38-V11n3-1994.pdf

HUMAN POWER

TECHNICAL JOURNAL OF THE IHPVA

ISSUE NO. 38

CONTENTS OF VOL. 11 NO. 3

VOLUME 11

3
ISSUE

SUMMER-FALL, 1994

Human Power
The technical journal of the International Human-Powered Vehicle Association
David Gordon Wilson, editor
21 Winthrop Street
Winchester, MA 01890-2851, USA
Phones: 617-729-2203 (home)
617-253-5121 (MIT)
617-258-6149 (FAX)
dgwilson@mit.edu (email)
Associate editors
Toshio Kataoka, Japan
1-7-2-818 Hiranomiya-Machi
Hirano-ku, Osaka-shi, Japan 547
Theodor Schmidt, Europe
Hoheweg 23
CH-3626 Hunibach, Switzerland
Philip Thiel, watercraft
4720 7th Avenue, NE
Seattle, WA 98105, USA
IHPVA
P.O. Box 51255
Indianapolis, IN 46251, USA
Phone & FAX: 317-876-9478

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

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

We are indebted to the authors, to Marti Daily and to Julie Drennan (MIT), whose dedicated help made this issue possible. *Dave Wilson*

In this issue

WHY YOUR BICYCLE HASN'T CHANGED FOR 106 YEARS

This exciting piece of history of the recumbent bicycle is written by Arnfried Schmitz from conversations with one of the people involved. The details of how recumbents broke records established by more-conventional bicycles and the rivalries that accompanied the desire to be the first to exceed 50 km in the one-hour unpaced record will both surprise you and will strike many familiar chords. This wonderful article was first published by our co-founder Chet Kyle in Cycling Science, which he also founded. He offered this and the next article because he felt (and we certainly agree) that they deserve a wider readership. (pp 4 - 9).

THE CUTTING EDGE STREAMLINED BICYCLE

Matt Weaver attained his present position as arguably the leader of the new generation of HPV designers, builders and riders with his radical "Cutting Edge" supine bicycle. Matt gives us his philosophy behind the design, together with data, analysis and predictions. This is the second of two remarkable articles reprinted from Cycling Science that we are proud to reproduce in Human Power. (pp 10-16).

LAND ROWING WITH DIRECT LEG-ASSIST

Dennis Schmidlin is intrigued, like many of us, with the potential for increased power being given by human beings using arm and back as well as leg muscles. He gives us here a progress report on a mechanism he has designed and applied to a semi-recumbent bicycle. He believes that the approach has considerable promise. (pp 17-19)

FAIRING VENTILATION NEED NOT CAUSE HIGH DRAG

Mark Drela gave HP permission to reprint a note he sent out on the "HPV" email net - and he added diagrams. If you suffer inside a hot fairing thinking that putting ventilation ducts in will result in a high drag, you should read this informative comment (p.23).

SHOULD HIGH-ALTITUDE DOWN-SLOPE RECORDS HAVE INTERNATIONAL STATUS?

Peter Sharp feels very strongly that the IHPVA rules should be changed. They presently allow international speed records to be made at any altitude where a competitor can find a road having a downslope close to (no greater than) that of the track where our records were initially set. HPV enthusiasts in other countries who don't have access to similar high-altitude roads generally agree. Our columns are open to reasoned advocacy of the status quo. (pp 20-22)

STREAMLINED BICYCLE

Jim McGurn, who fairly recently wrote a superb book on bicycle history called "On Yer Bike!", has now written a beautiful book of praise of the bicycle called "Encycleopedia". Your editor reviews it on p. 19 & 23.

CORRECTION!

We apologize to John Allen and to Steve Delaire for using an incorrect photo of the Delaire Rotator double-recumbent tandem in the last issue. The correct photo is on p. 23.

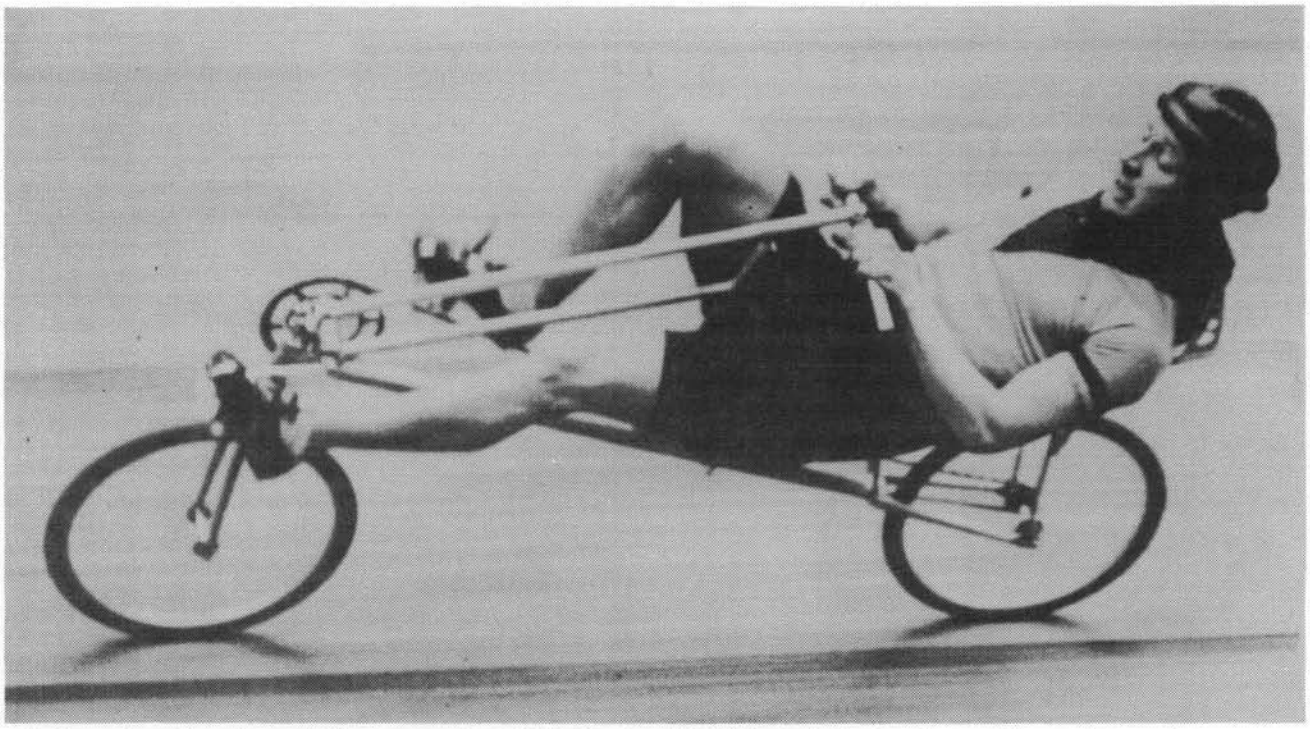
PREVIEWS OF HP 11/4

We also apologize to those authors who had hoped to see their pieces in this issue. We have several short technical notes ready to go into the next issue. Steve Koren has written on the aerodynamic effects of partial fairings. Bob Fairchild of Ecolotech has a note on low-cost-transportation projects. Izzi Urieli has contributed a full comment on Peter Ernst's paper in the last issue on assisted HPVs, including the definition of a new unit for application to human power, the "hup", equal to 75 watts. Mike Eliasohn has written a short commentary on human-powered lawnmowers. Andreas Weigl has given HP permission to use his article on future tire developments. John Kingsbury has sent a note and diagrams about a new pedalling mechanisms he is testing. Peter Sharp has two more concepts for your interest. And there is more!

Dave Wilson

HUMAN POWER

Vol.11, no.3 Summer-fall 1994 $5.00 ($3.50 members)



Francis Faure breaking the world hour record in 1933. See Arnfried Schmitz's fascinating article starting on the next page. (Editor's note: why aren't more recumbents made today with this attractive configuration: mid-length wheelbase with the pedalling axis over the front wheel; rear wheel of equal size; steering through a universal joint; straight chain line to back wheel and simple linear frame?)

Editorial

The state of the human-powered world

It is equally fascinating to me to wonder why some animals and plants have survived and why others haven't, and to wonder likewise why some human cultures and human artifacts have prospered while others, apparently equally suitable and qualified, have virtually disappeared. Most of us use computer operating systems based on the Apple Macintosh or the IBM PC-DOS or MS-DOS. They came about because of lucky breaks, of people being in the right place at the right time and grasping opportunities that others hadn't. It was a time, only a little over a decade ago, of extraordinary possibilities.

The human-power movement is different to the computer revolution. Human power has been something Joe Doe has avoided, and HPVs are less exciting than something that can be labelled a "revolution". And yet the times are extraordinarily propitious for HPVs.

In the week that I write this the U.S. national evening news programs have given great prominence to research results that show that women who exercise have dramatically lower rates of breast cancer. Similar research, less publicized a couple of years ago, noted that similar reductions in other cancers, and of course in many other diseases, resulted from sedentary people taking up quite low levels of physical activity. These recent reports will surely result in people searching for ways to incorporate exercise into their daily lives. There is something I - and you - find rather ridiculous in people choosing to avoid all possible physical activity in their home and work, and then going to a "health club" to manipulate exercise machines two or three times a week.

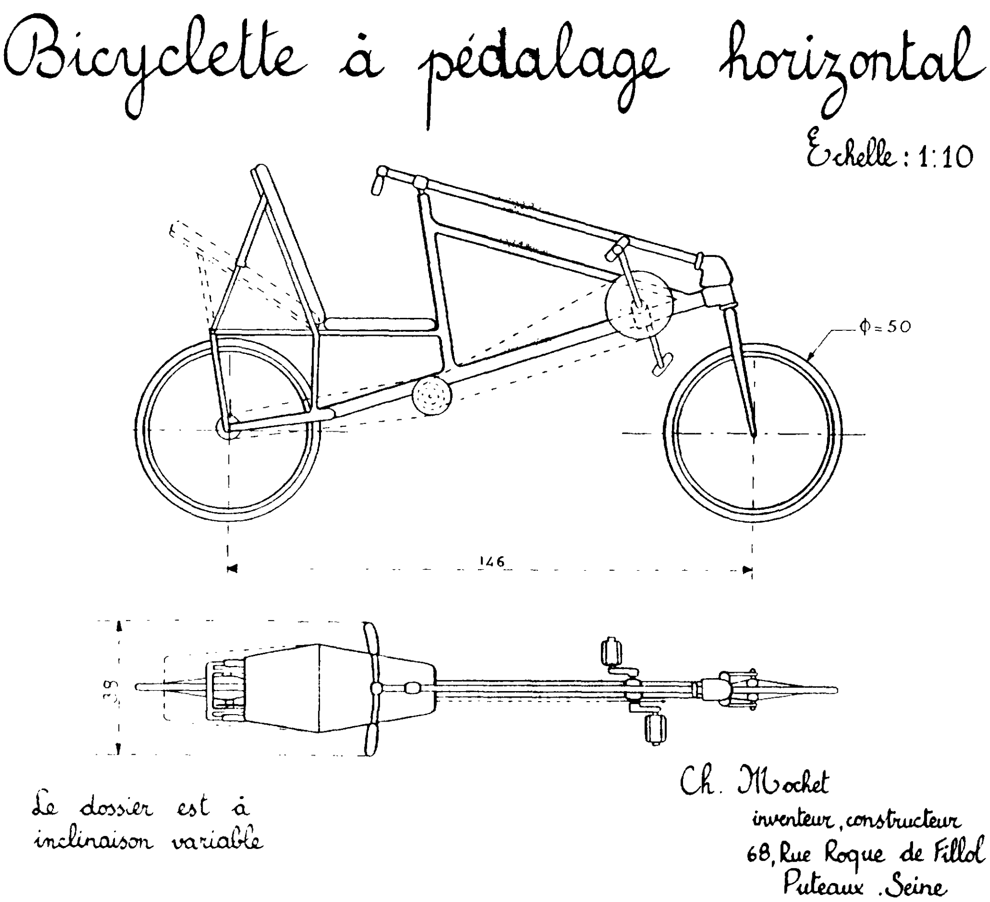
At the same time the roads of our cities become ever more crowded, and the resulting air pollution is beyond government-set limits in many areas. Ever stricter measures, including tolls on regular roads, are being mandated to reduce private-automobile emissions. Encouragement of bicycling is on the agenda, although difficult to discern as yet (at least in the Boston area). Advertisers at least think that bicycles are chic. More significantly, the newsletter of the British Human Power Club tells us that one government department is giving people higher mileage allowances for bicycling on business than for using a private car. That is a wonderful sign!

The opportunities are coming. Let us grasp them! *Dave Wilson*

WHY YOUR BICYCLE HASN'T CHANGED FOR 106 YEARS

Charles Mochet and his Recumbent Velocar were Torpedoed by the UCI in 1934. Streamlining was Banned in 1914.

ARNFRIED SCHMITZ; Lioux-Gordes, France

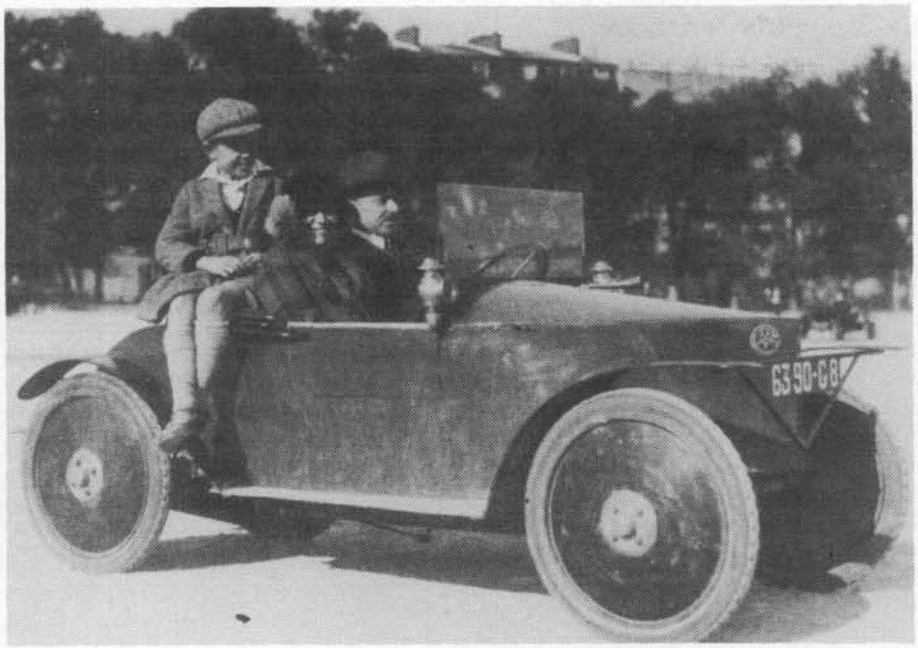


Original mechanical drawing of Charles Mochet's Velocar supine recumbent bicycle, 1933. Francis Faure broke the world hour record on this bicycle going 45.055 km, July 7, 1933, Parc des Princes, Paris.

