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HUMAN POWER

TECHNICAL JOURNAL OF THE IHPVA

Contents of vol.10, no.1 ISSUE 32

VOLUME 10

1 ISSUE

SPRING-SUMMER, 1992

Human Power
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Human Power is published quarterly by the International Human-Powered Vehicle Assoc., Inc., a nonprofit organization devoted to the study and application of human muscular potential to propel craft through the air, in and on the water and on land. Membership information is available by sending a self-addressed stamped business-sized envelope to the IHPVA address above.

Additional copies of Human Power may be purchased by members for \$3.50 each, and by nonmembers for \$5.00 each.

We are indebted to the authors, to Marti Daily and to Carolyn Stitson, whose dedicated help made this issue possible. Dave Wilson

Editorials

An historic battle

You may be blissfully unaware of it, but a battle that concerns us all is raging around us in learned circles. It concerns the originator(s) of the pedalled bicycle. We usually give a nod towards Kirkpatrick Macmillan, a Scots blacksmith, who seems to have made the world's first pedalled bicycle in around 1841 - but we have to rely on second- or third-party accounts that are either vague or conflicting or both. It doesn't matter too much, because he had virtually no effect on the world. Apparently he didn't write, and he shied away from publicity.

The position of the Michaux family seemed, on the other hand, assured. Historians have told us that they developed the front-wheel-pedalled bicycle in 1861, and that they were showmen and businessmen and started a craze that lasted for the rest of the century. I see that I wrote (in American Scientist, July-August 1986) ". . credit for the bicycling revolution belongs indisputably to Pierre Michaux and his son Ernest and to a controversial employee-turned-competitor, Pierre Lallement."

Now I am an amateur, not a professional, historian. I rely nowadays on the writings of a very professional amateur, Derek Roberts, founder of the Southern Veteran-Cycle Club in the UK. When I started adding historical notes to my writings I was not as careful in my choice of people to quote. I was gently taken to task by Derek Roberts over the historical section I wrote for Bicycling Science. He has the reputation of a curmudgeon, and at the time I agreed with that perjorative label. But increasingly he has become one of my heroes. Historical accuracy seems trivial until one tries to understand why an inventor did what s/he did, or until one becomes a victim oneself.

I found myself becoming curmudgeonly when, for instance, someone made a presentation of recent developments in some aspect of human power and used, without attribution, data and graphs produced by my students and myself as if they were his own. I decided to swallow my pride and to keep quiet - but since then people have used his paper as the fundamental reference, and my students have gotten no credit. Once a "history" has been written, it is taken as truth by others, and the falsehoods propagate like crab grass. Derek Roberts calls them "myths", and he has written a book about them. He also writes a correction sheet for each new book that repeats any bicycling myths

Derek Roberts still believes that the original invention of the so-called "French bicycle" in the 1860s was the work of Pierre and Ernest Michaux. He has translated a book from the French about the family. But another bicycle historian I respect, David Herlihy, believes that Pierre Lallement was the inventor, and that he was shafted by the Michaux family, who were very good at self-promotion. It turns out again that there was nothing written by the Michaux until decades after the supposed invention, and no patent, whereas Lallement did take out a (US) patent.

You may not be excited to delirium - I am - by this battle of the champions. I mention it, of course, as a sermon. Please make truth and accuracy and acknowledgment of the work of others your holy grail when you write for any publication, especially Human Power. So far, you have bestowed an unsullied reputation on the journal.

Upturn in the economy

Orders for recumbents have sharply increased lately. The reason can be traced to marital love. Vic Sussman, a writer for, among other publications, Newsweek, had given up conventional bicycling because of the pain he suffered. He happened to try out a Ryan Vanguard, took home Dick Ryan's video about it, and "watched it, fantasizing, twice a week ". Eventually his wife bought him a Ryan, and he has been crazy about recumbents ever since. His ability to channel his enthusiasm into a two-page spread in a national news magazine has produced a small but very welcome blip in the economy of several struggling recumbent-bicycle manufacturers. His piece could also encourage stirrings in designers of regular bikes. We are grateful for Vic's wife's loving concern for her spouse.

HP Olympics

When Chet Kyle and Jack Lambie organized the first International Human-Powered Speed Championships in 1975 (they formed the IHPVA a year later) there was one event: the 200-m flying-start speed trial. This year Chet brought the IHPSC back to California - to the beautiful area of Yreka in near Mt. Shasta. He and his small band of mainly local non-IHPVA members put on a tour de force. We now have so many

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HUMAN POWER

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Vol. 10, no. 1 | Spring-summer 1992 | $5.00

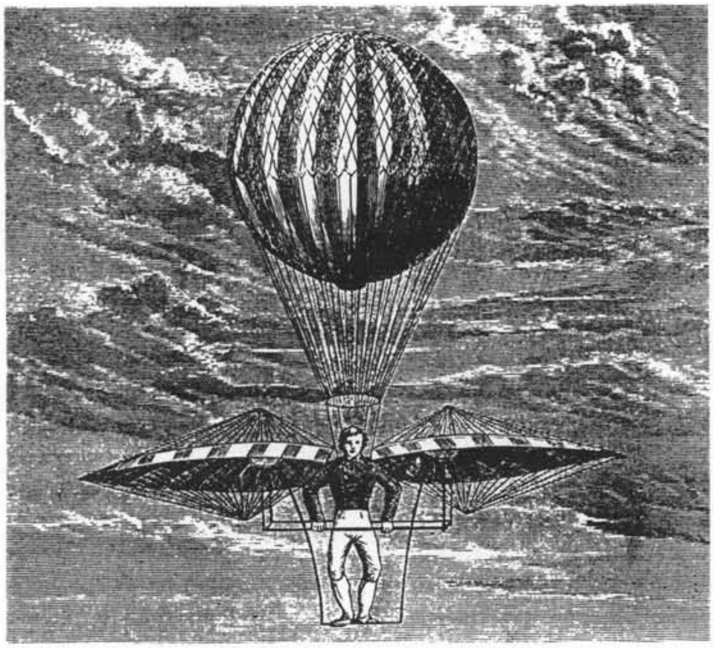

Figure 1 Degen's balloon *From "Transportation, a pictorial archive. . . Jim Harter, Dover, NY, 1984*

The history and present status of human-powered flight

by Chris Roper

Summary

This is an extract from the HPV Handbook, which will be published by Human Kinetics Publishers in, we hope, 1993. The manuscript of the book has been assembled from the writings of HPV experts, and edited by Allan Abbott and the editor of HP. This extract is from a chapter written by our VP, Air, Chris Roper. Every known craft that has been devised to enable human beings to fly using their own muscles for power input is listed in this and succeeding extracts, together with notes on many other aspects of human-powered flight. As the author, himself a pioneer in the field, observes, human-powered flight is a great deal more than designing and constructing an aircraft.

The craft are listed in historical order and notes are interspersed when relevant. The information given in this chapter should be invaluable not only for the historian but also for someone contemplating a new design of human-powered aircraft.

The editors

Blanchard's balloon.

Jean-Pierre Blanchard was one of the pioneers of the balloon, which was invented in 1783 by the MonGolfier brothers. His most significant contribution to human-powered aeronautics was his use of a propeller, manually rotated, mounted on a balloon. Using this he was able to exert some limited control on the speed and direction of flight.

Degen's balloon

Jakob Degen of Vienna appears to have obtained most, if not all, of his lift from a balloon beneath which he and a pair of umbrella-like devices were suspended (1808). By the use of levers he could move these up and down and thereby produce some control of altitude.

Degen was a ribbon-maker and later a clock-maker. It is said that reports of his (almost) human-powered flight reached Sir George Cayley without mention of the balloon. Cayley thereupon was encouraged with his development of the airplane, which he could be said to have invented.

The Peugeot prize

Robert Peugeot of France offered (in 1912) a prize for the first HP flight of at least 10m (33 ft). He gave several consolation prizes for "flights" of less than

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different events that a prodigious effort is demanded of the volunteers. Are the demands too heavy? Our new president, Marti Daily, and the board of directors are asking for your views on the future direction of the IHPVA. Some (see the next editorial) believe that the diversity of interests is becoming so great that we are losing our focus. When Ellen and I returned to our motel room each evening we would watch a little of the Olympics, and we were struck by the similarities with the modern IHPSC. There were sports that we had never heard of previously (e.g. rhythmic gymnastics) that nevertheless attracted enthusiastic audiences. The commentators were sufficiently skillful and knowledgeable that we could find ourselves rooting for some unknowns. Perhaps the IHPSC should use the Olympics as a model. We should set a limit to the duration and the number of events, and admit and drop events using a criterion of popularity or of worth.

Vigorous debate by correspondence

When Rob Price sent his manuscript on "what is and what is not a HPV, and why" I reviewed it and wrote to him that I would love to publish it in HP, even though I did not agree with all his opinions. I thought that he would raise the hackles of a few people. I was certainly right! His article stimulated more correspondence than HP has ever had on one subject. Some of the letters were a little more vitriolic than I would have liked. We are publishing all except one somewhat incoherent letter, although we have had to shorten some. Rob Price is a superb engineer and author, as we have seen from his earlier contributions, and his views are always thought-provoking and insightful. He has sent along a "side-bar" to his response to the correspondence that I hope I have room for in this issue. It is on the subject of the IHPVA's diversity. Rob, as usual, is unorthodox: he believes that the ICU was right to ban recumbent bicycles from competition so that it could concentrate on athletic contests rather than engineering. The IHPVA must face some limits to its scope eventually. Read and ponder!

Dave Wilson

Letters to the editor

Compliments and suggestions

I am pleased with the consistent quality of the publication *Human Power*. The authors have written technical yet very readable articles and the general layout looks professional. Vol.9 nos.3-4 are no exception. I especially enjoyed "Modelling energy consumption on the Tricanter HPV" by John Raine and Maurice Amor. Their work suggests some methods to try for testing rolling resistance (a problem I have been trying to solve), and shows the detail of their design process. Great publication!

Mark E. Mueller, 1161 I St. #6, Arcata, CA 95521-5558; 707-822-4771

HP is looking good! Great articles, interesting letters, and I fully agree with the editorial comments on international cooperation. John Allen's article "In search of the massless flywheel" was fascinating and thought-provoking. It prompts me to recommend another method for minimizing the dreaded deadspot.

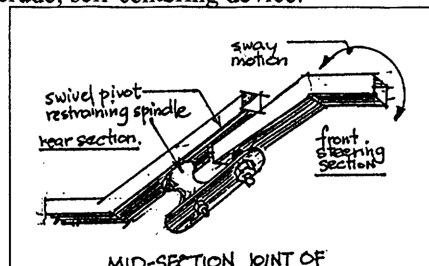
Add a pair of arm cranks. My recumbent trike, designed by Gary Hale of Eugene, OR, has substantially smoother power output with arms cranking. The weight penalty is about 5 kg, 10 lbm. The two pairs of cranks are offset about 90 so that the hands don't hit the knees. I discovered that the standard reciprocating crank arrangement caused noticeable zig-zagging, wasting energy and wearing out tires. This problem was solved by putting the cranks in unison. The action is somewhat like rowing with a sliding seat. Acceleration is tremendous and sustained speed is 10-15% greater than with reciprocating cranks. The technique takes a little practice . . . but the effort is well repaid. . . While touring, the arms really save my knees on the hills, sharing the load. The arms may be a flywheel to dampen the dead spot and enhance the power stroke.

Larry Warnberg, P.O. B. 43, Nahcotta, WA 98637.

The Flevo FWD

Please allow me to add my further observations on the Flevo bike as reported in Mike Eliasohn's article on FWD recumbents in HP 91/9/2 p. 14.

Unlike other FWD's swivel mounts, the Flevo's steering employs the principle of flap-banking. A dislocated mid-frame joint serves the dual purpose of producing lateral sway to the front wheel and at the same time, maintaining the rigidity necessary to utilize it as a drive wheel. As can be seen in Johan's diagram, the mid-section free swivel is restrained by a spindle-shaped PVC grommet producing an ingenious, but crude, self-centering device.



MID-SECTION JOINT OF FLEVO-BIKE

Mastering the Flevo bike requires a great deal of practice, patience and self-confidence. It took me almost fifteen hours and ten falls over a period of three weeks before I could counter the rodeo-effects of its steering mechanism and almost a year before I weaned from hand to leg steering. The constant new discoveries of slalom turns and leg steers make this one of the most interesting and challenging recumbents I have ridden.

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What is an HPV?

(All the following letters are comments on Rob Price's article in the last issue of HP)

I find Rob Price's article "What is and What is Not a Human -Powered Vehicle and Why" in Human Power 9/3 and 9/4 generally thoughtful and well-considered: but in describing canoeing, he gets in a bit over his head in the water; and in describing Nordic skiing, he goes into a snowbank.

Price describes canoeing as follows: "The paddler dips one end of the oar then paddles a few strokes on one side of the boat while providing a fulcrum for the paddle end with the other hand. The paddle then changes hands so the action is moved to the opposite arm for the next series of power strokes. In this way power is balanced on both sides of the boat and both arms, and the boat goes in a fairly straight line atop the water."

This describes a single-ended paddle (not "oar") technique used by rank novices. Experienced canoeists propel themselves forward primarily by straightening up into a sitting position out of a forward crouch while rotating the upper body from the waist, bringing the powerful muscles of the trunk into play. The arms are held relatively rigid and nearly fully extended; neither hand is used as a fulcrum.

