Flapper Facts

Newsletter of the Ornithopter Modelers' Society

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Polyethylene Foam Wings by Patrick Deshaye

I've recently been experimenting with built-up aeroelastic wings. I'm sure I'm not the only one who's run into numerous technical/structural problems in this endeavor, but I've come across a very common substance with some very friendly qualities: polyethylene foam sheet packing material. Here are some of its virtues:

1.) It is readily available. Any U-Haul station or moving company has miles of it.

2.) It is cheap. Five bucks gets you 40' or more.

3.) It comes in a variety of sizes. If you look around at different sources (such as Tap Plastics) you can find many thicknesses; most common is 3/32", but I've bought huge sheets of 1/2" for a couple bucks.

4.) It is quite light. A sheet 12"x12"x3/32" weighs about 3 grams. In other words, if you drop a sheet of it, you can die of old age before it hits the ground.

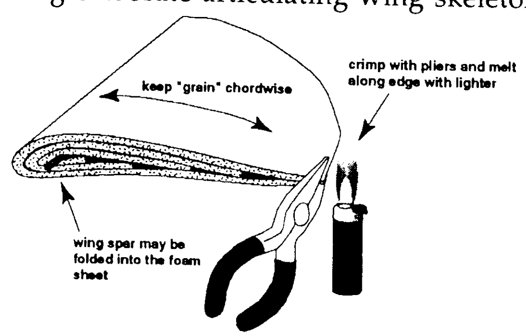
5.) It is tough. Though it isn't difficult to put a finger through one 3/32" sheet, it takes some effort to put a big hole into a pair of laminated sheets.

6.) It is resilient. The plastic foam has very good memory, so dents disappear almost immediately. Although susceptible to small punctures (what covering isn't?) the holes also disappear as the material rebounds.

7.) It is durable. Unlike latex and foam rubber, which have similar elastic qualities, polyfoam does not corrode in open air.

8.) It is airtight. 'nuff said.

9.) It resists wrinkling and buckling during distortion. This is perhaps its most attractive quality for ornithopterists, because we must deal with flexing compound curved structures, and few materials can maintain a smooth surface under these conditions. W.B. Stout complained bitterly that his flapper experiments were hindered by wrinkling materials. Polyfoam seems almost ideal for covering elaborate articulating wing skeletons.



10.) It is very easy to work with. The sheet can be stacked and cut into identical parts from patterns with scissors or a razor blade. The sheet can be folded into quasi-airfoil sections (see illustration) and laminated with spray adhesive. The edges of the outermost skin can be welded (see illustration) with needlenose pliers and a cigarette lighter.

11.) It is not unattractive. Although it comes only in white, it has an opalescent translucence and a leathery, reptilian texture. It is very easy to clean. Unfortunately, it cannot be colored except by applique... all paints just flake off.

12.) It often has a useful "grain". The foam in some cases appears to have been rolled out in very slightly corrugated sheets. These slight corrugations, when directed chordwise during covering (parallel to the airstream), give the impression of ribs.

All in all, I'd say this is too good a material to ignore. I hope some of the people working on larger engine-powered projects incorporate this stuff into their machines, and report their results.

Punctuated Equilibria and the Ornithopter Rule by Patrick Deshaye

One evening not too long ago, I found myself in the throes of the same feverish syndrome which seems to afflict Mr. Quermann, that is to say I became obsessed with trying to devise a simple, comprehensible ornithopter event rule. My plan centered on a "rule of three": only 33% allowable fixed surface, wings must flap at least 33 degrees, etc. Needless to say, my rule and proposed strategies for its enforcement became bizarre and ponderous. Not quite as bizarre and ponderous as the Quermann rule, however; it is simply amazing that Mr. Quermann attempts to justify the complexity of his Rube Goldbergian proposal by comparing it to the current rules for Easy B (an event originally intended to encourage novices!), as if one travesty justifies another. No, I came to my senses when I got to the part about the machine having to balance at no less than 3% of root chord (fore or aft) in order to satisfy that "pesky" center-of-lift issue-- I closed the file and trashed it. Then it hit me: maybe that's the answer! I will explain.

First, some history. In the '30's and '40's the Aeronuts devised simple, indoor monoplane models a la Penaud. The Aeronuts laid the classic groundwork, and over several years developed indoor ornithopter into a respectable event. No one came close to topping their achievements until the '60's when Johnson and Ganser took advantage of the "if-it-flaps-it's-a-flapper" rule of the day with their flapper-propelled models (sporting huge, fixed lifting surfaces) which achieved utterly unheard-of five-minute durations. After Johnson's fifteen minutes of fame (garnering him no less than a feature in Esquire!), Flapper development entered a dark age, because: 1) no one thought they could beat the flapper-propelled machines; 2) It was apparent to nearly everyone (especially Aeronut Lidgard) that the spirit of the rule had been violated, leaving a dearth of enthusiasm. It wasn't until the '80's that there was a resurgence of interest, and that came on account of Meuser's rewriting of the AMA rule and zeroing out the records, thereby breaking the stranglehold of the flapper-propulsion configuration. The Erbach postal contest and my founding of OMS followed, along with a flurry of development unprecedented in its variety and scope: tractor biplanes, teeter-totter flappers, articulated wings, tandems, canards, biplane canards... a veritable Cambrian Explosion of configurations.

Now, we find ourselves in a situation where one design configuration dominates the indoor scene (the brilliant Kieser/White canard bipes) and this configuration is so powerful (21 minutes!?!) that no one dares a record trial with any other, and there is criticism of the AMA rule for allowing this configuration. Sound familiar? This time around, the criticism of the rule centers on a perceived loophole that allows the preponderance of the lift to be produced by what little fixed surface is allowed by the Meuser rule... this "loophole" is an explicit design parameter of Kieser's canards. And fascinating and ingenious as they are, no one to my knowledge has ever described the canard bipes as "birdlike"; in fact, the nearest thing to a biological comparison I've heard is when someone said: "It looks like some kind of big plankton." Let's face it: there's nothing "orni-" about it; it has four wings and flies bassackwards for crying out loud! Seriously, the chilling effect of Kieser's and White's tours de force can be felt. Many OMS members seem to have lost interest in indoor duration and have turned their attentions elsewhere.

What to do? One solution would be to frame the rule in such a way that nothing like this ever happens again; this seems to be Mr. Quermann's plan. If such a strategy is even possible, it would probably require a rule of such complexity and restrictiveness that most innovators, and certainly most novices, would be frightened off.

