Flapper Facts

Newsletter of the Ornithopter
Summer Modelers' Society 1998

Editor/Publisher: Nathan Chronister, PO Box 376
Arkville, NY 12406 USA
Membership dues, payable to the editor:
New members: $14 for one year ($21 outside USA)
Renewal: $9 per year ($14 outside USA)

GRAVITY GLIDER and Aerial Yo-Yo by TR Quermann

Roy Clough's Gravity Glider [Spring 1998 issue of Flapper Facts] triggered my memory of a somewhat similar concept with an intended practical goal. I believe in 1947 someone proposed an aerial yo-yo. This device consisted of an autogyro-type rotor pivoted on the top end of a string. Pulling the string down changed the pitch of the blades and accelerated their rotation. Releasing the downward tension on the string caused the blade pitch to increase, causing the rotor to climb as it decelerated. Properly timed pulls on the string were supposed to keep the rotor flying at the top of the string. The practical goal was of course to market it as a toy or perhaps an emergency antenna support.

This is obviously a multi-wing, plunging-wing ornithopter flying in an extremely small circle having an external (downstroke-only) drive. Will it work? How would one go about launching it? A couple of equations and a little calculus led to some interesting conclusions:

Gravity Glider

1. Assuming steady-state, level flight and constant velocity of the falling weight, the wing supports essentially all of the weight. It is relieved only by the aerodynamic drag of the falling weight.
2. For a minimum velocity of the weight, the weight must be twice as heavy as the empty craft. See Note 1.
3. The maximum velocity of the fall of the weight will be approximately $(2.5C_D)/(EC_L)$ times the level flight velocity where E is the drive efficiency.

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SPECIAL PLANS ISSUE COMING SOON!

Fall 1998 Flapper Facts will be a special issue of nothing but plans! From indoor to engine-powered, vintage and new plans will fill the entire issue! Be sure to renew your membership today so you don't miss it! See instructions on the left side of this page.

Freebird 2 Now Online

www.catskill.net/evolution/flight/freebird.html

Get started in flapping flight with this simple but effective ornithopter, even easier to build than the original Freebird. Designed specifically for the first-time ornithopter builder, it also allows experienced designers to try new ideas quickly. Unusual system uses differential flapping amplitude to control flight direction, just like a real bird! Plans and complete instructions are available free online. Freebird 2 will also appear in Fall 1998 Flapper Facts!

People all over have been experimenting with Freebird. Simple construction means you can try more ideas in less time. From simple modifications of the flapping mechanism, to weight reduction, to major changes in the wing design, the possibilities never end!

Ben Hartley wrote: "This may not be a new hazard in ornithoptering, but my Siamese cat, who *loves* to chase flies and moths, thinks Freebird would be a dandy thing to chase and bat at!"

In This Issue:

Electric RC Flapper

by Les Garber

I've been reading about efforts with electric flappers in recent issues of Flapper Facts. Thought you might be interested in my own latest attempts. For several months I've been working on an electric-powered RC ornithopter that is essentially a scaled up (60 in span, 480 in^2, 20 oz, 6.0 oz/ft^2) version of one of my designs that appeared in Flapper Facts c.1985, a teeter-totter tractor biplane. Construction is mostly carbon fiber with several parts machined from aluminum alloys. As an engineering professor, I do quite a bit of work with composite materials and have access to milling machines and lathes. (I'm a marginally competent machinist.)

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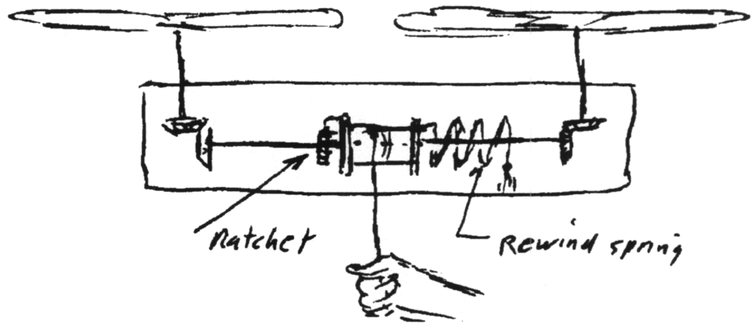


4. By juggling the propeller and spool parameters to permit a higher weight velocity, the model can be made to climb during the power phase.
5. The model will pop up when the cord is exhausted the same as a towline glider will zoom if the line is released under tension. It will also zoom when the weight is initially released and is accelerating.