The experienced canoeist does not change sides to steer when using a single-ended paddle, as the paddle is used to steer at the end of every stroke. The common technique (the "J stroke") uses the paddle as a rudder, but a more efficient technique is to pull down on the handgrip at the upper end of the paddle, using the gunwale at this time as a fulcrum to lever the paddle's blade away from the boat. I learned this technique from my grandfather, who learned it from the Algonquins.

The paddle is capable of a wide variety of specialized forward and reverse sweep strokes, push-off and pull-in strokes and sculling strokes. Though somewhat less efficient for forward propulsion than oars, the paddle is far more versatile; for this reason, and because the paddler faces forward, paddles are always used in white water and other situations requiring tricky maneuvering.

In the light of these facts, I am astonished by Mr. Price's disqualification of the canoe and kayak as human-powered vehicles on grounds that they lack an impedance-matching device. If he were correct, our language would lack the colorful saying "up the creek without a paddle;" bare hands would do nearly as well.

The paddle transforms impedance by increasing the sweep of the arms, and by improved connection to the water through its large blade. A wide range of impedances may be selected not only by the choice of a paddle but by varying hand positions and strokes. One valid conceptual difference between paddled and rowed boats is that the paddle lacks a constant fulcrum or point of support on the vehicle -- but the paddle is nonetheless an impedance-transforming device: so, if a rowboat is a hand-cranked human-powered vehicle according to Mr. Price's criteria, then so is a canoe or kayak!

As to skiing: not all Nordic skis have a "fishscale-shaped or stepped bottom surface construction." Instead, many use special waxes which have high sticking friction against snow, but very low sliding friction. Even waxed skis are capable of climbing grades several times steeper than the 0.5% which Mr. Price cites. Ski waxes are an interesting topic for human-power research even if this may not qualify as human-powered vehicle research.

The parallel-ski technique which Mr. Price describes has largely been replaced, at least in competition on packed snow, by a faster version of the "herringbone" or "skating" technique previously used only for uphill propulsion. To some degree, this development reflects changes in the Nordic skis themselves, including the adoption of composite materials, steel edges and improved bindings.

Note that this technique involves an impedance transformation of a slow drop in the skier's center of gravity and slow sideways motion of the leg into fast forward motion of the skier. There is also an inherent acceleration to coupling speed, as each stroke propels the body toward the opposite leg by action/reaction. An important impedance transformation also occurs through the ski poles, with a short downthrust becoming a longer backthrust.

Therefore I do not agree that Nordic skis disqualify as a human-powered vehicle on grounds that they lack an impedance transformation. Should they disqualify on grounds that they attach to the feet like shoes? The same question applies to ice skates, roller skates and in-line skates, whose means of attachment and propulsion are similar. I would opt for the broadest definition on grounds of consistency, recalling that the IHPVA was forced into existence some twenty years ago by the International Cycling Union's restrictive definition of "bicycle." While the IHPVA's approach produces true innovation, the ICU's rules lead only to evolutionary monsters, upright bicycles with aerodynamic parts which pretend not to be in order to beat the rules.

Price comments about Nordic ski braking that "Basket brake force may be increased by placing the poles between the legs and using the seat area as a fulcrum, a favorite of men contemplating castration. As with Alpine skis, the quickest way to stop is to fall over."

Perhaps YOU go into the snowbank, Mr. Price, but these gratuitous comments do not contribute to an understanding of the sport, and do not reflect the grace of the sport as practiced by trained athletes. I am sure that the U.S. Consumer Product Safety Commission would have devised an equally gratuitous safety regulation for ski poles, as it has for bicycles, if a Nordic castration epidemic had been demonstrated in the medical literature.

The discussion of skiing raises a serious question, however: IHPVA members' research has led to radical advances in land and water speed records -- and to human-powered aircraft, an entirely new category of vehicle. Can we expect to see similar radical developments in human-powered travel over snow?

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I have intended for some time to subscribe to the IHPVA . . . I enjoyed your review of my paper on high-speed Aleut kayak design (HP 9/2:10) and other items passed to me by your member Larry Warnberg. . . Now I have just received a copy of Rob Price's piece on (in part) why kayaks should not be considered human-powered vehicles. Without addressing his argument (you can infer the details) I am now sending in our $20 for membership and a subscription, to lend this little bit more weight to the opposing view. Lending more weight, I expect, will be the current work of . . . William S. Laughlin on the Aleut hypertrophic humerus.. . . The Aleut kayak incorporated impedance-matching technique and technology on several levels, perhaps not as immediately visible to an untrained eye as the gears on a ten-speed bicycle, but nonetheless effective in making the most of human power for long-distance work.

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98227-5454

In the 1991-2 Fall and Winter issue of Human Power, Rob Price attempts to define a human-powered vehicle ("What Is And What Is Not A Human-Powered Vehicle And Why"). The critical question he asks is whether each type of human-powered device achieves a "reasonable machine-to-rider impedance match". A "reasonable" match warrants its inclusion in the ranks of HPVs. He defines impedance matching as, to paraphrase, the ability of the device to most efficiently utilize the human power output. To do so would require the use of the best muscle groups, operating at the optimum balance of force and cyclic rate, and using an efficient coupling speed. He concludes that a bicycle with multiple-ratio gearing is the ultimate in impedance matching. He also provides a branching diagram which purports to be a taxonomy of human-powered machinery, and which designates which devices are HPVs, and which are not, on the basis of the quality of their impedance matching.

I appreciate Price's attempt to define an HPV. But, with all due respect, I reject both his premises and his conclusions. My own position is: 1) that a definition of HPVs should be as inclusive as possible, so as to encourage innovation; 2) that the concept of impedance matching is only one of many possible, and equally important, criteria that might be used as the basis of a definition; and 3) that only working definitions - as for competitions - are necessary.

The concept of impedance matching is particularly useful if our goal is competitive performance. However, Western culture tends to evaluate too many things in terms of competition, power and efficiency. It is often inappropriate to do so. For instance, what if our primary goal is practicality, or low cost, or safety, or reliability, or maneuverability, or simplicity, or versatility, or entertainment, or beauty? For any given vehicle purpose, impedance matching may have a greater or lesser degree of importance. So while the concept is useful, it is not at all definitive.

We need to be careful not to pick an arbitrary criterion that can have negative effects. Price's taxonomy has social implications. Anything defined as a non-HPV is more likely to receive less attention from IHPVA members. He defines HPVs in a way that is exclusionary - it creates an "in group" and an "out group". For instance, he excludes conventional push-type wheelchairs because their impedance matching is less efficient than

Bram Moens between races at the IHPSC
Photo by Ellen Wilson

Bram Moens is a well-known builder, innovator and racer of HPVs in Europe. He came to Yreka in August 1992 with his beautiful recumbent (and his beautiful wife Anja Koning) and produced some startling, winning, performances. He was interviewed by your editor.

"I teach art and sculpture in Holland. I became interested in HPVs after trying a Roulandt recumbent in 1982 and wanting to improve it. I made a three-wheeler in 1983 and bicycles subsequently. HPV races were started in Holland by the American Gary (?) Peterson in 1984 at Zandvoort. Our Dutch HPV association now has 1000 members. What comes next? It depends on the market. I have broken even in the last two years. I have worked with Flevo without success to interest manufacturers. Combined sales in Holland of all HPVs is about 1000, increasing at 50% per year. We need to get to 10,000 to be taken seriously".

wheelchairs. If the IHPVA were to accept Price's distinction, push-type wheelchairs would, by definition as non-HPVs, be barred from future competitions as an inferior form of human powered device. This, in turn, would be more likely than not to discourage IHPVA members from investing time and energy in their further development. It would also be likely to discourage wheelchair users from joining the IHPVA. But push-type wheelchairs are valued for their maneuverability and versatility more than for their top speed. Consequently, to accept a criterion that would define push-type wheelchairs as non human-powered vehicles would seem to be unnecessary, illogical, and socially irresponsible.

If anything, the IHPVA should continue to sponsor more, not less, competitions to promote the further development of the most effective wheelchairs - and for all types of applications, not just racing. While impedance matching would be considered during any design process, it should not be given priority over other, more relevant, considerations. Price's hierarchy would be expected to lead to similar discriminations and delays in the development of other types of HPVs as well. For instance, Parker MacCready's innovative Pogo Foil hydrofoil craft could be defined as not yet incorporating an efficient impedance match and so would not be an HPV (or HPB), could not compete, and therefore probably would not have been built.

Price offers no reason for creating his discriminatory definition for HPVs. He states only that defining an HPV "is always a problem". But what exactly is his problem? He also does not objectively define what a "reasonable" impedance match might be. Nevertheless, he uses a dividing line that excludes such classic examples of HPVs as canoes, kayaks, galleys, boats driven by a stern-mounted scull, pole-propelled boats, rope-pulled ferries, pulled canal barges, cranked rail cars, palanquins and stretchers, wheelbarrows, rickshaws, snow shoes, cross country skis, and ice skates. But is there actually any good reason to do so, other than to achieve an arbitrary and incomplete taxonomy? I see none.

The arbitrary and incomplete nature of his taxonomy becomes more evident if we consider current and future HPVs such as Hovercraft, all-terrain vehicles, air and/or water helicopters and autogyros, ram wing craft, oscillating hydrofoil craft, snowmobiles, ice trikes driven by studded wheels or air props or angle-action blades, and tank-tread amphibious vehicles. Consider also such common vehicles as Pogo sticks, surfboards, floating air mattresses and inner tubes and water-wings, little red wagons, hand trucks, push carts, unicycles, baby carriages, and castered secretary chairs. He also excludes less-well-known devices such as eccentric-wheel bounce-scooters, rowed tricycles, pedal-driven lawn mowers, rail bikes, pedal-driven dirigibles, directly-cranked-side-wheel trikes, and squirrel-cage paddle wheels. But why? Because they do not readily conform? What, for instance, is the quality of impedance matching of a Pogo stick?

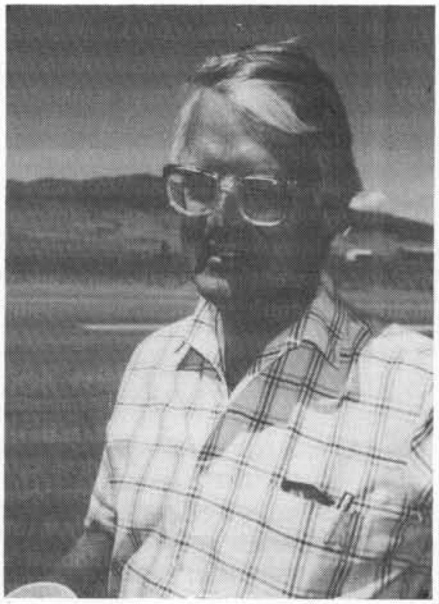
Note also that he does not attempt to classify more controversial devices such as swim-fins, stilts, vaulting poles, climbing and repelling ropes, and ladders. (Shoes he rejects, because "there is something about" them. But for climbing stairs and steep ramps, or for playing basketball, shoes would seem to have excellent impedance matching.) In fact, one might even make a case for the inclusion of such semi-stationary devices as trampolines, diving boards, swings, teeter-totters, push-go-rounds, and rocking chairs if we define "vehicle" broadly enough. And why not? What is to be gained by including so few and excluding so many? Should HPVs be defined from a single, narrow perspective, or should they be defined from a broad perspective that includes the full spectrum of past, present, and future vehicles? Would it be, or is it, appropriate for the IHPVA to be predominantly concerned with power and efficiency? Do we really want a definition that, in effect, proclaims the purity of master racing vehicles over other sub human-powered machinery?

The spirit of the IHPVA is to define HPVs in a way that is as inclusive as possible so as to encourage diversity and innovation. The rules of any specific IHPVA competition already effectively define what is and is not an HPV - at least for that competition. As I have contended in another article, those rules are already too restrictive. In my opinion, we should reject intellectual restrictions which may inhibit creativity, encourage social discriminations, or cause delays in useful developments.

Price's use of a branching diagram to list the various types of human-powered machinery is misleading. It implies that the various machinery can be neatly defined and categorized. But a more complete listing of known and possible vehicles would create a branching diagram with so many categories cross-branched in so many ways as to become hopelessly confusing, and with many sub-classes containing their superclasses. There are many ways of categorizing any given vehicle, such as by the type of drive mechanisms, by the manner of supporting the vehicle (wheels, blades, floats, etc.), by the functions or uses of the vehicle, etc. For instance, how might this vehicle be categorized: an amphibious tricycle ridden by a gorilla and using inflatable treads capable of functioning on roads, mud, gravel, snow, ice, and water? Or how about the familiar example of a Hovercraft driven by an air prop? How would a hydroplaning tricycle be categorized? Or a bicycle on training rollers? Such combinations are endless. It is doubtful that a precise and objective taxonomy of HPVs is possible, due to the way drive systems and other components can be endlessly mixed, and new ones devised; and due to the different manner in which components may function at different times and under different circumstances. The definition of a "vehicle" is also endlessly debatable. While taxonomies of HPVs may be useful, they are not definitive. They are inevitably arbitrary and incomplete. An open-ended and cross-indexed list, however, would be quite useful for generating new ideas. (For instance, see HP News, May/April l992, pg. 11, for Jim Kor's IHPVA "family tree".)

