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# PRONE-POSITION RECUMBENT BICYCLES

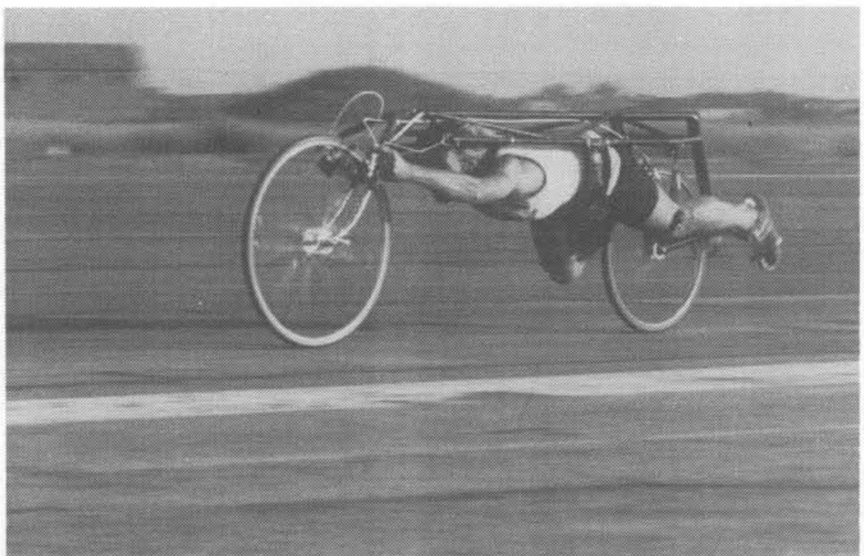
by Allan V. Abbott

## BACKGROUND

In the IHPVA, the term "recumbent" usually brings to mind a machine such as the Velocar or the Gold Rush. The word recumbent actually means "lying down". We generally think of the recumbent riding position as one where the rider is seated, leaning back against a backrest with his/her feet forward—the same position as sitting in an easy chair with feet on an ottoman. This is the riding position in both the Velocar and the Gold Rush.

A person can be in one of four positions while recumbent or lying down: the supine position with his face upward; the prone position, with his face down; or on his right or left side (right or left decubitus position). What we usually think of as the recumbent position in cycling, being more like sitting in an easy chair, is properly described as the supine semi-recumbent position. The true supine recumbent position has been used only rarely by HPV designers because of the obvious visibility problem (the rider looks straight up, and cannot see straight ahead easily).

The prone recumbent position has, however, been tried by several human-powered-vehicle designers dating back at least to 1900. This riding position has some immediately obvious advantages with the rider's head and arms forward for the front steering, and the legs to the rear where the pedals and drive wheel are usually located. Despite these apparent advantages the prone position has not become popular.



Allan Abbott on his first prone recumbent bicycle which was designed to minimize frontal area.

The position of the rider's torso is the same in the prone recumbent position as it is in the conventional bicycling position when in the fully aerodynamic racing tuck. It is the position of the pedals that most distinguishes the prone recumbent position from the conventional bicycling position. In the conventional bicycle the pedals are placed a short distance ahead of the seat while in the prone recumbent the pedals are positioned to the rear of the seat. Moving the pedals to the rear tips the pelvis forward and makes the conventional bicycle seat inappropriate because of the position of the genitals. Thus, the prone recumbent position is also distinguished from other positions in that a pelvis support must be located in front of the hips and pelvis.

Very little scientific work has been done to compare the prone position with other positions. Anecdotal comments from individuals who have tried the prone position vary greatly. It is the purpose of this paper to organize in an objective manner the experiences and opinions of designers and riders who have had experience with this unique riding position.

## METHODS

A questionnaire was developed and mailed to those individuals in the IHPVA who, to the knowledge of the author, have had the greatest experience with prone-position vehicles. Two general

(continued on page 11)

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# Editorials

## Before the Take-off

The lead article in the current issue (vol. 5 no. 3, October 1988) of *HPV News*, Marcia Lowe's "Bicycles Have a Powerful Future", impressed me because it described the situation of human-powered vehicles in terms that reminded me of nonsmokers' rights a mere twenty years ago. One can make a case that smokers have rights to smoke in certain circumstances. But in those days, one could be an asthmatic in the hospital and have doctors and nurses smoking over one, to take what might now seem like an extreme example but was then commonplace. Virtually one hundred percent of the US population, a proportion that includes almost all smokers, would today agree that it is wholly right that sensitive nonsmokers should be given some protection from secondhand smoke. Marcia Lowe's fifth paragraph struck me as analogous to the smoking physician situation: "The World Bank, the main source of urban transit investment in the developing world, published a 1985 study on the Chinese transport sector that does not even mention the word bicycle, although the overwhelming majority of trips in China's cities are made by bike. This is sadly typical of a policy environment in which only motor vehicles are taken seriously."

The protection of nonsmokers throughout the world came about through the action of one man, an MIT engineer-turned-lawyer named John Banzhaf, who petitioned the Federal Communication Commission that the overwhelming and unopposed advertising by tobacco companies represented an unfair and unequal treatment of a controversial political position. The FCC agreed, and the public service counter-advertising that Banzhaf brought about led rapidly to an astounding turnaround in what had seemed for a century to be tobacco's impregnable dominance.

The time is ripe for a similar transformation in the apparently universal sanction given to motor vehicles to clog our cities, put smog into our air and to make our whole way of life totally different from that for which we were equipped by nature. Virtually every city in the "western" world is facing massive problems of traffic congestion, to which there seem no easy answers. Human-powered vehicles are not the complete solution to these problems, but they can play a vital role in a "kinder, gentler" transportation pattern. The technical advances that we seek in the IHPVA are helping to prepare ordinary citizens to accept some future transformation in the present dominant role of motor vehicles. All we need now is a Banzhaf to take the vital catalytic step.

## In This Issue—



## The End of a Brave Effort

*Bike Tech*, "Bicycling Magazine's newsletter for the technical enthusiast", will no longer be published after 1988. While it is easy to criticize a publishing empire for not continuing to back a worthy experiment, we should, rather, pay tribute to the support that Rodale Press devoted for many years to something that could not promise any financial return. Although *Human Power* and *Bike Tech* should have been rivals, we have always had friendly relations, with someone from the IHPVA board usually one of the contributing editors. *Bike Tech* started out at a very high level under the editorship of Crispin Miller, now pursuing his doctorate at MIT, and ended in the same high tradition with Bruce Feldman, who will continue with Rodale as editor of its *Mountain Bike* publication. We salute them and their colleagues, and wish them well.

## How-To-Build Articles

It is always good to appear responsive. A letter from P. Michael Ditchen in the October 1988 *HPV News* laments not having many "how-to" articles. I hope that we will have several in this or later issues of *Human Power*. Three factors combined to bring this development. It seemed, as it did to Michael Ditchen, to be a good idea. I had seen several excellent articles in the NWHPVA newsletter (Seattle area) and in "hpv nieuws" (Holland) and had written for permission to publish them in their entirety or in a shortened form. And, third, there has been a seemingly sudden stoppage in the flow of articles coming in. Werner Stiffel's construction plans required translation from German, and the indefatigable Theo Schmidt, who contributes materially to almost every issue, volunteered from Switzerland. For the translation from the Dutch, I asked Ellen Warner of Oklahoma City, where she rides an Avatar 1000. Her photographs have appeared in previous issues. It seemed highly desirable that her many talents be tapped for *Human Power;* accordingly, she and I were wed on December 30, 1988. How else may I show my dedication to the cause of HPVs?

Probably not all of these pieces will appear in this issue. For an explanation of the uncertainty, read on.

## How *Human Power* is Published

Jean Seay has written something about how she operates as editor of *HPV News,* and I would like to do likewise for *Human Power.* Ideally I would be sent contributions and, every three months, I would select the most scintillating for the next issue. Actually, only a few contributions come unsolicited. I phone and write to many people to ask for papers and articles (if there's a difference it is something to do with technical or scientific content) and send a set of guidelines on how we would like material to be written and reproduced. About a quarter of these actually send something. (More established journals have room to publish only a quarter or less of what is sent to them). I edit everything that I believe needs changes to bring about more clarity or grammar, trying to keep our overseas readers especially in mind (many HPV enthusiasts write in a racy vernacular that is wholly impenetrable by most non-Americans), and occasionally I may shorten something that seems too long. If there are major changes, I send a copy back to the author(s) to check that my alterations are acceptable, or I ask her/him to do some re-writing. When a major contribution (as distinct from a letter or news item) comes in good time, I like to send a copy to one or two people working in the same area to ask for comments, and to give the author(s) an opportunity to respond. If a contribution is not on a diskette, Sabina Rataj, our generous suite secretary at MIT, will usually be able to transcribe it when there are no other high-priority claims on her time. (Alas! Sabina is moving on, and I don't know how we will manage for the next issue without her help. I do some transcriptions myself, and some re-drawing of diagrams, but I would not like to have to do the whole issue.)

I will do my editorial comments and reviews on weekends and evenings, and eventually send them to Marti Daily, who gets all the diskettes converted to a Macintosh format. Then she sends them to Kim Griesemer at The Professional Edge for the production lay-up and camera-ready copy. This is a major task. Kim has to arrange all these diverse pieces and photographs and diagrams so that we end up with exactly 20 or 24 pages, and so that the issue is easy to read. Newspapers have lots of little "filler" pieces to make the task easier. We have very few. Kim often has to delay an article because it can't be made to fit. She sometimes retranscribes a piece to achieve a more balanced layout. Eventually a camera-ready copy is produced and sent to Marti, who takes it to a printing and distribution house. Very little would get done in the IHPVA without the help of our intensely dedicated president.

What might seem to you to be a simple job takes many people a great deal of their spare time. Forgive us if sometimes we slip in some respects.

## A *Human Power* Index

In August I finished a longstanding goal: to index all the articles that have appeared in *Human Power* since it first appeared ten years ago. It is reproduced on pages 19 and 20. Just after I finished it, Marti Daily sent me a categorized listing made by an unknown (to me) hero. I will try to incoporate this into an expanded index later, and acknowledge her/him then. —Dave Wilson ❑

# Letters to the Editor

As the recent purchaser of a DeFelice recumbent, I have wondered about the possibilities of making some sort of simple enclosure that would improve air flow and exclude rain. It would have to be simple enough for commuting service, and not appreciably increase the overall dimensions. Some sort of plastic sheet over a framework of wood strips starting just in front of the front wheel would be easy to construct, or it could be done with thin plywood as was the "Cafe Racer" (vol. 6/2), or a combination. Some questions are these:

1. How detrimental is an opening to put feet down during stops in traffic?
2. Considering the benefits of the Zzipper fairings, would it be worth the trouble to extend it farther back than the rider's knees or hips?
3. If carried all the way back past a fairly wide seat and package rack, how should it be terminated without going behind the rear tire? I frequently carry it indoors by standing it up on its rear wheel. Many cars have some sort of turned-up fin across the back to do something (presumably beneficial) to the airflow when the rear of the body does not taper to a line or point. For a vehicle taller than it is wide, could there be a vertical fin on each side to accomplish something similar? Can the body be left open at the rear, or should it be closed; if the latter, where is the best location of an exhaust vent?

(On the topic of wheel-suspension systems for recumbents) I would like to offer my experience with an alternative. I purchased my DeFelice after a short ride to determine the required frame size. However, as I became more confident after some weeks of riding it, I found that I occasionally pedalled hard enough to stretch the nylon seat fabric sufficiently to push the straps against the rear tire (the fabric is in front of the seat-frame tubes, and the straps are behind). I decided I could gain the required clearance by replacing the fabric with a lawn-chair-style cord wrapping, but arranged in a figure-eight pattern around the frame so that the cords crossed in the middle. Since the backrest must resist the force of pedalling on a recumbent bike, I further strengthened the seat by using polypropylene rope, which does not have the elasticity of nylon. For the lower part, which supports the major portion of the rider's weight, however, I used nylon for its slight elasticity. The result was totally satisfactory: the backrest stays where it should, and the nylon "seat" allows several inches of vertical movement of the rider's body with respect to the frame. An additional benefit is that the "seat" and

*(continued on page 15)*

# Vibrational Stress on Cyclists

by Rainer Pivit


## ABSTRACT

*The vibrational stress on bicycle riders with different bicycles and on different (cycle track) surfaces was measured. Rough surfaces of typical West German city cycle tracks nearly always impair performance and even sometimes the health of the rider. Suspension systems can reduce vibrational stress.*


## INTRODUCTION

In Oldenburg, a town of 140,000 inhabitants in the lowlands of North West Germany, bicycle traffic plays an important role in the traffic. In the inner city about 10% to 25% of the traffic is done by bicycles. All major streets have cycle tracks on the sidewalks. The situation of the bicyclists is not as good as in the Netherlands but better than in most German towns where only motorized traffic is promoted.

The traffic safety for the bicyclists in Oldenburg is not better than in towns without sidewalk cycle tracks. The accidents happen at the crossings instead of along the street as in towns without cycle tracks.

Most cycle tracks in Oldenburg are made of concrete bricks because they are cheap and easily removeable for excavation. Riding on those surfaces is not very comfortable, but bicyclists are forced by law to use them and are not allowed to ride on the smoothly asphalted roadway pavement.

As a small group of physicists at the University of Oldenburg we are working on bicycles and HPVs. In order to initiate a public discussion about cycle-track quality we tried to quantify vibrational stress on the rider. The method we used is standardized by international ISO standard 2631 and German VDI (Verein Deutscher Ingenieure = Society of German Engineers) standard 2057. These standards are mainly used on tractors and other machines where the operational staff is exposed to vibrations. According to the standards the acceleration is measured at the interface with the rider. The acceleration is then filtered according to the frequency response of vibration of the human body. German VDI standard calls the resulting effective value the K-Value. K-Values go linear with the acceleration but differ with frequency. In the VDI Standard this K-Value—there is no corresponding designation in the ISO Standard—is used to get exposure-time limits for health or capacity of reaction or comfort impaired. In the ISO standard the limit of reduced comfort is identical to the VDI, the German limit of reduced capacity of reaction is called exposure limit in ISO standard, and is the upper limit. There is no limit of health impaired in the ISO Standard; vibration should always be below the exposure limit (ISO) or limit of reduced capacity of reaction (VDI).

