Flapper Facts

Newsletter of the Ornithopter Modelers' Society

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How to Join OMS: If you are reading someone else's copy of Flapper Facts and want your own membership, you can join now by sending $9 ($14 outside the US) to the address above. Payment should be made to "Nathan Chronister."

Member Survey and Contest

Since the summer issue is coming out earlier than expected, and since most of the survey reply cards are not in yet, these matters will be postponed until the next issue. If you did not already send in the survey card from the spring issue, please do this right away if you want your votes to be counted.

Ornithopters on the Internet

Some of my spare time lately has gone to setting up an ornithopters page on the World Wide Web. It presents a fairly thorough introduction to ornithopters, but it is also a new source of information for the more experienced. I've taken a unique perspective on flapping flight by relating it to several areas of advanced technology. The page also includes new information on designing ornithopters (including engine powered models) not found in the *Design Manual.* You will find several photographs, and there are even some movies of P.H. Spencer's gas powered ornithopters in flight. The URL is: http://www.bucknell.edu/~chronstr

If anyone is interested in participating in an unofficial e-mail mailing list for discussing model ornithopter design problems, let me know at chronstr@bucknell.edu.

RC Ornithopter

Francis Reynolds

This will be a short progress report on my RC ornithopter efforts. I don't recall if I sent you any photos of the first bits of mechanism, but here are a few. The skeleton mechanism shown in one photo (without the rest of the cog pulleys and belts on it yet) gets integrated into the wooden fuselage structure. I took its photo out in the open because it will be difficult to see it all at one time in the fuselage.

My machine will be a glow-powered 100-inch-span monoplane ornithopter, which will be rather seagull like. It will weigh around eleven pounds. You may recall that for the past year I was teamed up with two other engineers in researching and studying ornithopter theory. That team effort is now largely over, but I think we came up with a significant improvement in flapping aerodynamics over anything which has been done before. We are not disclosing that yet. I believe at least some birds use "our" concept in high-speed flight.

In addition to this supposed improvement, my ornithopter will have mechanically-pitched and twisted wings, RC controlled in pitching amplitude, which will be properly phased with the flapping action. All previous orni attempts which I am aware of have used passive or aerodynamic twisting of the wings.

Also, my bird will have a mechanism to level the wings to the proper dihedral for a controllable glide after the engine quits or when it is throttled down so the centrifugal clutch drops out. Without such a feature, if the engine stops with the wings down, it will be unstable and crash. DeLaurier and Harris had that problem. These additional mechanisms of mine are designed, but not yet built. They add weight and complexity, but I hope they will be worth it.

I had intended to design and build a tandem rocking-wing slightly-dragonfly-like RC ornithopter, which would have been efficient and easy to design and build compared to what I am now doing, but its lack of natural appearance led me to abandon it.

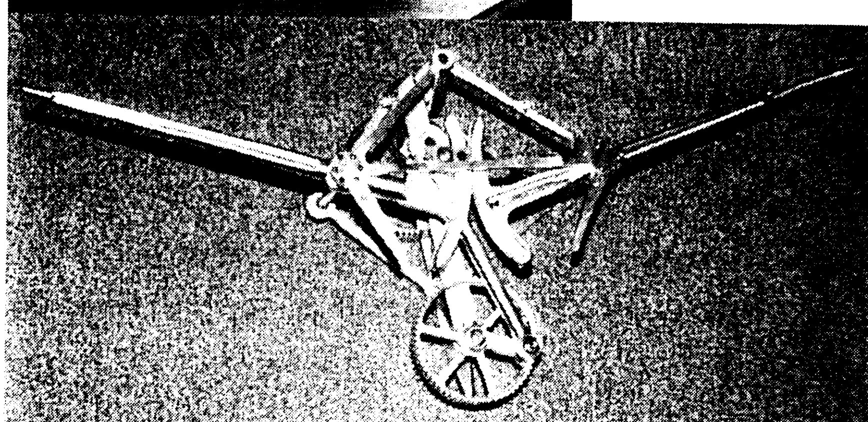
I am at least a year away from my first flight attempt. If I find I have bitten off more than I can chew in my present project, I may return to the simple and light tandem rocker concept.

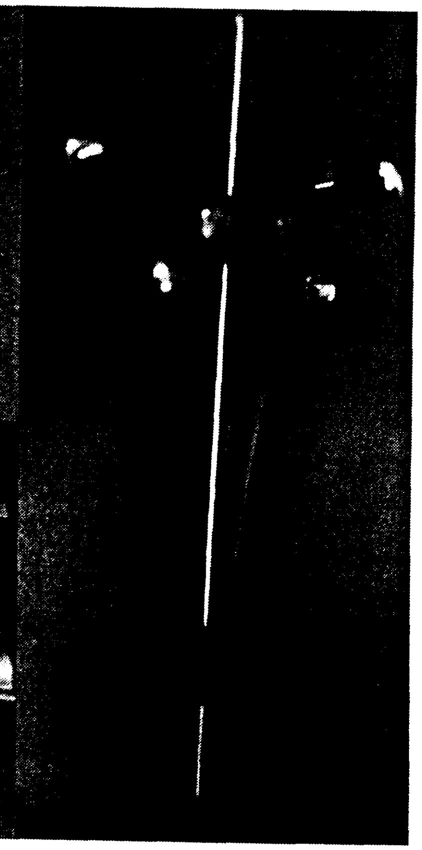
Top: The nose of Francis Reynolds' RC ornithopter. It will be cowled.

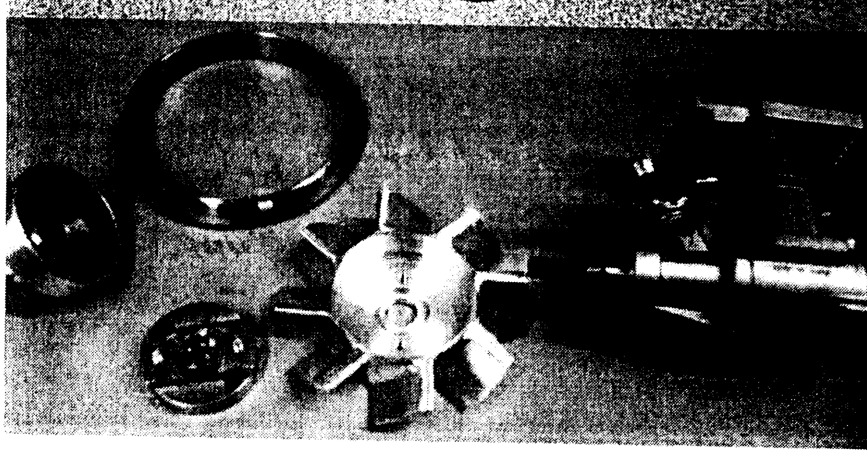
Center: Main flapping mechanism for Reynolds RC ornithopter. All home machined.