If anyone were alive today who rode the Starley Brothers' Rover Safety cycle in 1884/85, they could climb on today's bikes and pedal away without a second thought. They could recognize nearly every part of a modern bike except the seat stay which was added about 1889 to complete the familiar diamond frame. Why? Everything else in this turbulent world has changed beyond recognition, clothing, architecture, the automobile, the airplane -- why not the bicycle? The answer lies in a drama that unfolded in the early 1930s when Frenchman Charles Mochet shook the conservative, traditional bicycling establishment with his sensational Velocar.

The Velocar was a sleek recumbent bicycle, and when raced by several professionals of the day, it proved to be much faster than a standard bicycle. The reason was pure and simple - aerodynamics. But I'm getting ahead of my story, let's start at the beginning. I'm sure the readers of **Cycling Science** will want to know all of the details. Actually this story hasn't been published in the United States for more than 50 years.

I talked at length to Georges Mochet, the son of Charles, and he gave me copies of original documents as well as many of the photos that accompany this article. Georges lived through this whole era, visited the bicycle tracks of Europe, and ran his father's business after Charles Mochet's death in 1934. His story is an important part of bicycling history,



Charles Mochet, Madame Mochet, and son, Georges Mochet in a motorized Velocar, 1925

although it is little known.

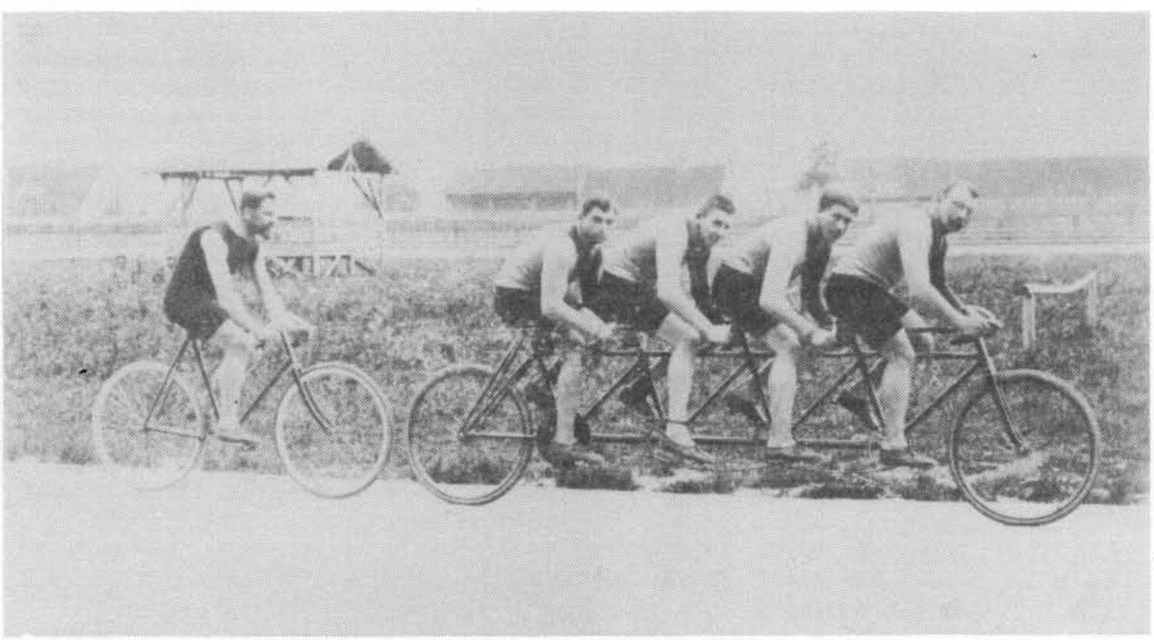
EARLY AERODYNAMICS; PACING

The events leading up to the 1930s started long ago, before 1900. It began with man's quest for speed on a bicycle. After the modern bicycle's invention in 1884, it wasn't long before cycling was the rage of Europe, and bicycle racers became just as famous as today's astronauts. In their search for more speed, they soon discovered the value of aerodynamics in the form of drafting or slipstreaming. By shielding the rider from the wind, much higher speeds were possible. Cyclists also discovered that multiple-rider bicycles could go much faster than solo bicycles since in effect the riders were drafting closely behind one another. They began constructing huge two-to-six-man bicycles and using them to pace single riders to new track and road records. In 1897, Stocks of England covered a record 32.6 miles (52.490 km) in one hour behind a four-man bicycle (at that time, the single record was only 24.4 miles - 39.24 km).

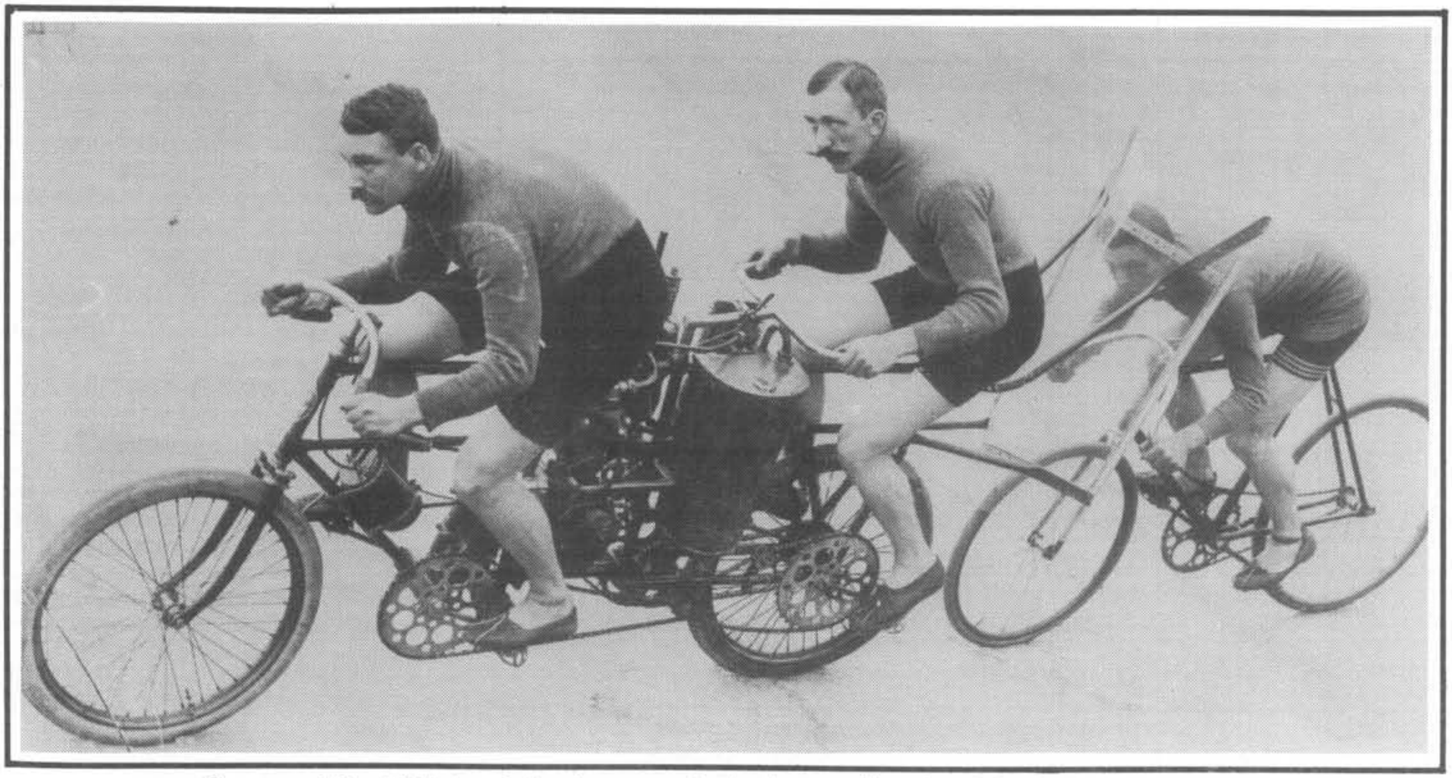
This soon led to the creation of special motorized cycles which were used as pace machines. By 1900, motor-paced bicycles were going over 40 miles in one hour (64 km), or about 15 mph faster than the best solo bicycle racers. By 1913 they were covering over 62 miles (100 km) in one hour. In fact, speeds got so high with motorpacing, that there were fatal crashes, causing the death of both cyclists and spectators. This led to rules governing the size of the motorcycle and the shielding. This strange hybrid sport still survives in Europe where bicycles paced by "stayer" motorcycles can cover about 60 miles in one hour.

THE FIRST STREAMLINERS

Long before 1900, another form of cycling aerodynamics became common with the appearance of dropped handlebars and the characteristic racing crouch. This gave the cyclist a better streamlined aerodynamic shape. In 1913, there occurred a series of events which triggered



The german racer Josef Fischer following a 4-man pace bicycle, 1896.



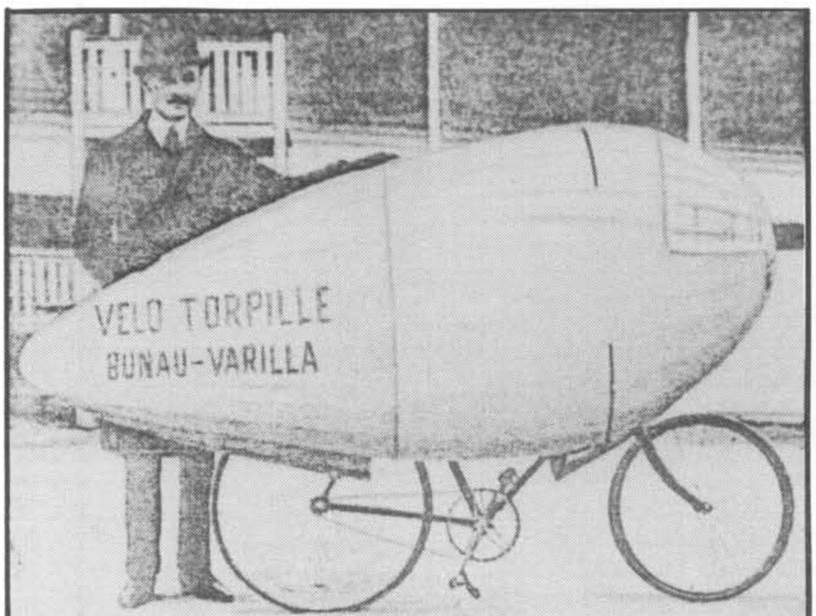
German Alfred Köcher following a motorized pace bicycle with wind shield, 1899.

the story in this article. It was then that the Frenchman Etienne Bunau-Varilla patented a completely streamlined enclosure for a bicycle. He and the aircraft manufacturer Marcel Riffard built a streamlined bicycle called the "Velo Torpille" (torpedo bike). The French hour specialist Marcel Berthet attempted records with this streamliner and managed to go 35.6 mph (57.3 kph) for one km. In 1913, the standard bicycle record for 1000 meters was only 31.6 mph (50.9 kph). Berthet also rode the Velo Torpille for 5000 meters at 32.5 mph (52.3 kph) which was 4 mph faster than he could manage on a standard bike over the same distance (28.5 mph).

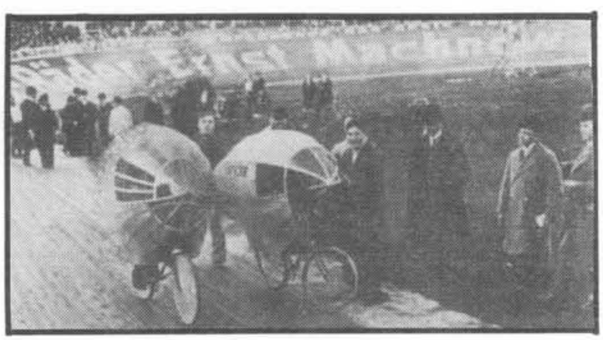
Realizing that the Velo Torpille was dramatically faster than traditional racing bicycles, the Union Cicliste International (UCI), passed a rule in 1914 that prohibited the use of aerodynamic enclosures or other devices (see the accompanying rules). This rule exists in modified form today. Because of the UCI ruling, interest in Bunau-Varilla's invention languished.

THE HOUR RECORD

Another event took place during this time which was to influence the future. Marcel Berthet and the Swiss cyclist Oscar Egg had been having a titanic duel for the standard bicycle hour record. First set by Berthet in 1907 at 41.520 km, the record changed hands six times in seven years, alternating between Berthet and Egg. Finally on June 18, 1914, Oscar Egg set a monumental record of 44.247 km, which was to last until 1933. Actually the hour record is the most famous and the most popular of all bicycle records in



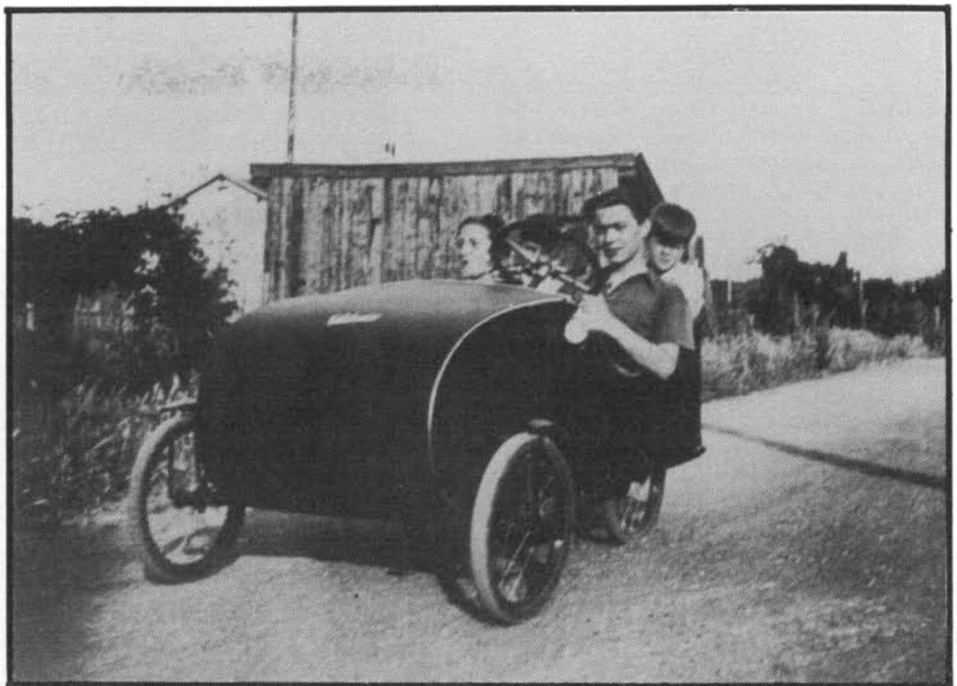
Bunau-Varilla and the Velo Torpille 1913.