The frequency response of (wo)man and the exposure-time limits are empirical results. This method is very similar to the standardized measurement of loudness. But (wo)man has a different frequency response concerning different directions and different parts of the human body. The hand-arm-system is, independent of direction, most sensitive between 8 and 16 Hz. The maximum sensitivity for vibration in the direction of the spinal column of the body lies between 4 and 8 Hz.

## MEASUREMENT

We measured the acceleration at the handlebar of the bicycle and at the underside of the saddle in direction of the backbone. The signals of the sensors were amplified and encoded to a PCM-system on the bicycle and sent to a data tape recorder in a nearby car by HF-telemetry. The data were evaluated with electrical filters corresponding to the frequency rating of the ISO and VDI standard.

Because the standards allow the interpretation only of signals lasting longer than 1 minute time we cannot make statements about the effect of single bad spots on cycle tracks like potholes and very bad transitions between cycle track and driveway at crossings.

We carried out the measurement on eleven different surfaces:

- a very old pavement of irregular field stones (Hochhauser Str. flank),
- pavement of small (Werbachstr.) and
- normal cobble-stones (Elisabethstr.),
- very old brick-stone pavement with stones on end (Hochhauser Str. middle)—this was an historic cycle track as they were built in Oldenburg at the beginning of this century: 0.4 m wide smoother brick-stone pavement at the middle of the street for bicyclists and field-stone pavement for the other, slower vehicles at the rest of the narrow street—,
- brick-stone pavement with old flat stones (Marschweg), and
- new (Damm),
- concrete-stone pavement in a figure-Y pattern, (Staugraben)—widely used in the inner city area—and
- rectangular shaped (Carl-von-Ossietzky-Str. cycle track)—this kind of pavement is used on nearly all new cycle tracks—,
- asphalted surfaces of cycle-track quality (Freibad cycle track),
- country-road quality (Kuepkersweg) and
- highway quality (Carl-von-Ossietzky-Str. drive way).

We repeated the measurement with six different vehicles: a roadster bicycle, two touring bicycles, a Moulton bicycle, an OLF (Oldenburger Leichtfahrzeug = Oldenburg Lightweight Vehicle) and a car.

The roadster bike was similar to the typical bicycles in the Netherlands and is the type most commonly used in Oldenburg. The tires were 37-622 mm (28 x 1-3/8") at 320 kPa (45 PSI).The saddle has large pressure and tension springs. The diamond-framed bicycle weighed 17 kg, the rider 80 kg.

Both touring bicycles had tires of the size 28-622 mm (26 x 1-1/8") at 600 kPa (85 PSI) front and 700 kPa (100 PSI) rear and an 'anatomic' saddle without springs. The bicycles differ in the position of the handlebar, wall thickness of CrMo steel tubes and weight. On no. 1 the rider's arm had an angle of approximately 70 degrees to horizontal, no. 2 was with 45 degrees more at the standard position on touring bikes. The wall thickness of the tubes of no. 2 were thinner (exact dimensions unknown). Bike no. 1 weighed 15 kg and its rider 80 kg, no. 2 14 kg and 72 Kg.

The Moulton bicycle was an AM 7 with its 17" tires at 700 kPa (100 PSI). The suspension system is at front a weakly dampened steel spring and at rear a rubber-block spring with internal damping. Resonance frequency front and rear is approximately 3 Hz. It had the same saddle as the touring bicycles. Weight of the bike was 14 kg and of the rider 80 kg.

The OLF is a three-wheeled recumbent prototype built by our bicycle research group (see *Human Power,* Spring/Summer 1988). It has a soft spring suspension system with a resonance frequency of approximately 1.5 Hz. The Moulton wheels were inflated to 600 kPa (85 PSI). The vehicle weighed 29 kg and the driver 82 kg.

The car we used was an old Volkswagen Rabbit. The whole payload weighed 280 kg and the driver himself 90 kg.

All vehicles had an additional weight of 11 kg for the measurement equipment. On the roadster and touring bicycles it was mounted in panniers on the rear carrier.

## RESULTS

The intensities of vibration are shown in the graphs. The scale is logarithmic as is the human response. The bright column shows the intensity on the hand-arm-system, the dark that at the saddle in direction of the backbone.

For interpretation there are shown the exposure limits at different times of exposure per day as they are defined in the VDI standard. The labels at the lines mean:

- H 1 at 1 min per day health impaired
- H 25 at 25 min per day health impaired
- H 60 at 60 min per day health impaired
- R 25 at 25 min per day capacity of reaction impaired
- R 60 at 60 min per day capacity of reaction impaired
- C 1 at 1 min per day comfort impaired
- C 25 at 25 min per day comfort impaired
- C 60 at 60 min per day comfort impaired

If for example a column for a bike exceed the H 60 limit, then the health of the rider may be impaired if the total riding time of one day on that (or worse) surfaces exceeds 60 minutes. If the exposure time is below 60 minutes per day, "only" the capacity of reaction is impaired.

On many surfaces vibration on touring bicycle no. 1 exceeds the limit of health impaired. Only on asphalted surfaces and new cycle tracks is health not impaired. Especially the strain on the hand-arm-system is very critical because the static load is very high in the forward-leaning position. On touring bike no. 2 the intensity of vibration on hand-arm-system is only half as much, presumably because of the thinner wall thickness of the fork tubes. Up to good and medium quality asphalted surfaces, capacity of reaction is always impaired.

On rough cobble-stone pavement health is impaired on the roadster bicycle. On many surfaces the limit of impaired capacity of reaction is exceeded. Only on good quality asphalted surfaces is comfort not impaired.

With the Moulton AM 7 Bicycle the intensity of vibration is similar to the roadster bicycle despite the low rolling resistance of the high-pressure tires. The highly damped rear suspension is especially troublesome. The vibrational strain is reduced by the front suspension much better than at the rear. But the only slightly dampened front suspension is unsatisfactory in driving behaviour. On smooth surfaces swinging of the rear suspension in reaction to pedal forces is noticeable.

The much softer OLF shows distinct advantages over the other human-powered vehicles. Under practical riding conditions capacity of reaction is not impaired and in many cases not even comfort is impaired. It is possible to optimize the suspension system even further and hereby the intensity of vibration will be further slightly reduced.

The car was the most comfortable vehicle as was to be expected. Comfort is impaired only on very bad roads. The suspension system of the car consists of three parts: the tire, the spring-suspension system and the seat. Our prototype OLF has only a spring-suspension system: seat and tire springing can be neglected. The automobile industry of course has had much more time and money to reach the comfort of today's cars than our small group was able to spend on the development of our prototype HPV.

The intensity of vibration, at least on touring bike no. 2, increases approximately linearly with speed in the range between 10 and 40 km/h.

The intensity of vibration below a K-value of 1 is not measurable with the equipment we used.

## CONSEQUENCES

To reduce the risk of impairing health and capacity of reaction (which means at least a reduced risk of accident) there are three possibilities:

- higher quality of cycle-track surfaces;
- bicycles with spring-suspension system; or
- cancel the obligation to use cycle tracks.

The last point is the cheapest and is the most realistic. And it has additional benefits to inner traffic by lowering the speed of cars.

Maybe someone thinks vibration is a part of bicycle riding. It is one of the differences to the tin-box-encapsuled car driver. That may be applicable for sports riding and ego-trips on bicycles. But for the commuting bicyclists—and increasing the number of those is what we need to reduce the environmental disaster following abundant driving of cars in cities—vibrations are very burdensome.

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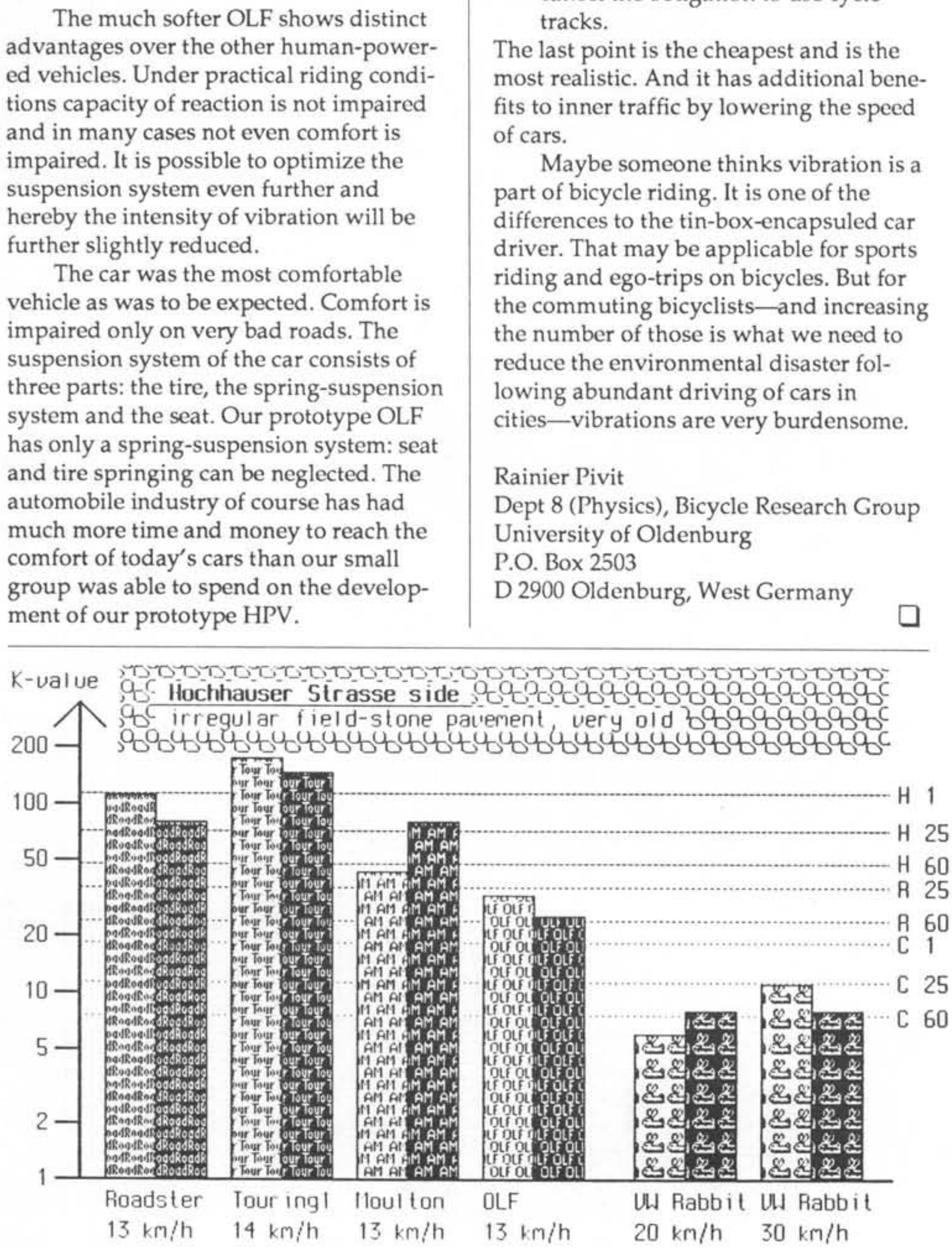
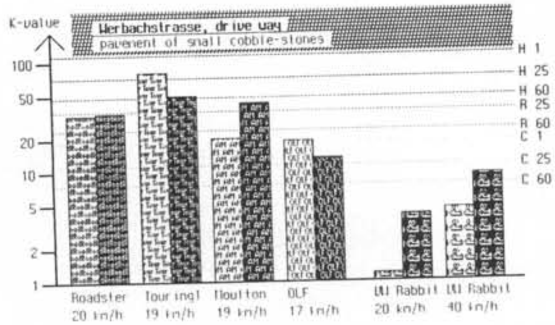
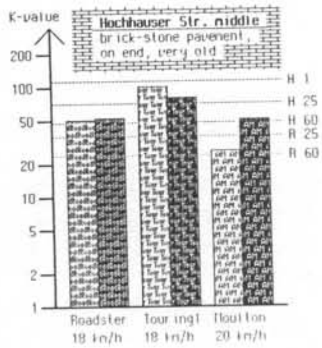
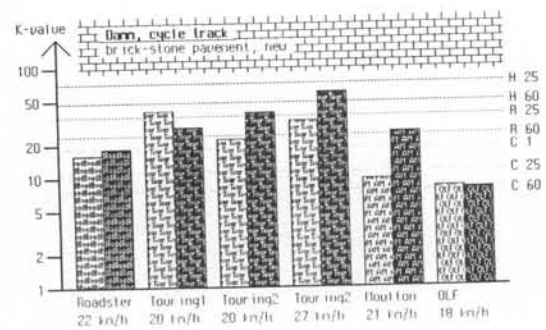
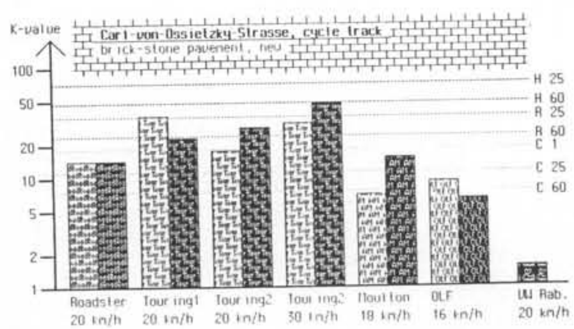
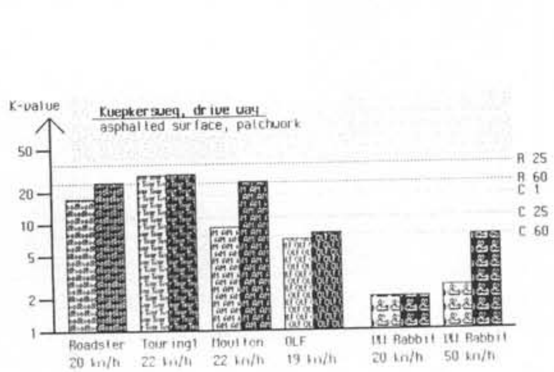