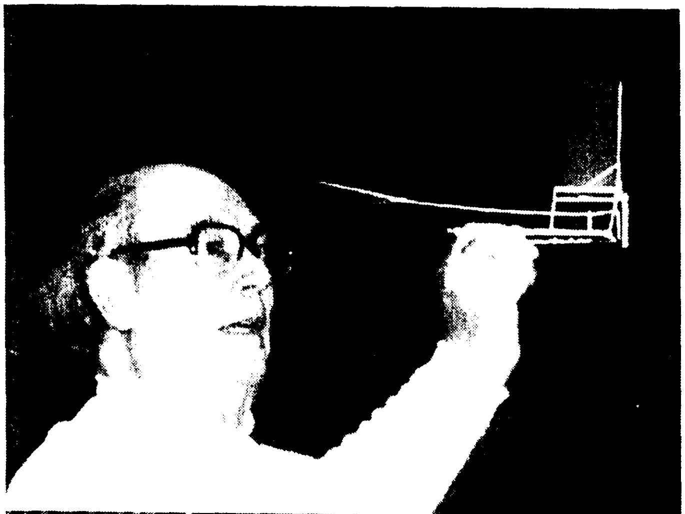
Bottom: Powerplant for Reynolds RC ornithopter. Centrifugal clutch, home-machined fan & flywheel ring were shrunk-fit together.

Below: Centrifugal actuator in Reynolds RC ornithopter will switch on an aux. electric motor to level the wings for gliding or landing.



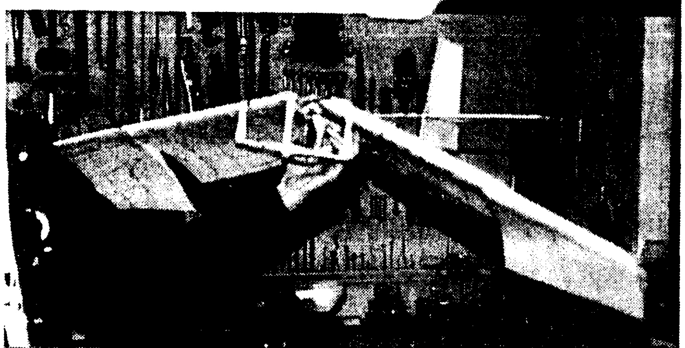






The Mosquito John White

Plan may appear in Aeromodeller some time in the future. A modified model with tailplane hinged at end of motor stick, driven by a conrod. Was flown outdoors on a calm day and was lost in a riser.



Electric Ornithopter

Electric freeflight ornithopter by Rob Jenny, Bellevue, WA, 1994. It has not flown yet. (Francis Reynolds photo)

DeLaurier and Harris

James DeLaurier (left) and Jeremy Harris in Reynolds workshop, October 1994. They are holding a test ornithopter wing panel by Reynolds.

WALTER C. ERBACH
2979 DUDLEY ST.
LINCOLN, NE. 68503-1847

Feb. 20, 1995

Dear Nate:

In your most recent issue of Flapper Facts (#9) McIlrath makes two suggestions for ornithopters: a mechanical linkage to alter the ratio of power stroke to return stroke and (if I understand correctly) the use of floppy covering with a rib type stiffner. In answer I would say this: A number of years ago, prior to my breaking a 40 odd years old ornithopter record of Turners, I did an enormous amount of experimenting in an attempt to break his record. After doing so I detailed my experimentation and the results thereof in an article which appeared in "Model Builder". Included in this work were the two items now suggested by McIlrath. Neither was an improvement.

One of my attempts was the building of a quick-reurn mechanism to do exactly what McIlrath proposes, so that up and down strokes of the connecting rods take difrent amounts of a revolution of the crank arm. All of my efforts with this linkage produced poorer results than the simplest connecting rod whether the quick return was for wing up stroke or down stroke! The same was true for McIlrath's suggestion of what seems loose covering, kept from appearing sagged by a crosswise stiffner. It produced poorer results than flat but not limp covering.

In fact, several years of experimentation produced only one improvement and this by serendipity. My son and I were regularly attending Chicago Aeronuts monthly record trials in Chicago area national guard armories (yes, over a thousand mile round trip monthly during the winters just for the sake of flying indoors). On one such occasion one of my powerful ornithopters of the usual configuration (close coupled tail) spanked off its tail section in midflight. To my utter astonishment the wing section kept flapping but flying, diving, then nosing up repeatedly, exhibiting a stable center of pressure travel, instead of plowing in as would have been expected. Well, you don't have to hit me over the head: If the wing alone acts stably why have builders been using a close-coupled tail with huge negative incidence that gulps lots of power? Back home I immediately began to try long tail booms to move the center of gravity well behind the wing (120%) and achieved substantial increases in duration with much less power. That's what finally broke Turner's record, an ornithopter that climbed vertically under high power, casually leveled out, flew without the rocking chair gallop and glided glided smoothly and shallowly as the power ran out.

In closing, several years of experimenting uncovered only one improvement in the ages old style of monoplane ornithopter, the lengthened tail boom (two if you include the first class lever arrangement for the wing-connecting rod system rather than the more common third class). Slatted wings, loose or tired paper (atrocious), stiffening ribs or thin balsa sheeting, nothing was an improvement. Obviously, if builders wish to experiment, they're free to do so. However, they should be forewarned before setting out to re-invent the wheel.

Sincerely,
Walter

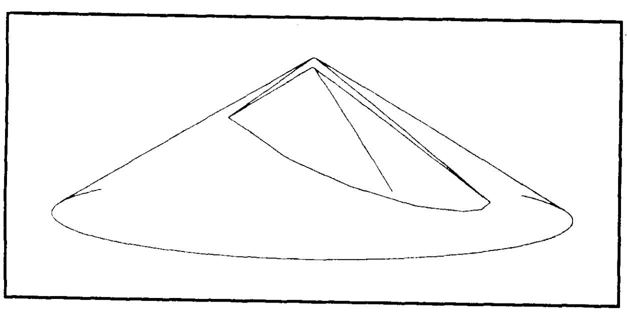
A New Twist For Membrane Wings

Nathan Chronister

Membrane wings have often been criticized for their inefficiency, yet most ornithopters still use them. Their simplicity and light weight seem to have won out over improved aerodynamics, at least for rubber powered ornithopters. Since they are so widely used, it may be worthwhile to take a close look at the membrane wing and see what can be done to make it not quite so inefficient after all.

The first point which must be made concerning membranes is that they can only form certain shapes. Unless the membrane material is stretchy, like cloth or latex, it cannot form compound curves. If the wing structure is poorly designed, then aerodynamic forces will try to force the membrane to form compound curves, and this will result in buckling of the wing surface. You can use a strip of paper to see which shapes a membrane can and cannot assume without buckling.

The supporting structure of the wing should be designed so that the membrane can change in pitch without being forced into a shape that will cause it to buckle. Many ornithopters have not done this successfully. As pointed out in the *Design Manual*, if the spar and root rib are straight, then the membrane will form the surface of a cone whose apex is at the point where the rib meets the spar. Therefore, any rigid membrane stiffeners should also radiate from the apex, or else they will force the



membrane out of a conical shape and it will buckle. If you use very flexible stiffeners, however, these may be able to conform to the conical surface of the membrane even if they don't radiate from the apex. This is essentially why we align the tissue grain perpendicular to the lines radiating from the apex. The flexible fibers of the grain are stiff enough to help prevent spanwise wrinkles, but flexible enough to allow the membrane to form a cone.

Wing gussets, always popular in rubber powered models, often get in the way of the conical shape of the membrane. The solution is simple; wing gussets should extend right to the back of the root rib.

If the wing gusset extends far out onto the spar, however, it will result in a less efficient wing cross section, not only because the gusset itself causes drag, but also because having an inflexible flat plate ahead of the flexible part of the membrane is detrimental during both the upstroke and the downstroke, contrary to a popular myth.