D.G. Wilson defined the concept of impedance matching as the relatively flat top-section of a power curve which is plotted by using force and velocity as the main axes (First IHPVA Scientific Symposium Proceedings, pg.132, Figure 1, "Impedance Matching"). But Wilson also notes that "forced" rowing using a fixed seat and moving feet produces much more power than pedaling - for a period of 5 minutes. That would seem to contradict Price's claim that a bicycle with multi-ratio gearing is the ultimate in impedance matching.

The concept of impedance matching may also be expanded so as to describe the overall strategy of energy expenditure while using a vehicle for a given route or purpose. For instance, in a personal communication, Doug Milliken used the concept of impedance matching to describe the strategy for achieving the highest speed in an IHPSC sprint. The acceleration profiles (a graph showing distance, speed, and the transition point from aerobic to anaerobic pedaling) for a sprint would be selected so as to make the most efficient use of the rider's maximum output. Another example would be the strategy for climbing Mt.



John Stegmann at the 1992 IHPSC
Photo by Ellen Wilson

John Stegmann has had a dramatic effect on HPV racing generally, but especially in his native South Africa. He flew over to the IHPSC at short notice and Chet Kyle immediately put him to very hard work judging the practical-vehicle contest. We were lucky to get to talk with him. As usual, we asked how he got into HPVs and what he would do next. *"I was making an energy-saving auto of 50 cc in 1976 using bicycle technology, and rediscovered not only the bike but the fact that it was socially unacceptable to use it. Then I came across a derisive account of the first IHPSC in California in a popular magazine, together with an interview of Chet Kyle. I wrote to him and became hooked. Why front-wheel drive for my bikes? I'm interested in practical vehicles, with equal-sized wheels and good load-carrying capability. FWD also enables folding bikes to be simpler. I was much influenced by Tom Traylor. I tried tandem streamliners and then singles, but it was five years before they became competitive. In 1983 & 84, Lloyd Wright won almost all the possible categories in the world's largest cycle race - and that when he was riding solo, whereas the regular riders were in packs. The media ignored the wins, however, and the organizers tried to ban HPVs the next year. I am most proud of negotiating the combination of UCI and IHPVA rules. I'm writing a book about these experiences."*

Tory Sokomoto at the 1992 IHPSC being interviewed by a (the?) member of the HP staff *Photo by Ellen Wilson*

"I first became interested in human power seven years ago when, in high school, we saw a TV film of the 9th International Birdman Competition for HP aircraft and gliders. My ambition was to become a pilot. I knew that I must get to the best university in that field: Nihon University, where Prof. Hidemasi Kimura had started the HPA project in 1962. Since then 30 HPA had been made, including, in 1977, the Stork with which was made a new world distance record of 2094m. Recently I was able to achieve the Japan HPA distance record and last year I won the HPA Birdman competition in a high wind and heavy rain. Now the Nihon Old Boys Club is building a HP hydrofoil for the Dreamship competition. Our main competition is Yamaha."

Everest, using a series of base camps, etc. Or the strategy of a bicycle commuter who selects a route with as few hills as possible so as achieve a higher speed and shorter travel time even though the total distance may be greater.

I might agree with Price's claim that a bicycle with multi-ratio gearing is the ultimate in impedance matching if the purpose of the bicycle were either to be run on training rollers, or to function as an air plow. The route or purpose of the vehicle needs to be considered as part of a more inclusive, or higher level, definition of impedance matching. In other words, to determine the overall quality of impedance matching, it is necessary to consider all of the links between the human energy output and the intended route or purpose of the vehicle. For instance, a mountain bike would provide a good impedance match between the rider and an off-road route, but the same bike would have a relatively poor impedance match if used for IHPVA road racing. Another example would be the non-use of forced rowing for human-powered streamliners - because the arm and body movements would seem to require a fairing with a larger frontal area, thereby producing increased drag which would more than offset the increase in power, and yielding a lower overall impedance match between rider and purpose.

For some types of road riding, even efficiently faired bicycles with multi-ratio gearing are not the ultimate in impedance matching. For routes such as sprints, road races, or stop-and-go city riding, an energy accumulator would provide an improved impedance match between rider and route by conserving energy that would otherwise be wasted or not generated while coasting, braking, or while stopped. The energy could be stored using pregenerative pedaling and/or regenerative braking. The average speed would be correspondingly increased, more or less, depending on the specific route. For relatively steep climbs, a lighter conventional bike would provide a better impedance match.

If the route or purpose were defined as a distance over which to transport a very large load, then a human-powered ship would achieve a much better impedance match than any other HPV. If the route or purpose were defined as climbing the stairs to the top of the Empire State Building, then the best impedance match would probably be achieved by using running shoes. If the intended route or purpose included a great many vertical oscillations, then a Pogo stick would probably achieve a much better impedance match than would a bicycle with multi-ratio gearing. If the route were defined as large oscillations in a vertical plane, then a reasonable impedance match would be achieved using a swing, and a better match by using a trapeze. If the route or purpose were to pull a small child in a little red wagon down the sidewalk, then a slow and easy walk would produce the optimum impedance match. And so on. While Wilson's definition of impedance matching would apply in cases where maximum power were the intended purpose of the drive-train, the best impedance match between the rider and the drive train might or might not provide the best impedance match between the rider and the intended route or purpose.

Price's use of the concept of impedance matching serves as an example of how not to define an HPV. What is needed in this instance is not a more exclusive definition of an HPV, but rather a more inclusive definition of HPV impedance matching. HPV impedance matching: the optimum compatibility of the separate and/or combined links between the human energy output, the drive-train, the HPV as a whole, and the intended route or purpose. Therefore, the quality of impedance matching cannot be determined without first defining the intended route or purpose of a vehicle, and vehicles and/or components may be ranked in terms of their quality of impedance matching only to the extent that they share an intended route or purpose.

The term "HPV" is often used informally to differentiate the higher performance potential of IHPVA streamliners from that of conventional bicycles. Such usage is acceptable in that any term may have multiple meanings. However, a more appropriate term would be "HPS" - for "human-powered streamliner" - which would be defined as a type of HPV designed to achieve low aerodynamic drag. Such a term would be descriptive without implying elitist or exclusionary distinctions. After all, even Price would not exclude conventional bicycles from the ranks of HPVs.

Peter Sharp, 2786 Bellaire Pl., Oakland, CA 94601

I found Rob Price's article . . . interesting and useful. However, it is clear that Price has a number of misconceptions about canoes and kayaks.

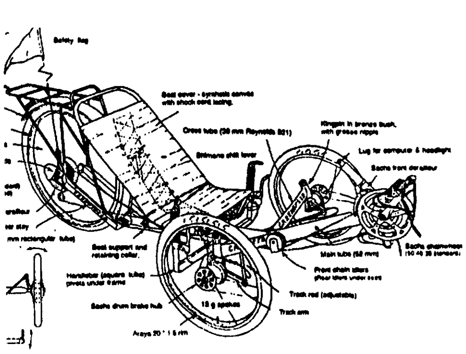
Canoes are paddles with single-blade paddles (not 'oars'), but directional control comes not from switching sides, but through the use of strokes such as the J-stroke, which provides both forward thrust and steering action. With the exception of marathon racers, anyone who controls a canoe by switching needs to learn to paddle. Any book on canoeing makes this clear.

The kayak, as suggested by the editorial note, was devised for use in the Arctic. The various Inuit groups developed boats and paddles to suit their local needs. Their boats were used on the open sea, and they, like modern-day sea-kayakers, often travelled considerable distances, in sometimes stormy conditions. Very different from the 'running water . . directional control. . fending off obstructions' that Price describes.

As for impedance matching, the choices are limited, but more than realized by Price. Change of hand position is used by some paddlers, but paddle length, and to a lesser extent blade area, are used to match boat speed to paddle cadence and paddler's power. To take two examples, paddles used in white-water and sea touring differ quite markedly. In white-water the speed is relatively low, but acceleration and maneuverability are important, and the paddle is relatively short. A sea kayak is faster and travels at more or less constant speed (about 1.5 m/s) and the paddle is long, 2350 mm being common. Matching the paddle to the boat and paddler is important. Just as too high a gear on a bicycle can lead to knee problems, so can the wrong paddle result in wrist injuries. Again, [these] are well explained in the literature, and familiar to those involved. (I might point out that I am an Australian Canoe Federation senior instructor and a part-time builder of sea kayaks).

Canoes and kayaks are definitely vehicles and certainly human powered. I suspect that they are closer to being HPVs than Price believes.

On another subject, I ride a vehicle that is definitely an HPV: an Australian-made Greenspeed GTR 20-26. It is made in Melbourne by Ian Sims (69 Mountain Gate Drive, Ferntree Gully, Victoria 3156, Australia). Enclosed is a brochure (*I'll send this on to Steve Des Jardins for the new Source Guide - ed)* and an illustration I drew for a local cycle-club newsletter.



GREENSPEED GRT 20-26

Peter J. Carter, 28 Rowells Road, Lockleys, South Australia 5032. (08)43-4298

Rob Price chooses to define HPVs by the quality of their "impedance-matching" and denies many vehicles their HPV status on this basis. I think he is looking at it too mechanically, as we are never concerned with just a vehicle, but rather with a vehicle-person combination. The human body achieves a fantastic range of impedance-matching all by itself, being able to sprint at up to 10 m/s, yet also climb vertically. Even when using simple devices like skates, skis, and paddled boats, people can maintain this degree of adaptability and often even extend the range. A good kayaker or canoeist can paddle efficiently at low or high speeds at various loadings imposed, for example, by the weather. Different strokes and grips help and "impedance-matching" is actually better than with boats using propellers with fixed pitch and fixed gearing, even if these have a higher peak propulsive efficiency. The reason paddling seems like such hard work to untrained persons is that most people have fairly weak arms which tire quickly just holding up the paddle whereas most have legs strong enough to support their bodies for hours each day.

In a similar manner nordic-skiers can achieve fairly high speeds on the level (and of course downhill) yet instantly adapt to steep gradients or poor snow. I fail to see an intrinsic difference between this sort of impedance-matching and that done with pedals and gears.

The other point is that except to people establishing racing categories or bureaucrats looking for things to ban or tax, it makes very little difference what we define as an HPV or not. In the IHPVA we are also concerned with human power in a wider context, e.g. for devices such as hand-drills, lawnmowers, pumps or generators. Even in this age of electric toothbrushes and pencil-sharpeners, good hand-tools are far from obsolete and well-designed ones are often more useful than many powered ones.

Theo Schmidt (assoc. editor, Europe)

I am rather disturbed by Rob Price's article. . . I am not an engineer or designer of any kind, but I am a skier, skater and cyclist. As such, many of Mr. Price's statements trike me as wrong.

Some of this "wrongness" seems to come from a simple lack of research. It is known, for example, that although the side cut of a ski helps to initiate the ski's turn, a turn at speed is achieved primarily by the ski's flex during the turn. In the extreme, one can see this by carving a turn with a track-style cross-country ski (one with no side cut). Discussions of how a ski carves a turn is rather common in the popular skiing magazines. Similarly, when Mr. Price talks about cross-country technique, he mentions only diagonal stride techniques, not skating techniques (very important in the current racing scene), he fails to mention the use of wax (rather than steps or fish scales) for ascending, and his working of "gradual slopes" is rather misleading.

During his discussion of wheeled vehicles, he claims that roller blades are not HPVs as 1) they can't be steered, and 2) they don't allow for "impedance matching". For 1), what can I say? Has Mr. Price ever used a roller blade? Although I spend more time on "regular" roller skates, I have used in-line skates, and I know that leaning one's foot relative to the ground causes them to track a turn. . ..

Impedance matching seems to be a major pitfall for me. . . After all, many "real" machines (such as steam locomotives and turbine engines in jet airplanes) don't use any impedance matching. Second, I quite frankly can't believe that a row boat is not a HPB, and by this criterion neither is the Decavitator. . . But to top it off, skating techniques in general . . . do allow for impedance matching, simply by varying the angle between the axis between the two skates or skis.. . . just like selecting the "right" gear on a bicycle.

Eric Schweitzer, 166 East 96th Street
New York, NY 10128

Rob Price replies.

John Allen details the more efficient paddling techniques used by experienced canoeists and describes a steering technique handed down from the Algonquins via his grandfather. This forces a point that I failed to make in the article: how much training is necessary to overcome idiosyncrasies in some drives to get a reasonable output? A good impedance match, or good efficiency, ought to be realizable by "rank novices", to borrow Allen's words.

Allen and George Dyson take me to task for excluding kayaks. Dyson made the point that the Aleut kayak used impedance-matching technique and technology on several levels, perhaps not as visible to the untrained eye as the gears on a ten-speed. In the absence of more data I suspect the training issue noted above would apply. I am pleased that I helped the IHPVA obtain another dues-paying member.

Allen and Eric Schweitzer would include Nordic skis, both citing the skating technique used in competition. Once again the novice-vs-trained-user argument could be applied.

Allen's comments on braking with ski poles between the legs and skepticism about my 0.5% ruling grade are entirely appropriate. My lapse into what I though to be a light-hearted relief from the frustration I feel as an eternally amateur skier was unfortunate and inappropriate for Human Power. Incidentally, I have never resorted to the castration technique, but have read about it in a newspaper article.