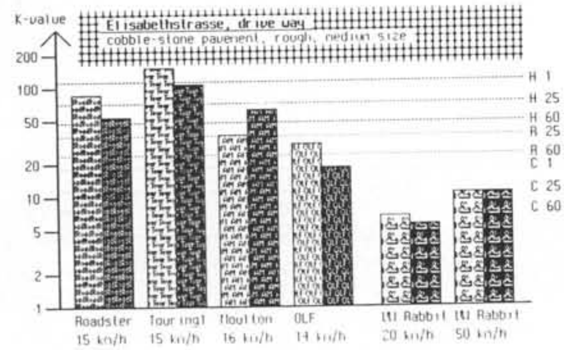

K-value
Werbachstrasse, drive way
pavement of small cobble-stones
H 1
H 25
H 60
R 25
R 60
C 1
C 25
C 60
100
50
20
10
5
2
1
Roadster 20 km/h
Touring1 19 km/h
Moulton 19 km/h
OLF 17 km/h
LW Rabbit 20 km/h
LW Rabbit 40 km/h

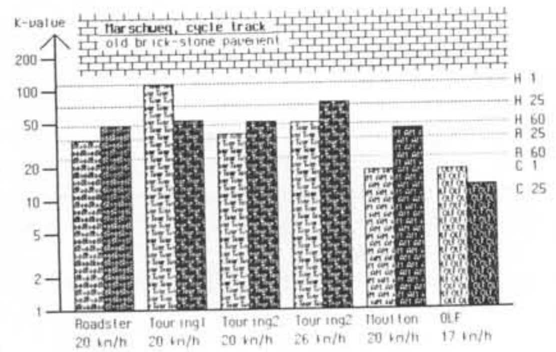

K-value
Hochhauser Str. middle
brick-stone pavement, on end, very old
H 1
H 25
H 60
R 25
R 60
200
100
50
20
10
5
2
1
Roadster 18 km/h
Touring1 18 km/h
Moulton 20 km/h

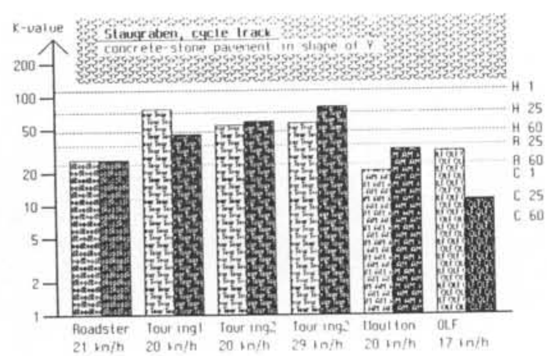

K-value
Damm, cycle track
brick-stone pavement, new
H 25
H 60
R 25
R 60
C 1
C 25
C 60
100
50
20
10
5
2
1
Roadster 22 km/h
Touring1 20 km/h
Touring2 20 km/h
Touring2 27 km/h
Moulton 21 km/h
OLF 18 km/h

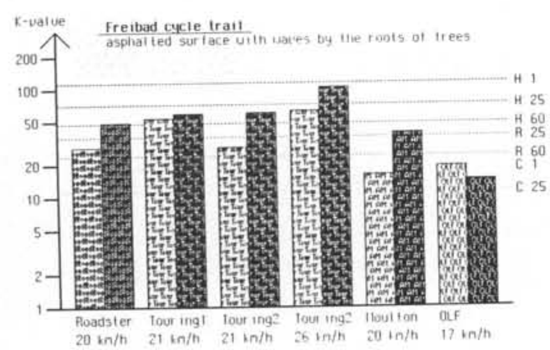

K-value
Carl-von-Ossietzky-Strasse, cycle track
brick-stone pavement, new
H 25
H 60
R 25
R 60
C 1
C 25
C 60
100
50
20
10
5
2
1
Roadster 20 km/h
Touring1 20 km/h
Touring2 20 km/h
Touring2 30 km/h
Moulton 18 km/h
OLF 16 km/h
LW Rab. 20 km/h

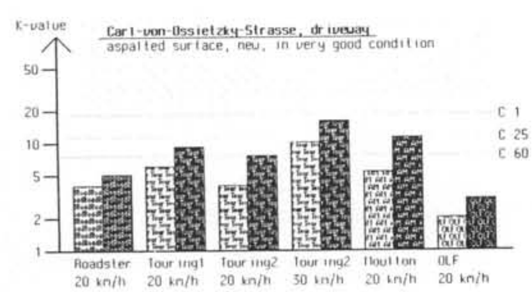

K-value
Kuepkersweg, drive way
asphalted surface, patchwork
R 25
R 60
C 1
C 25
C 60
50
20
10
5
2
1
Roadster 20 km/h
Touring1 22 km/h
Moulton 22 km/h
OLF 19 km/h
LW Rabbit 20 km/h
LW Rabbit 50 km/h


K-value
Elisabethstrasse, drive way
cobble-stone pavement, rough, medium size
H 1
H 25
H 60
R 25
R 60
C 1
C 25
C 60
200
100
50
20
10
5
2
1
Roadster 15 km/h
Touring1 15 km/h
Moulton 16 km/h
OLF 14 km/h
LW Rabbit 20 km/h
LW Rabbit 50 km/h


K-value
Marschweg, cycle track
old brick-stone pavement
H 1
H 25
H 60
R 25
R 60
C 1
C 25
200
100
50
20
10
5
2
1
Roadster 20 km/h
Touring1 20 km/h
Touring2 20 km/h
Touring2 26 km/h
Moulton 20 km/h
OLF 17 km/h


K-value
Staugraben, cycle track
concrete-stone pavement in shape of Y
H 1
H 25
H 60
R 25
R 60
C 1
C 25
C 60
200
100
50
20
10
5
2
1
Roadster 21 km/h
Touring1 20 km/h
Touring2 20 km/h
Touring2 29 km/h
Moulton 20 km/h
OLF 17 km/h


K-value
Freibad cycle trail
asphalted surface with waves by the roots of trees
H 1
H 25
H 60
R 25
R 60
C 1
C 25
200
100
50
20
10
5
2
1
Roadster 20 km/h
Touring1 21 km/h
Touring2 21 km/h
Touring2 26 km/h
Moulton 20 km/h
OLF 17 km/h


K-value
Carl-von-Ossietzky-Strasse, driveway
aspalted surface, new, in very good condition
C 1
C 25
C 60
50
20
10
5
2
1
Roadster 20 km/h
Touring1 20 km/h
Touring2 20 km/h
Touring2 30 km/h
Moulton 20 km/h
OLF 20 km/h

# Constructing a Fairing Mold Plug by Greg Trayling

*This article is reprinted with permission from the NorthWest Human Powered Vehicle Association. It originally appeared in its Nov-Dec, 1986 newsletter.*

If you're looking for an accurate and inexpensive method of building a sturdy, light-weight plug to make a molded fairing, try the following method which I used to make the fairing for the Paragon.

## Start With the Profile

Start your design by drawing just the profile that fits the rider and components of the vehicle. Cut out a template of this profile using a thin board, like eighth-inch (3mm) Masonite. Sand the edges along the cut to ensure a smooth curve. Draw vertical lines ten inches (250 mm) apart which will be stations for the perpendicular supports of the plug. Also draw a horizontal reference line; I suggest a line indicating 200 mm from the ground. Nail a wood stiffener on the sheet for reinforcing. Use thinner reinforcing near the tail where the form will taper.

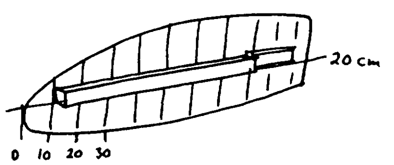



Figure 1

## Find the Width at Points Along the Profile

Next determine the shape of the fairing across its width. At such critical points as the wheel axis and shoulders, cut out one side of the station templates. Figure 2 shows a front view of a shape which accommodates the wheel. When desigining, note that 3mm (1/8 inch) will be added later by the surfacing layers over the whole plug.

## Design While Constructing

Make intermediate stations using the shape of the critical templates. One can design while constructing, an advantage over constructing a preset design. For uniformity, make all the templates curve into a 90° angle at the top and bottom. Measure the template height from the

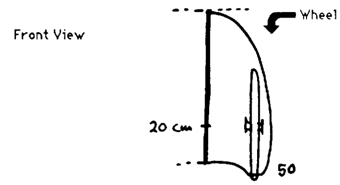



Figure 2

profile. Trace two critical stations, as shown in Figure 3, and interpolate the stations between. Keep in mind the height of the station from the profile. A NACA airfoil may be used to obtain the maximum station width.

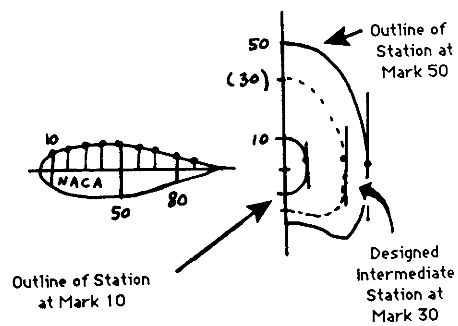



Figure 3

When all templates for one side are finished, make duplicates. I suggest clamping the duplicates together and sanding the edges to make identical curves.

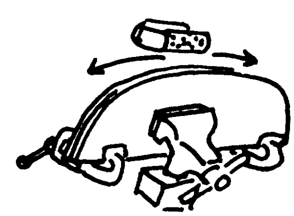


Figure 4

Glue the station templates to the profile; I suggest using a hot-glue gun. Add such horizontal supports as shown in Figure 5. Preview the overall shape, check that components fit, and adjust the design.

## Fill the Form with Foam

Next, finish the full form of the plug with a blanket of polyurethane. First, tape cardboard strips a half-inch (13mm) from the edge and seal off to conserve foam. Mix the two parts of polyurethane pour-in-place foam. (Avoiding the vapors from this mix requires a proper respirator.) Just

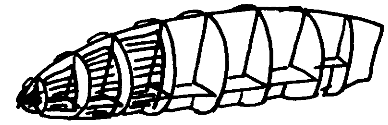


Figure 5

as the mixture begins to foam, pour it between the plug and such a barrier as a plastic sheet held against the edges of the stations. Hold in place until foam sets, then peel barrier off. Fill all sections.

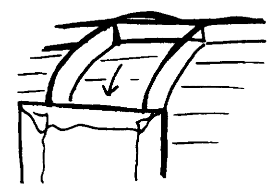


Figure 6

Smooth the form of the plug. Carefully sand any bulging foam down to the station edges. If in doubt, sand to below the fairing shape desired, rather than above. Fill in gaps, holes, and depressions by adding foam; simply paint on the liquid mix before foaming starts.

## Apply a Hard Surface

Lastly, make the hard surface for molding with fiberglass and filler. Apply two to three layers of fiberglass mat with polyester resin to entire plug. Let harden. Apply a layer of inexpensive talc resin filler. Sand and repeat filler application until the plug is finished. Apply mold wax and release solution to ready the plug for molding.

As an alternative to foam, all of the sections may be filled with carefully bent and taped pieces of cardboard. The fiberglass and talc filler layers give ample rigidity and accuracy.

The method described above yields a strong, light, and cheap plug. In addition, the fairing can be designed as the plug is built. This saves considerable time in visualizing the rider and vehicle components from a scale drawing. All materials and technical support can be found at your local lumber supply and fiberglass shop.

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CANADA

# A Simple Program for Propeller Performance Prediction by Theodor Schmidt

This is a simulation program. It does not design propellers, but rather works out various values such as power, thrust, efficiency, and slip from input parameters such as blade geometry, boat speed, and rotational speed. The copious output quickly gives insight into the effects of changing the parameters and thus allows designing in a "try it and see" manner. This is not so good if the best possible performance at a single operating point is sought, but works very well in establishing a good compromise over a range of conditions, which is usually what is needed, except for the most extreme racing craft.

The program works by calculating basic data such as blade aspect ratio, etc. dividing the blade into nine segments, calculating all values for these, and finally summing up and printing out.

Lift coefficients are calculated as a function of angle of incidence and aspect ratio. Drag coefficients are looked up in an array where they are stored as a function of CL, lift coefficient, and Reynold's number. Induced drag is calculated as a function of CL and aspect ratio.

Lift, drag, thrust, torque, and associated coefficients and efficiencies are calculated and a slip value is derived. All calculations are repeated using the new slip until all values stabilize, usually requiring about three passes. Then the segment values are summed up for the whole propeller and printed out. (Occasionally the loop oscillates instead of settling down. Sometimes increasing the value in line 1140 helps, but a proper solution would be to find a more positive way for converging the values. Another improvement would be to modify the program to handle negative slip values they occur at low rpms or when "windmilling").

No assumptions are made about minimum induced drag according to the methods of Gene Larrabee, but the formula for induced drag used is the usual one for an elliptical lift distribution. In a propeller, minimum induced drag corresponds to a uniform wash velocity distribution, i.e. all the segment slip values should be the same, which can be done for a certain operating point by adjusting the chord distribution. Results from the program seem to show that this is either not very important, provided that reasonable plan forms are used, or that an optimum distribution is implied to some extent so that the results given for a non-optimum plan form are too optimistic. I'm not sure which applies! However the results agree well with those of Mark Drela's "ROTOR" program given in *Human Power* vol. 6 no. 2 and roughly with some examples of Gene Larrabee's "HELICE" program, although this seems to give higher efficiency values.

The program is set up for fresh water. For exact results in sea water or for air the density and viscosity values implied in lines 910, 1030 and 1040, and 1200 should be altered. SI units are used and in this version there is no provision for other than geometrically correct twist values at zero angle of incidence (corresponding to CL of about 0.35 for the near-Clark Y section assumed). Hub-and-shaft drag is ignored. The output is set up for an 80-column screen or printer and gives total values, so for segment values a few more output commands are necessary. Depending on the computer used, some variable names may have to be changed. This runs on a Commodore VIC-20+16k.

The results should be accurate enough for most human-power applications, i.e. fairly large lightly loaded blades at low speeds. Behavior of most motorboat propellers is more complex and beyond the scope of the program, as blades are usually of very low aspect ratio, highly loaded and often ventilated or cavitating.

Anyone is welcome to copy this program for personal use only. I would welcome comparisons with more sophisticated programs and criticisms or suggestions.

