taking the motor out and mounting it on a bench, or you can do it the hard way and measure the wing torque, which varies with the crank position. Once you know the torque, you have to figure out the flapping rate so you can calculate power. I determined flapping rate by timing how long it took a particular number of winds to expire. The resulting flap rate applies to the entire motor run, though, and I was only interested in the flapping rate when the Bird was in level flight. I got around this by subtracting a short motor run from a long motor run to give the amount of time it took for the first 10 winds to come off the motor. I had to time real flights because the motor goes faster when there is forward motion, and I had to time a lot of flights to get the needed replicate sample. Of course if the Bird landed before the power was gone, I couldn't count it. Anyway, after all that trouble, I was quite surprised to learn that Tim Bird only needs 0.4 watt to fly. Because of friction in the torque measurement, the actual *input* power is probably about twice that, which would agree fairly well with Chanute's energy density.

Only a watt to fly? That's about what a bird the same weight would need! According to oxygen consumption data in Colin Pennycuick's *Bird Flight Performance*, a 350-gram pigeon needs about 35 watts, of which about 8 watts makes it to output. That's 23 watts per kilogram, compared with Tim's conservatively estimated 45 watts per kilogram. I was surprised at Tim Bird's close approach to birdlike power levels, because I had flown electric ornithopters that needed somewhat more power, like 25 watts per 100 grams, for level flight! I began wondering if using a rubber motor might somehow improve the wing efficiency.

One thing I thought should happen in a rubber-powered model is that, since there is almost no load on the motor as the crank goes through dead center, the motor should jump forward quickly without doing any useful work. A lot of energy would be wasted in the wing turnaround, and in Tim Bird a lot of it is converted to noise. I thought electric ornithopters would have an advantage because of their smooth wing turnaround and flywheel effect.

On the other hand, maybe the constant-torque, flywheelless rubber motor has the advantage. An electric motor produces a roughly sinusoidal flapping motion, whereas a rubber-powered wing flaps along a more triangular path. Which is better? I don't know. But considerations of unsteady flow characteristics *might* reveal that the more punctuated movement of the rubber-driven wing produces more lift and thrust.

Not so much to cash in on any advantages of a less sinusoidal flapping motion, but to allow a more constant engine speed in gas ornithopters, several people have talked about using a rubber band to transfer energy from the engine to the flapping mechanism. I don't know of anyone actually doing this, except that Joss Levy used a steel spring to similar effect in his $CO_2$-powered ornithopter. With each flap of the wings, the motor runs at nearly constant speed and torque, its job being to keep the spring wound up. The spring unwinds a little with each wing turnaround and during the upstroke. It winds back up again, half a turn, when the downstroke loading slows the motion of the wings. The device supplies more power during the downstroke, when it is most needed.

Concerned that the explosive unwinding of the rubber band between strokes might constitute a waste of energy, just as it does when the crank of a rubber-powered model goes through dead center, I conducted a simple experiment using a reduction motor, a rubber band, and a crankshaft which drove an ornithopter wing on my test bench. The flapping rate was determined in two states. First, with a rigid shaft, and second, with the rubber band connected between the gearbox and the crankshaft. A mechanical counter was used to measure the number of flaps per minute. The results were as follows:

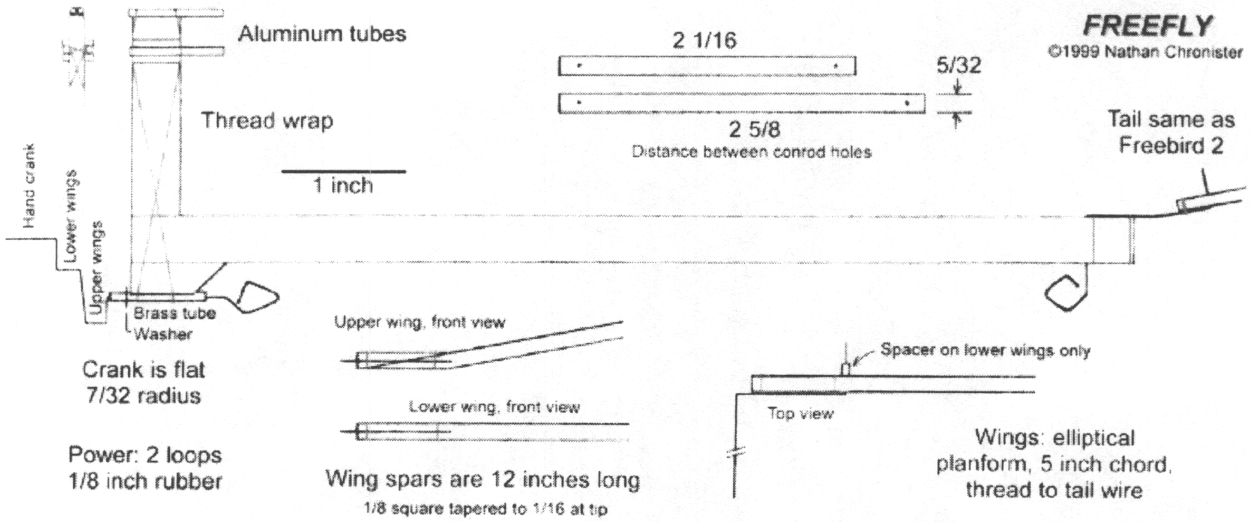
| Trial number | 1 | 2 |
|---|---|---|
| Rigid shaft RPM | 51 | 50 |
| Rubber band RPM | 49 | 49 |

To me, these numbers seem to suggest that there wasn't much power loss. Dead center unwinding of the motor probably doesn't waste energy in this case, because unwinding decreases the motor load. My equipment didn't allow me to address the more interesting question. Which one produces more lift and thrust, a wing sinusoidally flapping at 50 cycles per minute, or a wing flapping abruptly at 49 cycles per minute?