Streamlined bike race, Berlin Nov. 11, 1914.

Photos from the Wolfgang Gronen Archive, and the Georges Mochet Archive.

Europe, and whoever holds it automatically becomes a continental hero. World War I began in 1914, and cycling champions became soldiers, thus cutting many competitive careers short. The new crop of racers after WW I could not match Egg's record.



The pedal powered Velocar 1932.

CHARLES MOCHET AND THE VELOCAR

During the late 1920s, Oscar Egg's hour record still stood. Enter Charles Mochet. A self-taught engineer and manufacturer of small motorized cycle-cars, who held a patent on a valveless automotive engine, Mochet had constructed a one-seat, four-wheeled pedal car for his son Georges. Georges was able to amuse himself by pedaling fast and passing ordinary bicycles with ease. This started a demand for the vehicle, and Charles soon gave up manufacturing motor cars and concentrated on a two-seat, four-wheeled pedal machine which he called the Velocar. His business prospered as the 1930s approached.

His pedal-powered car was ideal for the depressed economy after WW I, being much cheaper than automobiles which ordinary people could little afford. The Velocar had freewheels, a differential, a three-speed gear, and room for luggage. It was fast, light and convenient. In fact it was sometimes used to pace cyclists on bicycle racing tracks. However, because of the four wheels, it could not corner at high speed and had to slow down in sharp turns. The idea occurred to Mochet to cut the Velocar in half (figuratively) and to build a two-wheeled sport-model recumbent bicycle. In Mochet's own words the new machine would have "two small wheels, connected by a girder which sloped slightly higher in front, a small seat with a back rest, and the rear wheel would be powered by a chain and sprockets through an intermediate axle. The front wheel would be steered through a bevel gear connected to flat handlebars by a long horizontal tube."

The Velocar bicycle versus standard bicycles. From the left Plassat, Lemoine, Francis Faure. Vel'd'Hiv Paris, February 15, 1934 .

By 1932, tests on the new Velocar were complete. The professional champion Henri Lemoine tried it and found it to be comfortable and easy to ride. But it was Francis Faure, a second-category professional track cyclist, who was fascinated by the Velocar's possibilities and became Mochet's most famous rider. At first, other cyclists laughed and said "come on Faure, you must be tired and will go to sleep laying down like that, why not sit up and pedal like a man". Their laughter stopped when they tried to keep up with him as he accelerated away from the start. With the Velocar, he began to defeat all of the first-category riders in Europe. He was particularly unbeatable in the professional 5000-meter pursuit.

By allowing Faure to ride in a low supine recumbent position, his frontal area was much less than a standard bicycle rider's, and his form was naturally streamlined, so the wind resistance of the Velocar was very low even though it had no aerodynamic equipment on it whatsoever. This gave it a very high speed potential even with a second-category rider like Faure.

THE VELOCAR BREAKS THE HOUR RECORD

The Velocar was not just effective on the track; in the Paris-Limoges race in 1933, the professional road racer Paul Morand won the race going away on the Velocar. With its success, Mochet decided to try for the 20-year-old hour record of Oscar Egg. To make sure any record set with the Velocar would be recognized, Mochet wrote to the UCI in October of 1932 and asked if his revolutionary bicycle met with the UCI racing rules. He was referred to the first paragraph of article 31 of the race rules (see the accompanying rules). There was nothing in them to prevent a record attempt, so on July 7, 1933, at the Paris Parc des Princes velodrome, Francis Faure covered 45.055 km in one hour to surpass Egg's famous record of 44.247 km.

A storm of controversy erupted. The press had a field day. Was this a bicycle? Was Faure's record legal? Would this strange machine displace the traditional bike? The controversy became even worse, when one month later, on August 29, 1933, at Saint Trond France, Maurice Richard rode a standard racing bike 44.777 km to also break Egg's record. It was a quandary of the first order; which record was legal? The fight began in earnest for a decision by the UCI.

At the 58th Congress of the UCI, February 3, 1934, in Paris, a heated debate took place over the new bicycle of Mochet. An amateur rider named Martin brought the Velocar into the meeting and pedalled it around the table to the amazement of the delegates. An elderly British UCI member recalled that people were just as amazed by the appearance of the Rover Safety Cycle when they compared it to the high-wheeled Penny Farthing. The Italian knight Bertolini insisted that Mochet's invention was not a bicycle but could not explain why. The French Secretary General of the UCI, Paul Rousseau, protested that the Velocar exactly met the UCI's definition of a bicycle. He said that the problem was that the rules precisely defined such things as motorized stayers but were very rudimentary in their description of ordinary bicycles.

Rousseau was barely able to maintain order. Some felt that Faure was unworthy to hold the record since he was really a sprinter and not a long-distance rider. These critics also felt that Maurice Richard was a much better athlete. Despite the controversy, the majority of the delegates favored legalizing Faure's record. At last Rousseau proposed that they temporarily approve the record, but appoint a special technical commission to make recommendations and report to the UCI. The vote carried 58 to 46. So for a short two-month period, Faure and Mochet were officially kings of the hour. Their triumph was brief.

THE UCI RULES AGAINST MOCHET

On the very significant date of April 1, 1934, the UCI published the special commission's report on what constituted a bicycle. The commission rejected Faure's record and officially approved Maurice Richard as holder of the hour record (see the accompanying rules). Actually, America shared in this decision, since the commission members were from Germany, Belgium, France, the USA, Switzerland, Denmark, and Italy. Faure's short-lived hour record disappeared into an obscure category called "special records set by machines without aerodynamic devices and propelled by human power". The record has long since been forgotten. The French journal Les Sports editorially applauded the decision with the comment, "Good sense always triumphs".

Charles Mochet was devastated, and he wrote a pleading letter to the delegates of the UCI, appealing their decision. The letter had no effect. Mochet's bitter disappointment probably led to his death later in 1934. Well, kind readers, that is exactly why your bicycle looks the same as the one invented by the Starley brothers in 1884/85, 106 years ago. With the rigid rules, the UCI poured the form, shape and function of a traditional bicycle into a concrete mold. The mold was not broken

PERTINENT UCI RULES PASSED IN 1914.

Article 31 - "Machines of all kinds are legal, equipped or not with components like gears, free wheels, etc, on the condition that they function by the power of man only and that they require no apparatus or device intended to reduce air resistance and that they do not exceed the dimensions of 2 meters in length and 75 centimeters in width. This applies to single rider machines that occupy one lane."

THE UCI RULES PASSED IN 1934.

All machines will need to have the following characteristics:

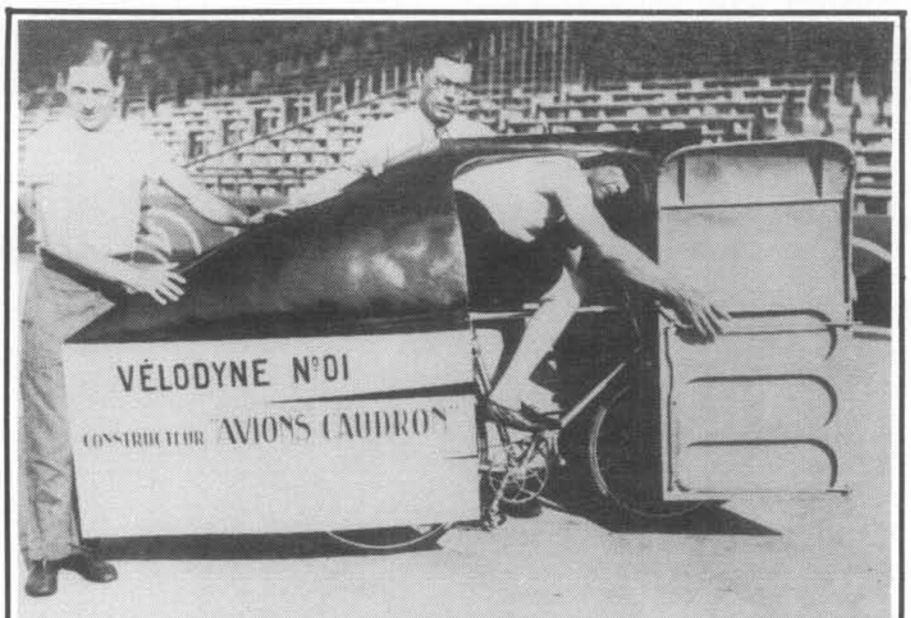
a.) The distance between the axis of the crank and the ground will have to be 24 cm minimum and 30 cm maximum.

b.) The distance between the vertical from the metallic extremity of the nose of the saddle and the axis of the crank must be less than 12 cm.

c.) The distance from the vertical passing through the center of the front wheel and the axis of the crank shall be 58 cm minimum and 75 cm maximum.

d.) The distance from the vertical passing through the center of the back wheel and the axis of the crank shall be equal to or less than 55 cm.

Any propulsion using a circular, alternating, or any other motion which utilizes the hands is forbidden. The use of protective shields, wind screens, fairings, and all other means of reducing air resistance is forbidden.



Marcel Berthet in the 1933 Velodyne Streamliner, (photo taken in 1951 when Berthet was 65 years old). Berthet went 49.992 km in one hour.

Francis Faure in the Velocar Streamliner Faure went 50.537 km in one hour, March 3, 1939..

for nearly 50 years. If the UCI had decided differently in 1934, you would probably be riding a recumbent today.

The publicity over the UCI decision made Richard and Faure very famous riders, and for a period, the track managers of Europe staged "revenge matchs" between Faure and Richard, and the recumbent Velocar was raced against standard bicycles. The Velocar was unbeatable. But since it was illegal according to the UCI, interest soon waned.

BERTHET AND MOCHET BUILD STREAMLINERS

But the story is not yet over. Let us go back to the beginning of 1933 and to the 47-year-old Marcel Berthet. Berthet wanted to become the first man to break 50 km on a bicycle and he employed the same aircraft manufacturer, Marcel Riffard (who built Bunau-Varilla's Velo Torpille), to design and fabricate a sleek streamliner he called the Velodyne. Berthet began to train so that he could ride it himself and on November 18, 1933 he covered 49.992 km in one hour.

There was an international storm of publicity over the event even though Berthet failed to break the 50-kilometer barrier. This record was placed in a special category by the UCI for machines with Aerodynamic devices. Charles Mochet had previously created a trophy cup for the fastest hour record, (regardless of the type of machine), and this was awarded to Berthet.

After the elder Mochet's death, Mochet's family and Charles' son Georges continued to manage the small but flourishing pedal-car business. In 1938, Francis Faure and Georges Mochet decided to try to regain the cup from Berthet, and they began tests of a streamlined Velocar. They experimented with the streamlined shell extensively, and some of these tests are still of interest today. To test the machine, Faure rode the streamliner at maximum effort for 4000 meters on the track. Here is a list of the results (see the photo):

1st test. Open bottom, head penetrates the top, no top cover behind the head. 48 kph (29.8 mph), 5:00 time. The machine is already faster than the standard bicycle test (45 kph), 5:20 time.

2nd test. Same as #1, except only a small opening for the head. 49.7 kph (30.9 mph), 4:50 time.

3rd test. Same as #2, except with the bottom enclosed. 53 kph (32.9 mph), 4:32 time.

4th test. Same as #3 only polish and varnish the body to a mirror finish. 55.4 kph (34.4 mph), 4:20 time. An hour record was tried with this machine, but Faure had trouble with the wind in his eyes and lost stability and couldn't continue.

5th test. Same as #4, only completely enclosing the head with a canopy. 56.5 kph (35.1 mph), 4:15.

On March 3, 1939, Faure succeeded in becoming the first man to pedal an unpaced bicycle over 50 kilometers in one hour, covering 50.537 km exactly. This feat gained much press notice in Europe, but it was hardly mentioned in the USA. I hope you note the date. On the heels of this event began World War II, and once again cyclists became soldiers. Beneath the powerful forces of world conflict, the interest in recumbent bicycles and streamliners vanished once again, only to be revived 30 years later with the establishment of the International Human Powered Vehicle Association. But, that is another story.

When the war broke out, Faure was in Australia giving exhibitions of the Velocar. He stayed in Australia and died in 1948 and probably the original Velocar disappeared down under. In France, after the war, Georges Mochet motorized the Velocar and produced the tiny vehicle until 1960. By then, because of government licensing costs, sales were cut in half, and Georges Mochet closed the business and was employed by a hydraulic equipment firm until he retired. He still lives in St. Aygulf, France today.

Amazingly, at this moment, four wheeled Velocars are still in use. In the Park Borely in Marseille, France, customers rent them by the hour and happily pedal them through the park. The owner of the rental business has more than 30 vehicles and is desperately seeking more since he says that "the Velocars are the only ones that can endure under constant punishment by the customers". My apologies for this long story, but often small events can create crossroads which change history. Such was the dispute between Charles Mochet and the UCI in 1934.

A U T H O R

ARNFRIED SCHMITZ is a retired engineer living in Liuox Gordes, France who has built working models of the 1933 and 1939 Velocars. The 1933 model won the mountain prize in the Tour de Sol, a Swiss race for solar cars, with a human-powered and hybrid division. He became interested in the Velocar while reading the French L'Officiel du Cycle (3/39 and 11/81), and he sought out Georges Mochet to get plans for the machine. Good articles are also available in L'Illustration (12/27/1913), La Bicyclette (1933), Revue des Agents (3/39), Les Ailes (3/39) and the Belgian Dossiers Records (11/84).

THE CUTTING EDGE STREAMLINED BICYCLE

Details in the Design of a Bicycle that Upset the World-Record Holder

MATT WEAVER

INTRODUCTION

Imagine Calvin in the cockpit of a soap-box-derby car - asking Hobbes, *"How fast do you think this thing will go down a 10-mile 20% grade? Heck, how fast will it go if we put a supertransmogrifier crank in it?"* Next thing you know, Calvin and Hobbes are zooming along at speeds beyond imagination! Well, that was my dad and I ten years ago. I was then flying down fire trails in the Santa Cruz Mountains on a bike I designed and put together for just that purpose. Last year, I hammered very successfully around Portland International Raceway in a streamlined bike called the **Cutting Edge**. Though not quite as good as Calvin's Derby car, it is unlike anything ever developed. Calvin might have told his mother, *"Hey Mom, you know what? Fast is fun!"* I agree, so I will try to answer some of Calvin's questions by detailing my findings and work aimed at discovering an ultimate streamlined bike and what it can do.