Theodor Schmidt
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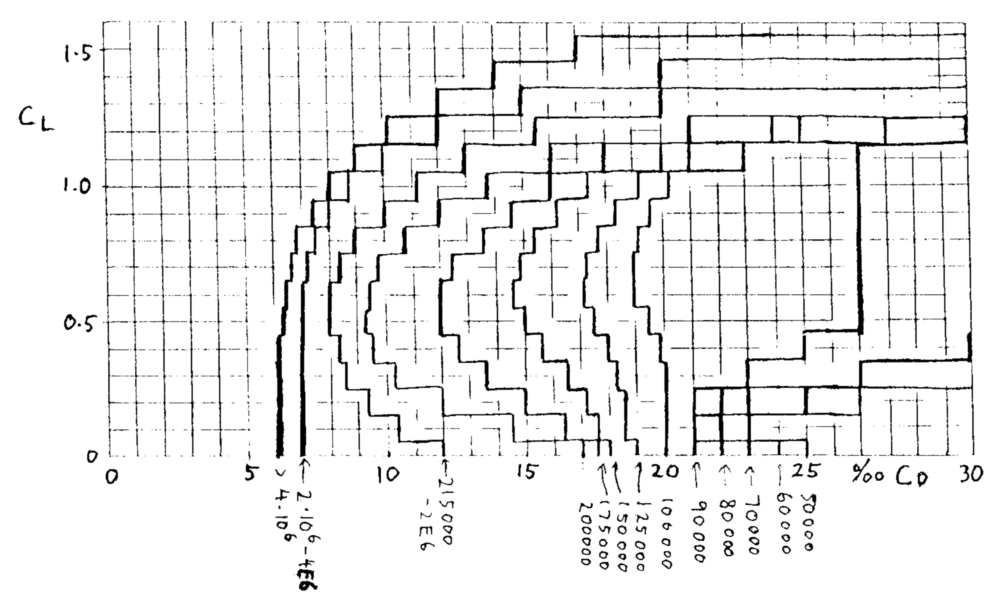
CH-4402 Frenkendorf, Switzerland

*Theo Schmidt is a prolific designer and developer of HPVs and HPBs, particularly solar-assisted and amphibious machines.—ed.*

## Table of Values for Clark Y



```
100 REM  Propeller Design 28.11.87
110 REM  By Theodor Schmidt
120 REM  Input data thru variables at beginning of program
130 REM  Program runs from low RPM to top RPM given by R1
         and R2
140 REM  in steps of "incr". Basic may take several minutes
150 REM  to work out first result.
160 Diameter = 0.50 :REM (Meters)
170 Ptch=0.66 :REM (Meters)
180 U=1.5 :REM boat speed in m/s
190 R1=100 :REM (RPM)
200 R2=600 :REM (RPM)
210 Incr=10 :REM (RPM)
220 Blades=2
230 Header$="Y" :REM "Y" or "N" (prints out basic blade
    parameters)
240 Range$="Y" :REM "Y" or "N" (Limits top RPM to low blade
    loadings)
250 CH(1)=.075 :REM Chord at radial station 1 (near hub) in m.
260 CH(2)=.080
270 CH(3)=.087
280 CH(4)=.091
290 CH(5)=.091
300 CH(6)=.087
310 CH(7)=.080
320 CH(8)=.070
830 CH(9)=.055
340 DIM FF(16,14)
350 FOR K=1TO14
360 FOR J=0TO15
370 READ FF(J,K)
380 NEXT J
390 NEXT K
400 PI=3.14159
410 CIRCUM=PI*DIAMETER
420 OPEN,4:CMD1 :REM TRANSFERS OUTPUT TO PRINTER
430 TA=ATN(PTCH/CIRCUM):TD=TA*57.296 :REM TIP
    ANGLE
440 SWPT AREA=PI*(DIAMETER/2)↑2
450 FOR I=1TO9
460 A(I)=CH(I)*DIAMETER/20* BLADES
470 BETA(I)=ATN((PTCH/CIRCUM)/(I/10))
480 A=A+A(I)
490 NEXT I
500 A=A+A(9)/4 :REM TOTAL BLADE AREA
510 BAR=A/SWPT AREA :REM BLADE AREA RATIO
520 AR=(DIAMETER/2)↑2/A*BLADES :REM BLADE ASPECT
    RATIO
530 IF HEADER$="N"THEN 650
540 PRINT "PROPELLER SIMULATION PROGRAM"
550 PRINT "____" :PRINT:PRINT "BLADE NUMBER=";BLADES
560 PRINT"DIAMETER= ";DIAMETER; "M"
570 PRINT "PITCH = ";PTCH;"M"
580 PRINT "SWEPT AREA = ";INT(SWPT AREA*10000+0.5)/
    10000;"SQ M"
590 PRINT "BLADE AREA RATIO = ";INT (BAR*10000+0.5)/
    10000
600 PRINT "BLADE ASPECT RATIO- ";INT(AR*1000+0.5)/100
610 PRINT "TIP ANGLE= ";INT(TD*100+0.5)/100; "DEGREES"
620 PRINT "STATION    CHORD (M)   ANGLE (DEGREES)"
630 FOR N=1TO9
640 PRINTN;SPC(9);CH(N);SPC(9);INT(BETA(N)*5729.6+0.5)/
    100:NEXT N;PRINT
650 PRINT DIA  PITCH  BT SPD  PR SPD  P IN  P OUT  ETA";
660 PRINT"ETA F  THRUST  CL(5)  SLIP"
670 PRINT"(M)  (M)  (M/S)  (RPM)  (W)  (W)  (%)  (%)  (N)"
680 R3=R1;R4=R2
690 FOR RR=R1TOR2 STEP INCR
700 VR=CIRCUM*RR/60
710 I=1
720 DELTA(I)=ATN(U/(VR*(I/10)))
730 ALPHA(I)=BETA(I)-DELTA(I) :REM ANGLE OF INCI-
    DENCE AT BLADE ELEMENT
740 IF ALPHA(I)<-0.1 THEN R3=RR+INCR:GOTO770 :REM
    LIMITS PROGRAM TO POSITIVE LIFT
750 IF ALPHA(I)>.26 THEN R=4=RR:GOTO780 :REM RE-
    STRICTS BLADE LOADING
760 IF I<8.5 THEN I=I+1:GOTO720
770 NEXT RR
780 IF RANGE$="N"THEN R4=R2
790 FOR RPM=R3TOR4 STEP INCR
800 VR=CIRCUM*RPM/60
810 PP=0:PW=0:T=0 :REM POWER IN, POWER OUT, THRUST
820 UR=U*(1+Q) :REM SPEED THRU DISC, Q IS SLIP FACTOR
830 FOR I=1TO9
840 UR(I)=U*(1+Q(I))
850 VR(I)=VR*(I/10)
860 W(I)=SQR(UR(I)↑2+VR(I)↑2) :REM RESULTANT SPEED AT
    BLADE SEGMENT
870 DELTA(I)=ATN(UR(I)/VR(I))
880 ALPHA(I)=BETA(I)-DELTA(I)
890 CL(I)=ALPHA(I)*5.75/(1+2/AR)+0.35 :REM COEFFICIENT
    OF LIFT
900 IF CL(I)<0 THEN GOTO1470
910 RE(I)=1E6*W(I)*CH(I) :REM REYNOLD'S NUMBER (for air
    replace 1E6 with 7E5)
920 X=ABS(INT)(10*CL(I)+0.5))
930 IF X>15THEN X=15
940 IF RE(I)<45000THEN Y=1:GOTO1000
950 IF RE(I)<105000THEN Y=INT(RE(I)/1E4-2.5):GOTO1000
960 IF RE(I)<212500THEN=INT(RE(I)/2.5E4+3.5):GOTO1000
970 IF RE(I)<2E6THEN Y=12:GOTO1000
980 IF RE(I)<4E6THEN Y=13:GOTO1000
990 Y=14
1000 CD(I)=FF(X,Y)/1000 :REM PROFILE COEFFICIENT OF
     DRAG
1010 IF CL(I)>1.2 THEN CL(I)=1.2 :REM PATHETIC ATTEMPT
     TO SIMULATE APPROACHING STALL
1020 ID(I)=CL(I)↑2/(PI*AR) :REM INDUCED DRAG
*1030 L(I)=500*A(I)*CL(I)*W(I)↑2 :REM LIFT
*1040 D(I)=500*A(I)*(CD(I)+ID(I))*W(I)↑2 :REM DRAG
1050 T(I)=L(I)*COS(DE(I))-D(I)*SIN(DE(I)) :REM THRUST
1060 F(I)=L(I)*SIN(DE(I))+D(I)*COS(DE(I)) :REM LATERAL
     FORCE
1070 PP(I)=F(I)*VR(I) :REM POWER IN
1080 PW(I)=T(I)*U :REM POWER OUT
1090 ETA(I)=PW(I)/PP(I) :REM EFFICIENCY
*1100 CT(I)=T(I)/(500*DI*(I/10)*PI*U*U*DI/20) :REM COEFFI-
     CIENT OF THRUST
1110 C2(I)=Q(I)*4*(1+Q(I)) :REM ALSO COEFFICIENT OF
     THRUST
1120 EF(I)=2/(1+SQR(1+CT(I))) :REM FROUDE EFFICIENCY
1130 Q(I)=1/EF(I)-1
```

* For salt water, replace 500 with 512. For air, replace 500 with 0.625

```
1140 IF ABS(C2(I)/CT(I)-1)>0.05 THEN 840
1150 T=T+T(I)
1160 PP=PP+PP(I)
1170 PW=PW+PW(I)
1180 NEXT I
1190 ETA+PW/PP
*1200 CT=T/(500*SW*U*U)
1210 EF=2/(1+SQR(1+CT))
1220 Q=1/EF-1
1230 C2=4*Q*(1+Q)
1240 UJ=U*(1+2*Q)
1250 P$=RIGHT$(STR$(INT(DIAMETER*101)/100),5)
1260 PRINTP$;SPC(7-LEN(P$));
1270 P$=RIGHT$(STR$(INT(PT*101)/100),5)
1280 PRINTP$;SPC(7-LEN)(P$));
1290 P$=RIGHT$(STR$(INT(U*100)/100),5)
1300 PRINTP$;SPC(7-LEN(P$));
1310 P$=RIGHT$(STR$(INT(RPM)),5)
1320 PRINTP$;SPC(7-LEN(P$));
1330 P$=RIGHT$(STR$(INT(PP+0.5)),5)
1340 PRINTP$;SPC(7-LEN(P$));
1350 P$=RIGHT$(STR$(INT(PW+0.5)),5)
1360 PRINTP$;SPC(8-LEN(P$));
1370 P$=RIGHT$(STR$(INT(ETA*100+0.5)),5)
1380 PRINTP$;SPC(7-LEN(P$));
1390 P$=RIGHT$(STR$(INT(EF*100+0.5)),5)
1400 PRINTP$;SPC(8-LEN(P$));
1410 P$=RIGHT$(STR$(INT(T+0.5)),5)
1420 PRINTP$;SPC(7-LEN(P$));
1430 P$=RIGHT$(STR$(INT(CL(5)*100)/100),5)
1440 PRINTP$;SPC(6-LEN(P$));
1450 P$=RIGHT$(STR$(INT(Q*1000+0.5)/1000),6)
1460 PRINTP$
1470 NEXT RPM
1480 PRINT#1:CLOSE 1 :REM CLOSES FILE TO PRINTER
1490 REM THE FOLLOWING VALUES ARE READ INTO THE
     ARRAY FF AND
1500 REM REPRESENT CD AS A FUNCTION OF CL AND RE
1510 DATA25,23,27,50,70,80,80,80,75,70,60,50,50,200,1000,1000
     (RE<45000)
1520 DATA24,22,25,40,50,55,57,58,55,50,45,42,46,180,1000,1000
     (RE≈50000)
1530 DATA23,21,23,35,40,46,46,46,46,46,42,38,45,150,800,1000
     (RE≈60000)
1540 DATA22,21,22,31,35,39,39,39,39,39,37,35,41,140,700,1000
     (RE≈70000)
1550 DATA22,21,21,27,30,33,33,33,33,33,32,31,37,130,700,1000
     (RE≈80000)
1560 DATA21,21,21,23,25,27,27,27,27,27,27,27,33,120,600,1000
     (RE≈90000)
1570 DATA20,20,20,20,19.9,19.5,19,19,19.1,19.5,20.2,23,30,100,600,
     1000 (RE≈100000)
1580 DATA19,16.8,18.6,18.3,18,17.5,17.2,17.3,17.8,18.3,19.2,21,28,84,
     600,1000 (RE≈125000)
1590 DATA18,17.7,17.2,16.5,15.6,15,14.6,14.8,15.3,16.2,17.3,20,25,
     80,500,1000 (RE≈150000)
1600 DATA17.5,16.3,15,13.6,12.7,12,12,12.4,13.6,14.6,16,18,24,60,
     400,1000 (RE≈175000)
1610 DATA17,14.5,12,10.2,9.5,9.3,9.4,9.8,10.8,12,13.8,16,21,42,84,
     168 (RE≈200000)
1620 DATA12,10.3,9.3,8.6,8.3,8,8,8.3,9,10,11.1,13,15.5,20,40,80
     (RE<2•10^6)
1630 DATA7,7,7,7,7,7,7,7.1,7.5,8,8.8,10,12,15,20,30 (RE<4•10^6)
1640 DATA6.2,6.2,6.2,6.2,6.2,6.3,6.4,6.6,6.9,7.3,8,9,10.1,12,14,17
     (RE<4•10^6)
```

## Propeller data taken from *HUMAN POWER*

**page 11 vol. 6 no. 2 (Summer, 1987)**

***compare with results in Table 1, page 11**

PROPELLER SIMULATION PROGRAM

DIAMETER = .4 M

PITCH = .46 M

SWEPT AREA = .1257 SQ M

BLADE AREA RATIO = .2021

BLADE ASPECT RATIO = 3.15

TIP ANGLE = 20.11 DEGREES

2 Blades

| STATION | | CHORD [M] | ANGLE [DEGREES] |
|---|---|---|---|
| 1 | .04 | .0834 | 62.04 |
| 2 | .06 | .0894 | 52.55 |
| 3 | .08 | .091 | 44.71 |
| 4 | .10 | .0874 | 38.33 |
| 5 | .12 | .08 | 33.16 |
| 6 | .14 | .0698 | 28.98 |
| 7 | .16 | .0569 | 25.53 |
| 8 | .18 | .0404 | 22.67 |
| 9 | .19 | .0293 | 21.42 |