The *Design Manual* points out that the membrane is shaped like the surface of a cone, but on a different page, it depicts the cross section as a flat plate. Obviously, because the membrane is conical in shape, it is not a flat plate at all; it is slightly cambered. The only places where it is not cambered are at the root and directly behind the gusset/spar junction.

The membrane forms a cone whose apex is at the intersection of the rib and the spar, if and only if the root rib and spar are straight. If they are not, then the apex of the cone may lie elsewhere, or the wing surface might not be conical at all. A variety of shapes are possible, none of which have compound curves. Care must be taken to insure that there is buckling in neither the upstroke nor the downstroke, and that the wing shape is appropriate.

An obvious "refinement" of the typical membrane wing is to introduce cambered ribs along the span. These are typically free to flop back and forth with the membrane. During the downstroke, these have no great benefit because the wing is cambered anyway. During the upstroke, they can be quite detrimental, because they prevent the membrane from assuming the appropriate negative camber. Only if the upstroke produced lift, as it does in birds and a few advanced ornithopters, would cambered ribs be acceptable.

One of the greatest inefficiencies of membrane wings is that, in most designs, they produce a large downward force during the upstroke. Some attempts have been made to minimize this upstroke negative lift.

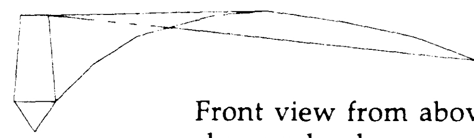
Several years ago, Larry Burks flew some models in which the root rib was inclined relative to the flapping axis. This affected the pitch of the entire wing, resulting in a more positive pitch for both the upstroke and the downstroke. The force produced by the upstroke therefore had a larger forward component and a smaller downward component. Burks has reported increases in lift and speed as a result of this modification.

By giving the wing a built-in twist, it is possible to do the same thing, without inclining the root rib. (At least for slow flight, the root rib should be declined, rather than inclined, relative to the flapping axis, to prevent stalling the proximal portion of the wing.) One method uses ribs (attached directly to the spar, unlike those discussed earlier) to define the pitch of the wing; this alternative is the torsionally flexible built-up wing, and regardless of whether the covering is single-surface or double, it is heavy and complex, not at all suitable for indoor models. Another, much simpler approach is to bend the spar downward.

In issue #9, Paul McIlrath presented an ornithopter using this technique. To avoid complications in membrane surface which might cause buckling of the membrane, McIlrath chose to extend the wing gusset all the way to the bend point. This allows the outer portion of the membrane to form a conical surface, which has a higher pitch than the triangular flat plate because of the down-bent spar. Because the average pitch of the distal portion is greater than that of the proximal portion, the wing is twisted.

In biplanes, wing twist causes a decrease in the amount of negative lift. In monoplanes, however, the duration of the upstroke is decreased, while the downward force component has the same magnitude (and the forward component has a greater magnitude). In either case, twist is beneficial.

The spar can be given a gradual curve rather than a sudden bend. This eliminates the need for an extended wing gusset and it allows a better cross section. Some buckling might occur during the upstroke, when the camber is forced to reverse, but careful design will eliminate this problem.



Front view from above shows why downward curve introduces twist.

At this point, the membrane wing still has two major shortcomings. These are the thin, single-surface cross section, which by definition, membrane wings are stuck with, and the loose flopping of the membrane which wastes power at the end of every stroke. The membrane becomes limp during the transitions between strokes, and at these times it produces no useful force. The rubber band unwinds a little, so energy is lost, but no lift or thrust is produced. The solution to this may lie in aeroelasticity, or the elastic deformation of the wing structure in compliance with aerodynamic forces. Aeroelasticity is normally associated with complex, thick airfoil wings with torsionally flexible, built-up structures. However, aeroelasticity is also a property of membrane wings, and it may have important implications for ornithopter design and performance. The *Design Manual* recognizes that the pitch of a membrane wing is influenced by the elastic properties of the wing spar as well as looseness of the membrane. What I would like to suggest is that it may be beneficial to increase the role played by the wing spar, and decrease the role of membrane looseness.

If the spar were completely rigid, the membrane (unless made of an elastic material) would simply flop back and forth to provide the pitch changes required for flapping flight. Most ornithopters approximate this situation fairly closely, as can be seen from the fact that very small forces such as the weight of the membrane itself can have a drastic effect on its pitch.

Loose flopping of the membrane is prevented by the use of a flexible spar which keeps tension on the membrane at all times. Because there is always tension, the membrane never experiences a floppy stage. Because the spar is flexible, the pitch changes whenever a force is applied, to an extent which is determined by the magnitude of the force. Thus, the pitch varies smoothly throughout the cycle, not abruptly at the end of each stroke.

Now it is fairly obvious that achieving this goal of more-aeroelastic membrane wings will require more-flexible spars than are currently used. Flexible spars cause some energy to be lost as the spar reverses its direction of bend at the end of each stroke. This is a problem especially if the flapping amplitude is low, since in this situation, the spar may spend more time bending back and forth than it does actually exerting force on the air. What we need is a way for the spar to bend forward and backward (allowing the spar to regulate wing pitch aeroelastically) without bending up and down. The obvious way of doing this is to make the spar cross-section taller than it is wide. Somewhat better aerodynamically is the use of a laminated spar which has a square or round cross-section but still has more resistance to bending vertically than it does to bending horizontally. For example, applying carbon fiber to the top and bottom of the spar would be very effective.

An additional refinement of spar cross-section is achieved by shrouding the spar in covering material. In other words, instead of gluing the covering on, you can form a leading edge sleeve into which the spar can insert. This provides a short tapered section just aft of the spar. It also produces a double-surface airfoil in that region, so to prevent wrinkles due to twisting, I make a series of cuts across the sleeve, perpendicular to the spar, before inserting the spar.

The most remarkable, nearly unexplored potential of membrane wings arises only when the wing is both aeroelastic and pretwisted. Only then can the pitch remain positive even when a lifting force is applied. A small force from below will result in a positive pitch, and a large force will result in a negative pitch. If the pretwist is great enough, the wing pitch can even exceed the angle of the relative wind during the upstroke. Then, this wing can do something no membrane wing has ever done, until recently. Like the built-up wings crafted by Rabiger, Harris and DeLaurier, and Levy, it can produce lift during the upstroke. (Levy's ornithopter has single-surface built-up wings.) This makes the power requirement for flight much lower, since the upstroke no longer generates a downward force at all; rather, it does just the opposite.