I propose that the existing rule be amended in an ad hoc fashion-- simply frame addenda to the rule to exclude violators of the "bird-like" spirit of the rule if, and only if, they come to monopolize the indoor scene in the manner of Johnson and Kieser. That way, the rule will not discourage innovation before the fact, and the loophole-exploiters can enjoy a day in the sun (and brag that the rule had to be rewritten to exclude them), and the rest of us can enjoy the parade. Would any of us prefer that Kieser's amazing plankton had never existed? I think not... but if a Quermann-type rule had been adopted ten years ago, no one would have had the pleasure of seeing it waddle through the air. Then again, the canard bipe has now cannibalized the entire event. Therefore, I think the existing surface-area rule (to prevent resurgence of the flapper-propulsion subterfuge) plus a "thou shalt not fashion unto thyself any canard biplane" addendum would do wonders for the indoor flapper scene right now. Perhaps in the future tractor biplanes (which would be the undoubted heirs apparent) would have to be excluded with another antitrust clause, but only after an exciting period of their development and evolution.

And let it not be said that the strategy I propose is contrived or unnatural. Evolutionary biologists have reached near consensus that rapid speciation occurs only after some massive environmental change (such as the formation of continental land bridges or climatic catastrophes) topples the dominant, entrenched oligopoly of species; thus the dinosaurs only developed after the great amphibians were mostly wiped out, and no large-scale mammalian development could occur until the dinosaurs crashed into the Cretaceous-Tertiary boundary. In much the same way, we can artificially stimulate ornithopter development by extinguishing the dominant configuration (through vote or decree) as if by an act of God, and then clearing the national record charts to provide incentive to experimentation.

My proposal is certain to raise the hackles of engineering graduates, who prefer quantitative rigor and predictability. I counter that the beauty of the ornithopter lies in its evocation of freedom, in the spirit of the organic arising, like phoenix, from the ashes of the mechanistic. I think it only fitting that the ornithopter rule should be a growing, organic thing, littered with extinctions but offering hope of new creation. So don't ask me to apologize, and I won't ask you to forgive me.

Mosquito by John White

I once watched a film sequence showing an eagle hovering. I noticed that following the downbeat of the wings, the tail was lowered. I thought the movement of the tail was to maintain the horizontal position of the body. Ever since I have considered the possibility of designing an ornithopter that used a beating tail plane to smooth the movement of a single pair of wings.

My previous designs have used a second pair of wings beating 90 degrees out of phase with the first pair. This resulted in a uniform transfer of power from the rubber motor to the wings. The lack of vibration allowed a much lighter construction which increased performance.

I recently built a small indoor ornithopter using a single pair of wings and a tail that beats 90 degrees out of phase with the wings. I found the wings beat smoothly without vibration. As it was hovering around the ceiling of my sitting room my wife instantly named it 'Mosquito'.

I flew the model at Potters Bar on the 4th February this year and at Crawley the following day. At both meetings the model quickly reached the ceiling and appeared very reluctant to come down. When the turns ran out the model had a reasonable glide which is rare for my ornithopters - they usually behave as if they had DTed. Fortunately Keith Miller was at Crawley and kindly photographed the model for me [as seen in Issue #12].

My interest in ornithopters was aroused when the plans of Parnel Schoenky's 'Flap Happy' were published in the 'Aeromodeller' in October 1949. Limited success with this rubber-powered monoplane ornithopter led me to consider ways of improving the design.

A rubber motor appeared to be a convenient power source but the most serious problem to solve was how to transfer power from the rubber motor to the wings at a uniform rate. If a geared-down engine had been used as a power source the flywheel effect would have smoothed out the effect of the non-uniform loading of the oscillating wings. As it was the simple crank that operated the wings slowed down when the wings were moving through their mean position but speeded up when the wings were changing direction at the top and bottom dead centre position of the crank. This variation of loading by the wings caused considerable vibration which indicated a loss of power stored in the rubber motor.

My first attempt to lessen the vibration was to cement two shaped pieces of soft rubber to the nose-block so that the crank rubbed against them at top and bottom dead centre. It reduced the vibration but did not improve performance.

It was clear to me that half the power stored in the rubber motor was being lost. The solution was obvious - a second set of wings operating 90 degrees out of phase with original pair would utilise the power previously being wasted.

Designing the crank system for my first bi-plane ornithopter was tricky since flapping wings are rather intangible. My first task was to plot the motion of each wing graphically. The wing angle was plotted against the crank angle for a complete revolution. A second curve was drawn 90 degrees out of phase with the first.

As I had decided to mount one pair of wings above the other, it was clear that the wings would overlap. The curves were re-drawn, raising the mean position of the upper, and lowering the mean position of the lower, so that the wings would just meet at a dihedral angle of 10 degrees. The double throw crank and conrods could then be drawn to operated the wings as designed.

A half-scale modified version of 'Flap Happy' was then built, boasting two pair of wings and a double-throw crank. It was a scaled-up version of this model that established the current British rubber powered outdoor ornithopter record. On the 20th June 1954 it made two consecutive flights of 1 min. 55 sec. and 1 min. 51 sec. at the Northern Heights Gala, Langley Aerodrome, Buckinghamshire, England.

I named by first model 'Dragonfly' as its flight appeared so similar. I began a limited study of entomology and discovered that the dragonfly does, in fact, operate its wings with a phase difference of around 90 degrees in some circumstances.