Radius corrected for 6cm ⌀ Hub

| DIA [M] | PITCH [M] | BT SPD [M/S] | PR SPD [RPM] | P IN [W] | P OUT [W] | η ETA [%] | η Froude ETA F [%] | THRUST [N] | CL(5) | Q (Slip) |
|---|---|---|---|---|---|---|---|---|---|---|
| .4 | .46 | .5 | 100 | 11 | 7 | 62 | 84 | 14 | .74 | .188 |
| .4 | .46 | .5 | 110 | 16 | 9 | 59 | 81 | 18 | .82 | .237 |
| .4 | .46 | .5 | 120 | 21 | 12 | 55 | 78 | 23 | .87 | .287 |
| .4 | .46 | .5 | 130 | 27 | 14 | 53 | 75 | 29 | .92 | .339 |
| .4 | .46 | .5 | 140 | 34 | 17 | 50 | 72 | 34 | .96 | .392 |
| .4 | .46 | .5 | 150 | 43 | 20 | 48 | 69 | 40 | .99 | .445 |
| .4 | .46 | .5 | 160 | 52 | 24 | 45 | 67 | 47 | 1.02 | .5 |
| .4 | .46 | .5 | 170 | 63 | 27 | 43 | 64 | 54 | 1.04 | .553 |
| .4 | .46 | .5 | 180 | 77 | 30 | 39 | 63 | 60 | 1.04 | .595 |
| * .4 | .46 | .5 | 190 | 91 | 33 | 36 | 61 | 66 | 1.06 | .643 |
| .4 | .46 | .5 | 200 | 106 | 37 | 35 | 59 | 74 | 1.08 | .697 |
| .4 | .46 | .5 | 210 | 126 | 41 | 32 | 57 | 82 | 1.09 | .746 |
| .4 | .46 | .5 | 220 | 151 | 44 | 29 | 56 | 89 | 1.11 | .79 |
| .4 | .46 | .5 | 230 | 161 | 51 | 31 | 54 | 101 | 1.12 | .864 |
| .4 | .46 | .5 | 240 | 183 | 56 | 30 | 52 | 111 | 1.13 | .92 |
| .4 | .46 | .5 | 250 | 206 | 61 | 29 | 51 | 121 | 1.14 | .977 |

(Bollard Pull)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| .4 | .46 | .01 | 100 | 19 | 0 | 1 | 4 | 19 | 1.2 | 27.334 |
| .4 | .46 | .01 | 120 | 32 | 0 | 1 | 3 | 28 | 1.2 | 32.916 |
| .4 | .46 | .01 | 140 | 51 | 0 | 1 | 3 | 38 | 1.2 | 38.485 |
| .4 | .46 | .01 | 160 | 76 | 0 | 1 | 2 | 50 | 1.2 | 44.081 |
| .4 | .46 | .01 | 180 | 107 | 1 | 1 | 2 | 63 | 1.2 | 49.666 |
| .4 | .46 | .01 | 200 | 111 | 1 | 1 | 2 | 82 | 1.2 | 56.77 |
| .4 | .46 | .01 | 220 | 144 | 1 | 1 | 2 | 100 | 1.2 | 62.563 |
| .4 | .46 | .01 | 240 | 173 | 1 | 1 | 1 | 121 | 1.2 | 69.012 |

| DIA [M] | PITCH [M] | BT SPD [M/S] | PR SPD [RPM] | P IN [W] | P OUT [W] | ETA [%] | ETA F [%] | THRUST [N] | CL(5) | Q |
|---|---|---|---|---|---|---|---|---|---|---|
| .4 | .46 | 2.2 | 220 | 10 | 3 | 27 | [illegible] | 1 | .02 | 1E-03 |
| .4 | .46 | 2.2 | 230 | 27 | 19 | 71 | 99 | 9 | .05 | 7E-03 |
| .4 | .46 | 2.2 | 240 | 46 | 36 | [illegible] | [illegible] | 16 | .13 | .013 |
| .4 | .46 | 2.2 | 250 | 65 | 54 | 82 | [illegible] | 25 | .19 | .02 |
| .4 | .46 | 2.2 | 260 | 88 | 74 | [illegible] | 97 | 35 | .24 | .027 |
| .4 | .46 | 2.2 | 270 | 113 | 94 | 83 | 97 | 43 | .28 | .034 |
| .4 | .46 | 2.2 | 280 | 139 | 115 | 83 | 96 | 52 | .33 | .041 |
| .4 | .46 | 2.2 | 290 | 168 | 138 | 82 | 95 | 63 | .37 | .049 |
| .4 | .46 | 2.2 | 300 | 199 | 160 | 81 | 95 | 73 | .4 | .057 |
| .4 | .46 | 2.2 | 310 | 232 | 185 | 80 | 94 | 84 | .43 | .065 |
| .4 | .46 | 2.2 | 320 | 268 | 211 | [illegible] | [illegible] | [illegible] | .47 | .073 |
| .4 | .46 | 2.2 | 330 | 307 | 236 | 77 | 92 | 108 | .5 | .082 |
| .4 | .46 | 2.2 | 340 | 348 | 265 | 76 | 92 | 121 | .53 | .091 |
| .4 | .46 | 2.2 | 350 | 392 | 294 | 75 | 91 | 134 | .56 | .1 |
| .4 | .46 | 2.2 | 360 | 438 | 324 | 74 | 90 | 147 | .58 | .109 |
| .4 | .46 | 2.2 | 370 | 488 | 355 | 73 | 89 | 162 | .61 | .119 |
| .4 | .46 | 2.2 | 380 | 540 | 388 | 72 | 89 | 176 | .63 | .128 |
| .4 | .46 | 2.2 | 390 | 596 | 421 | 71 | 88 | 191 | .65 | .138 |
| .4 | .46 | 2.2 | 400 | 655 | 455 | 70 | 87 | 207 | .67 | .148 |
| .4 | .46 | 2.2 | 410 | 717 | 491 | 68 | 86 | 223 | .69 | .158 |
| .4 | .46 | 2.2 | 420 | 782 | 527 | 67 | 86 | 240 | .71 | .169 |
| .4 | .46 | 2.2 | 430 | 851 | 565 | 66 | 85 | 257 | .73 | .179 |
| .4 | .46 | 2.2 | 440 | 923 | 603 | 65 | 84 | 274 | .75 | .19 |
| .4 | .46 | 2.2 | 450 | 998 | 643 | 64 | 83 | 292 | .76 | .2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| .4 | .46 | 2.2 | 270 | 113 | 94 | 83 | 97 | 43 | .28 | .034 |
| .4 | .46 | 2.2 | 271 | 116 | 97 | 84 | 97 | 44 | .29 | .035 |
| .4 | .46 | 2.2 | 272 | 118 | 99 | 83 | 97 | 45 | .29 | .036 |
| .4 | .46 | 2.2 | 273 | 121 | 101 | 83 | 96 | 46 | .3 | .036 |
| .4 | .46 | 2.2 | 274 | 123 | 103 | 83 | 96 | 47 | .3 | .037 |
| .4 | .46 | 2.2 | 275 | 126 | 105 | 83 | 96 | 48 | .31 | .038 |
| * .4 | .46 | 2.2 | 276 | 129 | 107 | 83 | 96 | 49 | .31 | .039 |
| .4 | .46 | 2.2 | 277 | 132 | 109 | 83 | 96 | 50 | .31 | .039 |
| .4 | .46 | 2.2 | 278 | 134 | 111 | 83 | 96 | 51 | .32 | .04 |
| .4 | .46 | 2.2 | 279 | 137 | 114 | 83 | 96 | 52 | .32 | .041 |
| .4 | .46 | 2.2 | 280 | 140 | 116 | 83 | 96 | 53 | .33 | .042 |

| | | | | Pw | | η | | T | CL(5) | |
|---|---|---|---|---|---|---|---|---|---|---|
| .4 | .46 | 1 | 100 | 1 | 0 | 13 | 100 | 0 | .02 | 1E-03 |
| .4 | .46 | 1 | 110 | 5 | 4 | 72 | 99 | 4 | .15 | .014 |
| .4 | .46 | 1 | 120 | 10 | 8 | 78 | 97 | 8 | .26 | .029 |
| .4 | .46 | 1 | 130 | 15 | 12 | 78 | 96 | 12 | .35 | .045 |
| .4 | .46 | 1 | 140 | 22 | 17 | 77 | 94 | 17 | .43 | .063 |
| .4 | .46 | 1 | 150 | 30 | 22 | 75 | 92 | 22 | .51 | .082 |
| .4 | .46 | 1 | 160 | 39 | 28 | 73 | 91 | 28 | .57 | .102 |
| .4 | .46 | 1 | 170 | 49 | 35 | 71 | 89 | 35 | .62 | .123 |
| .4 | .46 | 1 | 180 | 60 | 41 | 69 | 87 | 41 | .67 | .144 |
| .4 | .46 | 1 | 190 | 73 | 49 | 67 | 86 | 49 | .71 | .166 |
| .4 | .46 | 1 | 200 | 87 | 56 | 65 | 84 | 56 | .74 | .189 |
| * .4 | .46 | 1 | 210 | 103 | 65 | 63 | 82 | 65 | .79 | .213 |
| .4 | .46 | 1 | 220 | 121 | 74 | 61 | 81 | 74 | .81 | .237 |
| .4 | .46 | 1 | 230 | 140 | 83 | 59 | 79 | 83 | .83 | .261 |
| .4 | .46 | 1 | 240 | 162 | 93 | 57 | 78 | 93 | .86 | .286 |
| .4 | .46 | 1 | 250 | 185 | 103 | 56 | 76 | 103 | .88 | .312 |

## Prone-Position Recumbent Bicycles

*(continued from page 1)*

categories of items on the questionnaire pertained either to their "most successful prone-position HPV design" or to "prone-position HPVs in general". Items in each category were further divided into areas of comfort, power, and control, and in each case, respondents were asked to compare prone recumbents to conventional racing bicycles. A five-point scale was used for each specific item with "1" being poor, "3" being the same, and "5" being excellent as compared with a conventional racing bicycle. Respondents were asked also to comment on each of the above areas and to discuss the advantages and disadvantages of the prone position. The author has built and ridden four prone recumbent bicycles and also completed a questionnaire. Nine completed questionnaires were received. Means and ranges for each of the scored responses were calculated and comments relevant to each item are included in the results.

**Table 1**

**Means and ranges of ratings of prone-position human-powered vehicles by designers and riders***

| Category | Own Best Machine | Prone Machines in General |
|---|---|---|
| *Comfort* | | |
| General comfort | 1.9 (mean)(1-4)(range)** | 1.9 (1-4) |
| Head/neck comfort | 1.4 (1-3) | 1.5 (1-4) |
| Leg comfort | 2.4 (1-4) | 2.4 (1-4) |
| Visibility | 1.8 (1-2) | 2.1 (1-3) |
| *Power* | | |
| Peak (short-term) | 3.5 (2-5) | 2.3 (2-5) |
| Long-term power | 2.4 (1-5) | 2.5 (1-5) |
| Hill-climbing power | 2.3 (1-4) | 2.3 (1-5) |
| *Control* | | |
| Control when turning corners | 2.2 (1-3) | 2.3 (2-3) |
| Control on rough terrain | 1.5 (1-2) | 1.4 (1-2) |

* number of respondents = 9

** rating scale: 1 = poor, 3 = same as conventional racing bicycle, 5 = excellent

### RESULTS

The means and ranges of ratings for each item are included in Table 1. General comfort received a mean rating of 1.9 (as compared to a standard 3.0 rating for a conventional bicycle). All components of comfort, including visibility were generally rated as inferior to a conventional bicycle. Most respondents commented on the need for comfortable supports rigidly attached to the frame for the pelvis and shoulders. All used toe clips to support the feet. Some used a padded support for the chin. One used elastic supports for the knees. Several respondents commented on the rider's difficulty in turning his head while in this position to see directly to the rear.

Power generated in the prone position was generally rated as slightly inferior to that in the conventional position. There was, however, a great deal of variability in the opinions. Brief ergometry testing by Chet Kyle showed long-term power to be an average of 8% less than the conventional position. While most respondents agreed that long-term power was slightly decreased, the respondent with the most experience (GJ) felt that his ability to produce prolonged power in the prone position was excellent, and that long uphill climbs were no more exhausting than on a standard bicycle. Most felt that peak power was slightly better than in the conventional position and that having the shoulders against solid supports aided in the production of peak power. It was noted that training in the prone position is necessary to improve efficiency in this position. The inability to change positions while in the prone position was noted to be a disadvantage as compared to the conventional position where the rider can stand for hill climbing, stretching, etc. Two of the respondents utilized the prone position to facilitate hand and foot power to increase peak power for short periods of time.

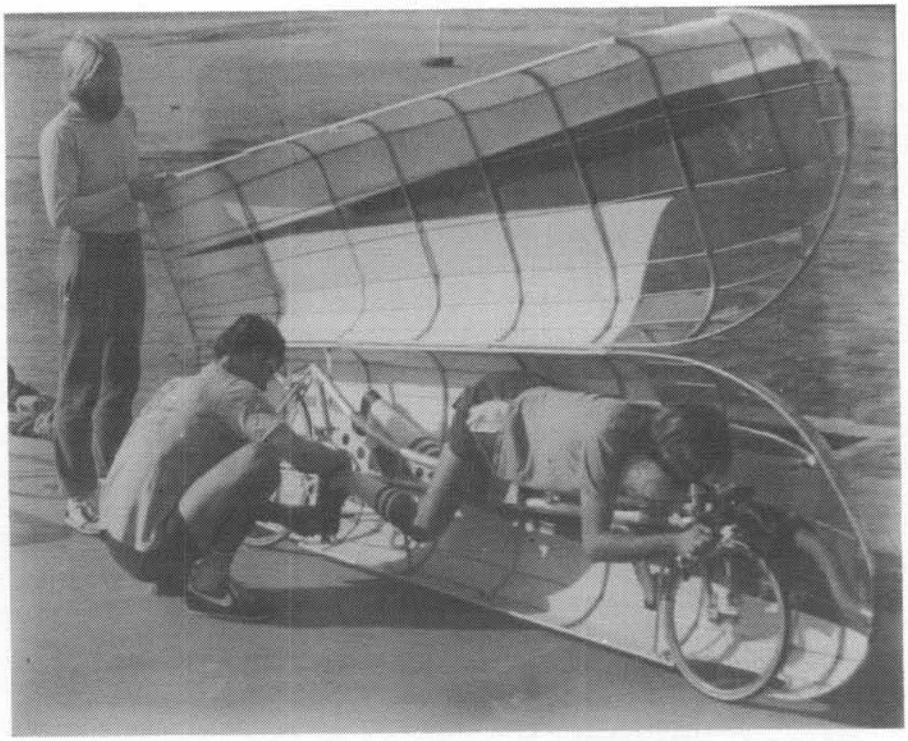
Control was rated at a level similar to comfort, moderately inferior to the conventional cycling position. Two of the respondents built three or four-wheeled machines and did not comment on control. Two of the respondents with a great deal of prone bicycling experience (GJ and CD) felt that cornering ability of a properly designed prone recumbent was equal to that of a conventional bicycle. All of the respondents used low-slung, long-wheelbase designs and stated that the long wheelbase and low ground clearance were disadvantages in some maneuvering situations. Control over rough terrain was a consistent problem.