The reason I excluded Nordic skis, canoes, kayaks and roller-blades is that they all share a poor impedance match because they use a power stroke that is intermittent, that is limited to less than half the available time, that requires considerable energy to reset the drive mechanism, and that involves wasted effort in bringing the drive up to synchronous speed. That low efficiency is why we on mountain bikes can easily pedal past well-trained and hardworking roller-bladers on level concrete paths.

Peter Sharp noted Dave Wilson's discussion of impedance matching and that forced rowing produced (some 15%) more power than pedaling - for a period of five minutes. This is possible for short periods using both arms and legs anaerobically. Wilson was using data from a paper by J. Y. Harrison. In that paper, Harrison said that hands-and-feet drive complexities are negated after the switch to aerobic work, after 4 or 5 minutes, because legs alone can utilize more oxygen than can be supplied by the bloodstream. Wilson discussed the advantages of forced rowing on p. 133, which is lacking in the machines I discuss in the previous paragraph. He extols the virtues of derailleur gearing on p. 141 (of the quoted reference). I should not have used the word "ultimate" in connection with derailleur-gear impedance matching; "unchallenged" would have been a more-appropriate word. Like many others I seek a better drive system.

Schweitzer indicated that many "real" machines do not use impedance matching, and he cited steam locomotives and aircraft gas turbines. The steam engine produces its greatest torque at the drive wheels when the machine is starting from rest, the exact point where the greatest traction is required to initiate motion in the train. The gas turbine is ideally suited to the cruise altitudes and speeds of modern aircraft. Both these transport devices are designed, or impedance matched, to maximize efficiency at the design points yet provide acceptable performance in off-cruise conditions.

Sharp makes a valid point that impedance matching should be expanded to include the usage of a vehicle over a route and for a given purpose. He goes on to say that multi-gear bicycles might be well-suited to a bicycle used on training rollers or as an air plow. I disagree with the former and agree with the latter. Rollers were originally designed for use with one-speed fixed-gear (track) bikes and the constancy of the roller-riding environment makes a fixed gear an excellent impedance match in that application. Conventional upright bicycles are excellent air plows and the variable gearing allows riders to work at optimum muscle speed in varying gradient and wind conditions. Since routes and purposes vary widely, even by an individual rider on any single vehicle, it seems plausible to provide a wide range of gears to allow driver selection of the optimum ratio.

Sharp labeled my figure 5 a taxonomy, stating they were inevitably arbitrary and incomplete, and indicated that a comprehensive list would become hopelessly confusing. He compared it unfavorably to Jim Kor's more comprehensive "open-ended and cross-indexed list" which he found quite useful for generating new ideas. My list is simply a subset of Kor's list. Kor stated that his list was not complete, which I did not explicitly do, and should have done.

Sharp made a long list of items that ostensibly qualify as HPVs. If he wishes to consider everything that humans touch to be an HPV he is welcome to do so. His frustration with the IHPVA is evident: he states (twice) that the IHPVA should sponsor more, not less, competitions to promote development. He has all but witnessed the barring of wheelchairs from competition because I found their drive system lacking. I saw two unique chairs at the Bolder Boulder foot race this year, one with three concentric push rings to effect ratio changes with speed increases, and another with a small-radius hand crank. These are much more efficient.

The intent of the article was to get people thinking about efficient drives in their HPV designs. Contrary to Sharp's near-racial slurs about proclaiming the purity of master racing vehicles over other sub-human-powered machinery, I am interested in the speed championships only for their contribution to efficient transport for the general public.

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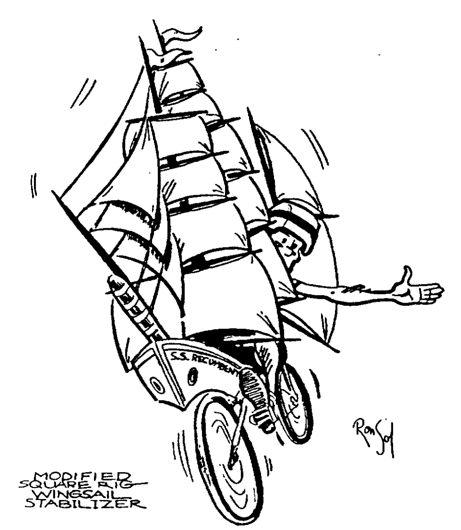
Littleton, CO 80123



Cartoon drawn and donated by Ron Sol - thanks!

(Continued from p. 3)
the then long-jump record, 7.61m. The prize was eventually won nine years later (see next entry).

Poulain-Farman

An HPA was built by the Farman company and was pedalled by Gabriel Poulain, a racing bicyclist and an experienced pilot, over the course in both directions on the morning of July 9, 1921, yielding a flight of 11.98m. The craft was a biplane with a span of 6.1m (20 ft) and a wing area of 12.3 sq m (132 sq ft). A fairing enclosed the bicyclist and rider. The plane had no propeller and, apparently, no aerodynamic controls. The all-up weight was 91.2 kg (201 lbm).

Lippisch

Dr. Alexander Lippisch, a prolific designer of sailplanes and other aircraft, built an ornithopter in 1929. This was always launched as is a glider. The wings twisted during the flapping cycle. The pilot, Hans Werner Krause, achieved a flight of 300m after Lippisch set up an attractive bonus as a reward for a successful flight.

Muskelflug Institut.

In 1935 the Institute of Muscle-powered flight (Muskelflug-Institut) was set up within the Gesellschaft Polytechnic, Frankfurt, and a prize was offered for the first German flight of 1 km. The director, Oskar Ursinus, carried out tests of the power developed by humans and made the data available in 1936. However, before these data were given out, Helmut Haessler and Franz Villinger, who both worked at Junkers, made their own tests by having one bicyclist tow another. Unfortunately, an error in measurement or interpretation resulted in false readings of power levels at least twice the actual power that it was possible for a human being to develop under the circumstances. Accordingly the aircraft design, although having a neat and valid configuration, a low frontal area, a pylon that did not interfere with the wing, and a short transmission, was incapable of unassisted take-off.

Hans Seehase

Seehase built an aircraft for the Muskelflug competition. There is no record of it taking off. It had, however, several interesting design features. The wing structure was an aluminum-alloy tube with widely spaced ribs and fabric covering, similar to that of modern hang-gliders. His aim was to reduce weight even at the expense of increased drag, a principle that was ignored by other designers for 42 years.

The transmission was also unique. The pedals drove, through a chain, a two-throw crankshaft. This was coupled through light connecting rods to a similar crankshaft on the propeller shaft, at right angles to the first. Compliant rubber "big-ends" were used to take up the small changes in length and angle setting that such an unorthodox arrangement theoretically requires.

Pedaliante

Enea Bossi, an Italian aircraft designer, started his research into HPF by fitting a propeller on to a tricycle in the 1930s. It was unstable, and Bossi concluded that two wing-mounted counter-rotating propellers would be required for an HPA. Hence his drive train was complex and heavy. The Pedaliante was of conventional glider construction, weighed 99 kg (220 lbm), and had a wing span of 17.7m (58 ft) and area of 23.2 sq m (250 sq ft).

Pedaliante made dozens of flights after towed launches. There has been much dispute as to whether it ever took off under the pedal power of the pilot alone. If it did, it would have been a world first, preceding SUMPAC (q.v.) by 35 years. Sherwin (1976) reviews the arguments for and against the validity of Bossi's claim that Pedaliante took off under human power.

Emiel Hartman

An ornithopter roughly sketched by Hartman, a sculptor, was built in England in 1958 by a glider-repairer. It used a mechanical linkage to provide the necessary twisting of the wings during the flapping cycle. Only towed flights were made, but the builder told the author in 1961 that by flapping the wings, forward progress had been made on the ground. Springs were used to give a natural flapping frequency similar to that of rowing.

Daniel Perkins

Perkins worked for the Royal Aircraft Establishment at Cardington, Britain's largest experimental-airship facility. He decided to build an inflatable-wing (parasol) HPA with a pod-and-boom fuselage. All his varied tests came up against a strange speed barrier of 6.3 m/s (14 mph). His later efforts reached success with the Reluctant Phoenix (q.v.).

Alan Stewart

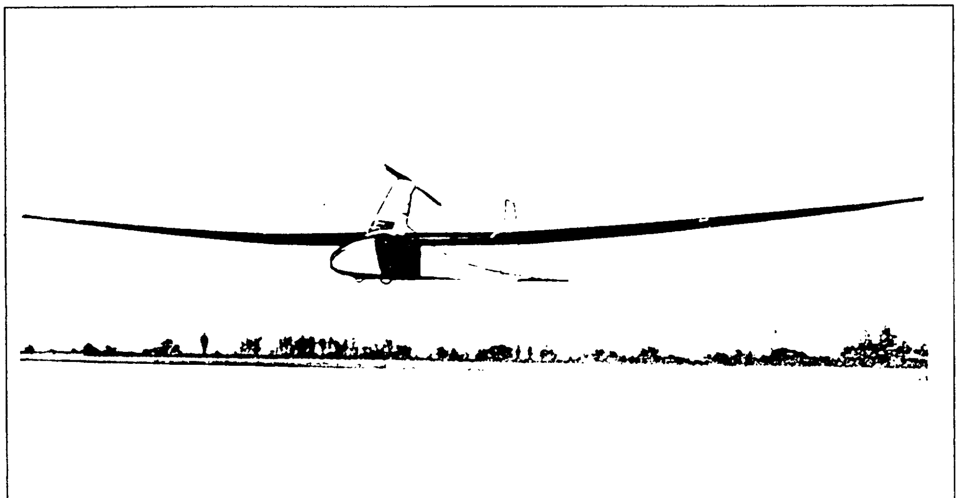
Stewart built HP ornithopters at least from 1959 - 1979 in and around Greenhill, UK. One succeeded in gliding.

Sumpac

Three undergraduates at Southampton University, Alan Lassiere, Anne Marsden and David Williams, decided in their last term (spring 1960) to attempt to build a man-powered aircraft (hence SUMPAC). The first Kremer prize competition had been announced the previous November. Other undergraduates soon joined them. Tests of human power output were first carried out by timing people running upstairs, but after a recumbent position was chosen for the single pilot an ergometer rig was built for more-relevant power measurements. Other choices were of the planform, the airfoil section, and the method of construction. (Lateral control through ailerons was regarded as the accepted method, not needing any analysis for choice).

The planform was that of a conventional single-seat monoplane. The span was chosen to be 24m, 80 ft. Their analysis showed that a larger span would require less power but the aircraft would be more difficult to turn. A NACA airfoil section designated as 65-818 was selected. The primary structure was a spruce-girder box-spar using spruce 1.6 mm (1/8th") thick. The propeller and the main wheel were driven, with the ratio between them chosen to match the prevailing wind speed.

Wind-tunnel tests were made of the wing section, the propeller, and of a model of the complete aircraft. The model showed excessive drag (almost



SUMPAC, from Southampton University man-powered aircraft, 1960-63

30% of the total) at the junction of the wing and the pylon, which had to be large enough to enclose the pilot's head. A compromise reshaping was adopted, as a complete solution was impractical.

Construction started in January 1961, and the first flight, with Derek Piggott as pilot, was on November 9, 1961. Sumpac made a total of 40 flights, mostly totally under human power, so that it was the first HPA (if Bossi's claims are not substantiated) to take off in addition to fly. Some later flights were made under tow or with the assistance of a model-airplane engine.

In early 1963 Lassiere, one of the original three in the SUMPAC team, took the plane to Imperial College and rebuilt the fuselage, the pylon (to avoid the separation problem) and used new materials for the transmission (fabric instead of steel belt) for the fuselage (Melinex polyester) and for the forward structure (light-alloy sheet). These modifications took longer to accomplish than did the building of the original plane. Unfortunately on its first flight in 1965 under the pedalling of a strong bicyclist, John Pratt, the plane went steeply up to 10m (30 ft), stalled and crashed, breaking the wing and fuselage beyond what was considered repairable.

(This is taken from a manuscript Chris Roper has written covering all known HP flight; part will appear in the above-mentioned HP handbook. He hopes to find a publisher for his complete manuscript.

Chris Roper (VP-air), 19 Stirling Court, 29 Tavistock St., Covent Garden, London WC2E 7NU, UK

AN AERODYNAMIC STABILIZER FOR BICYCLES
by Peter A. Sharp

In an article in Human Power (Spring 1989), Doug Milliken reported a simple, but elegant, experiment concerning bicycle stability. He wanted to determine the effect of cross winds. So he and his friend Max Behensky tied a string to a conventional bicycle and, while it was being ridden, pulled the string to simulate side forces. The attachment point of the string simulated the center of pressure of the bicycle-and-rider. They found that if the string were tied behind the center of gravity, the bicycle was unstable. But if the string were tied ahead of the center of gravity, the stability was quite good. The reason was that the tug tended to steer the bicycle quickly in the direction of the tug, but that then caused the bike to quickly lean away from the tug, thereby balancing the force of the tug. This finding is counter-intuitive, but it works. And the rider can keep the bike going pretty much straight ahead.