Aerial Yo-Yo

I don't know of an easy way to analyze this device. It's a question of how much altitude is lost during the acceleration of the rotor vs the altitude gained during its deceleration. In an attempt to examine the concept I started with the zoom launch characteristics of F1A gliders. From an article published in the 1991 NFFS symposium, a height of 40 feet was achieved with an initial velocity of 76 ft/sec and a final velocity of 15.3 ft/sec. This shows a conversion of about half of the excess kinetic energy to altitude. For simplicity I assumed acceleration along a path with a constant slope. Since all of the horizontal accelerating force must come from the aerodynamic forces which (assuming constant C_L) are proportional to velocity^2, the pulling force must increase as velocity^2. Assuming a flight path of -10° and L/D=10 I calculated a loss of altitude, in accelerating from 15.3 ft/sec to 76 ft/sec, of about 27 feet.

These numbers are certainly encouraging, but scaling things down to a rotor with an accelerating height loss of 3 feet is quite a jump. At the moment, my guess is that building and flying an aerial yo-yo will be very difficult — a task well suited to ornithopter modelers. See Note 2.

Line-Powered Tethered Helicopter

There is another approach to a helicopter that can be flown by periodic pulling of its tether. If a spool similar to Clough's Gravity Glider is rigged to drive a pair of helicopter rotors, it could (in theory) climb while the weight dropped. Now if the weight were replaced by a hand and the spool equipped with a ratchet and spring, the desired continuous manually-powered flight should be possible. Obviously one will have to pull quite fast, and the rewind will have to be fast. I suspect the time spent reversing the spool will be a significant factor.

Note 1: It didn't occur to me until after I went through the math and found that the maximum weight velocity for level flight required a weight twice that of the empty model that I realized that the falling weight is equivalent to a rubber motor. The energy stored is the weight times the length of the string whereas the maximum energy stored in a rubber motor is its weight times some constant depending on the rubber quality. The power required for level flight depends upon the total (weight)$^{3/2}$. The duration of level flight that can be achieved is the total energy stored divided by the power required. Maximum duration will be achieved when $R/(R+w)^{3/2}$ (R = rubber weight w = model weight) is a maximum. It is well known in free flight circles that the maximum is achieved when R=2w.

If this is true, why is this ratio not evident on record-holding models? The answer is that a model built to handle twice its weight in rubber is significantly heavier than one built to handle, say, half that amount of rubber. The loss resulting from using rubber weight equal to model weight is more than compensated for by having a lower model weight.

Before rushing out to build a gravity glider, one should note that the length of string required to match the powered flight duration of a rubber-powered model with the same weight of rubber as the falling weight is about 2000 feet. If you are already at 2000 feet, who needs power?

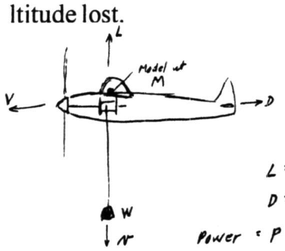
If you really wanted to build a gravity glider, I would recommend flying the model with rubber power so that the torque required for the type of flight desired can be determined. The spool radius is then torque required ÷ falling weight.

Note 2: [Unlike the wings of a typical ornithopter] the yo-yo blades move up and down the same amount at each point along their span. It is their horizontal velocity that varies along the radius. Thus to keep the leading edge pointed into the relative airflow, the pitch at the root must change from nearly 90° during the upstroke to nearly -90° during the downstroke. The corresponding angular changes are much less at the tip. Thus the pre-twisted flexible wing approach of the ornithopter is not a good choice for the yo-yo.

My choice would be a helicopter-like construction with the collective pitch spring-loaded to positive pitch for climb and held to a negative pitch by the pull of the string and the lift of the blades. Don't forget to add a freewheeling handle that can be used to pump it up and down to get the blades up to speed for launch.