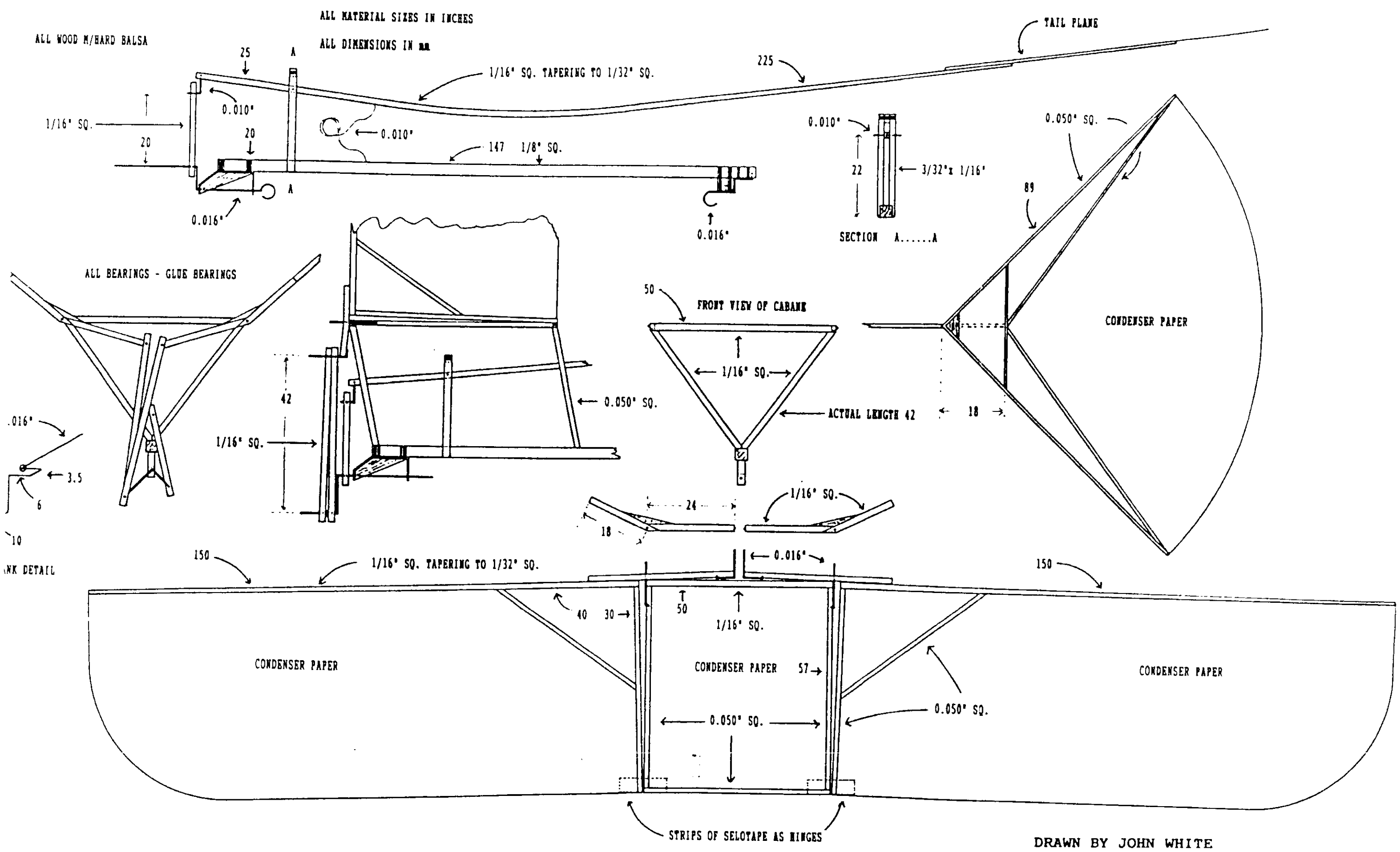
A uniform output of muscular power is obviously an advantage. Other problems have been addressed by flying insects. Because the wings have mass, kinetic energy is lost when the wings decelerate as they reach the end of their stroke, and energy has to be found to accelerate them at the start of the next stroke. A dragonfly's wings are extremely light and the kinetic energy at the end of each wing beat is stored as potential energy in the distorted plates of the thorax. At the start of the next stroke the thorax reform like a spring converting its potential energy to kinetic energy as the wing accelerates. Perhaps one day a model will be designed whose wings will oscillate when deflected and then released. The system has been perfected in nature as some flying insects have wings that beat resonately - electrical impulses are sent to the wing muscles, not at every wing beat, but at longer intervals.

Insects, like birds, have systems that reduce the wing area on the upstroke. There is a great deal to be learnt and a great deal of scope for further experimentation.

There are obviously two approaches to the problem of winged flight. We may find our inspiration either in the flight of insects or in the flight of birds. For my models I have been influenced by insect flight but for engine powered flight I can see the advantages of bird flight. However there are common factors and much may be gained by a study of both forms of flight.

John White

' MOSQUITO ' DESIGNED BY JOHN WHITE



DRAWN BY JOHN WHITE

Report from Horst Räbiger — March 25.1996

Translated by Martin Kluge (16)

Dear Mr. Chronister,

in the Flapper Facts, issue #12, fall 1995, Mr. Joss Levy and you had some questions about my model. I will try to give you an answer.

I use a selfmade mathematical model to determine the most important dates for the construction. It calculates the dates for a balance of forces in x- and z-direction in an extensive numerical calculation. To describe the circulation I use the equations especially of

Jones R. T. The spanwise distribution of lift for minimum induced drag of wings having a given lift and a given bending moment NACA, Technical Note 2249, 1950

Jones R. T. Wing flapping with minimum energy, Aeronautical Journal July 1980

In the mathematical model I do not account for rise and fall of the fuselage. This movement is zero in first approximation (in praxis about 0.07 meters, corresponding to a wave length of the stroke movement of about 7 meters). Moreover the effects are neutralized in one stroke. The fuselage is falling during the first semidownstroke and rising during the second semidownstroke. Conversely on the upstroke (because there is about a 90 deg. phase shift between flapping and fuselage motion).

The angle of incidence of the airfoil to the fuselage of my model EV7 is constant during the upstroke, downstroke and gliding. I guess the birds are doing the same at least in unaccelerated horizontal flight.

The constant angle of incidence at the root of the wing and transfer the aerodynamic center along the semispan is automatically resulting in a distribution of circulation, as demanded in the ornithopter theory

- during the upstroke transferred to the root of the wing and smaller than during gliding
- during the downstroke transferred to the wing tip and bigger than during gliding

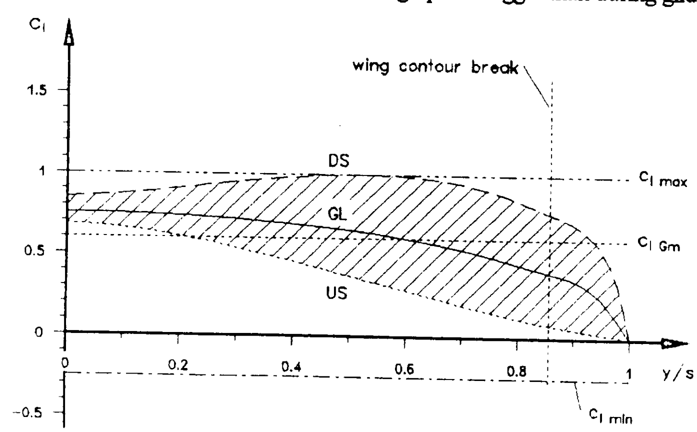


Fig. 39 distribution of the lift coefficient $c_{l(y)}$

Only if you have a big lift during the downstroke you can chose a small lift during the upstroke or the average lift will not be sufficient. Simultaneously the thrust is increasing the bigger the distance between the graphs of downstroke and upstroke is, especially near the wing tip (look at fig. 39).