Matt Weaver later used this principle as part of the design for his extraordinarily fast and stable bicycle, the "Cutting Edge". This bike is fully faired and has a very long nose ahead of the front wheel. It looks as if it would be quite unstable in cross winds. But the exact opposite is true. When a cross wind hits the bicycle, the nose of the bike is quickly pushed downwind, thus inducing a quick lean into the wind, and thereby enabling the bike to maintain a straight line. In fact, the bike steers slightly upwind. And Weaver uses the same technique to initiate a quick lean into a turn - he momentarily steers in the opposite direction. This technique is standard with motorcycle racers. Weaver has written a computer program that integrates the various forces. (Cycling Science, Sept. and Dec. 1991).

This basic aerodynamic technique could be used by conventional and recumbent bicycles to maintain stability in gusting cross winds. One way to do this would be to mount a vertical wing ahead of the bicycle. The best size and position of the wing would need to be determined for each type of bicycle, with adjustments made to compensate for different riders. This wing would serve to move the center of pressure ahead of the center of gravity. When bikes were equipped with partial or full fairings, the wing size and/or placement would need to be modified. However, the wing would need to be incorporated in such a way that it did not significantly increase aerodynamic drag if used for record attempts or sprints.

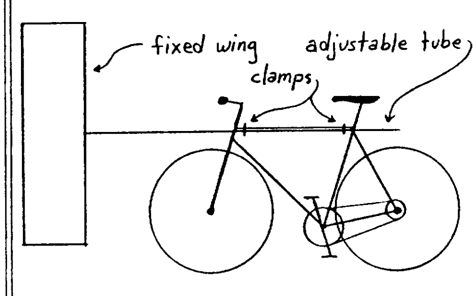


Figure 1 Aerodynamic stabilizer

For practical vehicles, a stabilizing wing would offer an additional advantage. It would produce some degree of lift and thrust when the wind was blowing. Chester Kyle has shown that even the aerodynamic tubing used for some conventional bicycles can provide measurable lift and thrust (Cycling Science, Sept. and Dec. 1991). A more significant contribution of lift and thrust could be made by the wing if it could be maintained at the most efficient angle of attack to its relative wind. A fixed wing would function like a Darrieus-rotor wind turbine (egg-beater type) that needs to spin at high speed to keep the relative wind within the efficient range-of-attack angles. A fixed wing on a bicycle would be efficient only at bicycle speeds that were many times the speed of the wind. But if the wing used a

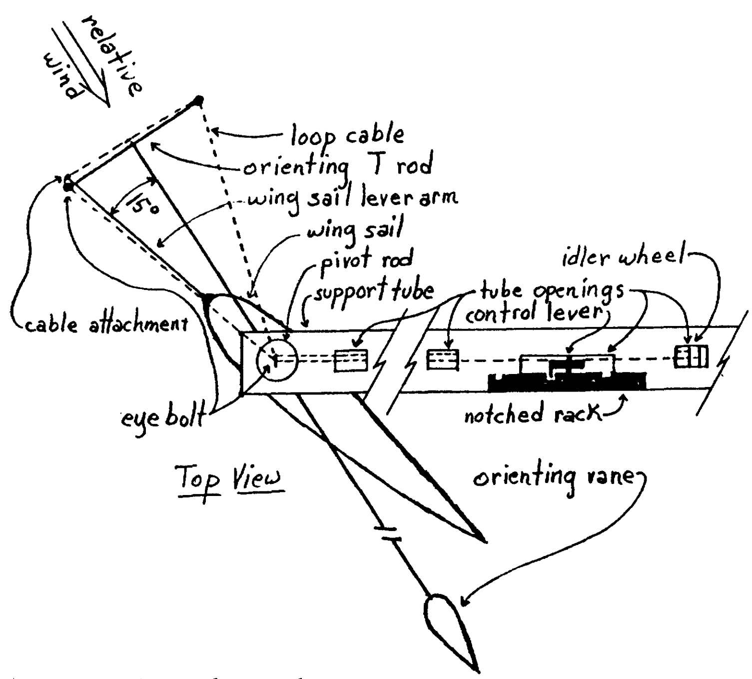


Figure 3 Automatic wing-sail control

variable angle, it would be able to function as a true wing sail while maintaining its function as a stabilizer. This is a counter-intuitive combination.

Cloth sails have been used a few times in the past on bicycles. They were fast and exciting, but difficult to control and not safe for normal bike riding. The Rans tricycle produced a few years ago was a combination of a pedaled tricycle and a cloth sail. It seems to have worked well, but the market was limited. It was perhaps too wide for normal bicycling, and not wide enough to function as a competitive landsailer.

A bicyclist has enough to worry about when riding without having to control a wing sail as well. So a wing sail would need to be automatically controlled. The increased lift of the wing sail would require the rider to lean more. The technique of leaning continuously into the wind for balance is common to bicyclists and wind surfers alike. Bicycles with full fairings do this as well but their placement of the center of pressure too far rearward has tended to make them unstable.

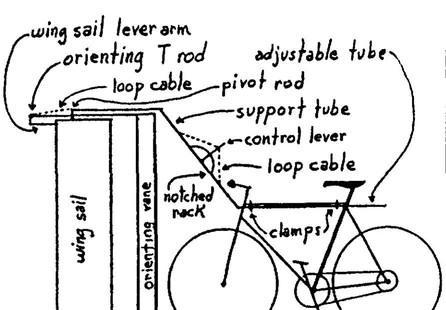


Figure 2 Stabilizer/wing-sail

Achieving automatic control of a wing sail would seem to be relatively simple. First, an orienting vane is placed behind the wing sail, and pivoted on the same axis as the wing sail. Then a control-cable loop is used to rotate the wing sail a fixed angle (the optimum angle of attack, left or right) relative to the orienting vane. The rider need only pull the cable loop forward or backward to adjust the wing sail for winds coming from the right or from the left. When the rider moved the lever/cable-loop to the middle, or neutral position, the wing sail would, like the orienting vane, merely face into the relative wind and produce neither stabilization nor thrust. Installing shock cords (bungee cords) on the cable loop would permit the wing sail to dump excessive wind pressures, and might thereby permit the use of a larger wing sail. This is made possible by pivoting the wing sail at its center of lift (about 25% of chord), so that it will naturally try to face the relative wind unless restrained. An interesting question is how large the wing sail can become before the increase in stability it provides becomes a source of decreasing stability. And another option to consider is that of using another wing sail mounted to the rear of the bicycle, but then moving the forward wing sail farther ahead.

A wing sail could also be used for tricycle propulsion. And it might also be used for aerodynamic stabilization, but in a quite different manner. When road racing, tricycles could use a wing sail to increase cornering speeds. The wing sail would be linked to the steering so that the wing sail turned as the wheels turned. This would create lift toward the inside of the turn (assuming windless conditions), and higher possible cornering speeds. The wing sail would be used to counteract the tipping forces. When the wind was blowing, however, things would get complicated. But some smart person who can solve that problem might end up with a very fast trike. (A partial solution would be to use the wing sail for propulsion on straight sections when the wind was blowing, and for cornering when the wind was not blowing.) This would then be the trike equivalent of down-force wings on racing cars. I wish the future would hurry up and arrive.

((Author's note: In a personal communication, Doug Milliken noted that, "...vertical surfaces are used by some race cars (sprint cars) to produce aerodynamic lateral force to aid cornering speed. We have a picture of a car leaning into a turn (rather than rolling outward) because of the aero effects of a large 'sideboard' while the car is at a big tail-out side-slip angle." This is sort of a "square rigger" (aerodynamic drag) version of what I am proposing (aerodynamic lift) for tricycles.))

Peter A. Sharp, 2786 Bellaire Place
OAKLAND, CA 94601, USA

Peter's success as an inventor allows him to earn his living as a self-employed craftsman. He is happily married to his Tour Easy, and they have recently conceived a new type of HPV, to be named "Quicycle".

Wind-noise reduction for improved bicycle safety

by Herb Treat

The ability of bicyclists to hear sounds emanating from **their** environment is impaired by the rush of the wind as it flows past the riders' ears. This wind-induced noise is a result of turbulence in the immediate vicinity of the ear. This paper reports the results of an effort to develop a device that will significantly reduce the level of this turbulence and, thus, the noise experienced by the rider. To this end, airflow studies in and around the ears of a life-size mannequin were performed. Experiments included measurement of noise, wind speed and turbulence. Wind-noise suppressers of various cross-sections were attached to the chin-straps of the rider's helmet just ahead of the ears. The most effective of the devices reduced the level of turbulence by one-half and the noise by nearly three-quarters.

I. Introduction

A serious problem for bicycle riders is their inability to hear cars approaching from behind. An undetected automobile overtaking a rider is an obvious danger: an unaware cyclist may move into the path of the car or may be startled when it passes. The inability of a rider to hear sounds from his/her environment is almost entirely due to wind-noise, which, especially at higher speeds, effectively masks all but the loudest sounds from the environment. This paper reports the results of wind-tunnel tests on several devices for reducing the level of this wind-induced noise.

II. Theory of aerodynamically generated sound

The nature of wind-noise and the mechanisms of its generation are described by Lighthill [1, 2, and 3]. Two different types of wind-noise are discussed. One of these, real sound, is produced by shear stresses in both laminar and turbulent flows. It propagates in the same manner as the sound produced by a vibrating solid, that is, as sonic pressure waves. The second type of aerodynamically generated noise is called pseudosound. Within turbulent air flow, rapid fluctuations in velocity occur, which, according to Bernoulli's equation,

Figure 1 Mannequin with muffling device

correspond to rapid fluctuations in pressure. Fluctuations in pressure within a turbulent region are perceived as sound but, as Lighthill points out, this is not "real" sound. Pseudosound does not travel at sonic speeds and its intensity diminishes very rapidly outside the turbulent region. Thus, a bicycle rider hears pseudosound only from the turbulent regions close to the ear drum.

III. Investigation of turbulence near the ear

An experimental study was undertaken to investigate turbulence in the neighborhood of the ear. In order to perform this study a wind tunnel was constructed and a life-size mannequin, complete with prosthetic ears, was mounted with its head at the center of flow. A hot-film anemometer was used to measure wind speeds, and microphones were placed within the mannequin's ears to measure noise. Velocities and turbulence were calculated from these data.

Several devices were tested; data from three are reported here. Formed from balsa wood, all were made so as to be attached by Velcro to the helmet strap in front of each of the mannequin's ears. As shown in figure 1, the devices are approximately 90-mm long - long enough to extend the full-length of the ear - and just wide enough so that the tip of the ear does not extend into the airstream.

Typical microphone readings - at a freestream wind velocity of 11.2 m/s [25 mph], the tunnel's maximum capacity - are shown in figure 2. The results at lower wind speeds are consistent with

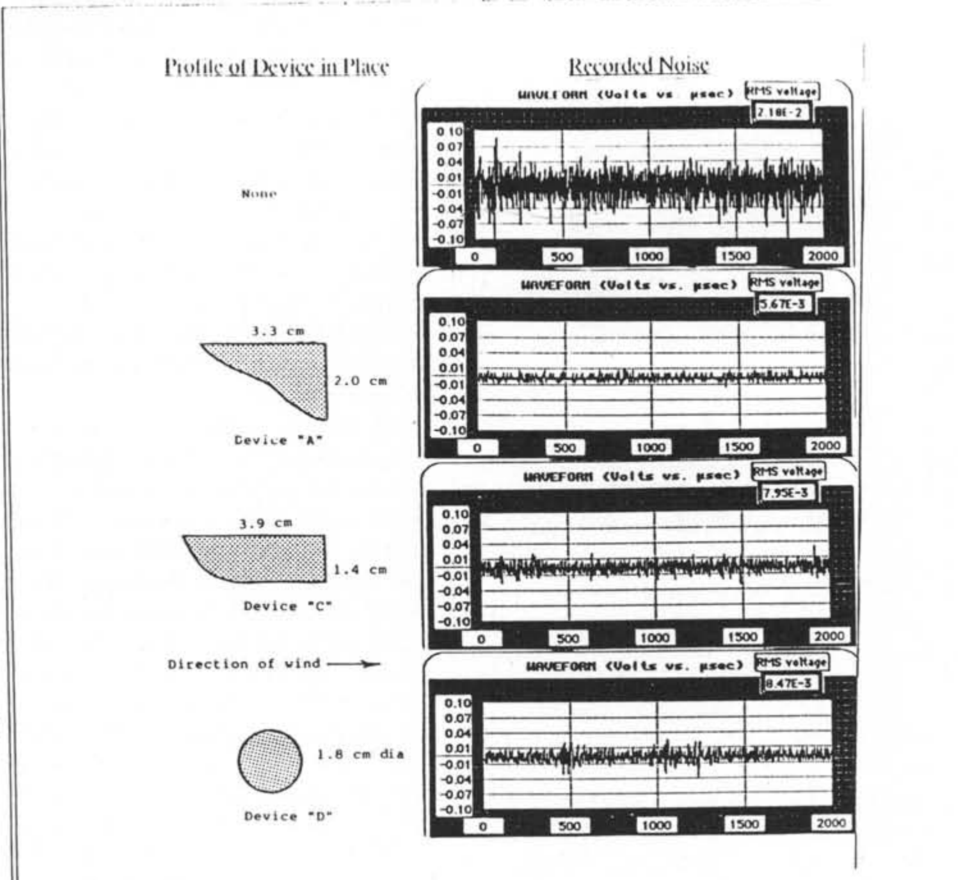


Figure 2 Wind-noise-reducer test results at a freestream velocity of 11.2 m/s (25 mph)