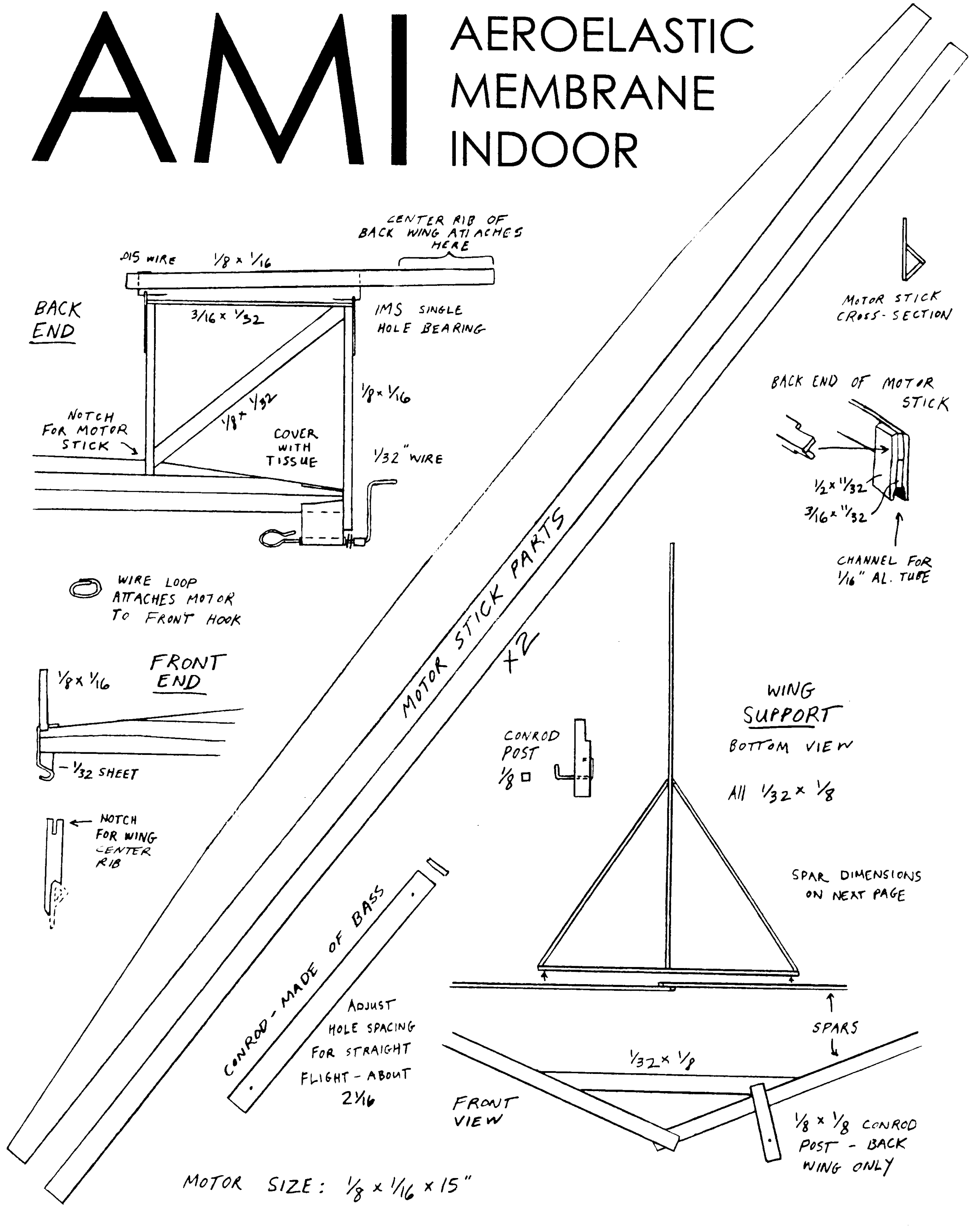
Consider a biplane ornithopter, in which the motor torque must act to raise one wing as it lowers another. With upstroke lift, the forces required in the upstroke and downstroke are not as different from each other as they are with traditional wings. The forces acting on the upstroke wings partially balance the forces acting on the downstroke wings, so less torque and less power are required.

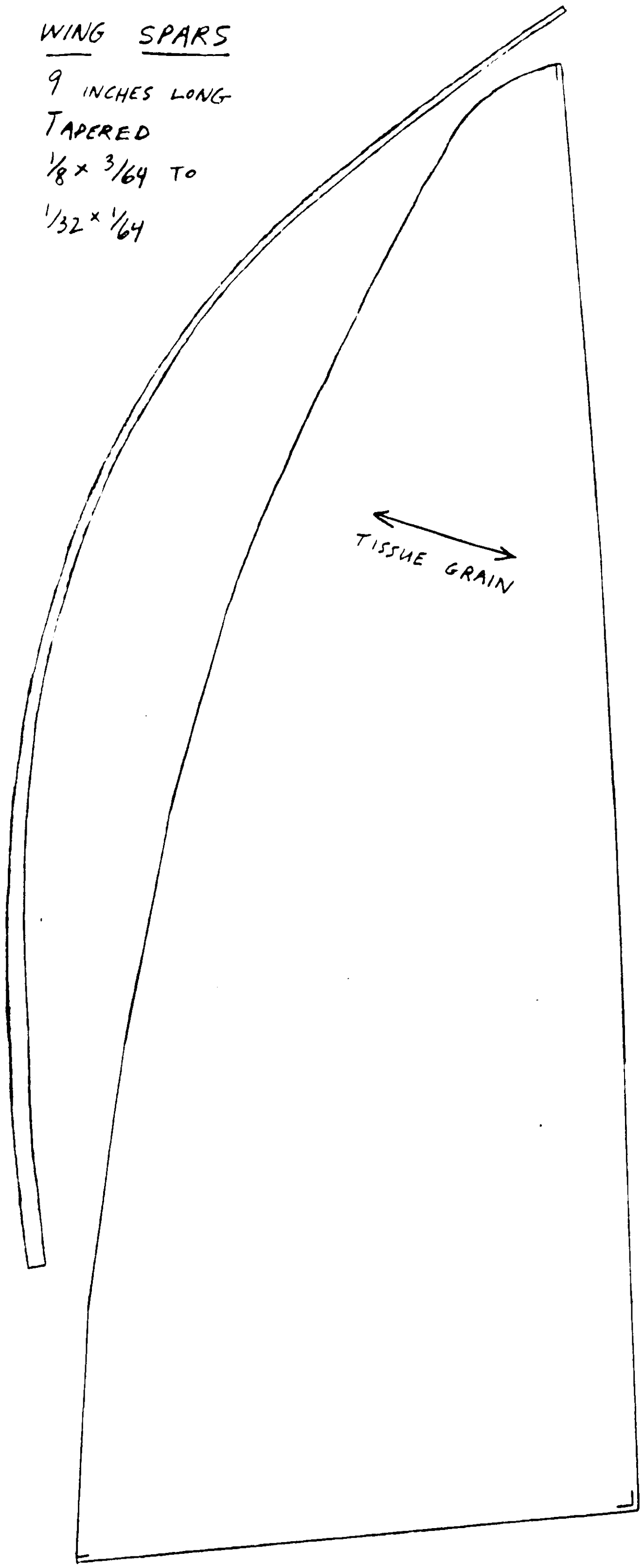
In a monoplane ornithopter, the constant torque output of the rubber motor prevents upstroke lift. Because torque is constant, the speed of the upstroke is automatically adjusted to maintain a downward force. The upstroke must be slowed down somehow in order for upstroke lift to occur. For gas powered monoplanes with flywheels, however, the benefits of upstroke lift remain. Energy is imparted to the flywheel or a spring during the upstroke, and this energy assists the subsequent downstroke.

Now I must return to the subject of membrane shape, for if the benefits of upstroke lift and aeroelasticity are to be realized in full, we must be able to design a wing using these principles which does not buckle excessively. Non-buckling thick airfoil wings are possible without the use of elastic coverings, and here we face the simpler problem of covering only one wing surface. Again, a sheet of paper is a good demonstrator. Holding the "wing" root firmly to the edge of a table, you will find that smooth twisting of the wing is possible if the (imaginary, in this case) spar is allowed to bend fore and aft. Fore and aft flexing of the spar has already been provided for the purpose of aeroelasticity, and you will notice that the required direction of bending is the same for aeroelasticity as it is for maintaining membrane shape. (Alternatively, the root may be allowed to slide in and out, while the spar is kept straight.) This demonstration works even if the wing root is cambered, and even though the spar is curved downward.