History and Motivation

I credit the roots of my involvement with streamlined bikes to my father, who on his own took up soap-box-derby racing as a kid. Of course, I watched my older brothers and sisters and then myself do the same! I became very involved — I saw what worked and what didn't, and I listened intently to all the talk about aerodynamics and suspensions. As far back as I can remember, my mind was occupied with the challenge of developing a faster vehicle.

I was intrigued with possibilities of a pedalled soap-box derby, but that was forgotten until the December 1983 *Scientific American* caught my eye in the library my freshman year of high school. On the cover was Al Voight's record-breaking **Vector** streamlined tricycle, and within a detailed article [1] on streamlined bicycles authored by Al Gross, Chet Kyle and Doug Malewicki. I was captivated, and spent many hours in class drawing pictures of streamlined bicycles.

Matt Weaver and the Cutting Edge. The front wheel is well back so that sidewind pressure will cause the bike to lean into the wind for stability. The fairing was designed for a linear drive; however, a circular crank made it necessary to cut openings for the knees and heels. Stretched, latex sheet normally covers the openings. In this photo, the bottom openings are not covered.

I later learned of the International Human Powered Vehicle Association, (IHPVA), and the DuPont Prize of $18,000 for the first bike to sprint over 65 mph. However, It wasn't long after that when Gardner Martin's Easy Racer **Gold Rush**, powered by former Olympic cyclist Fred Markham, reached 65.48 mph near Mono Lake on May 11, 1986. The prize was gone, and 65.48 mph is no doubt an incredible feat when you learn what it takes to get there. By this time; however, I had several promising designs. It appeared that a bicycle with nearly half the aerodynamic drag of the world record holder might be possible.

This was of course a very exciting prospect, and so I was intent on pursuing the challenge regardless of the DuPont Prize. I read much of what I found on aerodynamics, and began verifying the possibility of the designs by building some crude models. My progress was

For those who don't know who Calvin and Hobbes are! © 1986 Universal Press Sindicate.

slow due to extracurricular activities and then college. The **Cutting Edge**, the first bicycle I built, was completed in the summer of 1989, although I didn't prove it in a race until Fall of 1990.

At the 1990 International Human Powered Speed Championships (IHPSC) held on the two-mile Portland International Raceway, I pulled into the lead upon completing the second lap of the 20-mile criterium. By the finish I nearly lapped the entire field except the **Gold Rush**, which was 0.5 mile (47 seconds) behind and until then had never been beaten. I reached 56 mph on the straights, and averaged 42.4 mph for 20 miles while coasting and braking for nearly half the distance due to the many turns. The bike handled very well in the turns, and I found I could gain on the **Gold Rush** in the corners.

An improved Gold Rush, dubbed the **Gold Rush LeTour**, was built following Portland. With Fred Markham pedalling, it set the flying 1000-meter record of 41.870 seconds (53.426 mph) on July 4, 1991. We met at the 1991 IHPSC, and again I took first place in the 20-mile criterium, which circled 1.8 miles through a park. The **Gold Rush LeTour** was close on my tail for the entire race, but in the final lap I never dropped below 51 mph and won by several hundred meters. Even so, I have yet to try and challenge Freddy Markham's awesome top-speed record set in Gardner Martin's **Gold Rush**.

Prior to beating the **Gold Rush**, several experts said, "It's a pretty bike, but it's too low, etc...to handle well or allow the rider to power out. The speeds will be very limited...." After Portland I heard in contrast, "Of course, it's obvious...." Well anyway, I'll explain how I did it, since very few saw the potential of the bike before I raced it.

THE DESIGN PROCESS

It is well known that air drag dominates a bicycle's top speed on level ground. In fact, the power requirement to overcome air drag goes up with the cube of velocity (this assumes a constant drag coefficient with speed, a good approximation in this case). It is important to know relative drag forces, which have been tabulated by Gross and Kyle [1,2,12] for many vehicles and components. With this in mind, I first asked what is the ideal or theoretical limit for minimizing air drag. The concept of such a vehicle helps aim the design process in the right direction. Ignoring everything else, namely that a crank needs room to pedal, I found the ideal shape would be a two-wheeled, minimum-frontal-area, nearly axisymmetric teardrop enclosing a rider lying horizontal. Such a theoretical vehicle could average 90 mph with a 0.5 hp input, which is what many cyclists could sustain for an hour! The estimated vehicle parameters were the drag coefficient Cd = 0.05, the rolling resistance coefficient Crr = .003, and weight W = 180 pounds.

Unfortunately, Calvin's daredevil speeds don't come so easy. The vehicle must possess certain properties such as controllability, visibility, crash protection, and ventilation. It also needs elements such as a drive mechanism, a frame and fairing, and possibly suspension. You find yourself quickly deviating from the ideal limit of a teardrop pod. The goal of course is to deviate as little as possible. I worked hard on designs to achieve this, and succeeded in developing a functional design that is much closer to the ideal limit than had previously ever been devised. I will discuss my insights and findings that make such a streamlined bike possible and also enable it to possess excellent performance properties.

ELEMENTS AND PROPERTIES

Controllability

The property of controllability means a vehicle in which the rider can follow a desired path with relative ease. This is of course a simple task on most bicycles. However, when you add a fairing, get lower to the ground, and experience sidewinds it is an entirely different story. The popular solution for some time was to build a tricycle, but that has since been outperformed by the now prevalent semi-recumbent bicycle style initiated by the world-record-holding **Gold Rush** and others. The semi-recumbent style still has an excessive amount of frontal area; so, let's examine how we might be able to reduce this area further and still maintain good control.

Before making a turn, the bicycle must first be leaning in the same direction. In a conventional bicycle, the rider can shift his weight to initiate a lean. Within a small streamlined fairing, the rider may not be able to shift his weight. Instead he must rely on the steering in order to lean. A lean to the left is achieved by initially steering to the right, and vice versa. This effectively gets the wheels out from under you and to the side. The steering will float into the direction of the lean and then you will begin turning. The turn is finished by "leaning" out of it, or in other words by steering into the turn. This procedure puts much greater importance on the inherent stability of a bike.

A properly designed conventional bicycle will ride upright in a straight line with "no hands." This ability arises as a result of the steering geometry of the bike, the fact that it is moving, and various dampening forces. Contrast that with a unicycle, which is "stable" only with a trained rider who is dynamically compensating every little lean before hitting the pavement. It is desirable to have a stable vehicle so that the rider can concentrate on applying power.

The "no hands" stability of a bicycle changes considerably as the rider gets much lower to the ground. Lower is desirable because you can pack the rider and wheels "in line" in a single teardrop region with a much smaller frontal area. However, a bicycle is like an upside-down pendulum that pivots about the line attaching the tire contact patches. As the mass of the rider gets closer to the ground, the moment of inertia about this axis decreases, and the vehicle leans quicker for a given disturbance. Conventional road bike geometry works poorly here, so it is necessary to determine what if anything may work.

Modeling Bicycle Dynamics

Several articles [3,4,5] I've studied illustrate trends in the stability of the bicycle. There is much dispute in this area, and I consider it difficult to conclude anything if the rider is free to shift his weight as with a conventional bicycle. Fortunately I can assume the rider is fixed in this case, so I went about developing a numerical model in an attempt to simulate the behavior of the bike.

The model first consists of detailed geometric calculations which depend on many parameters including the width of the tires as well as the state of lean and steer angles. The values obtained are then used in a system of differential equations which account for all the dynamic forces such as the acceleration due to turning and the gyroscopic forces, etc. These equations were solved iteratively using a Runge-Kutta scheme. By applying different initial conditions and external disturbances, I could observe the response of various geometries - overshoot, oscillations, and even crashing. Rather than attempt to discuss the details of the modeling here, I will simply say a desirable geometry was found that closely resembles the **Cutting Edge**. The **Cutting Edge** uses a 20-inch front wheel, a 700C rear wheel, and has a 66° head angle, a 1-5/8 inch fork offset, a 2.7 inch trail and a 52 inch wheel base. If any of the readers want further details about my theoretical approach to solving the vehicle stability problem, please write to the address given at the end of this article.

Sidewind Stabilization

A final factor that strongly affects the controllability of a streamlined bicycle is sidewinds. Those familiar with using front-wheel disks know that sidewinds can produce some unpleasant torques on the steering. Similar, yet much worse, are the lifting forces on a typical streamlined bicycle moving along in excess of 40 mph. The force vector points predominantly to the side and slightly forward. This means you might get propelled forward a little, but most likely you'll get blown over.

There is neat solution, however. I found that by properly setting the geometry of the bicycle relative to the fairing and its associated center of pressure (the imaginary point on the fairing where the resultant aerodynamic lift force acts), the bicycle will automatically lean into a good range of sidewinds. This results from steering torques induced by wind pressure, causing the bike to momentarily steer away from the wind, and thus generate a lean into the wind. The trick is to try to tune this as best possible. The numerical model discussed previously can be used to analyze this, where the configuration of such a bike is characterized by the front wheel being relatively far back from the nose. The **Cutting Edge** approximates this; however, it actually overcompensates a little - I find myself gently steering out of a lean into the sidewind.

Visibility

The rider needs a windshield, and experience has shown that one has much better control with peripheral vision; therefore, a windshield should extend around the sides of the face. If the windshield gets too large, it could act as a greenhouse which cooks the rider inside. Second, the more light that gets inside the fairing, the greater the glare. Third, glare increases as the viewing angle is more parallel to the windshield surface, which is typical of large windshields. Finally, because of the poor structural properties of a large windshield, it is a vulnerable spot in a crash. Clearly, smaller is better so long as the full visual field is maintained.

To maintain the visual field in the supine position, you can either sit fairly flat, looking through the legs and have a large molded windshield on the front of the bike like the **Vector** tricycle, or you can sit in a more upright position, raising your eye level just above your knees and look out a small windshield and over the top of the car. The small windshield profile has slightly more frontal area, but I found it generally preferable over the disadvantages of the large windshield.

Crash Protection

Dangerous speeds are possible with streamlined bikes, so safety needs to be taken seriously. You can be severely damaged internally by a high-speed impact or get gored by something sharp. The best thing is to find a safe race course with no solid objects anywhere, but unless you are running the race you cannot be sure what you'll get.

For impacts you want a "crush zone" which will soften the deceleration. This can be achieved fore and aft, but it would require ridiculous aerodynamic costs to enlarge the sides. It is essential to assure that the sides will protect against abrasion, which most fairing materials will do, provided they remain intact.

You eliminate goring by careful placement of components and by making sure there is nothing sharp or blunt that might contact the rider in a crash. In my vehicle, the seat serves as a fairly effective seat belt, to restrain forward motion. Padding of frame members that might cause ugly bruises is a good idea. Also, it is essential to design the fairing so it doesn't fall apart. Fiberglass and acrylic tend to shatter and come apart - becoming lethal blades, and possibly exposing you to road rash at 50 mph.

Most fairings in the past consisted of a top and bottom half that were usually taped together, which has poor integrity in a crash. The **Cutting Edge** is a one-piece Kevlar fairing with a single split down the underside which is literally bolted shut. This has excellent integrity, and is also very aerodynamic since there is only one seam in-line with the wheels. There is no stress at this seam that would cause the fairing to distort as is the case with side-split fairings. There are other methods to achieve this sort of integrity, but they involve substantially more fabrication.

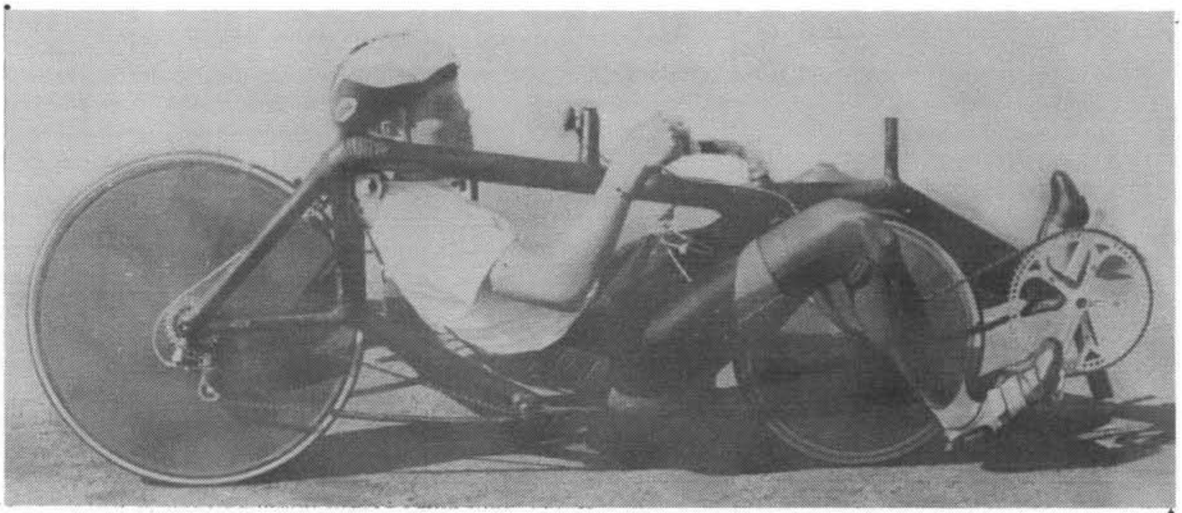
Ventilation

It is necessary to get cooling air to the rider for longer races. First, you don't want any more flow than necessary; secondly, you want to vent it as efficiently as possible. Zero efficiency occurs when the air blasts into the fairing and swirls around losing all its momentum. Excess ventilation or poorly controlled ventilation will raise the aerodynamic drag substantially. The most efficient way occurs if the air pressure inside the fairing is near the external stagnation pressure and you have proper ducts. Then, the air entering decelerates and pressurizes - preserving its internal energy to be later accelerated out a nozzle. The difficult part is selecting entry and exit locations such that a slight pressure gradient exists and sealing the fairing to maintain pressure. I was unable to achieve ideal ventilation due to limited time available for construction. However, with air entering at a small vent at the base of the windshield, and exiting at the rear of the front wheel, it passes downward over the body for effective cooling. I've also found that cooling can be enhanced by using an evaporative method such as a fine water mist added to the entry flow. I have not used this, however, in racing.

To eliminate undesirable flow at the wheel cutouts, a stretched latex panel with nylon trim was designed to go around the wheels. This not only eliminates almost all the flow into the wheel holes, but also forms a smooth aerodynamic fillet between the fairing/wheel interface. Under normal operation, the fillet does not contact the rotating wheel. Other ways to achieve this are more complex.