All of the respondents cited low frontal area and the potentially low associated aerodynamic drag as the chief advantage of the prone recumbent position. This position allows the possibility of a simple, lightweight vehicle design utilizing standard bicycle parts (no long chain paths, etc.). Two of the respondents felt that the prone position felt natural, powerful and aggressive. Most respondents felt that it is possible to produce more peak, short-term power in the prone position.

Comments about disadvantages of the prone position varied greatly and depended upon the respondent's experience and type of machine. Several comments were made about the potential danger in a head-first, "head-on" collision. Respondents frequently noted the disadvantages in maneuvering their long-wheelbase, low-ground-clearance prone machines. The low profile of these machines was also noted to make them hazardous when on the road with automobiles. Reduced comfort, poor visibility, inability to use "body English" in balancing, and inability to "post" to avoid shock input were also noted by some respondents.

### DISCUSSION

All but one of the respondents designed their prone recumbent machines primarily for top-speed competition. Thus, their experience and opinions must



Greg Johnson rode this prone recumbent bicycle which he built himself with great success in many road races. Greg needed help closing the full fairing, but could start and stop without assistance using a retractable skateboard wheel which he operated with his left hand.

be considered with the knowledge that their designs may have been compromised in order to attain low aerodynamic drag. It is, therefore, worth considering the opinions of the builders of the two most successful prone recumbent bicycles. Greg Johnson designed and rode a prone bicycle which apparently handled better than any of the other prone bicycles and was quite successful for several years in road racing. Cole Dalton also designed and rode his own machine at Indianapolis to the highest top speed ever attained by a prone recumbent bicycle.

Greg Johnson built several machines before settling on his final design, an aluminum-framed long-wheelbase road racer. He seems to have hit upon three important design successes: (l) his padded pelvic, chest, and chin supports were quite comfortable (2) he developed geometry which provided good handling (rated by several riders as equal to that of a conventional bicycle) and (3) he designed a very simple machine using standard bicycle parts. He also designed his full fairing so that he could enter the vehicle and start and stop (using a small retractable third wheel) without assistance. The geometry of his bicycle included a head angle of 70 degrees, a fork offset of 1 inch, and a trail of 1.25 inches. His wheelbase was 90 inches and center of gravity was about 22 inches above the ground. He feels that the prone position is naturally a very powerful position with a "feeling as if I were a cheetah,... head forward, arms back against handle bars, back slightly arched, legs ready to deliver power". He strongly recommends the prone position and suggests that new vehicles should have a shorter wheelbase and greater ground clearance.

Cole Dalton designed his prone recumbent bicycle with one goal in mind: speed-record competition. He built many prone vehicles experimenting with everything from caster to aerodynamics before arriving at a design which satisfied his criteria for stability. He stated that the biggest single factor in achieving stability was the addition of a small amount of mass to the rim of the front wheel. He also emphasized the importance of rigid rider support for stability. He added a crotch support in a position relative to the body similar to a conventional bicycle seat. He felt that this support both allowed the rider to sense roll in the vehicle and also reduced leg strain. He also stressed the importance of the rider training in the prone position to improve both control and performance. He feels that future designers should consider the prone position for high-speed vehicles when low frontal area is an important consideration.

The author's first prone recumbent bicycle had the rear wheel positioned between the rider's legs with the crank behind the rear wheel. This machine was rather unstable. The instability problems, as in Cole Dalton's case, were initially solved by adding mass to the front wheel rim. Much improved stability was obtained in a later machine which had the rear wheel positioned behind the crank with the load distributed equally between both wheels. This later prone recumbent used a standard lightweight 24-inch racing front wheel (no mass added to the rim). Excellent handling resulted from experiments with this bicycle using a device which allowed full adjustment of the head angle and fork rake. The optimum geometry for this machine was determined by repeated experimentation with different settings on curvy mountain roads. The final, seemingly unusual geometry included a head angle of 67 degrees, a fork offset of 4.8 inches, and a trail of 0 inches. The limitations to handling in this machine, as compared to a conventional bicycle, were primarily the result of the long wheelbase (97 inches) and the low center of gravity (approximately 24 inches from the ground).

Two other designers, Paul Van Valkenburg and Steve Ball, built four- and three-wheeled machines. They chose the prone position in order to facilitate combined hand and foot power and to minimize aerodynamic drag. These machines were designed to turn only the widest corners; thus handling was not a serious design consideration. Both of these machines were highly successful at attaining high speeds in a straight line, setting many 200-meter speed records.

Several questions remain to be answered. Carefully controlled ergometry tests have never been done to compare power output in the prone position with other recumbent or conventional positions. How much does riding experience and training in the prone position affect power production? What is the effect of hip flexion on power production (i.e. moving the crank closer or further from the ground with the torso fixed)? What is the optimal distance of the hip joint to the crank for the prone position (the equivalent to the seat height in the conventional position)? The fastest prone recumbent bicycles have been ridden in competition by their designers. What would happen if they were ridden by properly-trained top athletes?

What does the future hold for prone-position vehicles? The ultimate high-speed land vehicle might benefit from the low frontal area and potentially low aerodynamic drag which are possible with the prone position. The prone position might also be best for human-powered submarines because drag problems are multiplied many times under water. The overall combined opinions as summarized in Table 1 suggest, however, that the prone position is inferior to the conventional bicycling position in nearly every way. It should be kept in mind that those individuals who were the most enthusiastic about the prone position for human-powered vehicles were also the individuals with the most experience and greatest success with prone recumbents. Future designers considering the use of the prone position for human-powered vehicles should pay particular attention to the successes of these experienced designers.

The author wishes to acknowledge the following individuals who contributed their time, experience and knowledge to this paper: Steve Ball, Cole Dalton, Greg Johnson, Chester Kyle, Fred Markham, Gardner Martin, Paul Van Valkenburg, and Kurt Wold.

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*Allan Abbott was the first president of the IHPVA; he held the paced bicycle speed record until recently; offered the Abbott prize for the first HPV to exceed 55 mph; developed the Flying Fish hydrofoil with Alec Brooks, and is a physician.—ed.*

## Reviews

As reported in the editorial comments, *Bike Tech* ceasing publication—or perhaps has already done so (as of December 1988). There have been three issues—April, June and August, 1988, since our last review. In April there were articles on do-it-yourself grease fittings, the Campagnolo Synchro shifter, a short note on human power that continues in the next issues, an article on clincher tires (the successor, on mountain-bike tires, appears in June), and a piece by editor Bruce Feldman on the Long Beach show: "Steel springs back". He refers to bike frames. I for one am relieved. Aluminum-alloy frames, and particularly forks, scare me if they are subjected to hard use.

*(continued on page 16)*

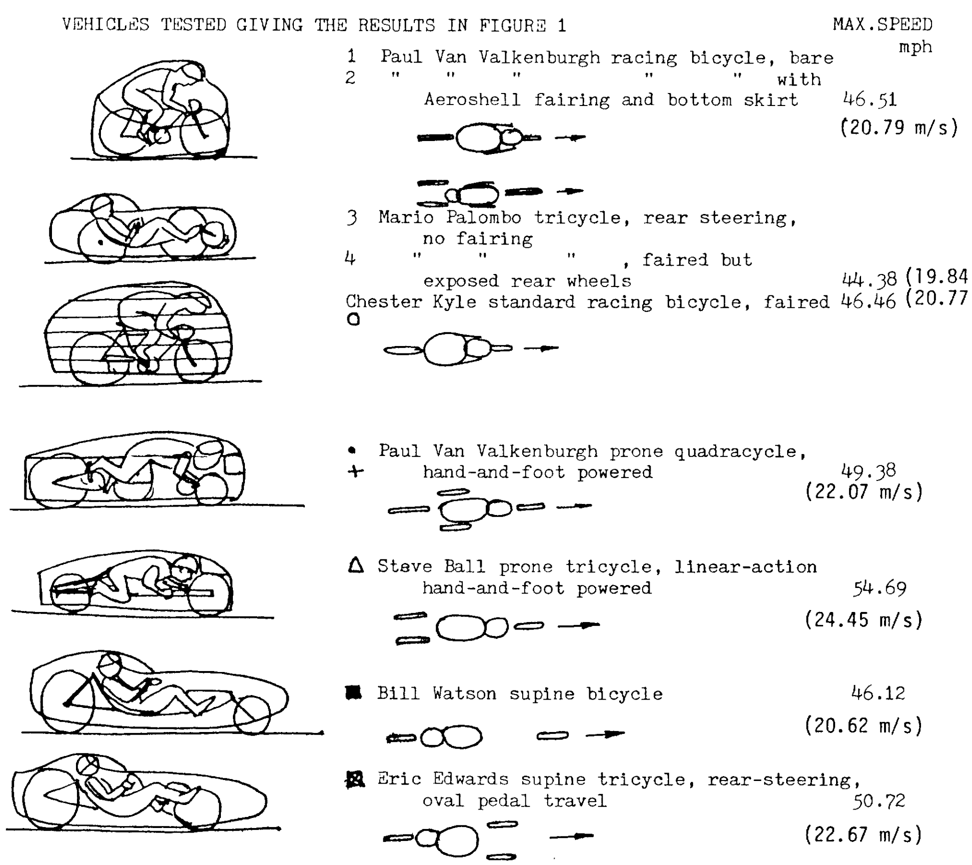
# Frontal Area Versus Surface Area—Prone or Supine?

## by Chester R. Kyle

David Gordon Wilson asked me to comment on a question posed by Allan Abbott's survey of prone recumbent designers. The question is the relative importance of frontal area versus surface area in achieving low aerodynamic drag. Although I can't answer this exactly, some discussion should help clarify it.

Since 1975, when competitors systematically began trying to build the world's fastest human-powered vehicle, various schemes have been used to achieve the lowest aerodynamic drag possible and the highest speed. To do this HPV builders have generally employed efficient aerodynamic shapes and minimum frontal area. The belief is common that minimum frontal area will produce minimum aerodynamic drag. This is true up to a point. Hoerner (*Aerodynamic Drag*, 1965, p. 6-16), reports that with symmetric streamlined airship shapes, the optimum length-to-fineness ratio is about 5. With very careful design of the profile, others find that this ratio can be from 3.5 to 5. This means that as the ratio of the length to width increases, the skin friction becomes more significant compared to pressure drag, until an optimum occurs within a certain family of shapes.

The proximity of the ground plane complicates the matter, but it is obvious that by increasing length, larger surface areas will sooner or later cause an in-




The coast-down tests, 1977-1984, involved two streamlined bicycles, two prone recumbents, and three supine recumbents.

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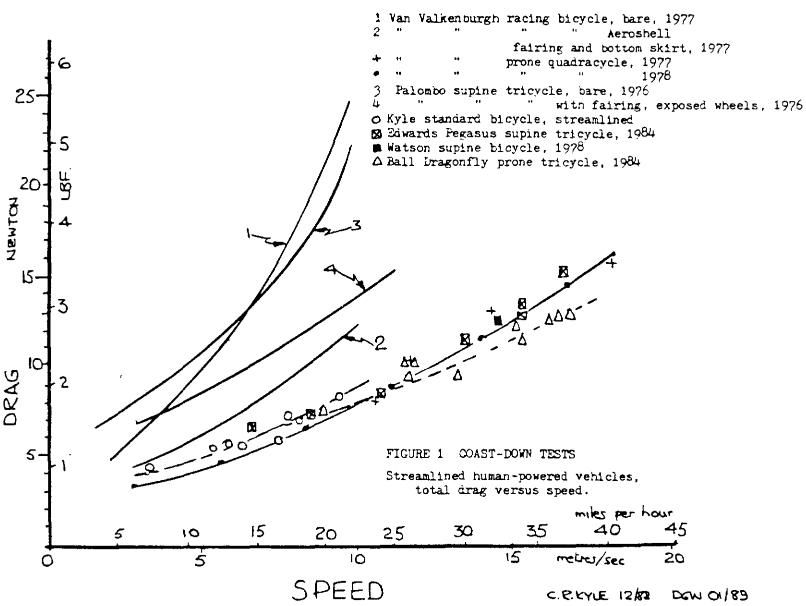


**Figure 1.** Coast-down tests, streamlined human-powered vehicles, total drag versus speed.

crease in drag, no matter how small the frontal area. Actually the most successful HPVs today are relatively short. Gardner Martin's Gold Rush, (a supine bicycle and the curent world-record holder— 65.49 MPH), is only 8 feet long. It has a frontal area of 5 square feet, and an equivalent length-to width ratio of only 3.2. Table 1 gives the dimensions of the Gold Rush plus Steve Ball's tricycle Dragonfly, (a prone recumbent with hand and foot power and linear pedal travel, top speed—54.7 MPH), Allan Abbott's prone bicycle (50.44 MPH), and several others. Five of them are also listed in Figure 1.

From the table, it is apparent that there can be a considerable advantage to a prone recumbent in achieveing low frontal area compared to a more upright supine bicycle. However as to actual comparative drag, the advantage is questionable.