I don't have any rigorous calculations but some simplified attempts indicate that the length of stroke required is proportional to the tip speed so it would be a good idea to keep it light. These studies also indicate that the rotor speed at the end of the downstroke will have to be at least three times the hover speed to gain back the a

ltitude lost.



Assume level flight, E = efficiency of drive

$$L = M + W = KV^2 \qquad (1)$$

$$D = \frac{C_D}{C_L} K V^2 \qquad (2)$$

$$\text{Power} = P = DV = \frac{C_D}{C_L} K V^3 = E W \nu \qquad (3)$$

from (1) $V = \sqrt{\frac{M+W}{K}}$

substitute in (3) $E W \nu = \frac{C_D}{C_L} K \left(\frac{M+W}{K}\right)^{\frac{3}{2}}$

(4) solve for ν $\quad \nu = \frac{C_D}{C_L E \sqrt{K}} \frac{(M+W)^{\frac{3}{2}}}{W}$

differentiate (4) with respect to W, $\quad \frac{d\nu}{dW} = \frac{C_D}{C_L E \sqrt{K}} \frac{\frac{3}{2} W \sqrt{M+W} - (M+W)^{\frac{3}{2}}}{W^2}$

to find W for min ν set $\frac{d\nu}{dW} = 0$ and solve for W

$$\frac{3W}{2} \sqrt{M+W} = (M+W)^{\frac{3}{2}}$$

(5) $\boxed{W = 2M}$

to find ν_{min} substitute (5) in (4) $\quad \nu_{min} = \frac{C_D}{C_L E \sqrt{K}} \frac{(3M)^{\frac{3}{2}}}{2M} = \frac{3^{\frac{3}{2}}}{2} \frac{C_D}{C_L E} \sqrt{\frac{M}{K}}$

but $M = K V_0^2$ where V_0: level flight speed of model without weight W

$$\boxed{\nu_{min} = 2.598 \frac{C_D}{E C_L} V_0}$$

In terms of V, $\quad \nu_{min} = 1.5 \frac{C_D}{C_L E} V$

Building Tip

In gear-driven ornithopters, the final gear often fails to grip the output shaft under the substantial loads encountered during flight. The shaft itself is also a weak point. You can avoid these problems by building the crank directly onto the face of the gear.

Garber, continued from Page 1

The flapping mechanism is made of aluminum, steel, and carbon fiber (CF) and has been built and rebuilt several times. It has been run a lot on a test stand and now seems adequate for further testing. My crude estimates are that a flapping rate on the order of 150 cycles/min and a power consumption on the order of 60 to 80 watts will be required. The mechanism is driven by a Speed 400, 7.2V motor and a 60:1 planetary gear box. I've done a lot of digging around in surplus stores etc. and have a collection of some 15 small gear boxes of various designs. The 60:1 planetary gear box I'm currently using on my test stand came out of a $10 electric screwdriver I found at K-Mart.

The wing frames are carbon fiber tubes with small machined aluminum fittings. The wing planform is a swept back leading edge carbon fiber tube with CF root and tip ribs. The tip ribs rotate to stops to vary the angle of attack on up and down strokes. The trailing edge is free to move up and down as is common in indoor designs. The wing covering material is a thin mylar sail cloth that has a fine nylon scrim reinforcement and weighs 0.55 oz/yd^2. This material has no elastic properties and therefore wrinkles under torsion. Perhaps a better covering material would be thin latex sheet; it is available in sheets as thin as 0.006 in.

[Garber later wrote:] Have continued working on a 62 in span, two-winged (540 in^2), electric powered (6V Speed 400, 60:1, 7-500 AR cells) ornithopter with a gross weight of 22 oz. Construction is mostly carbon fiber and machined aluminium fittings.

Began testing in my basement by stringing a 20 ft wire across a room. A trolley made of 3/32 Al wire and two small Al pulleys is mounted on the wire and the model is mounted upside down on the trolley. A big block of foam at one end absorbs the impact when the model reaches the end of the wire. These tests showed that the finalized design had plenty of thrust.

First flight test was 2 Jan 98; the model was hand-launched and climbed to an altitude of about 20 ft and then spiral dived to the right (crash damage was minor). Video tape analysis showed that total flight time was about 3 seconds and clearly shows that the model accelerated forward and climbed. I have rebuilt the tail feathers to provide more control and hopefully counterbalance the strong right turning forces. Hope to make further flight tests within the next week. If I get any good flights in the near future, I will send video tape.