For optimum performance, upstroke lift should not be produced near the wingtips,

AMI AEROELASTIC MEMBRANE INDOOR



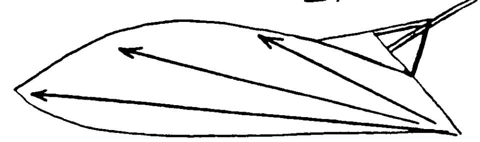


APPLYING THE MEMBRANE

The special characteristics which will allow this ornithopter to produce lift during the upstroke are not determined by the wooden structure. It is essential to apply the membrane correctly. To insure a cambered wing that is not floppy, the membrane should be applied so that it comprises a series of straight (not sagging) lines between the back end of the root rib and each point on the wing spar. The series of imaginary lines is shown in Figure 1. If you do this incorrectly, the wings will have negative camber.

Before the glue dries, you should carefully bend the spars forward and down as shown in Figure 2. Tape the wingtips to the table top with the underside of each wingtip facing straight up. This trains the spars in that direction and increases the amount of pretwist and membrane tension. You may wish to store the model in this position as well, because the twist tends to weaken over time.

FIGURE 1.



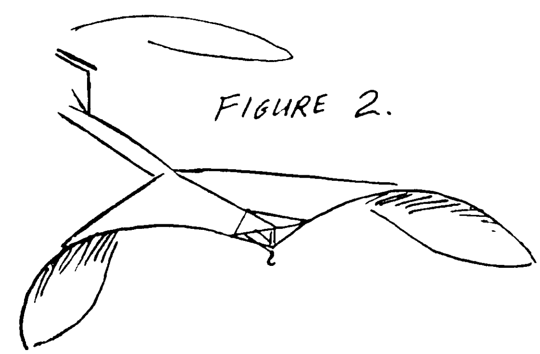


FIGURE 2.

In addition to adjusting the amount of twist, you may need to vary the hardness or thickness of the spars until the right amount of flexibility is achieved. The correct pitches for upstroke and downstroke should be reached when the wings are supporting 0.5 and 1.5 times the model's weight, respectively (a rough estimate).

The model is likely to require some noseweight. The conrod hole spacing may need to be adjusted to prevent uncontrolled yaw and provide a straight flight.

where the high pitch of the wings and angle of the relative airflow would result in a lot of drag being produced. Here, it is better to produce thrust and negative lift instead. Thus, it is desirable for the wingtip to have a negative camber during the upstroke while most of the wing has a positive camber. This is permitted by the use of a flexible spar and by the membrane tension maintained by lift acting on the rest of the membrane.

The most problematic feature of this aeroelastic, pretwisted wing design is that the amount of twist (throughout the cycle) should be carefully regulated for optimum performance. We can manipulate the spar flexibility, membrane tension, and amount of bend in the spar through trial and error. Fortunately, adjustments of spar curvature can be made after the model is built. Also fortunately, optimization is not required for a successful flight. Even if you don't get upstroke lift anywhere along the span, the upstroke force will be less negative than in other membrane wing ornithopters.

Experimentation with aeroelastic, pretwisted membranes has shown that membrane application determines the shape the membrane will have, once it is installed. For example, it wouldn't do to have a membrane which trails directly behind the spar as in most ornithopters; an aeroelastic wing must have its membrane applied so that its shape is entirely interdependent with that of the spar. To do this, the covering is carefully applied so that the entire surface conforms to the series of lines which radiate from the root rib to various points on the spar. This covering technique also insures that the membrane will be cambered.

Fortuitously, when pretwist is introduced to the aeroelastic wing, the requirement for spar flexibility is decreased. This is because the wing only has to operate on one side of the neutral pitch (pitch when no force is applied), so it can be a little floppy at pitches near the neutral pitch. Note, however, that this limits the amount of upstroke lift which can be produced.

I built a model to demonstrate the concepts discussed in this article. I decided to use a reaction tandem configuration because, even though the flapping amplitude is limited, the construction is simple and the upstroke is no faster than the downstroke. A biplane rather than tandem configuration should give better performance. The wings showed the required aeroelastic properties, including minimal up and down bending of the spar and high positive pitch, even when some lift was being produced. Photographs were not taken of the model in flight, so it is impossible to know what the pitch of the wing was like in flight. The neutral pitch was about 90 degrees and floppiness was slight, so upstroke lift seems likely. I only flew the model in my living room because duration measurement would have been irrelevant (due to the fact that decreased power and torque requirements paradoxically lead to shorter duration, with a given motor size). It had a good rate of climb.

The inefficiencies of traditional membrane wings are so great that even a sub-optimal upstroke lift ornithopter should do well against models using traditional wings for most of their support. The main advantages of the aeroelastic membrane wing over built-up wings are its simplicity and light weight.