Using high-speed coast-down tests between 1976 and 1984, I measured the total drag of seven streamlined HPVs. The measurements were done on smooth asphalt or concrete pavement (the Los Alamitos Naval Air Station Runway and the San Gabriel River Channel, California). The results are shown in Figure 1. With a coast-down test, all components of drag are summed including rolling-bearing friction, rolling-tire friction, and air drag. The curves show that some of the machines had a very high rolling drag (extrapolate the curves to zero speed). For example, the rolling drag of the Palombo tricycle is about double that of the rest, probably due to a sticky sealed bearing, or a gummy freewheel. Also, the curve for Steve Ball's Dragonfly shows a higher rolling friction than the others. This is probably due to a friction-clutch mechanism used in the linear drive.

If the rolling friction is disregarded, then the Dragonfly has the lowest aerodynamic drag of any of the vehicles measured. The highest would be the Palombo supine tricycle closely followed by the VanValkenburgh standard bicycle with the Aeroshell fairing. The other four machines are approximately equal. Coast-down tests therefore support the conclusion that a prone machine can have a very low aerodynamic drag.

However, a well-designed supine tricycle such as Don Witte's Allegro (62.98 MPH) probably has as low a frontal area as the Dragonfly, and it is probably somewhat shorter as well. Abbott's prone bicycle however holds the record for minimum frontal area at only 3.3 square feet. Even though Abbott's top speed was lower than some of the others, all of the other vehicles mentioned were ridden by nationally ranked bicycle racers. Abbott rode his own vehicle, so it is unclear what the potential of his machine really is.

Besides using the prone position to achieve minimum frontal area, designers have often resorted to linear pedal travel. Because of the increased complexity of linear mechanisms the lower mechanical efficiency could hamper speed. No one has measured the mechanical or biomechanical efficiency of linear-pedal-travel mechanisms versus the conventional circular motion, so their effect on speed is uncertain.

Another strategy to minimize frontal area with tricycles is to decrease the required width between the paired wheels. Two schemes have been used. Eric Edward's Pegasus drives the two front wheels and uses rear-wheel steering. He solved the rear-steering stability problem by using negative trail, dampeners, and a very limited steering angle. Don Witte's Allegro reversed this plan by combining

## Table 1

| Vehicle | Length | Width | Height | Frontal Area | L/W |
|---|---|---|---|---|---|
| Gold Rush Supine | 8 feet | 19 inches | 51 inches | 5.0 square feet | 3.2 |
| Abbott Prone | 12.5 feet | 18 inches | 31 inches | 3.3 square feet | 6.1 |
| Dragonfly Prone | 10.2 feet | 22 inches | 30 inches | 4.4 square feet | 4.3 |
| VanValkenburgh Standard Bike | | | | 7.3 square feet | |
| Kyle Standard Bike | 8.3 feet | 20 inches | 62 inches | 7.6 square feet | 5 |
| Palombo Supine Tricycle | | | | 5.0 square feet | |
| VanValkenburgh Prone | | | | 5.0 square feet | |

the drive and steering in the single front wheel, and by allowing the rear pair to freewheel.

Practical results have shown that a slightly higher frontal area does not necessarily result in a higher drag. The two fastest HPVs in the world are supine bicycles, Gardner Martin's Gold Rush, 65.49 MPH; and Tim Brummer's Lightning X2, 64.19 MPH).

Probably the breakthrough that led to these high-speed supine bicycles was the development of what could be called the Land Shark-Nosey Ferret-Lightning-Infinity-Gold Rush shape. Except for the Land Shark, each of the above vehicles has won the Speed Championships. This shape consists of a low, narrow, rounded nose, tapering upward and back and reaching the widest point at the rider's shoulders. From this point, the contour tapers back to a sharp trailing edge. As far as I know, this shape was not patterned on any wind tunnel or theoretical model, but was based on logic and eyeball intuition. The first of this generation was probably Danny Pavish's Land Shark in 1980, using the Easy Racer bicycle as a base. Over the years, the shape has been refined by numerous designers until it is superbly efficient in many forms. According to Danny Pavish, it leads to laminar flow over the forward part of the fairing, minimizing air-friction drag.

One conclusion that can be drawn from the above discussion is that frontal area is not the most important factor in designing a successful human-powered vehicle. Total aerodynamic drag, stability, visibility, biomechanical practicality and efficiency, mechanical efficiency, and low weight are some factors that can be of equal importance. It is a pity that more experimental information is not available; however, the typical designer is often too busy building and testing, and can't often afford the time to write about her/his observations and findings. For this reason, Allan Abbott's article is very much appreciated. I hope that it will lead to others of a similar nature.

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## Letters to the Editor

*(continued from page 3)*

backrest portions are not connected; thus the vertical movements of the rider do not cause the backrest covering to slide down the seat frame as the one-piece fabric did.

Theoretically, the unsprung weight is much greater in this case. In practice, the total weight of a bike frame is much less that that of a car, or even a motorcycle, which has a rear suspension similar to the Moulton upright bike, the German Radius recumbent, and a similar U.S.-made one. While it would not be possible to suspend the seat of an upright bike independently of the pedals, the bounce motion of the recumbent rider is perpendicular to the direction of pedalling, analogous to the swinging rear suspension that pivots approximately around the center of the driving sprocket. When the front wheel hits a bump, the entire bike pivots around the rear axle, but with the nylon-rope seat the inertia of the rider's body allows it to follow later, probably after the wheel has passed over the bump and returned almost to its previous road level. Thus the body is not required to deflect to the extent that it would on a more rigid seat (the rope seat has considerably more flexibility than the original fabric, which in turn is much more flexible than the customary bike saddle). A similar series of reactions follows as the rear wheel then hits the bump, except that the bike now pivots around the front axle.

I do not know how effective such a seat would be on a tricycle, where the outer wheels can impart both roll and pitch to the frame unless they are suspended independently, as on that in HP vol.7/1. That vehicle is intriguing as a mechanical engineering project, but in comparison to my suspension of the rider, I wonder if it is worth the additional weight and complexity. One must remember that in a car, the body constitutes the major portion of the sprung weight, with two passengers in a small car comprising some 15% of the total, whereas a bicycle is just the opposite—the bike alone is a similar fraction of the weight of the vehicle plus rider. Isolating the body from the wheels of a car allows much of the mass to move less than the wheels.

On the other hand, the controlled flexibility of the trike shown may reduce the required strength of the support members because they allow the wheel deflection by a bump to be dissipated through compression of the spring element, and thus do not need the rigidity to transmit the motion to the rider (compare the dimensions of the A-arms of the lightweight commuting vehicle in HP vol.7/1 with the size of the top and down tubes of a diamond frame). A complete engineering study of this aspect of complexity vs. weight would be very interesting.

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*(I combined two letters here —ed.)*

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This is a late comment on Ramondo Spinnetti's article, (vol. 6/3), because I was busy in Greece on the Daedalus crew.

First, I agree with the concern expressed by Prof. Bussolari in his comments that it is hard to draw conclusions from a single-subject experiment, especially when the test subject is the experimenter and author of the paper. It would be very useful to get more data with some other riders on the apparatus.

I will, however, disagree to an extent with (Steve) Bussolari's concerns about the differences in rider position. I feel that it is quite valid to choose any suitable position for the reverse-pedalling tests, with the possible restriction that it be practical for actual bicycle applications (which this position clearly must be, based on the photograph of the author's bicycle in issue 7/1). There is no reason to arbitrarily restrict the reverse tests to a position that may be unsuitable. On the other side of the issue, it could conceivably be that better results would be obtained for forward pedalling using some superior seating position that has eluded frame designers, but the author certainly cannot be faulted for using the "standard" position as his basis of comparison.

The biggest problem that I find, however, has to do with the lack of foot restraint on the test apparatus. If the photographs accurately represent the test setup, then it would seem that the bicycles had no toe clips. The force-vs.-crank-angle graph would seem to be consistent with this. (The bicycle in the photo in issue 7/1 also seems not to have toeclips.) It would seem quite possible that with no foot restraint, greater power could be obtained with a reverse pedalling motion; however, almost all applications that would attempt to extract maximum power would use some form of toe clips, and I feel that toe clips (especially if used with cleated shoes) could have a dramatic effect on the data, as they allow the rider to pedal "in circles", rather than just pushing down on the pedals.

I have wondered about the efficiency of reverse pedalling for some time, and in light of the fact that the author of the article is happy with his reverse-pedalling bicycle, it could well be of merit. The test apparatus undoubtedly took a lot of effort to set up, and it could well yield some useful results. More extensive testing with a wider variety of subjects, and with toeclips and cleats, would certainly be welcome.

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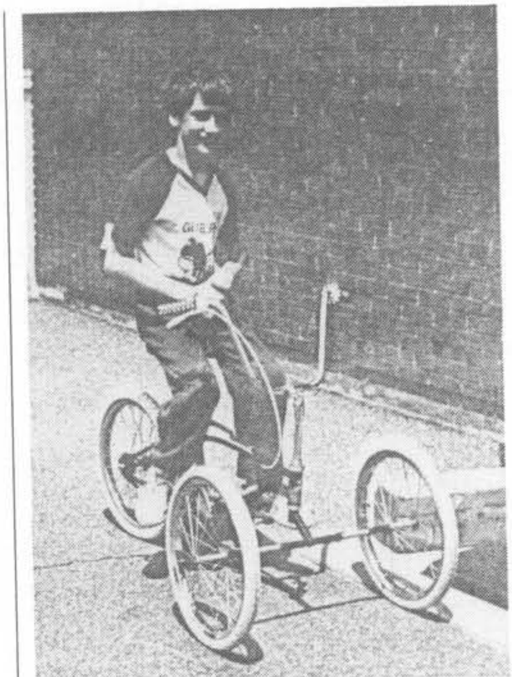
This year I have been involved with the mobility problems of students at a school for the physically and mentally handicapped . . , and the enclosed illustrates one of our spectacular successes—a highly rewarding and heart-warming experience.

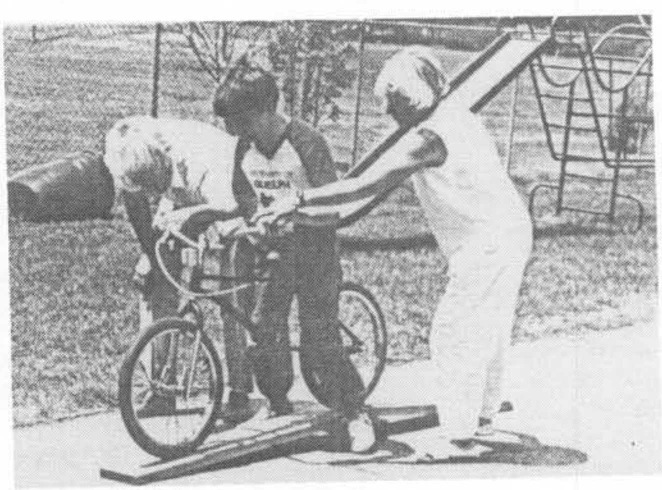
Our IHPVA members have now conquered the air, land and water, with performances which must be near the optimum, so maybe we should now encourage them to direct their energies to trying to lighten the burden of so many of our less-fortunate friends to whom mobility is but a dream. The thrill of seeing a severely handicapped child ecstatically riding an HPV and being mobile for the first time is more than sufficient reward for any expenditure of time and effort.

(Re) Ramondo Spinnetti's proposition that it is more efficient to pedal backwards than forwards (6/3/87), (and) Steve Bussolari's comments that suggested, among other things, that the change in leg geometry apparent on Spinnetti's two test bicycles probably contributed as much to his claim for additional efficiency as did the actual backward-pedalling mode: as I had used what might be termed "backward pedalling" on the Joyrider recumbent I built for Hull and Indy in 1985, and was consequently sympathetic to Spinnetti's claims, I decided to try a little experiment of my own.



Dougie on his Joyrider trike enjoying his new-found mobility and independence.

I thought it would be fun to build a bicycle that could be pedalled backward or forward at will using a common bottom-bracket spindle centre and by inference of course identical leg geometry. This turned out quite neatly and the enclosed photographs show the mechanism assembled on (a .. ) Raleigh Roadster. Power to drive the bicycle forward is applied in either backward- or forward-pedalling mode, and it can also be propelled by rocking the pedals up and down. The unit will freewheel, but will not run backward.



Dougie, who is a student at the Victoria Street School in Bracebridge, is a victim of short gut syndrome as well as cerebral palsy. He can walk with great difficulty using two crutches. The pictures show a little walker trainer which is teaching him to balance.

A great number of people have ridden this machine and although apprehensive at the outset experienced no difficulty whatever in pedalling it. No one, however, has expressed any preference for either backward or forward pedalling, and this in itself may be positive testimony to Spinnetti's theory. From childhood we have pedalled in the forward mode and consequently our muscles have been attuned to this over a lifetime of cycling. If the machine can be pedalled in the opposite manner with apparently no additional effort, then presumably with practice and training this method might prove to be the more efficient.

(Although) this machine was built for fun, it has transpired that it may be of real benefit to those of our handicapped friends who have yet to learn to pedal in the rotary mode. The Joyrider reciprocating pedal mechanism has been of great help to those who could not manage a full rotation, but it was limited to a predetermined stroke. The "two-way pedaller" can be ridden by such a person by rocking the pedals up and down, but the stroke can be gradually increased until a full rotation, either backward or forward, is attained.

Incidentally, I have since come up with a far simpler design by putting the drive clutches on the rear hub and utilizing standard cranks and chainwheels. Sometimes you don't see the wood for the trees!