What are your thoughts about my efforts? What would you recommend for a wing covering material? I would be most interested in comparing experiences via E mail: lgarber@d.umn.edu. "A wise man learns from the mistakes of others whereas a fool learns from his own mistakes." [Seldom more true than with ornithopters!]

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March 4, 1998

Dear Nathan:

Please find included some information on my EZE Flyer (tm) system, for the Ornithopter Modelers Society's web pages and publication. This system is necessary for giving ornithopters the ability to fly like true birds.

Before the EZE Flyer system, ornithopter wing movement had been severely hampered by the complexity involved in reproducing natural flight. As a result, ornithopters have largely been limited to linear flapping, usually at right angles to the fuselage. The EZE Flyer system reproduces natural flight quite simply (figures 1 and 2). It gives ornithopter wings the ability to flap in any direction, straight, curving and diagonally, singly or in tandem, to give ornithopters the astounding maneuverability of birds (figure 3).

The EZE Flyer system provides a much greater range of wing sweep than any variable geometry wing aircraft (such as the non-flapping F-14). And it does so with minimum weight, maximum strength, power, balance and control throughout the wingbeats. As on natural flyers, the propelling force on the wings always remains near the center of balance, instead of concentrating on the leading edge and causing extreme twist like on most existing ornithopter designs.

Allowing a wide and natural range of controlled wing movement prevents shocks to the wing mechanism that may result from gusts coming from any angle, it allows the wings to be trimmed for any speed to adapt to most wind conditions, and to flare for pin-point, bird-like landings. These features will greatly increase the flight envelope of ornithopters and of any non- flapping winged aircraft (see drawing of EZE Flyer Ultralite aircraft). The EZE Flyer system allows wings to be swept backwards and forwards with no radical changes in pitch (the wing root moves forward as the wingtips move back and vis.), without adding complexity (figure 3), something that birds accomplish by pulling in their articulated wings. In fact, with the EZE Flyer system, articulating wing surfaces will not be needed on ornithopters and most other non-flapping wing aircraft. The wings will be simpler, lighter and stronger than before.

On flapping, the wingtips of most natural flyers describe a figure 8 for maximum power and lift. The EZE Flyer system makes it possible for the pilot to move the ornithopter's wings in the same way. At the peak of the upstroke and start of the downstroke, the wing's leading edge spar bases on the cars are moved forward by the actuators and the wingtips move back (figure 3a). In mid-stroke or glide, the l.e. spar bases on cars lie midway on the car tracks (figure 3b). In the downstroke and beginning of upstroke, the l.e. spars bases on cars are pulled to the rear by the actuators, causing the wing tips to move forward (figure 3c).

On EZE Flyer ornithopters, control may be achieved via data gloves with force feedback from different parts of the flexing wings. The pilot will control the wings by moving his hands and arms in imitation of a bird in flight while in the prone position, hanging on a hanglider-like harness (figure 4). Or alternately, while sitting or supine on a seat or airbag. The tail can be controlled in the same way, by leg movements. Wings and tail can also be controlled by joysticks, autopilot and microprocessors. Though they may be equipped with automatic collision avoidance systems, piloted EZE Flyer ornithopters will be able to flare, flap and hover, and/or change direction quickly in mid-air, like living flyers do. Flying will become simple and instinctive to learn.

Extreme bird-like wing movement will also enable pin point take-offs and landings from almost anywhere on land and water without prepared airstrips. I have invented various ways to assist take-offs from any surface: Jump takeoffs can be made with a short onboard bungee system that will give the craft just enough flying speed and wing clearance. (please see drawing of the EZE Flyer system as used in ultralights). Kiting into the wind will assist this kind of takeoff. Amphibious ornithopters will be able to kite off the water, attached to a line with a retractable anchor or sea anchor. Ideally on land, long lightweight composite take-off (and landing) gear under tension will catapult the craft into the air for jump takeoffs (figure 4). The gear will also cushion the shock of pin-point landings. Sudden acceleration or deceleration would place great loads on separate structures, so the EZE Flyer Ornithopters will be modular, built around a simple, but strong central frame that unites the takeoff gear with the power and control source, the pilot pod and the wing and tail mechanism.