The airfoil Clark Y does not allow the lift to increase significantly in comparison with the chosen average lift during gliding. Therfore the airfoil can not be used in the lower range of the c_l-graph (except I chose a very low c_l-coefficient during gliding or a higher flight velocity during powerflight). Therfore its better to combine different airfoils (see Flapper Facts Issue #9, Winter 1995).

Jones demands for an ideal distribution of downstroke circulation that the induced downwash velocity at the root of the wing is passing through zero. I try to use the working range of the airfoils of my model as good as possible. Therefore the lift is chosen as big as possible by transferring the aerodynamic centre further to the wing tips. In this case the induced angle of attack at the root of the wing is not completely zero but very small, as to be seen in the next figure.

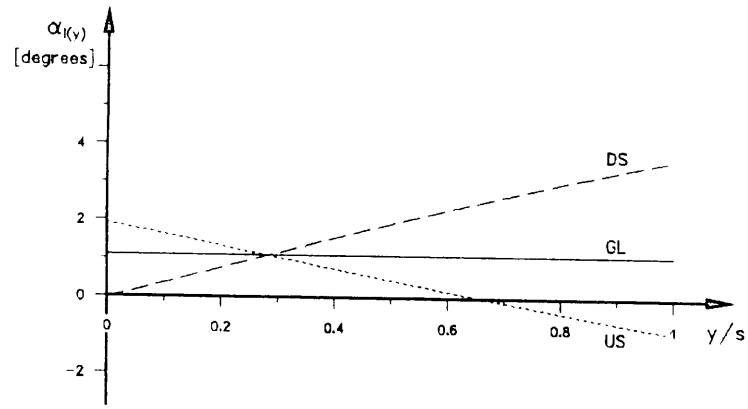


Fig. 45 induced angle of attack $\alpha_{i(y)}$

If the angle of incidence at the root of the wing is constant and the induced angle of attack is variable, the angle of attack must be adapted. It becomes bigger than in gliding flight during the downstroke and smaller during the upstroke. Using the airfoil data measured in the wind tunnel at Stuttgart you get the following graph of the angle of attack.

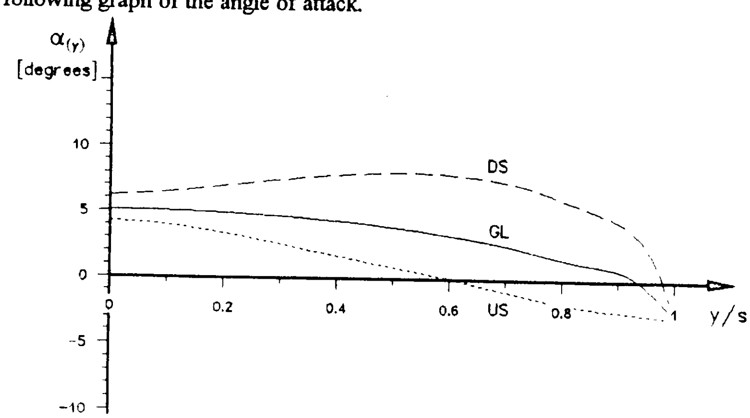


Fig. 46 angle of attack $\alpha_{(y)}$

Then the data at the root of the wing looks as following.

		US	GL	DS	
Add the					
- angle of attack	$\alpha_{(y)}$	4.23	5.06	6.20	[deg.]
- induced angle of attack	$\alpha_{i(y)}$	1.92	1.09	-0.05	[deg.]
and subtract the					
- feathered angle	$\delta_{(y)}$	0	0	0	[deg.]
- angle between the theoretical airfoil line to the tangent of the lower surface of the airfoil (Clark Y)	σ	2.0	2.0	2.0	[deg.]
then you get the angle of incedence on the root of the wing.	$\alpha_{E(y)}$	4.15	4.15	4.15	[deg.]

I think this will answer your questions.

You can determine the angle of incidence along the whole span in the same way.

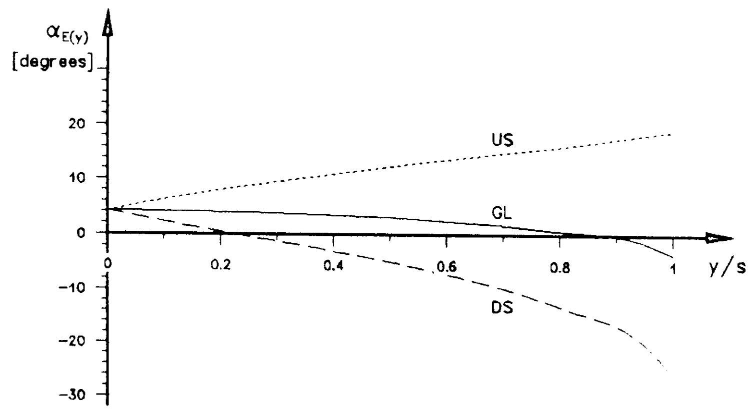


Fig. 47 angle of incidence $\alpha_{E(y)}$

Considering the angle of attack during gliding you get the angle of twist.

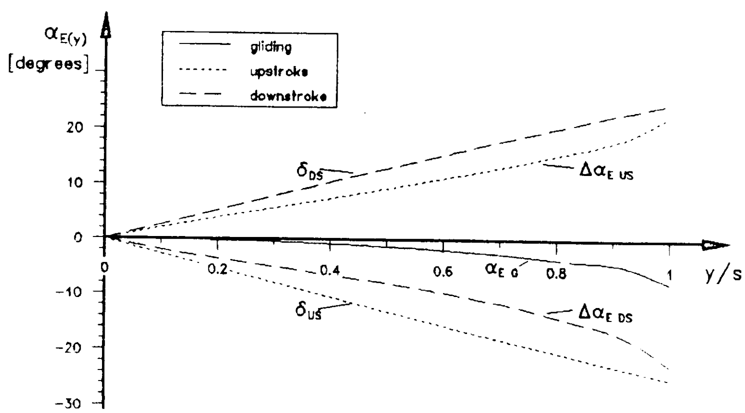


Fig. 48 angle of twist $\Delta\alpha_{E(y)}$

In praxis the slope of the wing twist can only be generated approximately. It is difficult for me to do so especially at the wing tip.