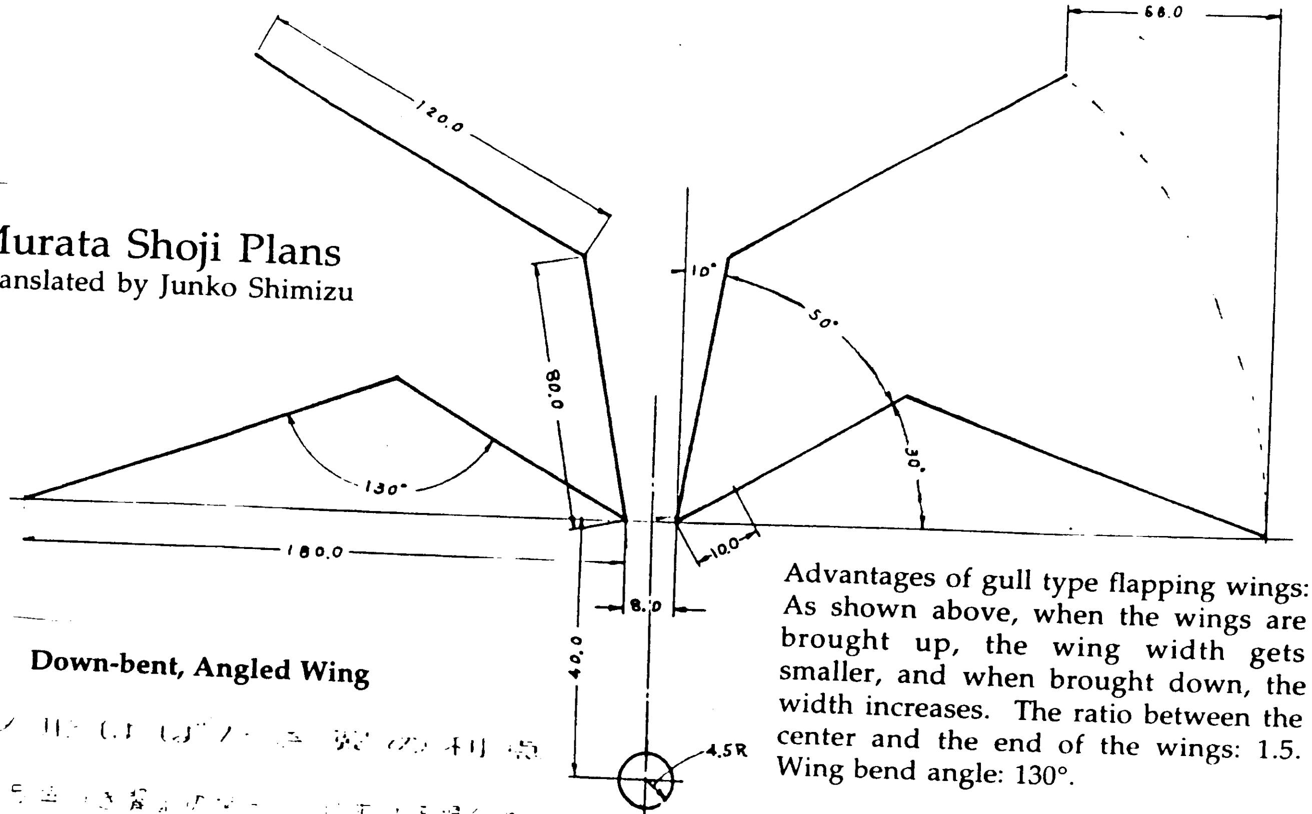
Kiselev's Ornithopters

I learned of Valentin Kiselev's ornithopters in a letter from Jeremy Harris. He sent some copies of articles (Soviet Union, N3, 1982; Flug Revue 7/1990), which are my only source of information on these mysterious machines.

A team directed by Kiselev at the Moscow Aviation Institute built several ornithopters. The first bench runs were made in 1979. At that time, a flapping frequency of several hertz was reached with 1.5 meter wings, and lift and thrust measurements indicated that flight was possible. A model flown in 1981 was electric powered and flew on a tether which supplied power to the motor. This machine took off from the ground and flew in circles about 15 meters in diameter. Flight performance was 35 kph, 1.5 Hz. The model was made of duralumin pipes, with a "webbing" of therylene film. A tandem, dragonfly-like model was later built with gas power. The wings apparently had a built-up, cambered structure and operated in a see-saw fashion, with each wing out of phase with the one on the other side.

Murata Shoji Plans

Translated by Junko Shimizu



Down-bent, Angled Wing

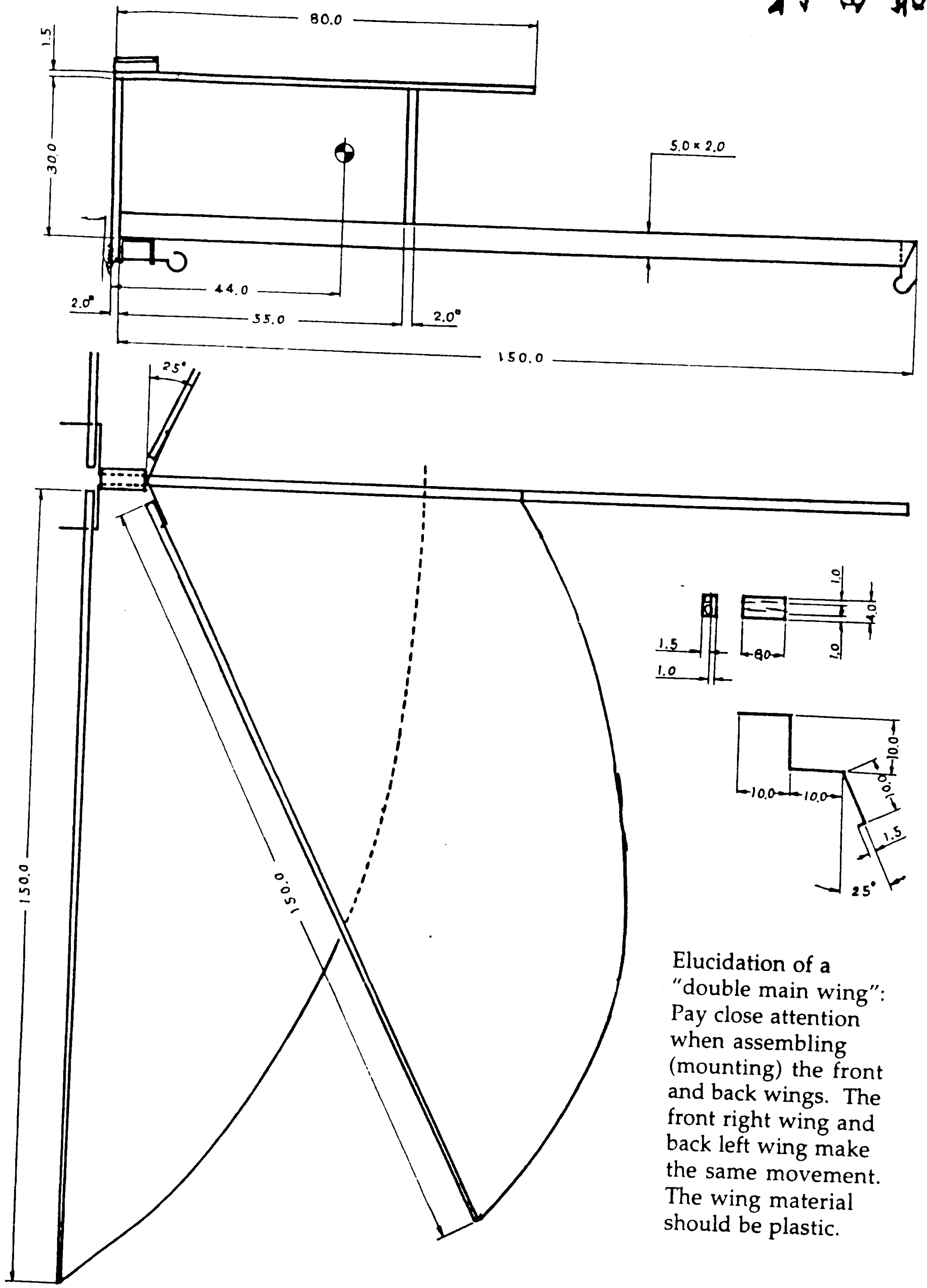
Advantages of gull type flapping wings: As shown above, when the wings are brought up, the wing width gets smaller, and when brought down, the width increases. The ratio between the center and the end of the wings: 1.5. Wing bend angle: 130°.

村田昭

無尾翼はばたき機『かげろう』

Tailless Wing Flapping Plane "Dragonfly"