Riding Position and Drive Train

Since maximum streamlining is desired, the riding position that can fit into the smallest teardrop-like shape is optimal. This can be achieved using a sitting position with the legs directly in front. It can also be done with a head-first position, but I consider that too unsafe to be an option. Deciding to have the legs in front is only the beginning. The actual drive mechanism, how you see out and how all the components that make a bike fit around you, are yet to be determined.



The first model Cutting Edge shown above has an asymmetric carbon frame with a suspended sling seat, stabilized by cross ties. The second model, as yet uncompleted, has a front-wheel drive.

The volume cut out by the motion of the legs with a crankset is quite large. This profile can be substantially reduced by using a linear pedalling motion, which not only allows a smaller fairing, but also allows a better-shaped fairing. However, then there are many new problems associated with developing an efficient, reliable and light-weight linear-drive mechanism. The primary question is whether or not the improved aerodynamics outweigh possible inefficiencies associated with a linear drive.

Arm-power is another possibility; however, the only chance of practical use would occur during intense anaerobic effort when the rider utilizes the high-energy, short-term phosphate fuel stored in the arms (ATP and CP). This power gain is found to be quickly negated when you account for the additional size in the fairing necessary to allow for arm motion. You must also figure out how the rider can control the vehicle and also maintain full arm and leg effort! Additionally, for longer durations the limiting factor is one's aerobic cardiovascular capabilities, which can be fully utilized by a trained rider's legs alone.

This leaves the routing of the driveline, which for the **Cutting Edge** was directed to the rear wheel using a long chain. I later developed two types of front-wheel drives which completely eliminate any induced torque on the steering since the crank is rigidly attached to the frame. Using these designs, I have sprinted up a steep hill while taking sharp turns with no problems. The front-wheel drives are lighter and cleaner mechanisms than the rear-wheel drive in this case. I have not yet raced with the front-wheel-drive recumbent.

Seat

With your feet out in front, you no longer have your body weight to counteract the net force on the pedals. For this I developed a sling-type Nylon web seat that wraps around the hips in such a manner as to completely support the rearward thrust. This relaxes my upper body and yet allows me to apply greater sprinting forces than I can on a conventional bike. The seat is suspended from the frame by Nylon bands sewed to the webbing, and threaded through Kevlar loops attached to the frame. The seat is also designed to relieve direct pressure on the gluteus muscles, which eliminates cramping. The seat forms a partial suspension for the rider, who comprises the primary mass of the vehicle, which is advantageous both for comfort and cornering ability since the tires will follow a rough surface better. A true suspension would be necessary to gain the full advantage here.

Components

In placing the components, it is necessary to get the front wheel between the rider's legs for the best sidewind and aerodynamic performance. This sounds like a real problem at first, but it turns out there is plenty of steering clearance using a 20 inch wheel for all cases except extremely slow speeds! This allows for a very simple and reliable direct steering linkage. By having a reverse stem in order to clear the leg motion, the steering acts exactly like a control stick in an airplane for governing lean angle! This fact was invaluable during the 1990 IHPSC on the twisting Portland International Raceway, where it felt like I was flying an airplane as low as one can get!

The brakes are another concern. In the **Cutting Edge**, I managed to smoke out a pair of conventional brakes as I blasted into one of the sharper turns on Portland International Raceway. I would choke until the burnt rubber smoke cleared out of the fairing. This problem was amplified by both the higher speeds, and also because the very low riding position allows me brake much harder - long after a conventional bike would have done a flip. I have continued to use conventional rim brakes, since the braking demands of IHPVA races are not acute; however, it would be suicidal to go down a long hill with such brakes - they would melt and you'd soon find yourself at breakneck speeds! There are other brake designs which will handle these demands, but they generally weigh substantially more.

BUILDING THE CUTTING EDGE

The result of the preceding analysis is the achievement of a controllable bicycle which possesses substantially improved aerodynamics along with excellent visibility, protection, ventilation and comfort. The **Cutting Edge** is the first realization of such a bike. It was created in the summers of '88 and '89 with limited time, tooling and budget. I used a number of creative ways to keep the cost to about $1500 for materials. The tradeoff was a slightly heavier bike than I would like, yet at 36 pounds, it is still one of the lightest streamlined bikes ever built. The body shape was developed using laminar 2D foils slightly modified for the 3D semi- axisymmetric application. The leading edge was an NACA 66 series symmetric wing section, and the trailing edge was based upon an NACA 16-015 profile [6]. Transitions were filleted based on experience and Hoerner's findings [7,8].

A male "plug" representing the fairing was built by shaping and glassing a 0.5" layer of Clark foam over bulkheads. Instead

TABLE 1. SPECIFICATIONS OF THE CUTTING EDGE.

Height	35 inches, (89 cm)
Width	16 inches, (41 cm)
Length	114 inches, (290 cm)
Wheel base	52 inches, (132 cm)
Head Angle	66 inches, (168 cm)
Fork Offset	1-5/8 inches, (41.3 mm)
Trail	1.7 inches, (43.2 mm)
Weight	24.0 lb frame, 10.9 kg 12.0 lb fairing, (5.4 kg) Total 36 pounds, (16.3 kg)
Frontal Area	2.8 ft^2 (average, pedalling), (0.26 m^2) 2.65 ft^2 (not pedalling), (0.246 m^2)
Drag Coefficient	0.11 - 0.13
Drag Area CdA	0.30 - 0.35 ft^2, 0.028 m^2 - 0.033 m^2)
Wheels	700C rear, 20" front; 32 spokes with Mylar covers
Tires	20x1 inch IRC Roadlight clincher front 700x20C Specialized Turbo VS clincher rear.
Brakes	Conventional side-pull rim brakes
Gearing	70 tooth front sprocket 24x9 rear cluster 76 to 206 gear inches
Engine Size	6' 2" (188 cm), 175 lb (79 kg), 1.5 HP (1120w) for 30 sec, 1.18 HP (880w) for 60 sec, 0.5 HP (373w) for 1 hour.
Construction	carbon fiber/epoxy frame, kevlar/vinylester fairing

of building an expensive female mold, I laminated two layers of 5 oz. Kevlar with vinylester resin directly over the plug. The outer surface was meticulously smoothed using microballoons, and finished with a coat of white enamel paint with a flex agent. The fairing was originally designed for a linear-drive mechanism which was shelved in favor of a conventional crankset due to limited time. This meant I'd either start over or else painfully cut holes in the fairing to allow for leg motion. The holes are of course terrible aerodynamically, but rather than make "bubbles" they were covered with a latex film and an internal nylon liner thus maintaining nearly the original flow. The latex stretches temporarily when the knees penetrate the fairing.

The frame was decidedly asymmetric, and the geometry was analyzed using a finite-member approach. Other geometries were considered, but they require certain considerations I didn't want to deal with at the time. The frame was built using carbon-fiber tubes mitered together followed by layering unidirectional carbon fiber at the joints to form lugs. The carbon fiber was manually impregnated with epoxy between sheets of plastic using a method which achieved near-optimal resin ratios before compressing the laminate together. Aluminum and steel inserts were embedded at critical stress points. The seat was sewn together using nylon fabric and components.

As soon as the bike was assembled, I went tearing off around my neighborhood to discover with great satisfaction and relief that it actually worked! My father and brother-in-law rode next. Later I was fortunate to have the experienced support of Gardner Martin and Freddy Markham when I first rode the bike with the fairing on. Everything has worked flawlessly - not even a single derailment of the chain! To give you an idea of just what the bike is like, the finished **Cutting Edge** is summarized in Table 1.

PERFORMANCE

The big question is, "what will it do?" To make any estimate we need to know the drag characteristics, the masses involved, and also the performance of the "engine." From there we can determine cruising speeds in different conditions as well as the acceleration behavior.

Drag Characteristics

Modeling the aerodynamics of something as complex as the **Cutting Edge** is next to impossible. To truly account for all the interference, internal flows, etc... would require a model probably as complex as that of a large airplane. Likewise, a wind-tunnel model cannot account for all these factors. About the only reasonable thing you can do using these methods is to see if there are any gross errors such as separation of the flow from the fairing using these methods.

Not too surprisingly, this leaves field testing as the only option. A coast-down, or deceleration, test on a level road with no winds will give the best quantitative result one can hope for. It is possible to deal with small slopes (<1%) if a level road cannot be found. The test consists of first recording a time history of the velocity of the vehicle coasting from some initial speed. Then you calculate the time derivatives of the velocity data to get the negative acceleration rate. Rearranging each sample point into the form given in Equation 1 followed by a least-squares polynomial fit to the data will reveal the unknown coefficients on the right-hand side.

Note that I have neglected rotational inertia in this case. Also, uncertainty may drown out the small terms in the equation. There are also other methods of determining coefficients from coast-down testing. I've found CdA to be between 0.3 and 0.35 ft^2 for the **Cutting Edge**, and used Chester Kyle's measurements of rolling-resistance coefficient, Crr = .0035 [9].

The Engine

The human body is a very dynamic engine as we know from its aerobic and anaerobic modes of energy utilization. Once fatigue sets in, an extended amount of time is necessary for recovery. This strongly affects the approach taken during top-speed accelerations. To determine power output, you can either find some sort of ergometer or trainer as Kyle [10] has shown, or else time yourself up a steep hill of known slope. I did the latter on the same 12.5% slope first used by Pavish [11] to determine Freddy Markham's output. I simulated the entire climb and the slope variations that occur during it by integrating Equation 2 to get position and solved iteratively for power.

1. $-[(W/g + I_w/r^2)dV/dt + W\sin(\tan^{-1}(\text{slope}))] = C_{rr}W + (1/2)\rho C_d AV^2$

2. $dV/dt = (g/W)[\eta P/V - C_{rr}W - (1/2)rC_d AV^2 - W\sin(\tan^{-1}(\text{slope}))]$

where:

V = Velocity, ft/sec

W = Weight, 211 pounds

Iw = Moment of Inertia of the wheels Slug-ft^2

r = wheel radius, ft.

P = Power output, ft-lb/sec

g = gravitational acceleration

η = Mechanical Efficiency = 0.95

ρ = Air Density = 0.002378 slugs/ft^3 @ sea level

Crr = Roll. Res. Coeff. = 0.0035

Cd = Drag Coefficient = 0.125

A = Frontal Area = 2.8 ft^2

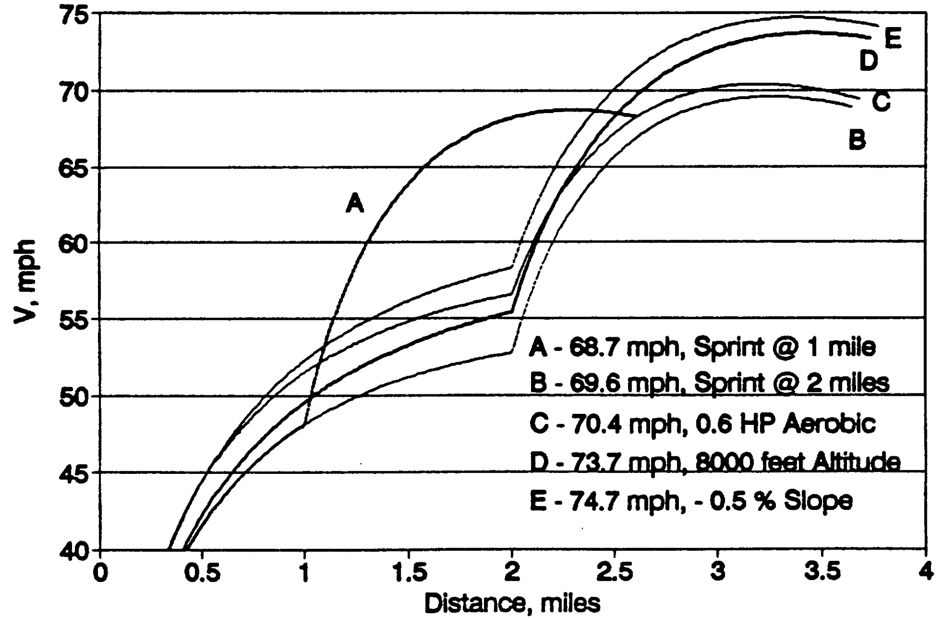
Slope = rise/run

All aerodynamic and rolling drag forces are included, but their contribution is minimal and consequently uncertainty in those parameters is not critical. What you need to know accurately is starting velocity, distance, time, and total weight. I found that I could produce 1.18 ± 0.02hp for a little over 60 seconds, and between 0.45 and 0.5hp during steady 1-hour training rides that included the hill. I rode the **Cutting Edge** *unfaired* to 39.5 mph during a 30.00-second quarter-mile drag. Simulation shows that this drag would require a 1.5hp average output. Other studies of power versus time reveal similar results [12].

Maximum Sprint

A maximum speed will be obtained if the cyclist first reaches near steady state with an aerobic output, and then follows with a maximal effort. The rider will naturally fatigue during the sprint, and ideally he will pass through the timing traps when his power just equals the drag power. To see just what can be done, I will assume an aerobic output of 0.5hp to be followed with a 90-second linearly decaying effort that varies from 1.4hp to 0.8hp. I solved Eq. (2) for velocity and position using a Runge Kutta scheme, and the resulting acceleration curves are given in Figure 1.

Figure 1. Acceleration Profiles



Several variations of the sprint are illustrated such as: (A) starting the sprint at one mile, (B) starting at 2 miles, (C) increasing aerobic output to 0.6 hp prior to sprinting, (D) increasing altitude from sea level to 8000 feet, and (E) running on a constant 0.5% downhill. It is interesting that the 0.5% downhill does more for increasing velocity than the 8000 foot altitude (air density = 0.001869 slugs/ft^3. Also the top speed is largely determined by the anaerobic power profile. It would be useful to record time/power histories for different anaerobic power profiles of the cyclist and determine what is optimal.

Several variations of the sprint are illustrated, such as: (A,B) starting the anaerobic sprint at 1 or 2 miles, (C) increasing aerobic output to 0.6hp prior to sprinting, (D) increasing altitude from sea level to 8000 feet, and (E) running on a constant 0.5% downhill. It is interesting to note that the 0.5% downhill does more for increasing velocity than the 8000 foot altitude (air density = 0.001869). Also, the top speed is largely determined by the anaerobic power profile. It would be useful to record time histories for different anaerobic power profiles of the cyclist and determine which is optimal. Unfortunately, because of wind, or curves along the race course, I have never had the chance to use an optimization strategy to achieve top speed with the **Cutting Edge**. This remains as a future project.