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Orillia, Ontario L3V 6J6
CANADA

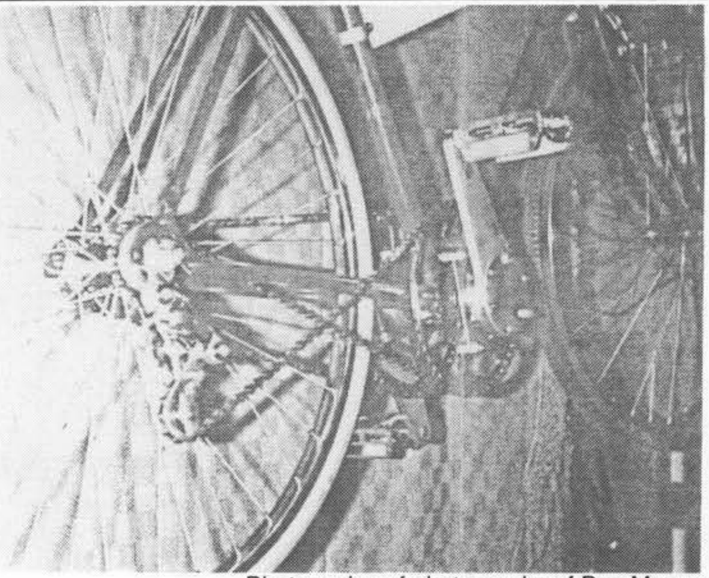
*(Photocopies of two photographs showing the mechanism discussed are included on the next page. Parentheses in the middle of a letter may indicate that I have edited the original and that the exact words may be different from those of the writer. —ed.)* ❑

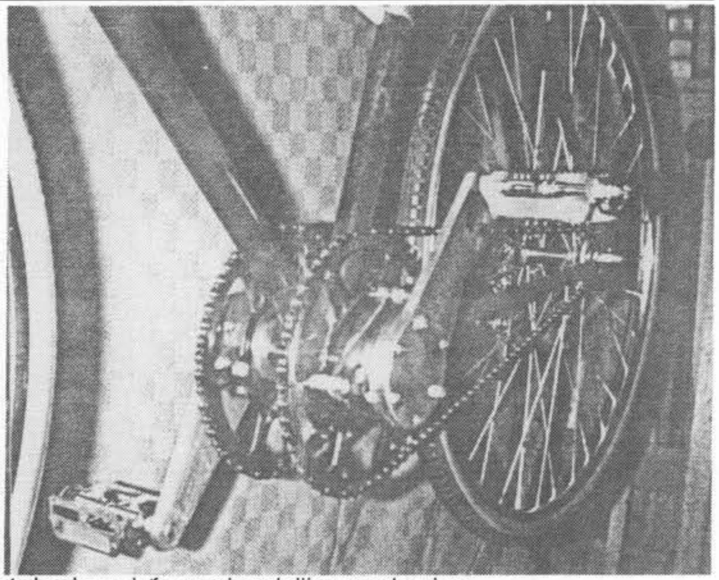
## Reviews

*(continued from page 13)*

In June Ed Burke, Chet Kyle and others plan for winning strategies at future Olympics; Shimano's development manager discusses index shifting; and Robert Cook advocates the twin-drive dual-freewheel tandems. Incidentally, there is usually an extremely well-produced technically informative full-page advertisement from Shimano.

The last issue, August, leads off with an article by your editor on Daedalus. (I





Photocopies of photographs of Des Messenger's backward-/forward-pedalling mechanism.

was given permission to repeat it in HP—but I have been promised a super article by one of the principals in the Daedalus team). Jobst Brandt has a valuable article on headwinds, crosswinds and tailwinds. David Noland advocates—perhaps—hydraulic transmission. He is honest about the low efficiency that one would get (70-85%, compared with 90-95% with a chain). This was to be a lead-in to a description of a design by Les Claar from Vickers for the probably cancelled October issue. There is also a discussion on a new Campagnolo components group, and on calculating gear ratios using a spreadsheet program.

We shall miss *Bike Tech*.

—Dave Wilson

THE STRUMEY-ARCHER STORY
by Tony Hadland
published by Tony Hadland,
December 1987

Tony Hadland is an enthusiast. He is an enthusiast on the Moulton bicycle, and has already written and published a book about it. I ordered a "special limited (hardcover) edition" of *The Sturmey-Archer Story* from The Pinkerton Press (522 Holly Lane, Erdington, Birmingham B24 9LY, UK) and sent $34.00, but I recommend asking for a catalog first for the lower-price softcover; John Pinkerton sells nothing but bicycling books, mostly reproductions of books from the last century, and you might decide to invest in a collection.

I greatly enjoyed reading this book. Hadland writes well, and includes many detailed illustrations of mechanisms and of their inventors. He puts the Sturmey-Archer development in its historical context. "The first practicable patent for an epicyclic cycle gear seems to have been Scott and Phillott's, 1878. . ." It turns out that neither Sturmey nor Archer had much to do with the invention or design of the gear. That was mostly the work of William Reilly "the forgotten hero of epicyclic bicycle gearing". However, he owes much to Seward Thomas Johnson, a machinist living in Noblesville, Indiana, who applied for a British patent in July, 1895, for a "bicycle wheel hub with driving mechanism". In the 1908 book *Variable Gearing* by someone writing in Britain under the name "Logos", Johnson is described as "the father of the modern speed-gear". He is another forgotten hero.

Some of Reilly's story reads like a cloak-and-dagger mystery. Hadland gives flesh-and-blood to his story, while also presenting all the technical details one could want. In fact, I had no idea that there could be so many possible variations of one concept. I made the mistake of trying to read through the book as if it were simply a biography. In fact, it is a combination of a historical account and a reference book. It deserves to be on the shelves of libraries, including yours. I recommend reading the narrative parts of the 192 pages of the book, and only those technical descriptions of immediate interest. Tony Hadland is a member of the Veteran-Cycle Club, a group that takes bicycling history extremely seriously, and the historical information in this book can be taken to be authoritative. I highly recommend it.

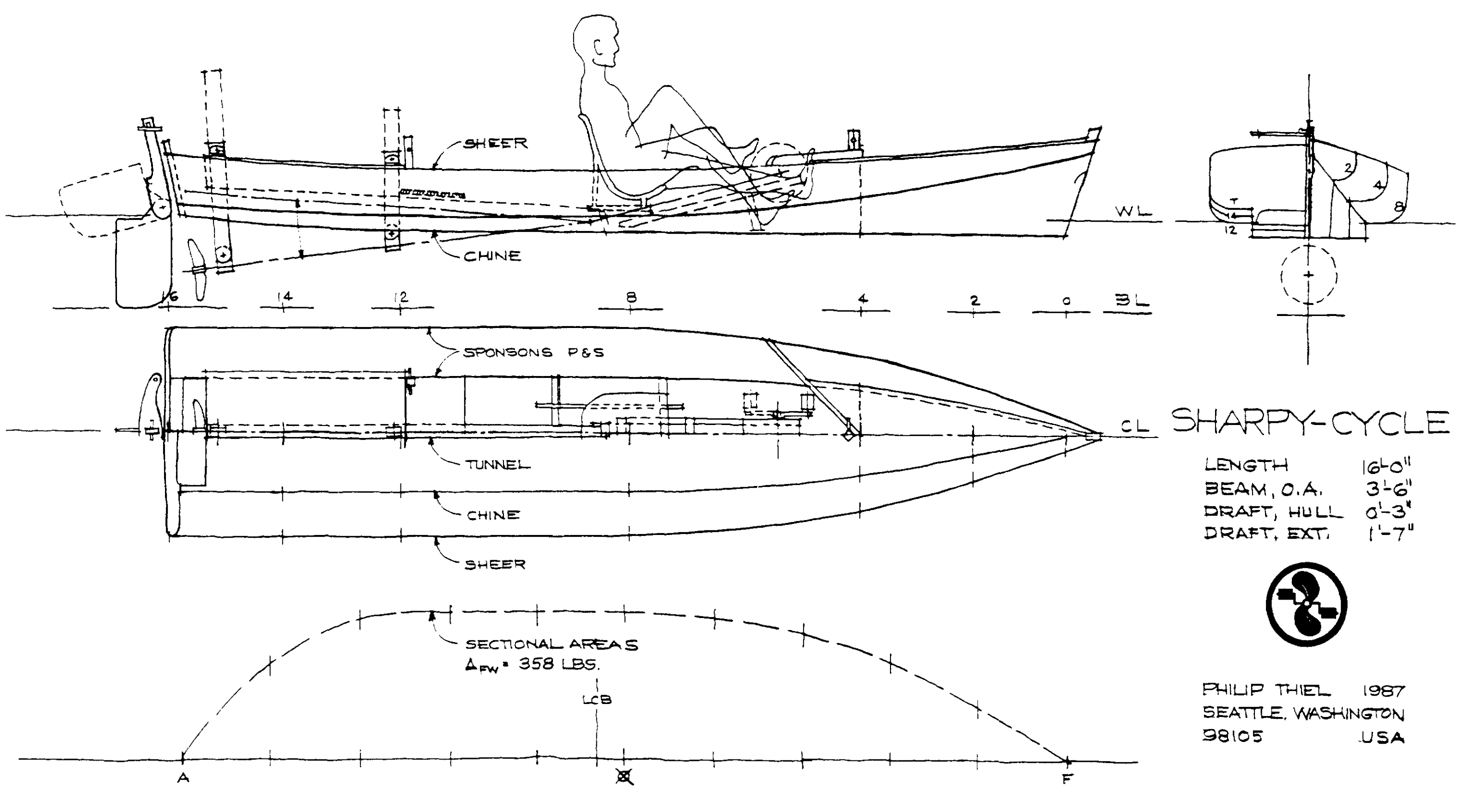
—Dave Wilson

PIERRE MICHAUX AND HIS SONS
by Jean Althuser
translated by Derek Roberts
published by Jim Willis
30 Newfield Avenue
Kenilworth CV8 2AV, UK
about 1987

One of the difficulties of celebrating the glorious history of the bicycle is that the developers were practical people: foresters, blacksmiths, machinists and the like, and were not given to writing. Nor were biographies made of them, not even, apparently, of Karl von Drais, who was at least a minor aristocrat when he invented the first bicycle in around 1816. We're not even sure of the date of Kirkpatrick Macmillan's pedalled velocipede within better than a year or two of 1840. And until now there was not very much known about the Michaux family, who set the Western world aflame with enthusiasm for their Paris-produced bicycles. In 1986, Jean Althuser published a short book in France, and we are lucky to have Derek Roberts, a founder of the Veteran-Cycle Club and the world's foremost bicycle historian, to translate it. He has added many footnotes.

I have seen a rather sour review of this 35-page booklet stating, in effect, "we didn't know much about the Michaux before, and we are not much wiser now." But I, for one, am much wiser. Pierre Michaux was an ironworker and coach-builder who was trying to build human-powered vehicles at least in the 1850s, with his young son Ernest. This account gives Ernest the credit for adding pedals

*(continued on page 18)*




# SHARPY-CYCLE: An Experiment in Pedal Power and Screw Propulsion by Philip Thiel

What do you do if you like boating but do not care to cope with the whims of the wind, suffer the noise and smell of a motor, or fuss with oars or paddles? *Use pedal power, of course!*

Then you may sit comfortably facing forward, use your powerful leg muscles to spin an efficient propeller, and have your hands free for things more interesting than rowing or paddling.

The *Sharpy-Cycle* is one of a series of boats exploring these possibilities. This experimental model is a narrow version of the traditional "sharpy" hull form and is lightly and cheaply built of exterior plywood and cedar, with fiberglas-covered styrofoam sponsons on the sides for added stability. A tunnel and well are built into the hull so that the propeller and shaft may be retracted for ease in beaching and trailering. The drive system uses stock bevel gears, pillow blocks, shaft seal and universal coupling to turn an aluminum propeller. The outboard swing-up rudder is controlled by a yoke with lines carried forward to the operating position.

After further testing this prototype "demonstrator" will be available at a reasonable price.

Philip Thiel
4720 7th Avenue NE
Seattle, WA 98105
USA

## Reviews

*(continued from page 17)*

to a Draisienne brought to them for repair in 1861, when Ernest was 19 (although one version puts the date at 1855, when Ernest would have been 13). Ernest later invented and built a steam tractor. Of his other sons, Edmond was the sales genius, Henry the promoter and manager, and Francisque was another fine engineer and teacher. But the book also taught me much about France of those days. For instance, it seems that engineers and technicians were forced to relocate frequently as the economy changed and businesses sprang up and went under, just as today. Derek Roberts' footnotes are invaluable. He has a double mission in life: to record the history of the bicycle and to expunge the many myths that are repeated endlessly in most supposed "histories." What you read here is either true or questioned. There is scope for further work. Meanwhile, you will undoubtedly learn much from this unpretentious but valuable book.

—Dave Wilson

ALTERNATE ENERGY TRANSPORTATION

This typewritten newsletter that should, presumably, be called "Alternative-Energy Transportation", unless it is designed to complement one of those schemes in which motorists are allowed to use their cars every other day, is published monthly by Campbell Publishing in New York, NY. It is subtitled "The newsletter of technology in motion. Incorporating chopper noise." I cannot help you decipher this. But once beyond the title and subtitle you can find interesting pieces about HPVs, inter alia. It's true that Daedalus, for instance, is referred to as a "flying moped," which seems to indicate further confusion by the headline writer. The Sunraycer and the Tour de Sol are covered extensively and an *HPV News* comment on the inclusion of hybrid vehicles in our fold is quoted well.

—Dave Wilson

## HUMAN POWER
## INDEX 1977-1988

This is a first cut at an index of all the major articles and many of the topics in all the 22 issues of HUMAN POWER produced up to August 1988. The four numbers after each entry refer to the volume/no/year/page. The first issue was vol.1 no. 1 Winter 1977/8 -I have used the year in which the winter started in all cases. The next five issues have no volume nor number, and I've designated them as volume 1, nos. 2-6. A further complication is that no. 2 was "Winter 79" but came out before no. 3, "Summer 79" - so for conformity I've re-designated no.2 as "Winter 78". Likewise no. 5, "Winter 81", which came out before no. 6, "Fall 81", I have redesignated 1/5/80. There is only one issue for vol. 4, and that is no. 4. After that the numbering system is, I hope, logical. To keep entries to one line I've put in the author's name only if there is room. Only the number of the first page of a multipage article is given.

Paul Van Valkenburgh edited the first five issues, with Dick Hargrave as co-editor for layout and art work. Dick Hargrave was editor-in-chief of issues 6-8, with Tom Milkie as technical editor in 6 & 7, and Dave Swertsen, Stuart Huston and Chuck Champlin as co-editors in issues 6, 7, & 8 respectively. I took over as editor with the ninth issue, 3/1/84, with help from many dedicated people. Mike Eliasohn edited all or most of 4/4/85 and 6/4/87, the HPV source directories.

Let me have suggestions for improving the next publication of the index.

Dave Wilson

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