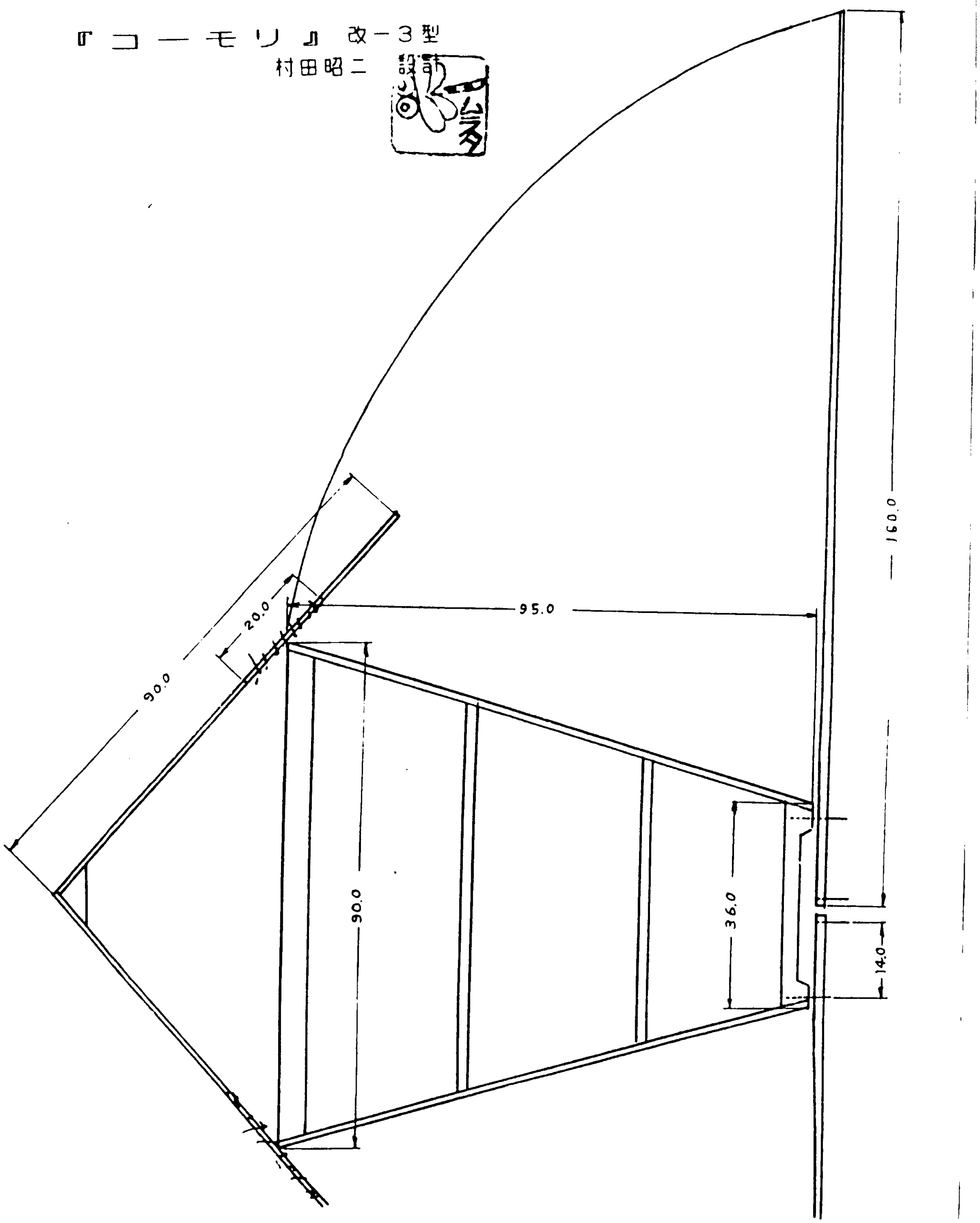
村田昭

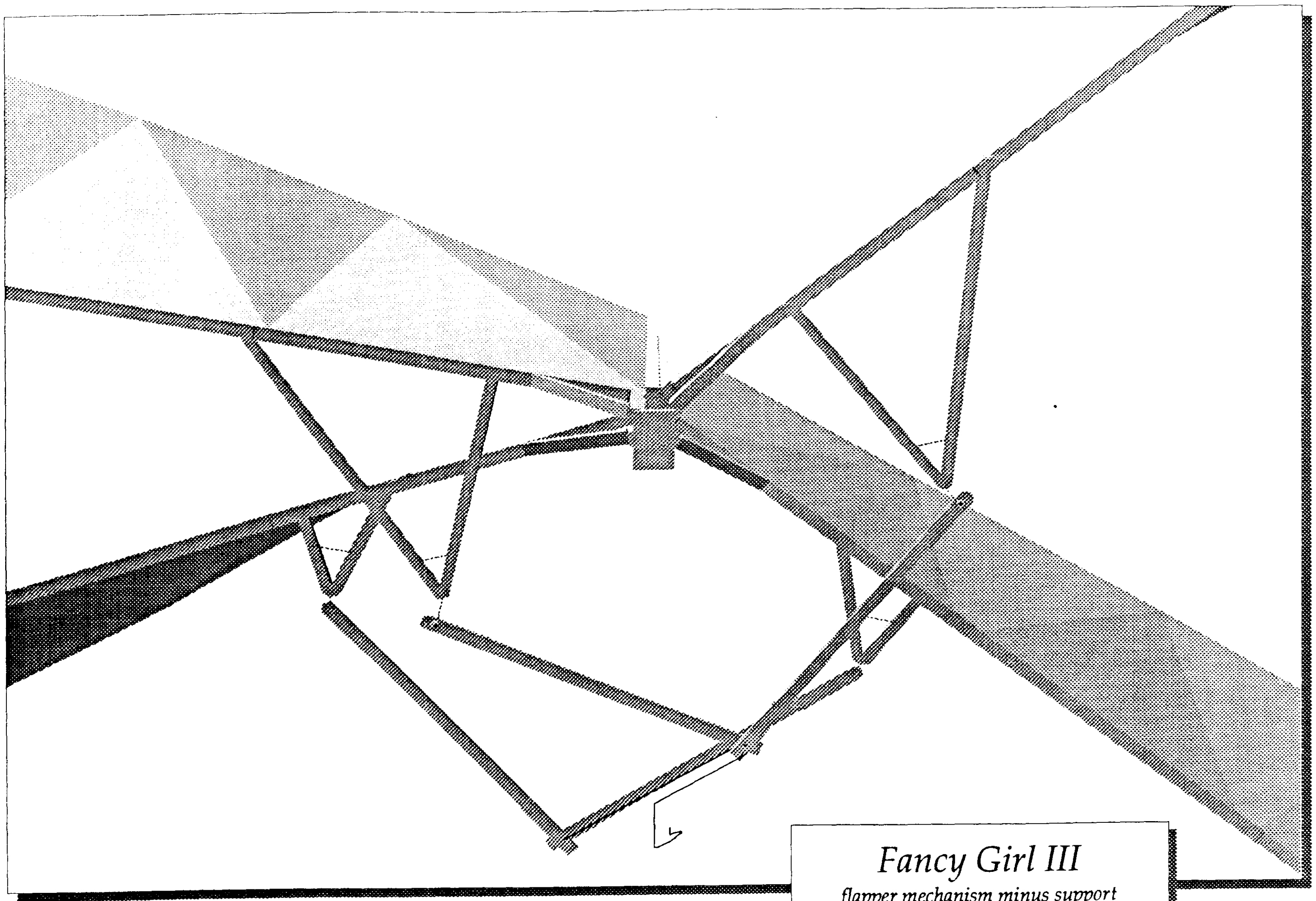


Elucidation of a "double main wing": Pay close attention when assembling (mounting) the front and back wings. The front right wing and back left wing make the same movement. The wing material should be plastic.