Now some details of the construction. The following figures show the principle I use to transform the move from round to straight. Unfortunately I dont have a photo of my drive unit.

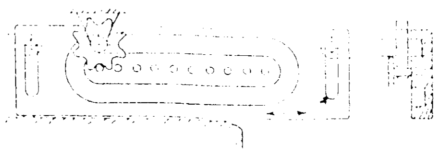


Fig. 1

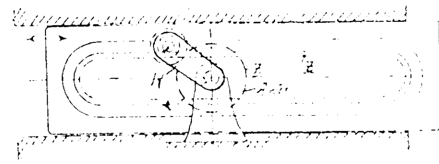
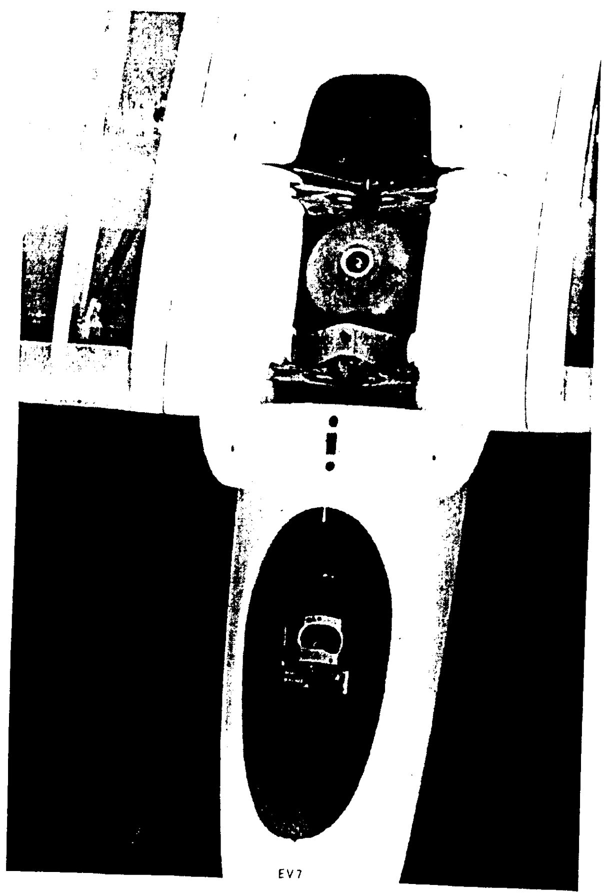


Fig. 2

The photo shows the mechanic in the fuselage with the big air pressure spring (about 500 N).
In addition to this spring for compensating the wing lift, I am also using a strong spring of steel (max. 900 N), that positively und negatively accelerates the wing-weigt at the end of the stroke.



You can see the small cylinder in front of the airpressure spring. Both springs are mounted on the same frame, which is moving up and down.The batterys are mounted on both sides of the mechanic.

The wings are twisting aeroelastically and not controlled by the mechanic. The gear wheels you can see at the auxiliary spar are only used to adjust the angle of incidence in the middle of the halfspan.

Some theoretical dates of my ornithopter model EV7 (1988)

Gliding initial parameters

wing span	3.0	m
aspect ratio of wing	10	
mass of the total model	4.5	kg
mass of the wing	1.15	kg
coefficient of lift (gliding)	0.6	
coefficient of drag (rest)	0.01	
airfoil	Clark Y (11.7)	

Powerflight initial paramerters

flight speed factor power/glide	1.00	
climbing speed of model	0.30	m/s
flapping period length	0.56	s
flapping comparison up/down	1.00	
flapping angle, final	± 27	deg.
inclination of the flapping plane	0.0	deg.
battery capacity	40.000 watt seconds	
efficiency from the battery to the wing	0.33	

Power flight result

average flapping performance	48.4	W
initial motor performance	147	W (the motor of EV7 has about 200 W)
model altitude	81	m
model flight distance	3377	m
model flight duration	273	s

The problem of the EV7 in praxis is the fact that the flow is stalling already in a very small climb or if you are increasing the flapping frequency. I am working about it.

with best wishes

A Variable Stroke Mechanism for Ornithopters

by Peter L. Valentine 5-11-96

In the article entitled 'Flapping Wing Models' (Spring 1987 Flapper Facts), Horst Handler lists a number of 'good things to have' in a mechanism for a powered ornithopter, among which: " A regulatable amount of flapping angle is des:reable". I'll call this variable stroke and paraphrase Handler to say it's also good if an ornithopter mechanism can be stopped with the wings held at a certain dihedral angle to allow stable gliding flight.

It's been over ten years since I researched the field of variable stroke mechanisms and I'd like to share what I found with the OMS. Consider the schematic in Fig. 1 with a driving crank, 1, and a driven block, 8 (Ref. 1, pp. 371-372). With the control lever at 0, there is no movement of block 8 at 0'. With the lever at 1, the block cycles between 0' and 1'. With the lever at 2, the block cycles between 0' and 2', and so on. If the block is attached to a wing (or a pair of wings), the crank driven by a geared motor, and the lever moved and held by an actuator, we have all the ingredients of a variable flapping angle ornithopter.