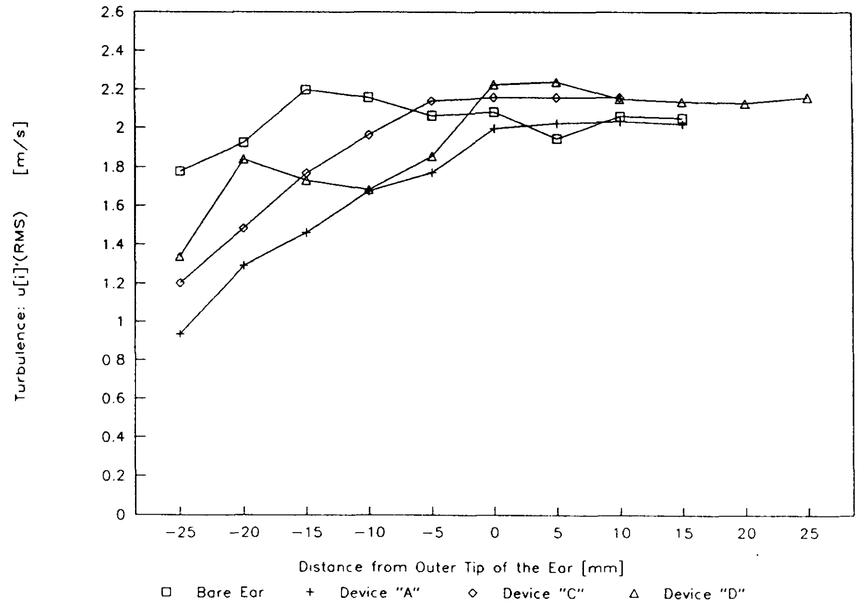


Figure 3 Turbulence vs anemometer position (at freestream velocity of 11.2 m/s, 25 mph)

those in figure 2 but are, of course, less pronounced.

Also shown in figure 2 are the root-mean-square (RMS) values of the microphone readings. We see that, as indicated by the RMS values, the noise level when device "A" is in place is only 26 percent of that when no device is present. The other two devices yield less significant reductions.

Turning now to the relation between noise and turbulence, turbulent flow is typically described by the equation

$$u[i] = \bar{u} + u[i]' \qquad (1)$$

where u[i] is the instantaneous fluid velocity, $\bar{u}$ the mean velocity, and u[i]' the fluctuating component of the velocity. Since the time average of the fluctuating component of turbulent flow is zero, it is common practice to describe the magnitude of the fluctuating component, that is, the magnitude of the turbulence, by a root-mean-square value [4]:

$$u[i]'(RMS) = \{ \ (u[i] - u) \ /N\} \qquad (2)$$

where N is the number of datum points.

Figure 3 shows typical turbulence values when (2) is applied to the velocity data collected in the vicinity of the ear. We see that the magnitude of the turbulence falls dramatically as the anemometer moves into the ear and that, in every case, when a device is in place, the turbulence within the ear is less than that when no device is present. Finally, we note that, as indicated by the output of the microphone and consistent with Lighthill, reduced turbulence within the ear corresponds to reduced noise levels [5].

As may be obvious, it is important for the entire ear to be in the "dead air" behind the device. This was confirmed by attaching a string to the pinna (the outer cartilage shell of the ear) and pulling it into the airstream. The result was an increase in noise level of up to ninety percent.

IV. Summary

The experimental results show that some very simple passive devices attached to the leading chin-strap of a bicycle rider's helmet greatly reduce wind-induced noise and, therefore, improve the bicyclist's ability to hear sounds emanating from his/her environment. The results indicate that, for the conditions tested, noise levels can be reduced by approximately 75 percent.

The early work on this device was featured on Cable Network News (CNN) in August, 1990.

Acknowledgments

The author wishes to express his appreciation to the following former undergraduate students who contributed significantly to the endeavor: Paul Millman, Parker Shectman, Jimmy Whitney and Karl Zimmermann.

References and footnote

1. Lighthill, M.J., On Sound Generated Aerodynamically, Proceedings of the Royal Society, 1952, Vol. 211, pp. 564-587.
2. Lighthill, M.J., On Sound Generated Aerodynamically II: Turbulence as a Source of Sound, Proceedings of the Royal Society, 1954, Vol. 222, pp. 1-32.

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Herb Treat has been on the faculty at Trinity University in San Antonio for the past 25 years. An enthusiastic bike-rider himself, he reports here the results of one of his senior-engineering-student design projects.

Book review

Velomobile
by Vytas Dovydenas

German Edition: Verlag Technik Berlin
1990, ISBN 3-341 00790-3
Original Russian: Leningrad 1986
127 pages

Reviewed by Theo Schmidt

This book gives an East-European view of HPV development, describing many vehicles which will be unknown to western IHPVA members. Basic design criteria for HPVs are also competently described. An HPV-based transport system for the 21st century is presented. Although written in German, the many excellent drawings and colored pictures (not photos) make the book interesting for anyone to look at. This book is difficult to get but may be borrowed from the IHPVA library for a deposit plus postage both ways.

Editor's apology: apologies for being late with this issue! Producing a journal seems easy, but around five hours of my time per page is needed to get HP to the point I can send it to Marti Daily. Now, for the next issue, we need more input from you. Send papers, letters, reviews, reports!
Dave Wilson

OFF THE BEATEN TRAIL: EXPERIMENTS IN BICYCLE STABILITY

Warren A. Berger

SUMMARY.

Caster or trail effect does not contribute to bicycle stability as some maintain. On a front-wheel-steered single-track vehicle the wheel-centering force caused by positive caster is a destabilizing force, an unavoidable artifact which must be overcome by the forces which actually stabilize the bike.

SINGLE-TRACK AND MULTI-TRACK VEHICLES.

Single-track and multitrack vehicles do not steer in the same way. Many articles on bicycle stability begin by describing a shopping cart. While the shopping cart and its caster wheels are familiar to everyone, they do not explain bicycle stability.

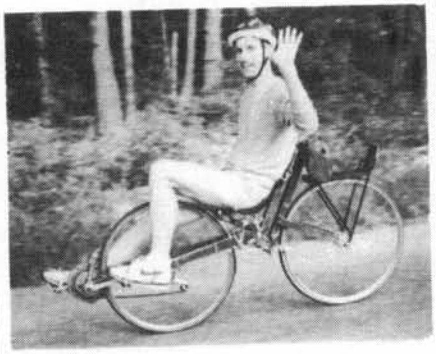

Figure 1 The author riding QED I

Imagine a multitrack vehicle rolling straight down a hill. A bump or a gust or some other momentary disturbance causes its wheels to turn from a straight course. All that is necessary for it to return to a straight course is a force which will bring its wheels back into alignment. This could be gravity working through some clever mechanism that raises the vehicle when the wheels are turned from a straight line. It could also be caused by springs (pneumatic, metal, rubber, etc.), or it could be caused by servo motors responding to a position sensor as in the case of radio-controlled cars.

All of these methods have been used with success alone or in various combinations on multitrack vehicles of many types. Positive-caster effect has been used alone or in combination with any of the others.

Now that the multitrack vehicle has had its wheels pulled back in line it will continue on its straight course as before until it is disturbed again. It is irrelevant that it may be on an entirely different heading from when it started. That is the problem of control, which will be left to the driver. Of course, if one were not concerned about our destination one could bolt the wheels on straight and not eliminating the need for wheel-centering mechanisms.

Now imagine a single-track vehicle rolling down the same hill and being turned from its straight course by the same momentary disturbance. One could again use springs, servo motors or positive caster to pull the wheels back in line. There is a problem, however. The initial disturbance that caused the wheels to turn from straight ahead also upset the fragile balance of the single-track vehicle. It is falling over! Depending on which way the wheels are turned from straight ahead, pulling them back in line may not help matters but may in fact make things worse.

Let us say the vehicle was hit by a large snowball from the right. The wheels are turned relative to each other such that the vehicle is heading off on a left turn and it is also falling over to the left. Pulling the wheels back in line at this point will get the bike going in a straight line again. However, it will also eliminate the centrifugal force that was acting to lift the vehicle out of its fall to the left.

Try this simple experiment yourself. Attach bungee cords near the outer ends of your handle bars and stretch them back to the seat post. Adjust the tension on the cords so that the front wheel is centered. Notice that if you turn the handle bars to either side the cords will pull the wheel back to center. This is analogous to positive caster. Now ride the bike. You will find it less stable. The more you increase the self-centering force by tightening the bungee cords the more unstable it becomes.

When a bike is moving forward and falling right or left, which it is always doing, any force which causes it to turn into the fall and hence be lifted back up from the fall by centripetal action is helpful and any force that tends to resist or correct that turn exacerbates the fall.

A turn that is too little or too late allows the bike to lean quite far before recovering or, at worst, hit the ground before it recovers. Too much turn causes it to overshoot past center.

Most bikes in fact do both, depending on speed and turn radius, but the rider is a bipedal animal with millions of years of balancing experience and has learned to compensate. He accomplishes this by varying the turn radius slightly through turning the handle bars, or leaning, or by varying speed. This is generally an unconscious adjustment and takes deliberate attention to notice. As long as the net forces acting on the bike tend to turn the bike into the fall, allowing centrifugal force to lift it back up, the bike can be ridden with little effort.

Stand your bike up straight and turn the handlebars right or left. You will notice that the frame (and rider) move lower to either side of center. When the center of mass is thus lowered, gravity assists stability.

However, by itself this mechanism will not initiate a stabilizing turn into the fall. This effect is lean neutral. That is, it will fall to the right or left with equal indifference to lean. The fall will add to any stabilizing force once the turn from center has been initiated. This force tends to offset caster effect but is not necessary for stability.

The main force initiating a turn into the fall is gravity acting on any mass ahead of and, in the case of a positively inclined steering axis, above the tire-contact point. Everything on the bike has mass adding to or subtracting from the stabilizing force.

The primary mass acting for balance or imbalance is the rider, followed by loaded carriers and full water bottles.

Front-mounted carriers, fenders, water bottles, friends sitting on the handlebars, etc., act directly to pivot the front wheel about its contact point on the ground when the bike is leaned. The rider, rear carriers, etc., act on the steering head which on conventional bikes is always ahead of the steering-axis line through the front tire's contact point. They act through a long lever arm which has the rear wheel's contact point as its fulcrum.

Gyroscopic precession and pneumatic "trail" also have small secondary effects on bicycle stability. These will not concern us here.

One other force has a relatively large effect on bicycle stability. This is the force that the rider applies to the wheels through the handlebars to vary turning radius to effect balance, as mentioned earlier. It is also applied to change heading.

Back on the multitrack vehicle, this turning force was balanced by the rider's body pushing on the seat and the seat in turn pushing on the wheels and the wheels in turn pushing on the ground. As long as the rider is strong enough to apply enough force to twist the handlebars he may get awfully tired but the trike, quadracycle or whatever will go where it is aimed.

Now consider the single-track vehicle. Imagine the bike has a lot of frame drop when the bars are turned from center. Centrifugal force will not overcome this down force at low speeds. Any portion of this down force not cancelled by caster effect must be overcome when returning the wheel to center.

Also, turning the bars quickly or changing the direction of turn requires overcoming the inertia of all these masses. If the force required to overcome this inertia is significant the rider will be twisting around in his seat without widely spaced wheels to push against. This can be quite disconcerting at speed.

Unless the steering effort required is quite light, a steering input intended to correct an imbalance may only make things worse.

On the trail of the perfect HPV

From 1987 to mid 1988 I bought, had built, and modified three recumbent tricycles. The first was a single-rear-wheel drive (RWD) with joystick steering, the second a single-front-wheel drive lean-to-steer (FWD), and finally a single-rear-wheel drive lean-to-steer.

I rode these around on the public streets and roads long enough to draw some conclusions. On the plus side, a lightweight, multispeed trike with full fairing would be great for racing. On the minus side, sitting a foot or less off the ground looking at hub caps and bumpers is impractical for touring or commuting. Also riding for hours with my feet above my seat reminds me of Gravity Boots - possible but just not natural.

This experience led me to consider a single-frontwheel-drive lean-to-steer version for touring with the bottom bracket down a foot (300 mm) from the ground and the seat up at 1.5 - 2 ft (450 - 600 mm). It would still be stable as the rider leans into the turn along with the seat and front-frame section. Riding around making high-speed turns while sitting up on top of the seat back proved this to be true.

By mid-1988 I decided that I liked the layout of the high FWD lean-to-steer tricycle but the added weight and complexity of a three-wheeler did not have the appeal of riding on two wheels. There is something "magical" about riding along on a single-track vehicle and not falling over.

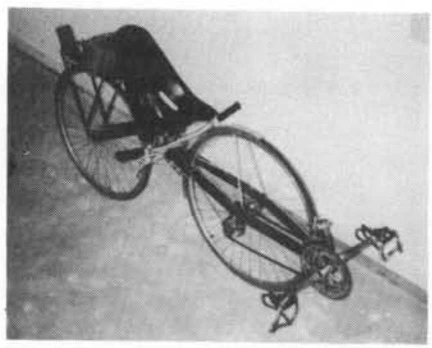

Figure 2 QED I at the 17th IHPSC

Q.E.D. I

A two-wheel version of this tricycle seemed ideal. Only one problem remained. Almost everything I had read said that a rear-wheel-steered bike should be impossible to balance. The bike that emerged from these experiments is called QED: which was to be demonstrated.