Aerobic Speeds

In extended aerobic events the rider can reach a steady velocity where his power output equals the drag power. The results for the **Cutting Edge** are found by integrating and solving Equation 2 for velocity. I have shown velocities for several slopes, including Calvin's favorite, -20%! It is clear that the velocities increase dramatically with even small slopes. Part of the explanation lies in the fact that as you

TABLE 2 - PREDICTED STEADY STATE SPEEDS, CUTTING EDGE

POWER	UP (+)		SLOPE %		DOWN (-)		
(HP)	+1	+0.5	0	-0.5	-1	-6	-20
0.0	0.0	0.0	0.0	18.8	39.2	115.3	213.1
0.1	12.0	17.3	26.3	37.6	48.5	116.8	213.5
0.2	21.8	28.4	36.7	45.8	54.7	118.2	214.0
0.3	29.5	36.1	43.7	51.6	59.5	119.6	214.4
0.4	35.7	42.2	49.2	56.4	63.6	120.9	214.8
0.5	41.0	47.1	53.7	60.4	67.1	122.2	215.2
0.6	45.5	51.4	57.6	64.0	70.2	123.4	215.7

SPEEDS ARE IN MILES PER HOUR

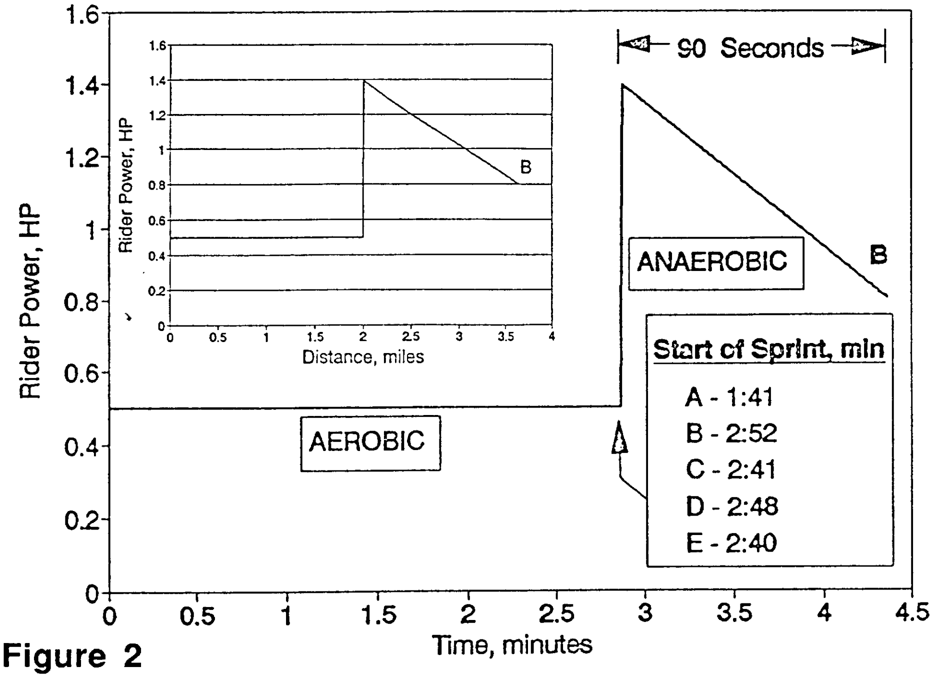


Figure 2

go faster down a hill, you extract more "gravity power" and consequently build considerable speed.

Table 2. shows that with a rider of the likes of Francesco Moser, you are knocking on the door of a 60 mile 1 hour time trial! Likewise, for ultra-distance events, 1000-mile 24-hour trials may be possible!

CONCLUSION

As a result of hammering away at the limits of cycling science, a totally new streamlined bike with excellent performance characteristics has been realized. We have shown that: 1 - The rider and wheels can be mapped into the same frontal area and thus produce a very small and nearly axisymmetric profile, which has the potential to have the smallest drag coefficient and also the least sidewind sensitivity. In fact, you cannot squeeze into a more streamlined profile without performing undesirable physical contortions. 2 - Only two wheel-fairing interfaces are necessary, and they are far back so as to not disturb the laminar flow at the nose of the fairing. 3 - Sidewind stability is achieved, allowing better control and rider concentration. 4 - The low center of mass enables highly responsive turning - theoretically, quicker than anything else through a tight slalom because less time is spent in transitions. 5. - Excellent visibility, protection, ventilation and riding comfort were achieved with little compromise. Historically, record-setting streamlined human–powered vehicles have not performed as well. Faired upright bikes, low tricycles, and finally semi-recumbent bicycles have suffered from such things as excessive frontal area, poor aerodynamic shape and ground effects, rolling over in turns, and adverse sidewind behavior.

Top speeds in excess of 70 mph are presently possible, and are largely limited by one's anaerobic power capability. Aerobic speeds approaching 60 miles for the hour, and 1000 miles for 24 hours are also possible! Of course, you might catch Calvin saying, "Who needs a hill with a bicycle like this?!"

REFERENCES

1. Gross, A. C., Kyle, C. R., & Malewicki, D. J., "The Aerodynamics of Human-powered Land Vehicles," Scientific American, pp. 142-152, December 1983.

2. Kyle, C. R., "New Aero Wheel Tests," Cycling Science, pp. 27-30, March 1991.

3. Jones, D. "The Stability of the Bicycle," Physics Today, p.34, April 1970.

4. Lowell, J. and McKell, H., "The Stability of Bicycles," American Journal of Physics, p. 1106, December 1982.

5. LeHenaff, Y., "Dynamical Stability of the Bicycle," Human Power, pp. 15-18, Spring, 1987.

6. Abbott, I. H., and Doenhoff, A. E., Theory of Wing Sections; Including a Summary of Airfoil Data, McGraw Hill, NY, First Edition, 1949.

7. Hoerner, S. F., Fluid-Dynamic Drag, 148 Busteed Drive, Midland Park, NJ, 1958.

8. Hoerner, S. F., and Borst, H. V., Fluid-Dynamic Lift, Hoerner Fluid Dynamics, Brick Town, NJ, 1975.

9. Kyle, C.R., & E.M Burke. Improving the Racing Bicycle. Mechanical Engineering. 109:6:35-45. September 1984.

10. Kyle, C. R., "The Power Output of Bicycle Trainers," Cycling Science, pp. 4-10, September 1991.

11. Pavish, D. L., "Unsaddling Horsepower," Bike Tech, pp. 13-16, Feb. 1988.

12. Nonweiler, T., "The Work Production of Man; Studies on the Racing Cyclist," Proceedings of the Physiological Society, January 1958.

AUTHOR

Matt Weaver, is a senior Mechanical Engineering student at the University of California at Berkeley, who will graduate in December 1991 with a BSME. He was awarded the prestigious Drake Scholarship which covers 4 years of full expenses to attend U.C. Berkeley. In high school he was a winning middle-distance runner who was offered a University track scholarship, but he decided to pursue Engineering studies full time. Weaver has had extensive experience in Computer Science and Engineering, and was originally considering a double major. The first year he entered the International Human Powered Speed Championships in 1990, he won the road race, beating former U.S. Olympic rider Fast Freddy Markham, who had not been defeated for several years. Weaver also won in 1991. He has not had a chance to test the machine on an ideal course for top speed. For those interested in more information on the stability analysis computer code, write:

Matt Weaver
1760 Wilshire Dr.
Aptos, CA 95003. (408) 688-5389.

LAND ROWING WITH DIRECT LEG-ASSIST

by
Dennis Schmidlin

Introduction

It is well known that rowing is one of the best motions for exercising all of the body's major muscle groups. It is less well known that this motion can produce more power than that of turning a pedal crank with just your legs.

In Human Factors, Vol. 12, No. 3, 1970, J.Y. Harrison compared several forms of motions people could use to produce power based on the rowing form and pedaling. He showed that a type of rowing mechanism, where motion was forced by the system's kinetic energy and which utilized a stationary seat with sliding footrests, "allowed maximum power production, and in most cases the output was considerably greater than that possible using the cycling motion." Harrison called this "forced rowing".

The test bicycle

Since then, there have been several land HPVs designed around the principles of rowing, but their overall performance has never reached their potential due to overly complex drive mechanisms and inefficient design. What has never been created is a vehicle that can utilize the rowing motion in a light-weight, energy-efficient system while at the same time providing a comfortable body position and easy handling, for an overall superior human-powered vehicle. One of the latest attempts is the short-wheel-base "Rowing Bike" featured on the cover of the May/June 1993 IHPVA newsletter. After seeing it, I was encouraged to publicize the details of my land-rowing machine.

Rather than "forced rowing" as coined by Harrison in 1970, its action could be described as direct leg-assisted rowing, or just power rowing. My patented drive mechanism is compact and lightweight. It solves many of the conservation-of-energy problems associated with linear drives and oscillating mechanisms, and it is highly efficient. So much so, in fact, that my first crude test vehicle's speed performance is competitive with that of a bicycle. The included drawings and text contain many concepts that may be of interest to readers. Note that the drawings are not to scale but do accurately depict the mechanics of my H.P.V.

Operation

At rest in figure 1 with the steering assembly at its forward-most position, the bike's basic configuration resembles a long-wheel-base recumbent bicycle with above-seat steering. It uses mostly standard bicycle components with brake levers and shifters located on the handlebars. To operate, a rider places his feet on the sliding footrests "F", and pulls back on the handlebars "H". The handlebars serve as the oars for the rowing mechanism, and also steer the vehicle. The footrests are driven forward by arm power via the toggle-type levering assembly, and with the direct force from the rider's legs. The combined output force is transmitted to the rear wheel through an overrunning clutch on a jack shaft "J", along with a standard bicycle drive train, as shown. This gives all the gearing options available to bicycles.

The motion is that of rowing, or sculling, with a sliding seat; however, sliding the relatively low mass of the footrests is more energy efficient than using a sliding seat. It also results in a much smoother overall operation on the road, with no detectable "lurching" effect - even while cornering. This is because the mass of the rider's arms and upper drive assembly counterbalance the mass of the legs and footrest assembly, which always move in opposite directions. The mechanism coordinates the motion of the arms and legs together into the optimum rowing form with stroke amplitude and impedance matched for each. It improves on standard rowing by allowing the legs to drive the oars directly, which provides the option of doing very little work with the arms. Riders can sit back and work their legs or lengthen their strokes as they choose.

The link-up in the drive train that is made on each stroke is quick and smooth. It is also cushioned by a small, very powerful compression spring "C" in the primary drive chain. It compresses about 10 mm under full load and returns its energy to the drive train at the end of the stroke. This works wonders and link-up is almost unnoticeable. The overrunning clutch on my test bike is a 24-tooth sprocket with a fine-tooth brass machine ratchet and pawl. It is heavy, but the single, large external pawl can be flipped over, disengaging the drive. It gives me a neutral which is convenient for backing up. My new bike, however, will probably use an 18-tooth Shimano single-cog freewheel adapted to the jack shaft. Smaller chain rings will be used to maintain proper cadence while reducing weight.

Power production

The drive mechanism is integrated into the frame of the vehicle for further weight reduction. The stainless-steel guide-rails "R" that the footrests run on also serve as structural members of the frame (figure 2). The remainder of the frame is square-section steel tubing and the truss design is very rigid in all directions to maximize energy transfer. My next prototype will be 4130 chrome-moly steel and will be designed for

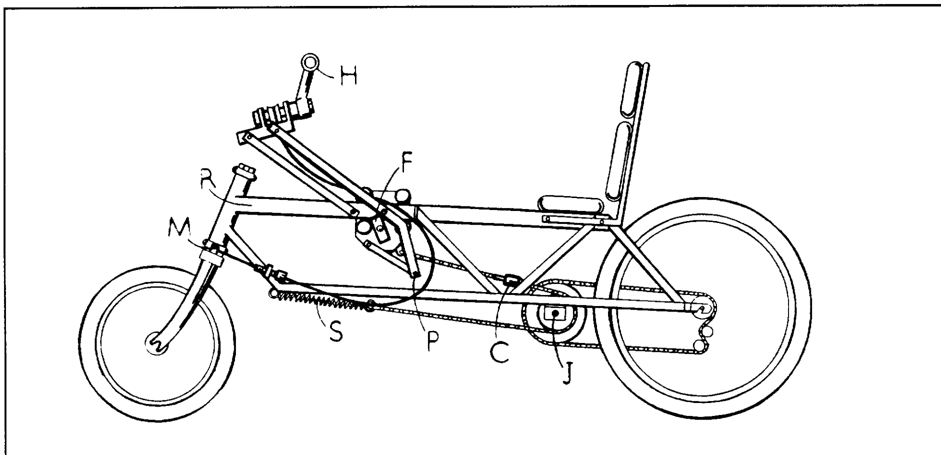


Figure 1 Elevation drawing of the leg-assist rowing bicycle

lighter weight and ease of manufacturing. Overall vehicle weight will be around 15 to 18 kilograms (35 to 40 pounds) with ball or needle bearings at all pivots.

Laterally balancing the drive mechanism gives a smooth, non-binding motion even while pushing with one foot. In addition, the downward angle of force from the rider's legs on the footrest assembly

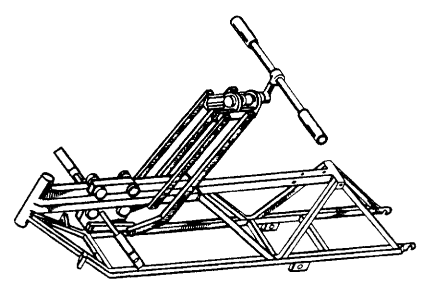


Figure 2 Space frame and mechanism

counters the upward angle of force from the lever arms. All of this greatly reduces friction in the linear motion of the footrests and increases the overall mechanical efficiency of the system.

The design utilizes all available energy in the power stroke and is aided by the deflection of the primary drive chain by the journal shaft at pivot "P", figure 3. By "folding" the chain at the end of the stroke, the rider's arms and legs, along with the drive mechanism, are decelerated, and the energy is transferred directly into the drive train. This occurs at the point in the motion where the rider's mechanical advantage is very high, and delivers a small power burst at the end of each stroke instead of wasting the rider's energy in stopping the motion with arm muscle. Acceleration of motion in the return direction is aided by the return spring "S", and the return stroke decelerates as the rider's legs lift and compress. Thus, kinetic energy is naturally conserved in both directions.

More usable energy may be obtained through the use of spring biasing. With biasing, energy can be stored from the return stroke to be added to the drive stroke. I still experiment with it, but through trial and error, I soon discovered that the return stroke (bench-press and stomach-curl motion) is a poor exercise for driving a H.P.V. Power contribution, overall, is very small. For anyone disputing this, try lying on your back and bench pressing even the weight of your empty hands for one hour. Control of the vehicle also suffers when alternating between pulling and pushing hard on the bars. For distance riding, I prefer just the return spring shown, to lightly bias the mechanism in the return direction. It keeps things simple, and it gives me a quicker return through this low-power or no-power stroke. (This quick return would not be possible with Harrison's hypothetical forced rowing machine, nor would the ability to coast or choose stroke length.) Power rowing combines the best of forced and free-rowing forms.