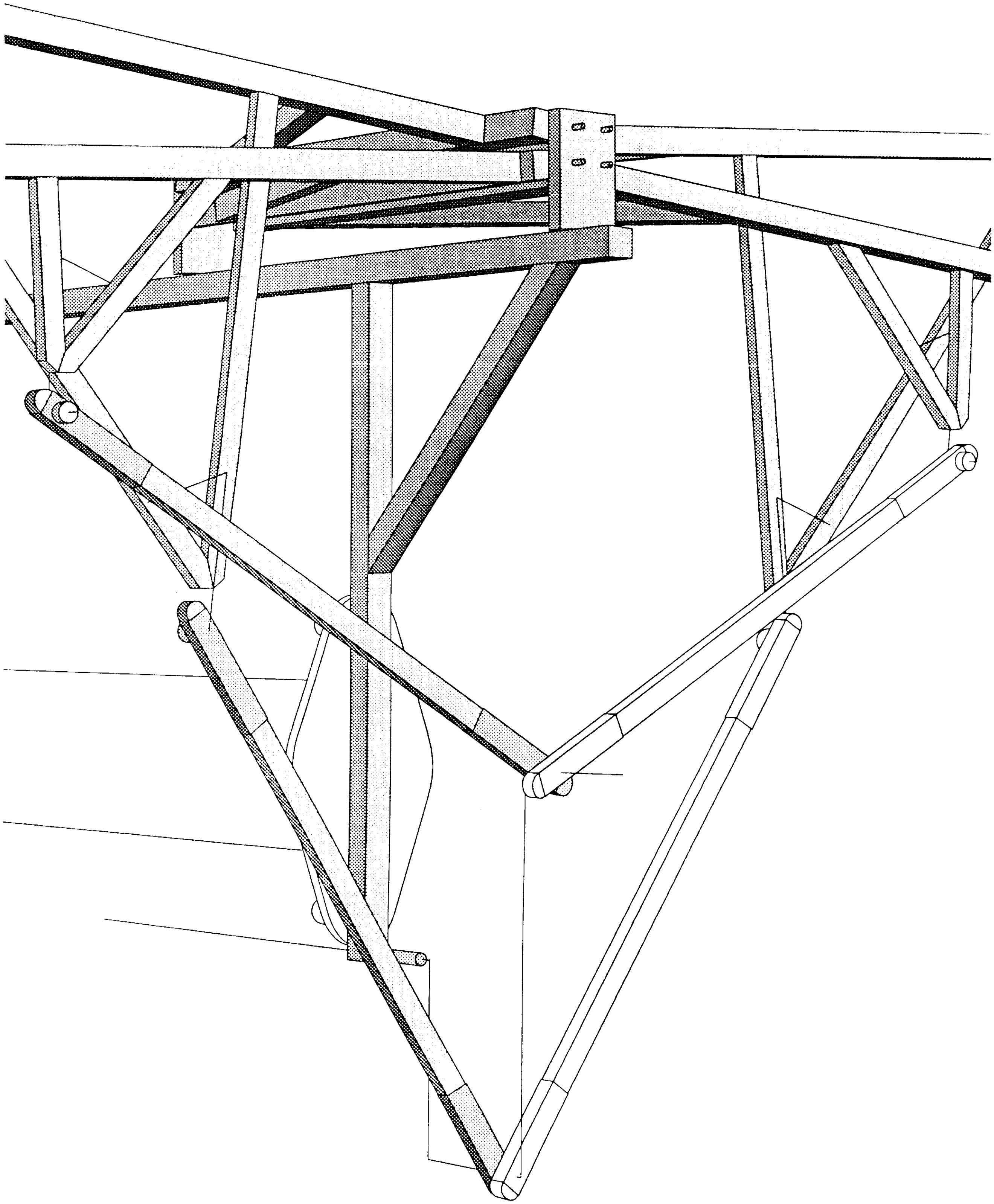
"Bat" Murata Shoji

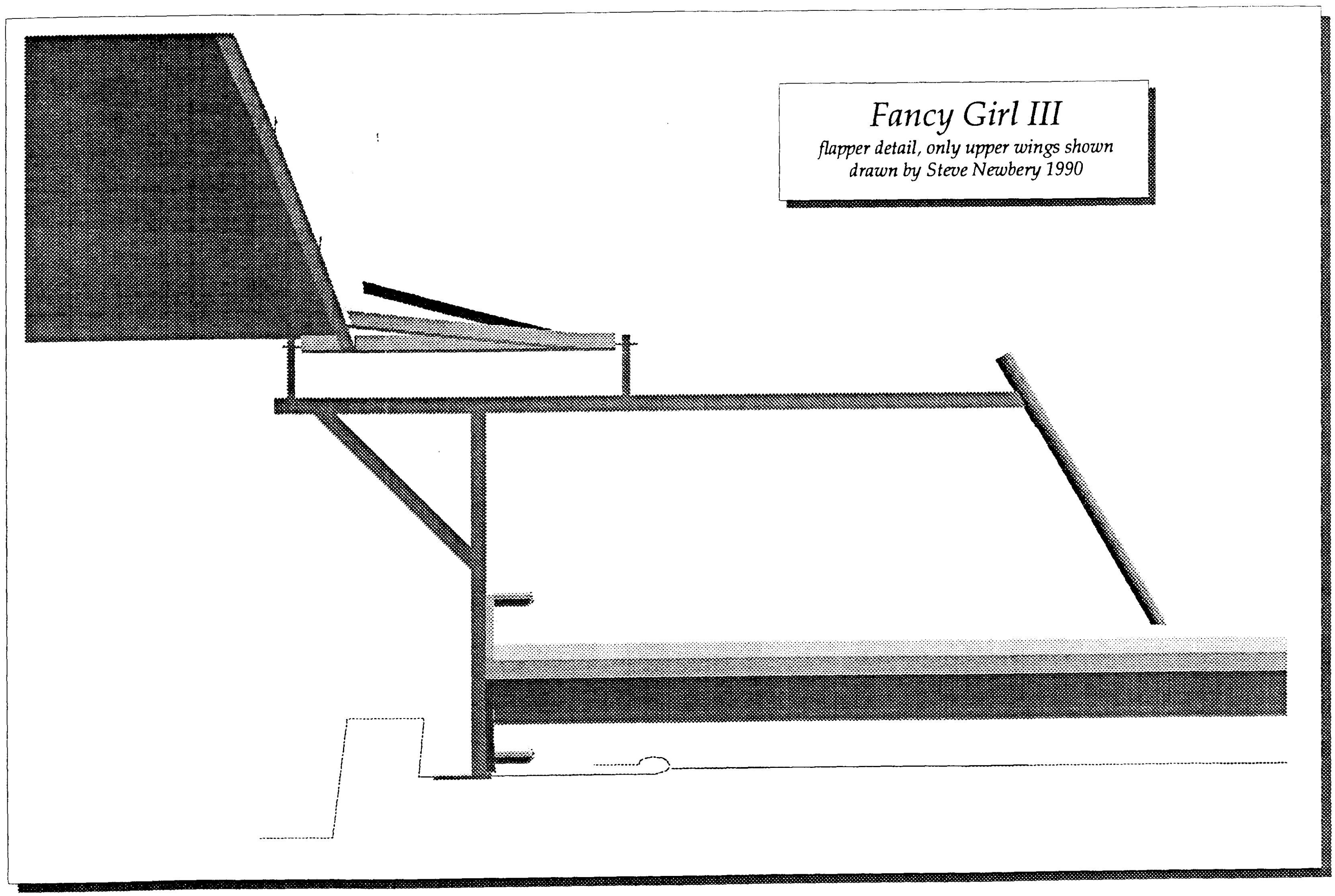
Characteristics of "Komori Bat" flapping plane: When the main wing is on an upward angle, it tends to go up, and vice versa. The tail (triangular balancing wing) counteracts. (This is determined through trial and error.) Place a metal piece on the main junction of the triangular wing.





Fancy Girl III
flapper mechanism minus support
drawn by Steve Newbery 1990




Fancy Girl III
flapper detail, only upper wings shown
drawn by Steve Newbery 1990