My first attempt had the steering axis set at 45 degrees. The shallow steering axis caused too much frame drop for the amount of turn, and lifting it up out of the turn at low speed required a Herculean wrench on the handlebars, which of course only made things worse.

Steepening the steering axis to 56.5 degrees was better, but still not enough. I shortened the rear frame section to reduce wheelbase from 42" to 36" (1050 mm to 900 mm) to reduce the amount of turn needed for a given radius curve. This was better but still not good enough.

The next cut allowed three possible steering-axis angles: 70, 72.5, and 75 degrees, and an adjustable steering ratio to reduce the effort below 1 to 1.

Success at last! All three steering-axis angles were workable, but a 1-to-1 steering ratio was still much too high for quick steering movements. This is because of the rider's greater moment of inertia on a rear-wheel-steered bike.

Basically, 70 degrees was most stable (most turn into fall) but also was heaviest steering (most frame drop), requiring the greatest steering -ratio reduction for steering at speed without twisting around in the seat. At 2.5 to 1 I can do anything my normal ten-speed will do except turn around in our narrow two-lane road, especially with gravel strewn at the edges.

At 1.6 to 1 I have 30 degrees of turn between front and rear. This is enough to allow correcting for a fall into the turn at slow speed, but is heavier steering at speed than I would like.

I could shorten the wheelbase. This would reduce the turning radius for a given amount of turn between front and rear.

I installed a 20" (500 mm) rear wheel on makeshift brackets to allow moving the rear wheel forward 4" (100 mm) without altering rear frame height or steering axis. This configuration rode just like the 36" (900 mm) version but would turn around in the road with no difficulty with the 2.5 to 1 steering ratio.

Incidentally, this shorter version handled very well at all speeds, despite the rear-wheel trail being 4" (100 mm) shorter. This and the earlier reduction of rear-wheel trail provide evidence that positive rear-wheel trail, like positive front-wheel trail, does not contribute to bicycle stability.

I did not permanently reduce the wheelbase to 32" (800 mm) because bringing the rear wheel that far forward requires using a 20" (500 mm) wheel, with its increased rolling resistance. Also, the shorter wheelbase combined with the smaller rear wheel caused a harsher ride over bumps, something to be avoided on a touring bike.

I am currently riding the 36"-wheelbase version of the QED I with the 70-degree steering axis and a 1.6-to-1 steering ratio for 30 degrees turn right and left.

This seems to be the best compromise so far. The steering is light enough, even with 17 pounds (7.6 kg) of stuff in the rear panniers. And I can usually still turn around in our road without putting my foot down.

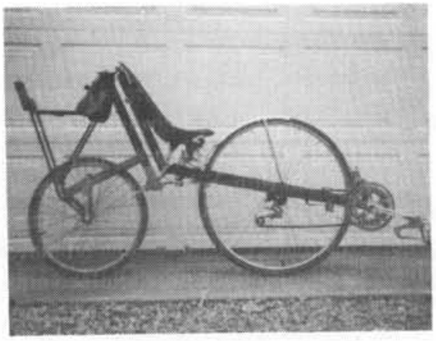

Figure 3 Short-rear-trail version with 800-mm (32") wheelbase; just as stable.

Q.E.D.II

The chrome-moly-framed QED weighs 31 lbm (13.9 kg) complete. The next one may be aluminum because I cannot get the square and rectangular chrome moly tubing in as thin a gauge as I would like. This will bring the finished weight down in the 25-pound (11-kg) range.

On QED II the bottom bracket will be raised to 15" (375 mm) for more pedal clearance during low-speed maneuvers. Lowering the seat from 22" (550 mm) to 18" (450 mm) should make the steering somewhat lighter. The use of 20" (500 mm) wheels will allow pushing the bottom bracket and seat back 3.5" (87 mm). This will change the front-to-rear weight distribution from 62/38 to about 53/47, improving braking and reducing front-wheel plowing (understeer) when turning on gravel. I hope that this change in weight distribution will leave enough traction for practical acceleration and climbing. The QED I climbs 20% grades on asphalt without wheel slip. I am aware of about a half-dozen two-wheel- or rear-wheel-steering FWD bikes which have been rideable to one degree or another. I would appreciate hearing from anyone who has experimented with front-wheel-drive bikes.

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Warren Berger was born in Wisconsin 45 years ago. For the last 16 years he has been working and living in central Virginia with his wife and two children. In his early teens he tried to talk his father into letting him convert his Robin Hood "English racer" into a prone recumbent. Instead, they built a mini-bike and played with a series of sports cars and motorcycles. He soon returned to avid bicycling. He is a former machinist, kite manufacturer and amateur inventor, whose successful projects were lucrative mainly for others. His favorite inventions "don't pollute, maim, or oppress, but unfortunately also have so far had little commercial value."

Book reviews

"Stirling Motor: history-theory-practice"

by **Ivo Kolin**

Zagreb University Publications 1991,

285 pages

Reviewed by Theo Schmidt

This book has little to do with human power, although one page is devoted to muscular power. It is included here because it is a jewel of a book which will fascinate anyone interested in elegant low-power mechanisms, as is the HPV is also. As a heat engine, the Stirling engine cannot really be called efficient unless operated at high temperatures. (The ideal efficiency of any heat engine cannot exceed (TH-TC)/TH, these being the hot and cold temperatures measured from absolute zero). The machines developed by Prof. Kolin work with low temperature differences; indeed he can be called the father of the low-delta-T Stirling engine. As the theoretical efficiency available is already so low, these machines can do useful work only if they work as well as is theoretically possible and Kolin appears to have achieved this. Any low-grade source of heat will suffice to run such engines, such as hot bath water or warmth from simple non-concentrating solar collectors. The engines can be made from simple materials like wood, Plexiglass, and stryrofoam and are readily home-built, as dimensioned plans are included in the book. To produce any appreciable power, such motors get rather bulky and you won't be able to run your HPV with one, although a boat would probably work.

The book is human-powered in the sense that it is entirely typed and drawn by hand. Far from degrading the quality, this is one of the most attractively laid-out books I have come across. Hundreds of very nice drawings and graphs fill nearly every page. There is enough theory to interest thermodynamicians but it is stated simply enough for anyone to understand the implications. Simple rules are given for making one's own designs. The history of the Stirling engine is described using the examples of some 40 engines from 1815 to 1990. The drawings of these are also included as a poster to hang on your wall!

The book can be ordered within the USA from Brad Ross, Stirling Machine World, 1823 Hummingbird Court, West Richland, WA 99352-9542, USA, for $60 or direct from Prof. Dr. Ivo Kolin, Medvescak 19, 41000 Zagreb, Croatia by paying the equivalence of $60 in any currency into his account at CREDIT-ANSTALT BANKVEREIN- FIL. GRAZ / AUSTRIA, Herrengasse 15, Graz, BLZ 11870 -SPB.NR. 608 70512294

Humanpower

Cars, planes, and boats with muscles for motors

Macmillan, 1992

by **Roger Yepsen**

reviewed by Dave Wilson

The cover photo is of Bill Watson's White Dwarf HP blimp. After the historical introduction, most of the illustrations are of IHPVA-connected machines and events. This is a well-produced book for children in (I would guess) the 7-14 age category. Its style is necessarily simple but it isn't childish: the author wrote it because he admires HPVs. He has his facts, and his sentiments, generally right. I'm going to buy some copies to give to young friends and relatives.

EFFECTS OF CRANK-ARM LENGTH ON PHYSIOLOGICAL RESPONSE IN ARM ERGOMETRY

by Brent L. Gravelle and Richard R. Powell

SUMMARY

Physiological responses associated with varying crank-arm lengths in arm-ergometry indicate that during submaximal steady-state arm exercise, an optimal crank length may exist. Furthermore, when using an arm-ergometry work test to fatigue, a higher power-output level may be achieved with a relatively longer crank-arm. Unfortunately, no significant differences were found in efficiency values comparing crank lengths to suggest an optimal length for power production.

INTRODUCTION

With the development of arm powered vehicles for the lower-body disabled (i.e. "Freedom Ryder", New England Handcycle, etc.) as well as development of arm- and leg-powered HPVs, the characteristics of arm-crank-drive systems are of technical importance to overall efficiency. Although there is ample research on leg-drive systems and leg ergometry, there is little knowledge available to guide one when designing a HPV with a physiologically efficient arm-crank-drive system.

Efficient power production depends on a number of factors such as body-segment lengths, muscle mass, spinning or cranking rate and the length of the crank-arm. Identifying an optimal crank-arm length for average riders was the focus of this study.

By keeping power-output constant and maintaining the crank rotational velocity at a constant revolutions per minute (RPM), one can vary the crank-arm length and determine the body's physiological response to such a variation.

A crank handle attached to a longer crank-arm must turn through a larger circumference and at a higher velocity and therefore will put a greater demand on a subject's speed of muscular contraction. However, because of a longer radius arm, there will be an enhanced mechanical advantage due to increased leverage. The result is less force being required to turn the crank and less demand in terms of force of muscular contraction of active muscles.

A shorter crank-arm, by contrast, would require more force to turn because of reduced leverage; however, this extra demand is theoretically offset by a physiological advantage gained as a result of the point of force application turning through a shorter distance and at a slower speed. With this in mind, it seemed unlikely that different crank-arm lengths would greatly affect the physiological cost of producing work, because the power-output in both cases would be the same. However, with a significant variation in crank-arm length, this assumption may not be true due to possible variation in the underlying physiology of muscular contractions producing the power-output. The purpose of this study was to help clarify this uncertainty.

BACKGROUND

Research that has addressed crank-arm length variation has related to leg cranking only. In this regard, however, Simpson (1979) has argued:

"A longer crank-arm permits the use of a bigger gear with less fatigue, even though the feet are moving in a circle of greater diameter. With a shorter crank, the advantages are reversed: more force is required, but the smaller circle of rotation makes for smoother pedalling, the quality called 'souplesse'. Where spinning is desirable, a shorter crank is more efficient." (p.29) Simpson's sentiments are echoed by Hull and Gonzalez (1988) in their statement:

"On the one hand, at a constant power and constant crank-arm length, increasing the pedalling rate allows a corresponding reduction in the pedal force and hence joint movements due to pedal force. On the other hand, at constant power and constant angular velocity, increasing the crank-arm length also allows a corresponding reduction in pedal force. Intuitively, a longer crank-arm would lead to reduced pedal force but increased dynamic action of the limb whereas a shorter crank-arm would result in increased pedal force but decreased dynamic action." (p. 840)

Clearly, the pedal or handle speed is not the same as the crank rate. The pedal-hand speed is faster for the longer crank than for the shorter crank even though both travel through the same degrees of rotation per unit of time. The force dynamic of muscular contractions at varying rates of speed can be illustrated by the force-velocity curve (figure 1), and can help to clarify the nature of muscular force production as it relates to differences in velocity of movement due to different lever-arm lengths.

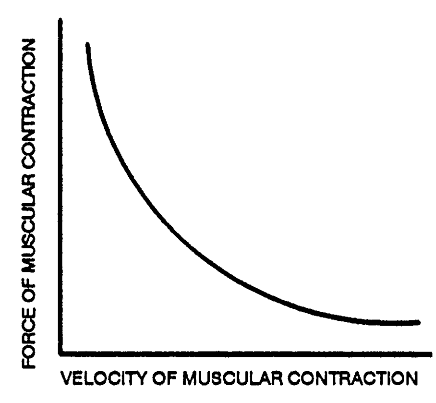

Figure 1 Force-velocity relationship

Increased handle or pedal speed can be obtained only by the muscles exercising or contracting at a faster rate. The increased velocity of contraction will decrease maximal force production capable in the muscles and limit the force applied to the crank handle or pedal (Kreighbaum and Barthels, 1985; Bolourchi and Hull, 1985). When shorter crank-arms are employed and the RPM is held constant, the handle or pedal must travel at a slower speed than the longer crank to maintain the same RPM, while at the same time leverage is sacrificed. With less leverage the body has to apply a greater force to turn the shorter crank-arms. Slower cranking speeds necessitate the development of greater muscular tension to perform the same power-output. Such muscular work may therefore become more anaerobic at higher power-outputs and more inefficient. The reason for this can be observed in the power-velocity curve of muscular contraction (figure 2). Here it can be seen that highest power-outputs are achieved at relatively higher contraction velocities despite the sacrifice of contraction forces.

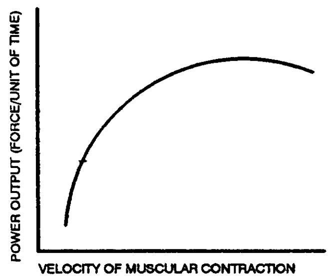

Figure 2 Power-velocity relationship

Based on the theoretical power-output being equal under varying crank-arm length conditions, it could be supposed that the interplay among the above variables would render all crank lengths equal in terms of submaximal and maximal muscular-performance outcomes. However, it was suspected that maximum power-output achieved as measured by time to exhaustion would favor a longer crank-arm length because of the more dominant influence of aerobic metabolism (characteristic of a lower total muscular force and higher velocity) in a multistage progressive ergometry test to fatigue.