Speed Results

Of course, performance is the real test of any H.P.V., and my results so far have been very promising. I can cruise comfortably at 6 to 7 meters per second (13 to 16 mph) for long periods of time and can reach 11 or 12 m/s in short sprints. This is about as good as my performance on my aluminum diamond-frame racing bicycle, using just a crudely made 30 kg. (65 pound) test vehicle. Also consider that I have relatively little rowing experience in my lifetime as compared to bicycling for the last 35 years, and the results look even better. I fatigue a little sooner while rowing, but, again, I attribute much of this to lack of rowing experience.

My initial results indicate that my top speed may be hindered slightly more by wind resistance than that of a pedal-driven vehicle. The row bike begins to decelerate quicker between power strokes at high speeds. The same thing becomes apparent when climbing hills. Fortunately, the mechanism's quick-return stroke and the excellent aerodynamics of the sculling position help to offset this effect. Perhaps a row bike would be a perfect place to implement a short-term energy accumulator or "massless flywheel" such as described by John S. Allen in the Fall/Winter 91-92 issue of Human Power.

Handling

For obvious reasons, I am trying to perfect the bike's handling first, rather than concentrating on speed. The steering system is another departure from the norm, but it is actually very simple and handling feels quite natural. The handlebars are mounted on a "floating" steering head, supported by the articulated parallelogram linkage as shown. This positions the handlebars at a more operable angle to the operator throughout the stroke. The only controlling link to the front wheel is through flexible sleeved cables. I think most people would expect the steering to be mushy due to cable-sleeve compression but the heavy-gauge motorcycle control cables that I use give a very solid feel. The system is lightweight and offers many new possibilities.

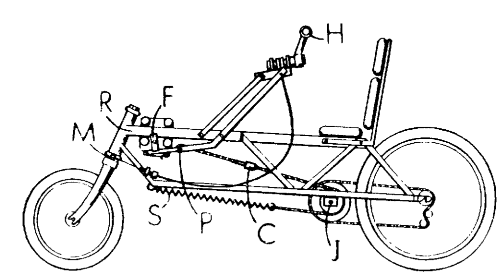


Figure 3 Details of energy-conserving mechanism

One option is the use of steering ratios other than 1 to 1. I have experimented extensively with this and to my surprise, very stable handling characteristics were obtained with a continuously varying ratio! To accomplish this, I use mounting pins "M" on my fork for the cable connections, similar to those used by Don Barry on his Infinity recumbent bicycles. The opposite cable ends are wrapped over a round pulley on my steering head. This arrangement results in steering that is slow while on center and quickens as you turn in either direction. Along with the enhanced stability, this solved my only real problem concerning handling, which was "twitchy" steering while pulling hard on the bars. I am experimenting with a bolted-on head tube with which I can vary the angle from 60 to 80 degrees, and several different fork rakes to perfect my handling. Factors affecting control include: pulley diameter, stem length, handlebar width and shape, stroke length, parallelogram geometry, cable friction and preload, rake, trail, wheel base, and width of seat. I've discovered that the bike's handling becomes a matter of personal taste, but I am working towards the most natural feeling combination that requires the least attention from the rider in all situations. Overall, I am as pleased with my handling performance as I am with my speed.

Dual-Drive and Tandem Capability

Another embodiment of the vehicle could include crank arms and pedals on the jack shaft operating as a standard bicycle crank. This dual-drive model would enable the rider to stand and pedal as an aid in hill climbing, and the only additional weight would be the pedals and crank arms themselves. If a luggage rack were designed to double as a back seat the bike could then be ridden as a tandem. The captain would row and the stoker would pedal. Some sort of quick-release crank arms would be nice because a rider would probably not want the pedals under him while rowing alone on flat ground. I also considered a stair-climber-type lever-drive system integrated into the jackshaft for climbing, but I think the added weight would be prohibitive.

Closing

I am 37 years old and in average physical condition. The various results and conclusions given are the result of very informal testing and observations made by me during a couple hundred kilometers of test riding the vehicle.

Speeds were recorded on an inexpensive cycle-computer, calibrated to my measured wheel diameter. My purpose was merely to test the feasibility of the design and get a rough estimate of its capabilities. The test vehicle's performance surpassed my expectations. I believe I can safely say that although power-rowing may not set new top-speed records, very high average speeds for medium-duration rides will likely result.

I think the time has come for row-bike technology with its total-body work-out benefits and its intensely enjoyable ride. For the image-conscious, the machine has very good aesthetic qualities. The compact, long-wheel-base recumbent chassis is beautifully suited to rowing and its look will be that of a high-tech piece of exercise equipment on wheels.

The patent issued January 25, 1994, on my power-rowing mechanism, which could be adapted to other types of H.P.Vs as well. I hope to market my complete vehicle, a kit, or possibly just the plans at first to raise capital. I'd like to see my land rowing vehicles help bring about more widespread popularity of all H.P.Vs. Unfortunately, on my budget, the world will have to be patient. I am still in the process of optimizing the design and drawing plans for a showable-quality prototype.

If I've failed to mention something of interest, you may write for more information. I welcome any serious questions, comments, suggestions, or propositions.

Dennis Schmidlin
20798 W. S.R. 105
Woodville, OH 43469

Dennis Schmidlin holds journeyman's cards as a millwright and as a machine repairman, and is active with special projects at Modine Manufacturing Company. With an engineering education from Owens Technical College he enjoys, tennis, rowing and cycling along the rural roads along the Portage River in NW Ohio.

Review
ENCYCLEOPEDIA
the alternative buyers' guide to quality cycling around the world
Alan Davidson & Jim McGurn

Reviewed by Dave Wilson

This beautifully produced book - it is more than a catalog - is being recommended by all who see it. It is more like a song of praise to cycles of all kinds, with HPVs and recumbents featured prominently. Mike Burrows and Richard Ballantine are contributors, and I suspect that the superb photography owes something to the perfection demanded by Richard Ballantine in Richards' Ultimate Bicycle Book. It is a large-format glossy paperback, the European equivalent of this sheet size, and the standard entry is a two-page spread. It starts with surveys of the cycling scene by the three principals. Then there are reviews of all types of cycles other than standard "ten-speeds" and mountain bikes. There are recumbent bicycles and tricycles, foldables, power-assisted, machines for people with handicaps, goods-carrying cycles, trailers and some components. In ninety pages there has to have been selectivity, and if you have the slightest tendency towards jingoism you will feel that U.S. designs have been mainly passed over. In fact, many of the designs appear to be fairly close copies of some U.S. predecessors. But Encycleopedia doesn't make any pretence of being encyclopedaic, and the authors, having put as much effort and as much money (one finds it easy to believe them when they state that they have lost a bundle on it) into the book's production and distribution as they have, are surely entitled to choose what they want to feature.

(Review concluded on p. 23).

AN OPEN LETTER TO THE RULES COMMITTEE OF THE IHPVA

by Peter A. Sharp

The purpose of this paper is to confront four serious problems and to recommend solutions. The problems include the continued use of 1) high elevations, and 2) down slopes, for top-speed record attempts; 3) the placing of accumulators in the hybrid category; and 4) obstructing the development of practical HPVs. Currently, the rules of the IHPVA are being updated by the Rules Committee, and I was invited by Dennis Taves, the coordinator, and a member of the Board, to contribute my input. I am grateful for the opportunity. I respect all the members of, and advisers to, the Rules Committee (RC), and some are heroes of mine. But I am concerned that the RC (despite some notable dissenters) is about to make decisions that could harm the IHPVA, or worse.

PROBLEMS

High elevations

I request that the RC consider the negative implications of using high elevations for top-speed record attempts. Using high altitudes to reduce aerodynamic drag is really no different than using a pace car. It only <u>looks</u> legitimate. Low air density is equivalent to a significant increase in power. **At31 m/s (70 mph), at 2440 m (8,000 feet)**, where the air is about 20% less dense than at sea level, it is worth about **138 watts (0.185 hp)** (the power required at sea level to overcome aerodynamic drag, minus the power required at 2440 m). (I have used the figures for Matt Weaver's HPV, and for air density, from his article in Cycling Science, Sept./Dec. 1991).

Would we accept as legitimate a top speed record set in the (currently allowable) vacuum on the moon, where the top speed could exceed 90 m/s? Of course not. A slightly less improbable scenario would be for someone with enough resources (like NASA) to set the record using a banked track, a space suit, and a very large low-pressure chamber (probably a donut-shaped tunnel). This would certainly be dramatic, but it would be irrelevant to real-life conditions. Only a bit less extreme would be to use scuba gear for breathing (or a native cyclist) and find the highest road in the extreme-altitude plateaus of Tibet. Records should represent the HPV, not the location.

We want our records to reflect the realistic, meaningful, and incontrovertible capabilities of our outstanding HPVs. That means near sea level. Also, high elevations favor members in some countries, like the U.S., over other countries where long, flat roads at high elevations are not available. That is simply not fair. The use of high altitudes is largely responsible for creating the problem of finding long-enough roads for record attempts. They should not have been permitted in the first place, and their use should be discontinued. That would make many more record sites available. The main problem with their use is that they are deceptive. Just as a balloon will expand at high elevations, high elevations create artificially inflated records.

Down slopes

The IHPVA currently permits the use of a "legal" 2/3% down slope for top-speed record runs. The reason is to make it easier to find long roads (at high altitudes) for record attempts. The RC is already considering the use of a 1% down slope, and might permit it sometime in the future. That solution would be a slippery slope. Steeper down slopes would produce higher speeds, thus requiring longer runs, which would require steeper down slopes, and so on. Down slopes provide a large increase in power. At what point would we have a Soap Box Derby with pedals? A lot sooner than you might think.

Each mile (1.609 km, 5,280 ft.) of run, using a **1% down slope**, for a 91-kg (200 lb.) HPV/rider combination, stores (5,280)(.01)(200) = 10,560 ft-lb (14.3 kJ) of gravitational potential energy. Therefor, a 5.1-km (3.2-mile) run (a low estimate), which would be required for reaching 31 m/s (70 mph), would store (10,560)(3.2) = **33,792 ft-lb (45.8 kJ)**. This is equal to descending a hill almost as high as a 17-story building ((51.5 m, 168.96 feet). The faster an HPV goes, the faster it is descending, and the more power it gains from a given down slope. Heavier HPVs (like tandems) gain more power because more weight is descending. 1 hp is equal to 746 watts or 33,000 ft-lb per minute. At 31 m/s (70 mph), the amount of power derived from gravitational assist would be approximately (70/60)(10,560) / 33,000 = **0.37 hp (276 watts)**. At 31 m/s (70 mph), a currently legal **2/3% down slope** would store 2/3 of that total **(30.542 kJ, 22,528 ft-lb)** and produce 2/3 of that power (**184 watts, 0.247 hp**). This last figure of approximately 1/4 hp was recently pointed out by Andrew Letton, a member of the RC and the Board. It is in direct violation of the power rule: "Vehicles must be driven solely by human power" (3.1.1). Gravity power is not human power. (It could be human power, but only if were stored human power or accumulated human power, neither of which is permitted.)

The IHPVA's use of net down slopes is based on a fantasy physics peculiar to the IHPVA: the denial that gravitational potential energy storage is a form of energy storage. The use of down slopes requires the storage of large amounts of gravitational potential energy in the mass of the vehicle and rider. That turns the entire HPV/rider combination into an energy storage device.

The IHPVA has been using down slopes, and therefor energy storage, for many years to set top-speed records. But the use of any net down slope whatsoever is in direct violation of the "no stored energy" rule. That rule is <u>absolute</u> - <u>no exceptions</u>. "No device which stores energy... may be used in any event...." "...this means absolutely no... potential... energy storage at the start" (3.1.2). That means no gravitational potential energy storage. It is not possible to use a net down slope while excluding stored energy. Admittedly, that rule was poorly written, since all HPVs inevitably store or accumulate energy in a variety of ways. But the use of down slopes is, without doubt, prohibited by that rule. The rule permitting the use of a 2/3% down slope (3.3.1) directly contradicts the rule prohibiting any stored energy (3.1.2), and the power rule (3.1.1).

The use of stored energy (but not accumulated energy) defines an HPV as a hybrid vehicle. The use of a net down slope turns any top-speed-record HPV into a <u>hybrid vehicle</u>. Consequently, all top-speed records, since the first use of down slopes, have been set by hybrid vehicles. <u>At present, the IHPVA has no top-speed record for HPVs</u>. The "record" applies only to <u>hybrid</u> vehicles. Any other record set using a net down slope of any amount is also invalid. The rules allow a competitor to use a 2/3% down slope, but if he uses it, his record does not count. That is, of course, extremely misleading and unfair to the competitors.

If the RC claims that a down slope is a legitimate exception to the "no stored energy" rule, then it will establish the principle that energy may be stored in order to make more record sites available. It would also establish the principle, by implication, that there is no real difference between an HPV and a hybrid vehicle (an HPV using stored energy). I certainly hope that the RC will not establish those principles. There are better solutions.

But competitors should not be using either down slopes or high altitudes. At 70 mph, the approximate power to be derived from the combination of an **altitude of 8,000 feet** (0.185 hp) and a **2/3% down slope** (0.247 hp) is **0.43 hp (320 watts)**. That is a very large amount of extra power, considering that the rider's maximum output at that speed, near the end of his anaerobic sprint, would be around 895 watts (1.2 hp) (down from a peak of about 1100 watts, 1.5 hp). It amounts to a **36% increase in power**, or roughly a 1/3 increase in power at 70 mph.

Besides the fact that the use of down slopes invalidates the records, the use of all this extra power is deceptive. In principle, it is no different than secretly using an electric power assist. The general public and the media have no idea that this much hidden power is permitted by the IHPVA. They trust that the IHPVA is above reproach as the official sanctioning organization for HPV world records. No record is worth risking the reputation of the IHPVA. That reputation is now at risk.

Accumulators

The RC may ban the use of accumulators from all records and races - even from the road races where accumulators are currently legal, and have been for the last ten years. The RC may place accumulators strictly in the hybrid category.

Besides the hypocrisy of this decision, it would be totally arbitrary and regressive. There is no justification whatsoever for classifying a human-energy accumulator as a hybrid device if the accumulated energy is produced on board by the rider and is not accumulated prior to the intended route or purpose as defined by the rules. There are clear and meaningful differences between the use of an accumulator and the use of stored energy. Regenerative braking and pregenerative pedaling are entirely legitimate ways to increase the efficiency of HPVs. Accumulators are completely consistent with the physics and functions of bicycles, just as they are for other types of vehicles.