Included is a copy of an article that appeared in Machine Design in September 1994. It shows a promising source of ornithopter flapping power. It is a type of linear electric motor, a pneumatic-electromagnetic actuator called a PEMRAM, which produces great controlled power on demand, with minimal energy usage and comparatively light weight. Invented to be used as actuators in flight simulators, they give the shock damping advantages of pneumatics combined with precise linear actuator positioning. One actuator on each mainspar is sufficient to power the EZE Flyers (two small actuators will also be needed to sweep the wings). As of this date, it is likely Pemrams will have been improved upon. However, I have not been able to contact Phillip Denne, of Denne Developments, who is the inventor. Other existing combinations that can produce power on demand can be also used.

Bill Moyes, the Australian father of hangliding, studied my EZE Flyer hanglider/ultralite model in a visit to my home during a North Florida fly-in last year. He commented, "this is the future". With such an endorsement, I decided to present it to Lockheed Skunkworks in California. They found the EZE Flyer system so promising, that I decided to patent it.

Advanced Sailcraft's EZE Flyer Ornithopter project (EFO) is looking for investors and collaborators on the world's first, practical human piloted ornithopters. Projects on non-flapping wing craft with the EZE Flyer variable sweep system will be also be evaluated.

Best regards,
Enrique
Dr. Enrique G. Petrovich
President, ADVANCED SAILCRAFT

EZE Flyer (tm) System

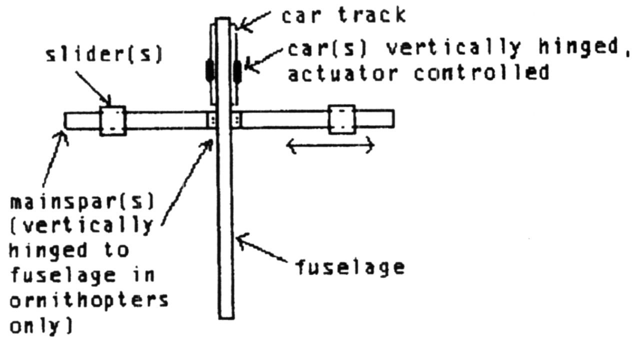


figure 1

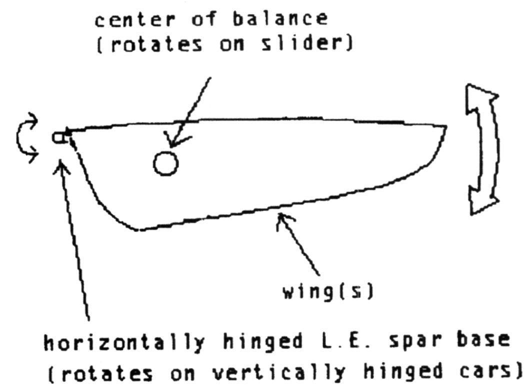


figure 2

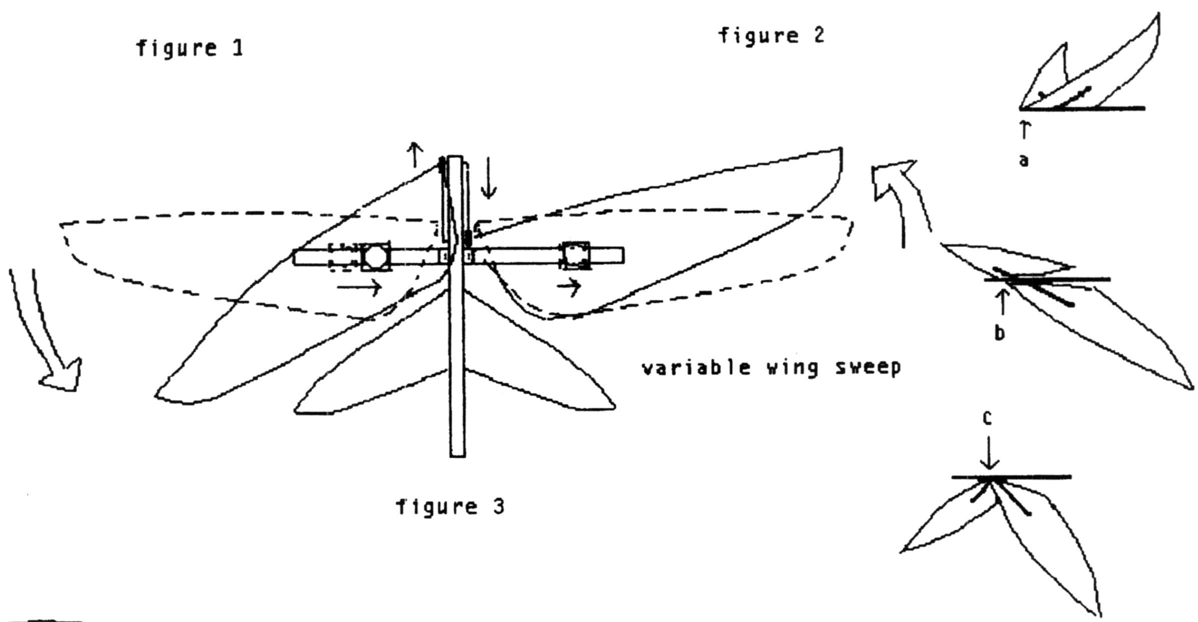


figure 3

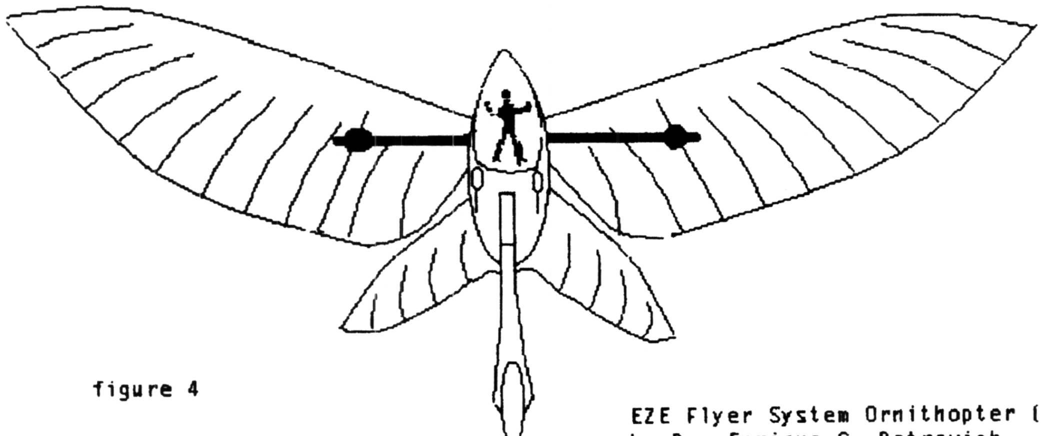


figure 4

EZE Flyer System Ornithopter (pat.pend.)
by Dr. Enrique G. Petrovich

Innovative motor lets low-cost simulators rock and roll

Until now, flight simulators and virtual-reality arcade games relied on inefficient hydraulic pistons to supply the realistic motion. These hydraulic rams waste up to 98% of the input energy and are also expensive, heavy, noisy, and prone to leaks. A new type of electric motor, called a Pemram — for pneumatic electromagnetic ram — developed by Denne Developments Ltd., Bournemouth, U.K., could replace hydraulics and dramatically cut the cost of virtual-reality games and simulators.

According to its inventor, Phillip Denne, a physicist and engineer, the new motor can be visualized as a typical electric motor sliced down the middle, rolled out flat, and then rolled back up again by bringing together the long edges of the strip to form a cylinder. Denne did the same with the armature, and put the armature shaft down the cylinder's center to make a piston.