I'd like to see some actual flight experiments comparing sinusoidal to triangular flapping cycles. Or other flapping cycles. While it would be a big project to build an electric ornithopter with a spring in the drive system, it might be somewhat easier to build a rubber-powered model with a flywheel to level out the crank rotational speed.

# OS Directory

Want a copy of the new *OS Member Directory*, or a directory sign-up sheet? Send a business-size, self-addressed envelope to the address on the front cover.


FREEFLY
©1999 Nathan Chronister
Aluminum tubes
Thread wrap
1 inch
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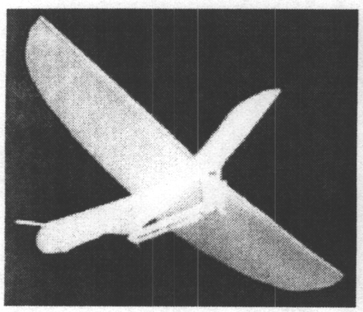
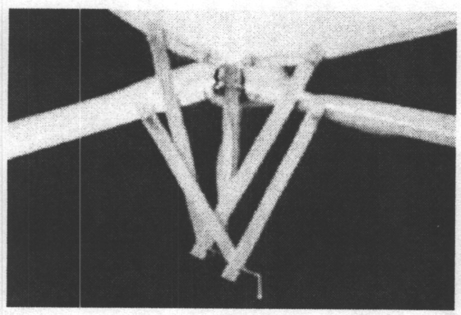
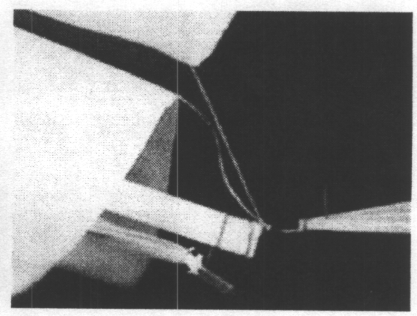
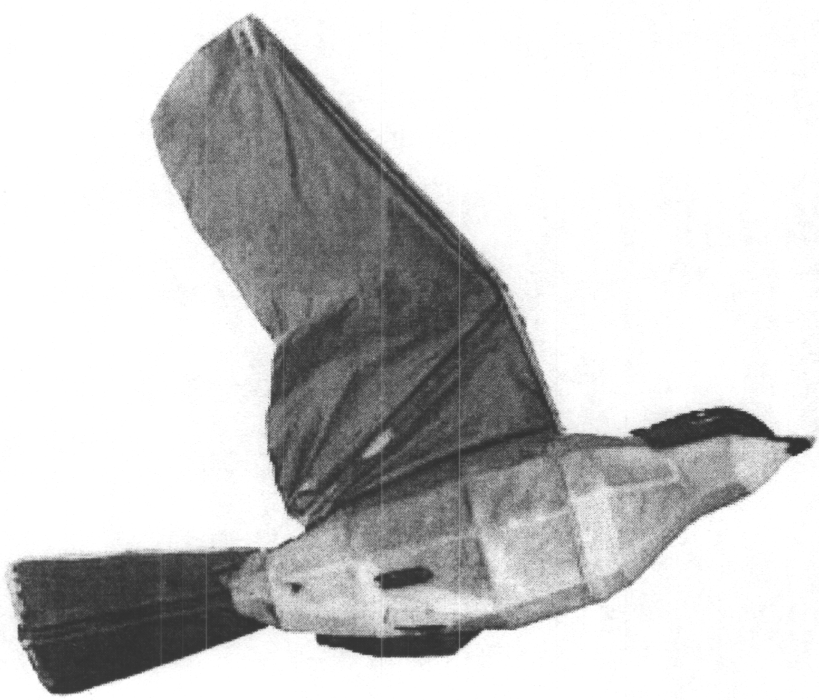
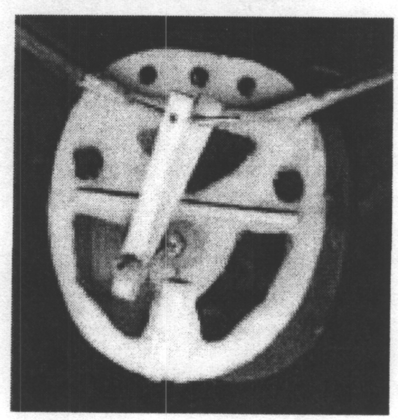
Distance between conrod holes
Tail same as
Freebird 2
Hand crank
Lower wings
Upper wings
Brass tube
Washer
Crank is flat
7/32 radius
Power: 2 loops
1/8 inch rubber
Upper wing, front view
Lower wing, front view
Wing spars are 12 inches long
1/8 square tapered to 1/16 at tip
Spacer on lower wings only
Top view
Wings: elliptical
planform, 5 inch chord,
thread to tail wire











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## FlapDesign Makes it Easy to Plan Mechanisms

Here is a screen snapshot of Nathan Chronister's new computer program for designing ornithopter mechanisms. The program is easy to use, comes with instructions, and runs within your web browser. Use the program to make sure your mechanism will produce the desired flapping amplitude, and use it to avoid common problems like lockup. It can be accessed at the Flapping Flight Web Site, www.catskill.net/evolution/flight. At the Welcome page, click on "Resources".