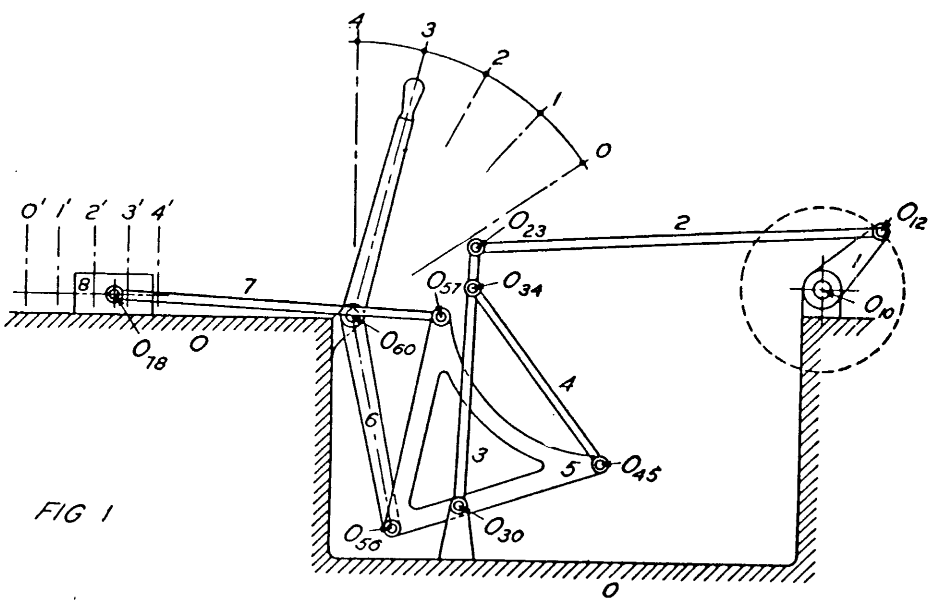


FIG 1

From the description of the operation of the Fig. 1 mechanism it's apparent that the 'mean' stroke angle changes with stroke amplitude. In Fig. 2 I've sketched an ornithopter design where this characteristic is used to give the wings the greatest dihedral angle when the stroke is zero, and this might just be what Handler would want for a stable glide. You'll note I installed stroke control on both wings to provide turning capability as well as thrust control. If I was building models, I might start with one mechanism driving both wings and use rudder and elevator for turns. Another possibility would be to forget about fixed wing gliding, use stroke frequency (motor RPM) as thrust control, use fixed stroke on one side and variable stroke on the other so that more or less stroke amplitude on the controlled side would cause turning one way or the other.

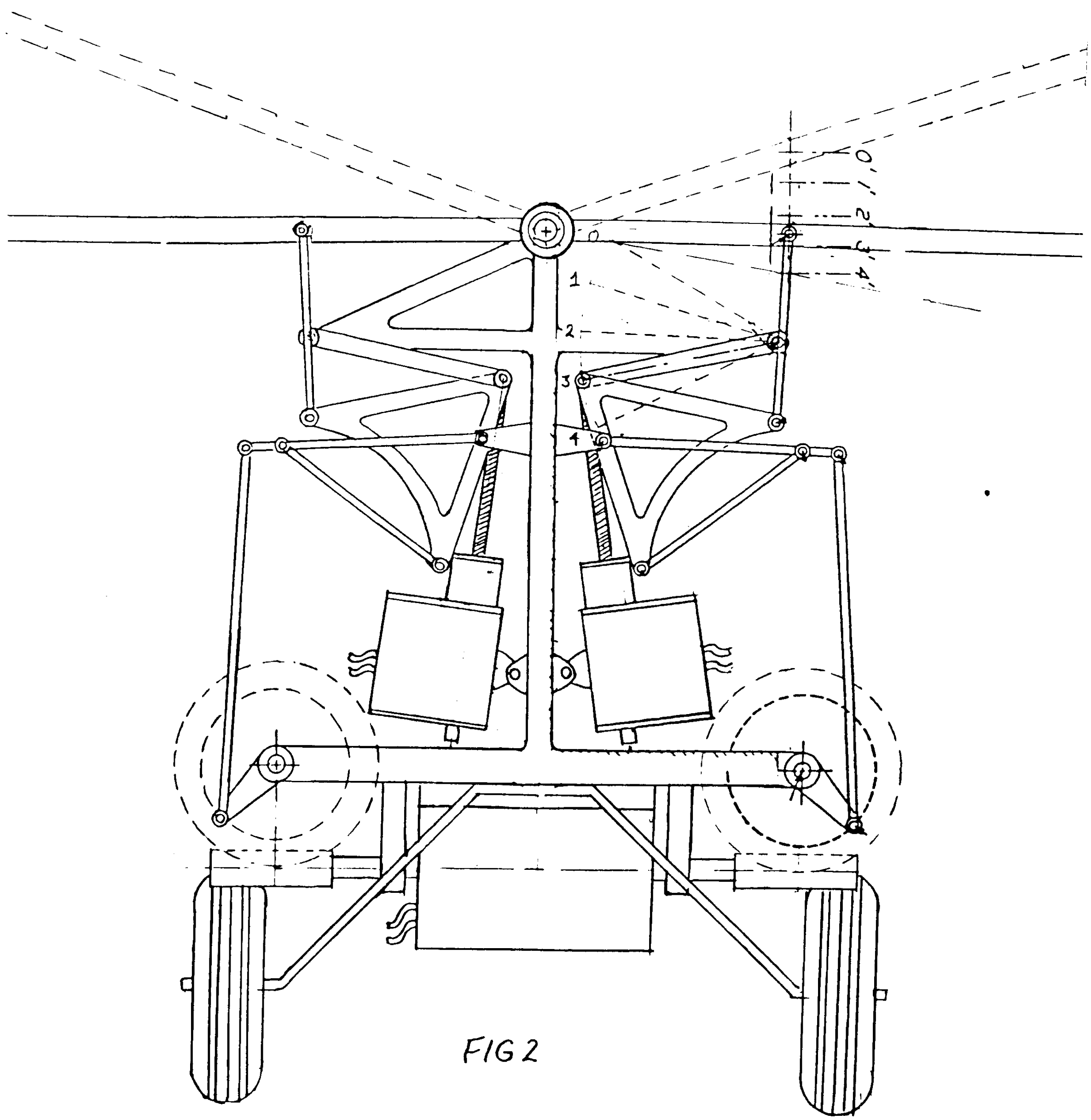


FIG 2

This is all I have to say about ornithopters and stroke control for now. But in case anyone's wondering where this mechanism came from and what, if anything, it is, or was, used for, I thought I'd write some more about what I learned about variable stroke mechanisms. Enjoy.

Variable Stroke Mechanisms from the Age of Steam

Fig 3 shows a simple double acting steam engine with a slider valve driven by an eccentric. An eccentric performs the same function as a crank except that it's designed to be used with an existing circular shaft (by bolting it on in pieces if necessary) as opposed to fabricating a shaft with an extra crank built in. Figure 4 shows that if one eccentric is nested inside another with some kind of key or other method of holding them together, a variable eccentric results. If the eccentricity e is the same for both eccentrics, it is possible to change the stroke from zero to a maximum of 2e as shown . Such devices are used for laboratory fatigue tests to impose an adjustable amount of cyclic deflection, say, on the end of a beam, but they must be stopped and reassembled in order to change the stroke amplitude. Recently, inventors have incorporated helical splines between the nested eccentrics so that differential shaft movement 'in and out of the page' can be used to adjust the stroke 'on the fly', but if fixed eccentrics are never used for serious power transmission because of machining expense and limited torque capacity, variable eccentrics become even more undesirable.