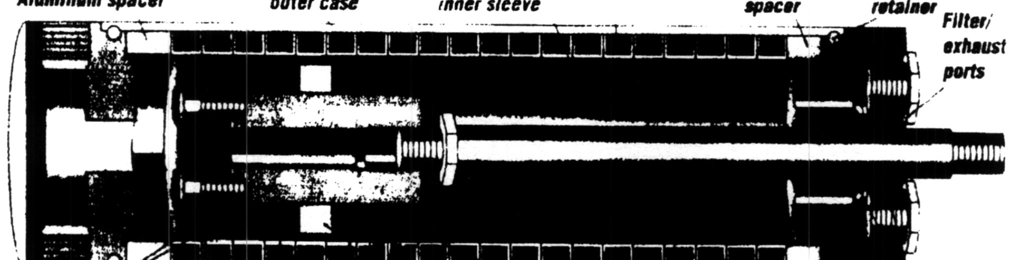
The new linear motor, which doubles as a pneumatic cylinder, combines fast and precise positioning with the force of fluid power. Air pressure supplies the static load, but electromagnetics produce the dynamic forces.

In simulator applications, Pemrams support the user on a platform or chair. They are gas pressurized to bring the user to the midposition, then sealed. No more gas is needed during the simulation. During operation, the user floats on these gas springs, and the electromagnetic actuators provide impulse forces. Unlike hydraulic actuators, Pemrams need no power to keep the user in the midposition. They only consume power when the simulator is in motion, and even then only enough to change the kinetic energy of motion and to overcome frictional losses.

Pemrams might also be used to control vibrations, in active suspensions to stabilize platforms, or as robotic components. Designers once considered pure pneumatics for such tasks, but air's elasticity makes precise positioning with pneumatics difficult. Adding electromagnetics makes positioning consistent and precise. And the natural bounce of pneumatics makes Pemrams well-suited for applications demanding compliance. Pemrams could also find a niche in medicine because they lack rotating/moving parts and have hermitic seals that allow them to be sterilized. ■

With Pemram actuators, motion-based simulators consume only a few hundred watts of power, compared to several kilowatts required by even the smallest hydraulic-based simulators.

The first production model of the Pemram will be 120 mm in diameter and produce a thrust of about 1,500 N over a 200-mm stroke. It will support a maximum airsprung deadload of 660 lb and weigh 53 lb.



Upstroke Efficiency by TR Quermann

I just read the Spring 1998 Flapper Facts and as usual found it very interesting. Kinkade's VT2 seems to demonstrate that Spencer's approach is still a practical way to go. I'm sure most of us feel there must be a better way, though, or we wouldn't be fooling around with ornithopters.

In the Fall 1997 issue, Joss Levy commented that his ornithopter required twice the power of an equivalent fixed-wing model. Assuming that power required is proportional to $C_L^{3/2}/C_D$, the ornithopter exhibits a C_L of 0.63 times the fixed wing C_L. Based on some calculations I made a few years ago, this looks pretty good to me.

As I see it, the two fundamental problems associated with ornithopters are: 1. What is the most efficient flap and twist cycle and 2. How can one best implement this cycle. With fixed wings, the general goal is high aspect ratio, elliptical planform for best efficiency. For ornithopters? The wide variety of flap strategies has not, to my knowledge, been distilled to any theoretical optimum with an associated maximum effective C_L. If we don't know what we are trying to do, how can we know how close we are to achieving it? How bad is the membrane wing? How much better can we hope to make a fully controlled wing?

In an attempt at understanding the operation of a highly idealized sinusoidal up and down flapping motion, I looked at two upstroke twist configurations. The first twisted the inner portion to operate all of its elements at C_L=1, while the tip portion was positioned and twisted to operate at a C_L=-1. The relative areas of the inner and outer portions were varied to achieve a thrust (average full cycle) of 0.2 times average lift with a peak tip vertical flap velocity equal to flight velocity. The average lift coefficient turned out to be a little over 0.8.

For comparison I looked at an idealized wing that linearly varied the upstroke C_L from 1 to a value that would make the average thrust equal 0.2 times average lift at a peak tip flap velocity equal to the flight velocity. This turned out to be a tip C_L of 0.3. The surprising result was an average C_L of a little over 0.8, essentially the same as the first scheme.

I'm not sure what it all means, but I am convinced that deviations from a linear C_L vs span characteristic are not likely to produce significant improvements. Since a teeter-totter wing can be built with a fixed difference between upstroke and downstroke tip angle of attack, I'm thinking of trying it on a tandem. One still must build in the proper elasticity to achieve the desired C_L=1 on the downstroke. So far I haven't come up with a good way to make an adjustable spring.