Accordingly, we proposed the following two hypotheses:

1. when performing submaximal arm-ergometry power-outputs at three different crank-arm lengths, physiological responses would remain unchanged; and
2. when performing a multistage arm-ergometry exercise test to exhaustion using three different crank-arm lengths, a relatively long crank-arm would result in a longer work time prior to exhaustion.

APPROACH

An arm-crank ergometer was used that was an electrically braked system enabling a standard power-output regardless of ranking speed (Unit PE, Pedal-Mode Ergometer, Warren E. Collins, Inc., Braintree, Mass.). The ergometer was mounted on a wooden frame and a seat was positioned in front of the crank-arms so that the axis of rotation was at shoulder height. Three sets of interchangeable crank-arms of 4, 5 and 6-1/2 inches (101.6, 127 and 165 mm) in length were used.

Twelve physically active male students were selected as experimental subjects with a mean age of 21.8 years, R = 18-25. Subjects were selected for similar arm lengths in an attempt to control for variations in leverage associated with force production. An anthropometric caliper, graduated in centimeters, was used in conjunction with a method by Plagenhoef (1971) for locating joint centers and determining limb lengths. The upper and lower right arm of each subject was measured to insure an average upper-arm length of 31.5 cm + 1.5 cm and an average forearm length of 25.5 cm + 1.2 cm. Variance was relatively small, measuring 1.01 for the upper arm and 0.38 for the forearm. Consequently, subjects were considered similar in this anatomical feature.

The three different crank-arm lengths constituted three test conditions with each subject randomly exposed to all conditions. During each exercise session, physiological determinations of oxygen consumption (VO2), heart rate (HR), and pulmonary ventilation (VE) were made at rest and every fifteen seconds until exercise ceased. The work rate of power-output started at 25 watts and increased 25 watts every two minutes until the subject reached exhaustion.

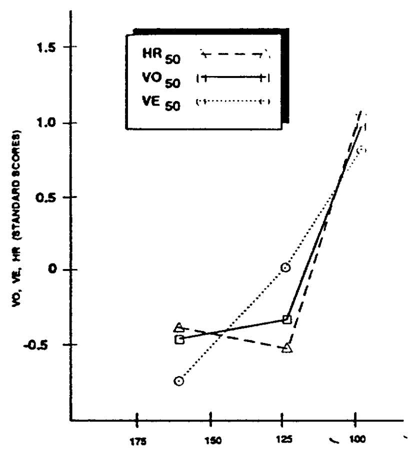

Figure 3 Oxygen consumption (VO), pulmonary ventilation (VE), and heart-rate (HR) responses during steady-state arm exercise at 50-W power output using three different crank-arm lengths: 102, 127 & 165 mm.

By monitoring VO2, HR, and VE at 25- and 50 -watt work outputs, steady-state physiological cost was determined for each crank length. Time to exhaustion (TIMEEXHST) was also used as a measure of maximum power-output for each test condition. Collected data were statistically analyzed to determine significant difference.

FINDINGS

No significant differences among the three crank lengths were found for the physiological variables at a power output of 25 watts. However, at a 50-watt work output, VE, VO2 and HR responses were significantly affected by crank lengths (figure 3). Results indicated significant differences between crank lengths of 102 mm and 127 mm and 102 mm and 165 mm on all physiological variables. In contrast no significant differences ($p<.05$) were found between the 127 mm and 165 mm crank-arms. Had more data points existed over a wider range of crank-arm lengths, these relationships may have been extrapolated to more clearly definable curvilinear relationship.

Figure 4 represents the maximal power-output achieved and time to exhaustion plotted against crank length. As crank length increased from 102 mm to 127 mm then to 165 mm, TIMEEXHST significantly increased ($p<.05$) from 6.75 min. to 7.85 min., and then to 8.79 min., respectively. Accompanying the gain in exercise time is a corresponding rise in power-output with a mean maximum power-output of 125 watts achieved at a mean time of 8.79 minutes using a 165 mm crank-arm.

CONCLUSIONS

This investigation explored physiological responses associated with varying crank-arm lengths in arm-ergometry. Physiological responses suggest the following. 1) During submaximal arm exercise, an optimal crank length for average-sized male adults exists 127 mm

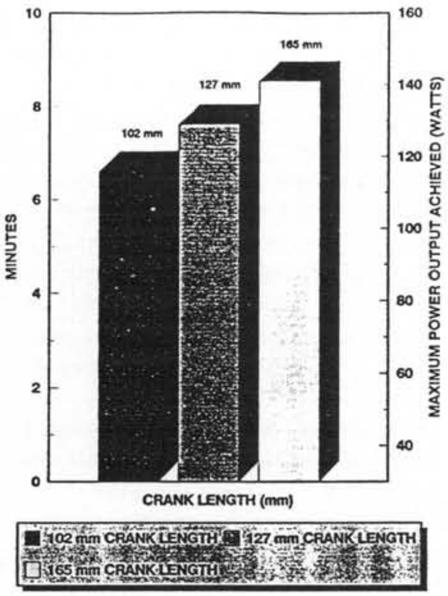

Figure 4 Time to exhaustion and maximum power output for various crank lengths

and 165 mm at a steady-state power-output of 50 watts based upon VO2, VE and HR response. 2) When using an arm-ergometry work test to fatigue, a higher power-output level may be achieved with a 165 mm crank-arm compared to shorter lengths.

In summary, crank-arm length clearly appears to influence work performance. For the adult population studied, optimum crank-arm length for arm-ergometry was approximately 150 mm. Use of smaller arm cranks to fit within aerodynamic shells or other applications would likely be counterproductive, and use of crank-arm lengths in excess of 165 mm appears to compromise steady-state efficiency of arm power-output.

POSTSCRIPT

In this study, we were limited to only three different crank-arm lengths. Further information might be gained from experimenting with a larger number of crank-arm lengths, especially those longer than were used in the present study. Crank arms varying in length by increments of approximately 5 mm could be compared and a precise optimal length relative to arm length could be determined. It appears at this time, however, that adults having an average upper-limb length perform best on arm-ergometry power production using a 150 mm crank-arm.

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IT'S TIME TO CHANGE THE RULES

by **Peter A. Sharp**

I am a new member and an enthusiastic supporter of the IHPVA. I ordered and read the past issues of HP and then invented a simple energy accumulator to be used to store the energy of pregenerative pedaling and regenerative braking. I then requested a copy of the IHPVA rules so as to be sure there would be no problem. I found, of course, that energy accumulators are not permitted in the sprints. They are allowed only in the road race, and in other events of greater than one mile (where they would be of little use). I found that quite puzzling since the IHPVA makes a big deal out of having rules with the fewest restrictions so as to encourage innovation. Obviously, I was discouraged.

I then asked myself what else these rules prohibit. And I found that the rules, as they are written, actually prohibit just about everything. The rules prohibit fairings. They aren't supposed to, but they do. The rules also render HPVs almost completely unusable for competition. I'll explain.

There are two rules to be considered. The first one is: "Power - Vehicles must be driven solely by human power. Non-human power sources (batteries, solar cells, etc.) are permitted only for powering sensors, displays, communication equipment, and lights. Control devices, cooling fans, powered aerodynamic devices, etc., may not be powered from non-human sources." One problem with this rule is the over-inclusive term "powered aerodynamic devices". The wind is a non-human power source. A wing sail would therefore be a powered aerodynamic device. Fairings are universally acknowledged to function as wing sails. Therefore, wing sails and fairings, since they are powered aerodynamic devices which are powered by a non-human power source, are prohibited by the IHPVA rules. All wins and records set using wing sails or fairings are therefore invalid, since vehicles must be driven solely by human power. Any wind whatsoever would render fairings illegal, and there is always some wind. In fact, any component with an aerodynamic shape capable of producing lift would be similarly illegal, and would constitute grounds for disqualification. (Sound familiar?)

The second rule to be considered is: "Energy Storage - No device which stores energy over more than one input power cycle (e.g. one leg stroke), or which releases energy under control of the operator, may be used in any event except the road race, or speed events longer than one mile. Energy-storage devices are permitted in these events provided no energy is stored before the start of the race (this means absolutely no chemical, electrical, kinetic, potential, or other form of energy storage at the start)." The problem here is that an HPV, itself, is an energy-storage device. A bicycle includes an aggregation of various energy accumulators that store energy produced by the rider. The most obvious one is the whole bicycle/rider combination which stores kinetic energy as long as it is moving. Another obvious example is that of the wheels acting as flywheels to store kinetic energy. In addition, merely standing up a bicycle requires storing potential energy - until it falls down again. The various springs and the steering mechanism also store potential energy, and usually for more than one leg stroke. Note carefully that the restrictions on energy storage before any road race, and before or during any other race, are "absolute". No exceptions. Therefore, any flying starts, or any pedaling in excess of one leg stroke (except in a road race, etc.), is strictly prohibited. Also prohibited are starting any race with a bicycle upright, or with any spring at other than minimum compression, or with steered wheels pointing other than straight ahead, or even with inflated tires. Any win or record set in violation of this absolute rule is therefore invalid.

It is ironic that an organization whose intent was to prohibit as little as possible should end up prohibiting just about everything. Of course, the solution to the problems created by these rules - the invalidation of probably all wins and records - is to simply rewrite the rules correctly and then to validate all previous wins and records using a grandfather clause. But I also suggest that the current prohibition against energy accumulators be eliminated. It is contrary to the goals of the IHPVA; contrary to the recommendations of our international president, Paul MacCready; and contrary to the best interests of bicycle development. It is certainly contrary to my interests, since I and others in the bicycling community might profit from the invention of an improved HPV. And we should be encouraged to do so rather than being handicapped by prejudicial rules.

To quote the IHPVA rules, "The spirit of these rules is to avoid inhibiting design innovation by not establishing unnecessary restrictions." To prohibit an energy accumulator which stores human energy through pregenerative pedaling and/or regenerative braking is in direct violation of the spirit of the rules.

Our international president wrote, in his recommendations for rules and goals, "In open categories, especially as exemplified by the IHPVA races, a useful philosophy is to have the rules lag technical developments and so not inhibit the developments. Thus, although the IHPVA rules prohibit stored energy from sources outside the rider, a rider might be permitted to store energy (as in a battery) during one part of the event for use in a later part. Also, the vehicle could be permitted to exploit real-time wind power via a sail wing or onboard windmill. If energy storage or wind augmentation produce a race winner, great! If the advantage was so large that the new technique would be essential for future winners, then a new 'open' category could be set up permitting it, and another 'semi-open' category could be devised prohibiting it, or a single dominant category could be selected. Innovation is served by this attitude." (HP, Summer '87) The current IHPVA rules directly contradict this recommendation.

My own argument is that energy accumulators would enable HPVs to achieve much-improved acceleration from a standing start using pregenerative pedaling. In combination with good aerodynamics, that would enable HPVs to accelerate with and run with automobiles on level city streets, thus enabling HPVs to catch the majority of stop lights and significantly improve commute times on favorable routes. (Hills would still be a problem.) It would also be great fun for an average rider to be able to out-accelerate and outrun a professional cyclist on a conventional road bike. For IHPVA road racing, an energy accumulator would be charged using primarily regenerative braking, since there would be little time for pregenerative pedaling. The tighter the road course, and the more braking that was required, the greater would be the advantage of using an energy accumulator. It would be of little or no advantage in events requiring continuous maximum aerobic pedaling, such as timed events or specific distance events. Since an energy accumulator's main advantage is in providing improved acceleration, it should definitely not be prohibited from the sprints. Would it provide an unfair advantage? Of course it would. That's the whole point of using an energy accumulator - to gain an advantage by means of a technical innovation. That's just what the IHPVA is supposed to encourage.

The original reasons for banning energy accumulators from the sprints are not clear. But a knowledgeable member suggested two possible reasons. First, based on some informal studies by Chester Kyle indicating that energy accumulators would not be likely to improve commuting times, it may have been decided to save competitors the time and money that developing energy accumulators would have required. If this was one of the original reasons for the ban, then I would contend that the reasoning was, however well intended, anti-innovation and a self-fulfilling prophesy. A second possible reason may have been that energy accumulators present difficulties in insuring that competitors do not store energy before the race. But I would contend that this is a non-problem. Let the energy be stored! That's what an energy accumulator is for! All that is required is some reasonable time limit (so as to prevent pedaling all year just to provide the power for one sprint). A one-, five-, or ten-minute limit would be practical. My reading of the rules suggests a third possible reason: that of simple prejudice, i.e. the assumption that an energy accumulator would not be consistent with the "purity" of a bicycle.

The critical question is, "Is a bicycle with an human-energy accumulator still a real bicycle?" That is precisely the question that was answered so infamously in the negative by the UCI when it banned recumbents and fairings. The IHPVA is now doing exactly the same thing by banning energy accumulators from the sprints. It's time for a change.

Peter A. Sharp, 2786 Bellaire Place
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(see earlier for Peter's bio)

<u>Editorial retraction</u>: in an editorial in the last issue, I made some snide comments about an article in CYCLING SCIENCE and about its editorial policy. I apologize to Chet Kyle and Peter Stegmann! Dave Wilson

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