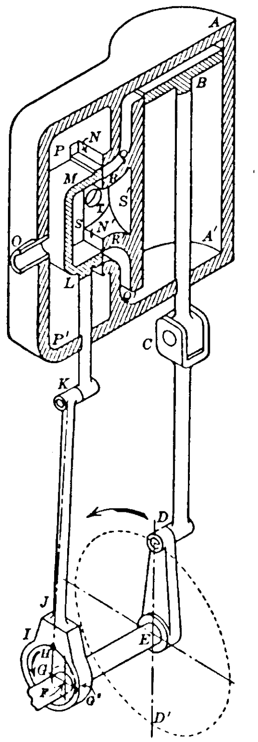


Fig. 3 Simple Steam Engine

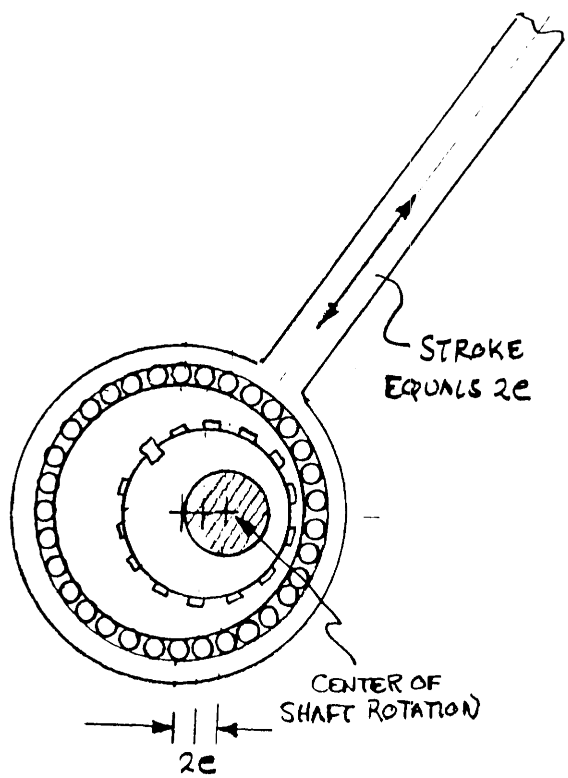


Fig. 4 Variable Eccentric, Stroke from 0 to 2e

Developing a variable stroke device for steam engines is one of the two things needed for control in applications such as rail locomotives (the other is reversing ability) where varying degrees of torque are required and conservation of steam is important. Without such a device, the only way to control the output of the engine in Fig 3 is to throttle the steam and this is wasteful. As we have seen, something like a variable crank or eccentric is needed, but the variable 'on the fly' eccentric described was, in the days of steam (and maybe still is), too difficult to machine and therefore too expensive for the application. Instead, one mechanism that appeared was the Stephenson Valve Gear in Fig 5 (this and the following illustrations from Ref. 2). As is apparent, there are two fixed eccentrics driving the ends of a Link with a curved slot. If the Link is raised up with the Reversing Rod so that the Saddle block is situated on top of the Slide Block, the two ends of the link pivot madly about without producing any stroke in the Valve rod. From here, if the Link is raised, the Valve rod strokes with increasing amplitude 'fore and aft' and if it is lowered, the same thing happens except now the motion is 'aft and forward', that is, in the reverse phase relationship. The variable stroke feature acts as a throttle by allowing more or less pressurized steam onto one side of the piston or the other and the phase change around 'zero stroke' allows the engine to be started and run in one direction or the other. Some of the nicer toy steam engine models were equipped with working valve gear of this type.

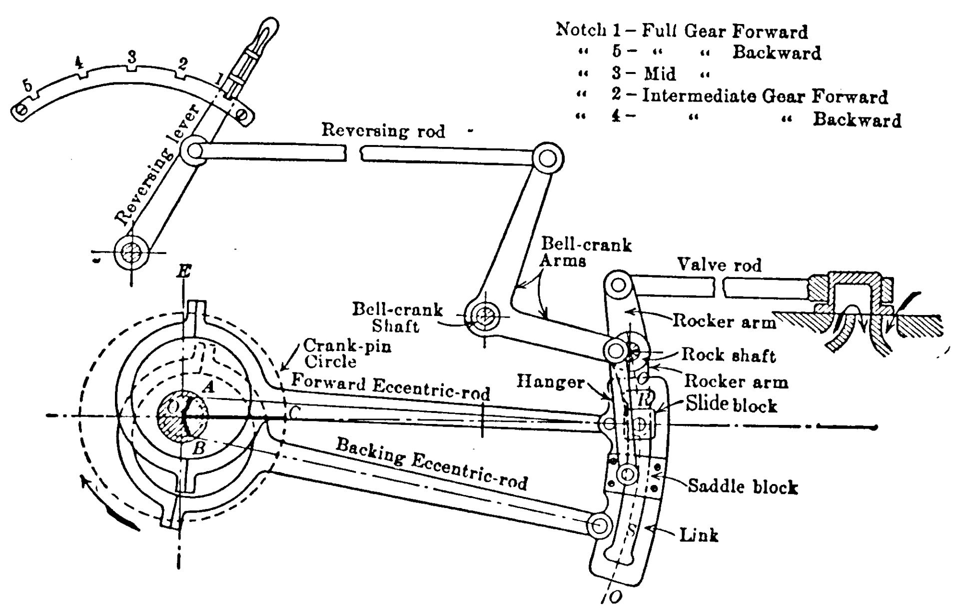


Fig. 5 Stephenson Valve Gear

As the age of steam progressed, numerous valve gear mechanisms were designed to produce precise valve motions while meeting the requirements of specific applications such as compactness, light weight, low cost, easy maintainability, and others. For example, Fig. 6 shows the Gooch Gear which was used in preference to the Stephenson for stationary powerplants. Note that the Stephenson Gear in Fig. 5 needs a notched quadrant in order to hold the reversing rod at a particular position. This is partly due to the reversing lever supporting the weight of the link and a part of the weight of the eccentric rods and partly due

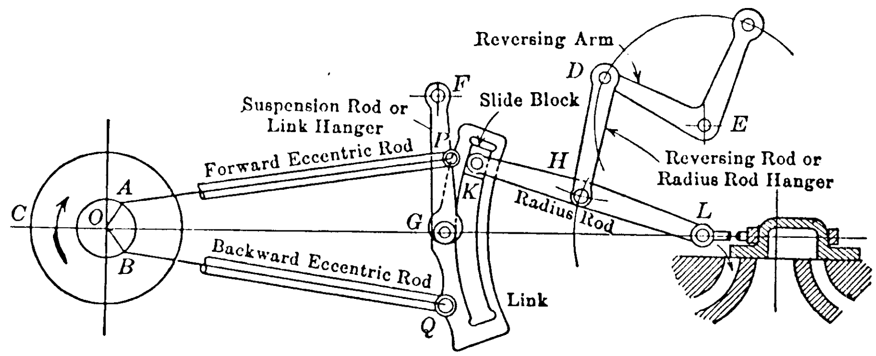


Fig. 6 Gooch Valve Gear

to the dynamic loads experienced when the mechanism is in motion. The Gooch Gear, on the other hand, pins the Link so that only the weight of the Radius Rod is carried by the Reversing Rod, and this makes for a more easily balanced load, which is what is wanted if the engine is to be controlled by a speed governor. As an aside, I've been working with locomotives at GE Erie for that last two years. The throttle quadrants on diesel electric locos still carry numbers to indicate relative power level (1-8) and these are still, always, refered to as 'notch levels'.

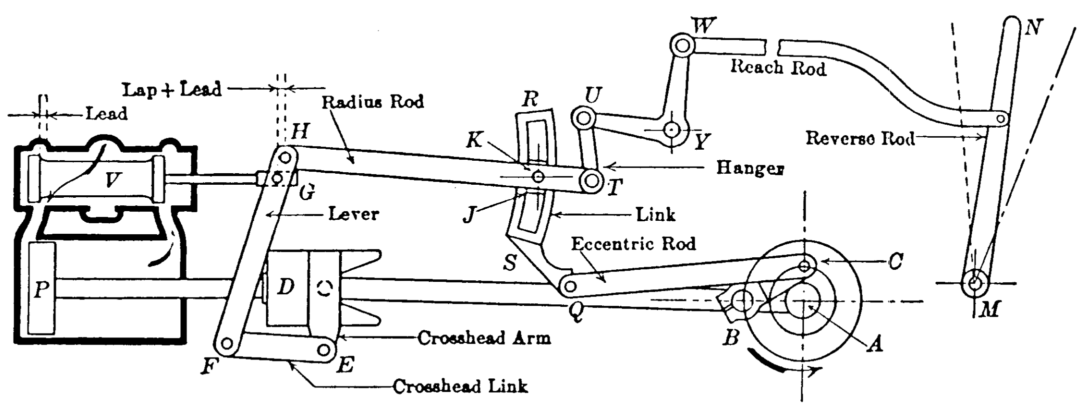


Fig. 7 Walschaert Valve Gear

Two more examples and I'm done. Fig. 7 shows the Walschaert Gear which was used extensively on steam locomotives until they were no longer built. As with the Gooch Gear, the Link is pinned and the Radius Rod is moved for operation. A big change from the preceding examples is that there is only one eccentric, and this is made (for cost and maintainability reasons) by bolting a lever on the end of the crankpin. To get the required 'lap' and 'lead', a second input is taken from the crosshead. An advantage with this gear was that once set up

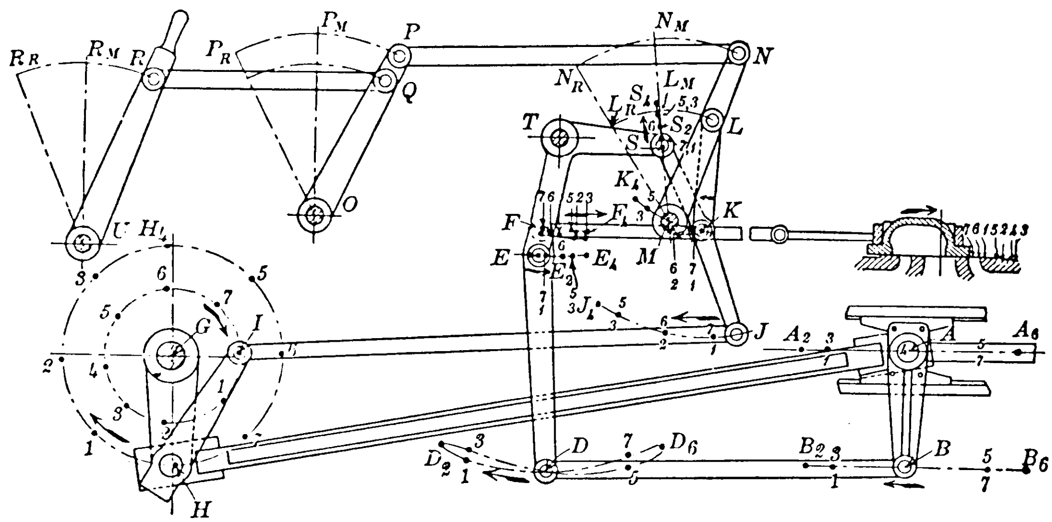


Fig. 8 Baker Valve Gear

correctly, it was easier to maintain than the preceding examples. Finally, Fig. 8 shows the Baker Gear which is what I was trying to get to all along. This gear was also used up to the end of steam locomotives, and depending on who you ask, was either the best gear ever developed for the purpose and an American invention, or just a modification of a good European design (The Walschaert). Whats different about it? The link with it's curved slot is gone. It's therefore cheaper to make and there are no sliding surfaces to wear and become loose in the mechanism, just pinned joints that can be given journal or even ball bearings if desired. If you look closely at the links nearest the valve, you can see an arrangement quite similar to the variable stroke mechanism of Fig. 1. So I've said who needed this mechanism and why, and I've said that the Fig. 1 mechanism was perhaps the best ever developed from a cost, ease of manufacture, and durability point of view. So the last thing I'll say is that in practical application, there is more detail than is seen in these '2-D' pictures (a lot of the links look like wishbones). If you want to see how it was done, go look at an old steam locomotive with the Baker Gear, such as the 125 Texas Type 2-10-4's built from 1942 to 1944, one of which is at the Conneaut Railroad Museum in Conneaut, Ohio.

References

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