An accumulator would increase the efficiency of an HPV under most circumstances. Banning accumulators would actually require HPVs to be less efficient than they could be. That would be a severe restriction which would show a flagrant disregard for the values of the IHPVA. "The spirit of these rules is to avoid inhibiting design innovation by not establishing unnecessary restrictions" (2.0).

I recommended, in my article on accumulators (HP, vol. 10, no. 3, 1993) that the time limit for charging should be set at 1 minute. An accumulator for a top-speed-record attempt would be charged at a rate of about 375 watts, 1/2 hp, so as to stay within the aerobic limit of the rider and to avoid exhaustion prior to beginning the run. That would be approximately 33,000 / 2 = **16,500 ft-lb (22.4 kJ)**. By permitting the use of a 2/3% down slope for a 70-mph record attempt, the IHPVA already permits far more energy to be stored (22,528 ft-lb) than what I have recommended as the legal limit for accumulation!

As I mentioned in my article on accumulators, I favor the use of vacuums inside tubes with pistons. Such accumulators are gravity devices. They lift the atmosphere an infinitesimal amount. What they store is gravitational potential energy, the same form of energy as a down slope. But whereas using an accumulator would make a clear statement that the HPV is deliberately using that extra energy, a down slope (and a high altitude) serve to disguise all that extra energy - and a lot more of it as well.

What is the equivalent total of stored energy? At 70 mph, the power equivalent to be derived from an 8,000 foot altitude (.185 hp) is almost exactly the same as using a 1/2% down slope (.185 hp). So the **total equivalent down slope**, at sea level, would be 1/2% + 2/3% = 7/6% or **1.167%**. The **total equivalent**, in terms of **stored energy**, would be (7/6)(33,792) = **39,424 ft-lb**. Compared to using an accumulator, that amount of energy is about (39,424 / 16,500) = 2.39, or **239%** as much energy as would be stored in an accumulator, using 1 minute of pedaling.

Based on the evidence, it is obviously nonsense to claim that down slopes (and high altitudes) are reasonable and legitimate while accumulators, using one minute of preaccumulation, are not. If any "purist" still thinks that using an accumulator might somehow be a form of "cheating", then that person has to first explain how the use of a net down slopes (and high altitudes) is not cheating. Good luck! Note carefully that if the RC insists on unreasonably placing accumulators in a "hybrid" category, then that is where the top-speed records for the Gold Rush and the Cheetah, and all other "down-slope records", must go as well. That hybrid category could get very crowded.

Practical HPVs

There are wider and more serious implications to consider as well. The members of the RC are aware of the long-term consequences of the ICU's infamous declaration - on Fools Day, April 1, 1934 - that recumbent bicycles are not bicycles. Fundamental progress in bicycle technology was almost frozen until the IHPVA was founded 40 years later to remedy that kind of irrational obstructionism. But now, in order to defend its own obsolete notion of what a bicycle is supposed to be, the RC is about to make exactly the same kind of absurd declaration: that accumulator-equipped bicycles are not bicycles. This time, however, the consequences of freezing technology would be far more serious.

Many members, including I myself, believe that advanced HPVs can become a major component in the world's transportation mix, including North America and Europe, and that they can replace automobiles for the majority of trips. Half of round trips are less than 16 km, specifically 15 km in the U.S., and less in Europe, according to a recent study by economists at the Lawrence Berkeley Lab. (The Christian Science Monitor, 8/24/94). This replacement could have enormous environmental, economic, and social benefits, especially if combined with public transit, more road access, and high-speed piggyback systems. But the necessary technical advances will probably require, at least, the combined use of streamlining, accumulators, and direct wind and solar assist. I refer to such practical, super HPVs as "Ambient-Energy HPVs". (Paul MacCready has referred to this type of HPV as a "natural energy" HPV.) Some of them may also require the use of power assist for hills as proposed by John Tetz, and promoted by Peter Ernst.

Both energy accumulation and wind assist have always been part of the normal operation of HPVs. There is no way to avoid them. Simply moving, or riding up any hill, accumulates energy, and any tailwind provides wind assist. In cross winds, streamlined components provide wind assist because they inevitably produce lift and thrust. The critical choice is whether to use human energy accumulation and wind assist most efficiently, or whether to officially ban the energy they could provide, and thereby to seriously handicap the development of practical HPVs. To opt for wasting that energy would be symptomatic of the energy gluttony and energy waste that we take for granted in North America.

To the extent that the RC fails to nurture, or continues to obstruct, the research and development of practical HPVs, it will adversely affect environmental, economic, and social conditions around the world. In the eyes of future generations, that decision would cast shame on the IHPVA - especially so, since that negativism would have been entirely unnecessary. The development of advanced, practical HPVs should be strongly encouraged by the IHPVA, not discouraged or impeded, as at present.

The RC must not continue to require advanced, practical HPVs to conform to the same overly narrow definition of an HPV that it now applies to conventional racing HPVs. Racing and records are to be used only as a means to an end - which is innovation, the evolution of HPV technology. "In general it shall be the intention of the IHPVA rules to avoid defining what type of vehicle may enter individual competitions, but to let the competition itself determine which type of vehicle is superior by a normal evolutionary process" (2.0). Any elected or appointed official of the IHPVA who believes that innovation should be subordinate to racing, is in the wrong organization and is likely to do more harm than good.

SOLUTIONS

I wish to recommend straightforward solutions to these problems. There is no need for conflict between "purists" and "practicalists". Both can be easily accommodated without imposing on the other. The IHPVA can comfortably embody a wide diversity of opinions and types of HPV. Now is the time to make that possible.

Four basic steps need to be taken: 1) Acknowledge that small-percentage net down slopes store large amounts of energy, that their use for record attempts was a mistake, disallow them, set an altitude limit of 1,000 feet, and allow small undulations in the surface of the road (plus or minus 1 meter); 2) Acknowledge the current top-speed record as official under the "special conditions" of the Pre-'94 Rules, and establish a new Post-'94 Record; 3) Acknowledge that human energy accumulation and wind assist are valuable energy resources, and that they should be developed to the fullest extent possible for the benefit of practical HPVs; and 4) Establish an ambient energy class, with separate and different records and events - so as to encourage practical innovations while avoiding conflicts with traditional racing and records.

The **ambient-energy class** would permit streamlining, accumulators, and direct wind and solar assist. It would limit human energy accumulation to 1 minute, allow wind speeds for its own records up to 5 meters per sec. (11 mph), limit vehicle widths to 1 meter, and prohibit the use of net down slopes, high altitudes, and energy prestorage. Ambient-energy events would be designed and updated to encourage innovative solutions to specific problems. That way, the development of practical HPVs would not in any way interfere with the current records and race events.

Current HPVs would be classified as **gold-class HPVs** (in honor of the Gold Rush). The IHPVA's top-speed record would not be available to ambient-energy HPVs. That record would be reserved for gold-class HPVs. However, the ambient-energy-class records and events would be open to all gold-class HPVs who chose to participate, thus providing more opportunities for competition. (An additional class with special events could be used to encourage the research and development of power-assisted HPVs.) I have submitted a preliminary outline of the proposed classes to the RC and the board.

Please note that a failure to establish an ambient-energy class would probably force our "practicalists" to create a competing organization. That organization, using limited accumulators and limited wind assist, could legitimately break all of the IHPVA's records, thus leaving the IHPVA with no records, few incentives, and little purpose. From that perspective, an ambient-energy class would be excellent insurance against competing organizations, since our own members would remain at the leading edge of practical HPV technology.

It is very important that the builders of the superb HPVs that have set the top-speed records should not be faulted or penalized. They conformed to the rules, and triumphed. Only the rules were at fault. The current top-speed record would remain as official under the special conditions of the Pre-'94 Rules. But we would recognize the "Post-'94 Record", under the fully legitimate and more difficult conditions of the Post-'94 Rules, as the superior record.

Anyone who proposes a different solution must be careful not to destroy the official record, and unfairly penalize the record holders. We can still assume that the use of down slopes (and high altitudes) was an honest mistake, an oversight, and not a deliberate attempt to circumvent the "no stored energy" rule. But if the RC were to continue to insist on the legitimacy of down slopes, then the record would become a deliberate violation of the "no stored energy" rule, a deception of the public, and a disgrace. Incidentally, I would like to know which HPV would presently hold the Post-'94 Record, and what is its record speed? How fast can a current HPV really go without hidden sources of power? Matt Weaver's calculations indicate that a Post-'94 Record could still be higher than the Pre-'94 Record, even without those hidden sources of power.

For members who still want to use down slopes to go faster, I recommend that we establish a "Gravity Derby". Matt Weaver has calculated that a 6% down slope, without pedaling, could provide speeds in excess of 100 mph, and a 20% down slope could provide speeds in excess of 200 mph. Pedaling would be used only to ride up to the starting line, where each HPV's drive mechanism would be temporarily disabled (by tying the chain). All HPVs would carry the same weight. This competition would really be a coast-down test to compare the aerodynamic efficiencies of our HPVs. Owner/builders could demonstrate the speed potential of their designs without having to use a professional caliber rider. We could learn a great deal from this event. Of course, for the safety of our competitors, we would appropriately limit the slope and the distance for acceleration, and the consequent speeds.

The basic ideas of accumulators, ambient-(natural)- energy vehicles, and separate classes were all proposed originally by our esteemed International President, Paul MacCready. Now is the time to implement his ideas and recommendations. On behalf of the membership at large, I call upon the Rules Committee to protect the credibility and integrity of the IHPVA, and to set a course toward a truly innovative future.

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

(Editorial note: the IHPVA slope and wind limits came, I believe, from an attempt to keep continuity of the records after the Ontario Motor Speedway in California, where early IHPVA races were held, was demolished.

The European and British HPV clubs are as unhappy as Peter Sharp over the use of high-altitude roadways, which are not available elsewhere in the western world. Dave Wilson)

ALL-SEALED FAIRINGS: VENTILATION GIVES VERY LOW DRAG
Mark Drela

It seems surprising that people are seriously attempting to run long-distance HPV events with all-sealed fairings. The aerodynamic drag due to adequate ventilation can be made extremely small if done properly. Let's say that we have one air intake, and one exit nozzle, with no other air leaks. The mass-flow rate at the intake and exit then balances:

$$m = \rho \times V_{in} \times A_{in} = \rho \times V_{ex} \times A_{ex}$$

where ρ is the air density;
V_{in} & V_{ex} are the inlet and exit velocities in the ducts, and
A_{in} & A_{ex} are the inlet and exit cross-sectional areas of the ducts.

Let's assume that the air flowing in through the inlet duct completely mixes out inside the fairing before it exits at ambient pressure. This will be true if the inlet-duct area is larger than that of the exit duct, a situation that, as shown below, is desirable. Then we can use Bernoulli's relation to connect the vehicle velocity, V, with the air velocities in the inlet and outlet duct:

$$V^2 = V_{in}^2 + V_{ex}^2$$

From a simple momentum balance, the ventilation drag, D, is

$$D = m(V - V_{ex})$$

which, using the relations above, can be given as

$$D = q \times A_{ex} \times 2r(1-r)$$

where

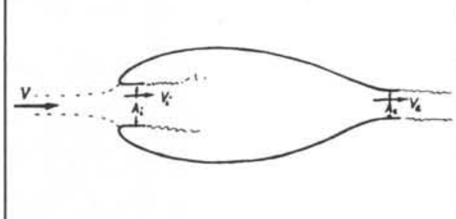
$$q \equiv 0.5\rho V^2;\; r \equiv \frac{V_{ex}}{V} = \left[\frac{1}{1+(A_{in}/A_{ex})^2}\right]^{0.5}$$

The important result here is that one wants a small exit area but a LARGE intake area - the larger the better. This requires tightly sealing all possible unintended air exits in the fairing.

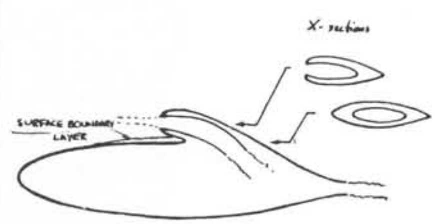
If the inlet area is much larger than that of the exit, the air flows into the fairing very slowly and the power lost due to mixing is very small (proportional to $(V_{in})^3$:

$$P_{loss} = \tfrac{1}{2} m \times V_{in}^2 \sim (V_{in})^3$$

A very good inlet is a hole with nicely rounded edges in the very front of the fairing, although to make best use of the incoming air you would want to duct it onto the rider's head and shoulders. This is apparently where most of the body's heat rejection takes place, and of course it's very nice to have a stream of fresh air flowing onto the face.



Nose scoop



Side-scoop

(The side scoop is <u>much</u> more difficult to design properly, and may trigger external separation on the aft body. The nose scoop is almost foolproof by comparison.)

If a scoop is placed near the rider's head, it should have a curled-in leading edge to allow for the deceleration of the flow stream-tube before it gets to the scoop, as shown in the sketch. The scoop must also be offset from the fairing surface so as not to ingest the fairing's boundary layer. This would stall the inside of the scoop duct and prevent maximum deceleration of the incoming air.

Mark Drela MIT Aero & Astro,
Cambridge MA 02139
email: drela@henry.mit.edu

Mark Drela is on the MIT Aero/Astro faculty, and has been responsible for most of the aerodynamic design and much of the construction of a long series of record-breaking MIT human-powered vehicles from the Chrysalis to the Decavitator.

(Review of "Encycleopedia", continued from p.19)

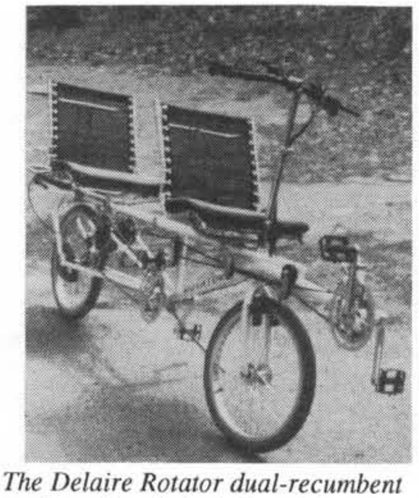
There are many famous European builders whose products are also not to be found here. It is a sign of the strength of the HPV movement that one could produce several books of similar size showing highly regarded commercialized HPVs without dipping below a high-quality threshhold. Most books on bicycles and HPVs are to be found in the workshop or on the drawing table. This, as for the Ultimate Bicycle Book, would grace any coffee table. That is not a perjorative comment. It will win many converts to human power who probably never previously had any interest in the field.

Jim McGurn, the principal author, is well-known for his highly regarded history of bicycling "On Yer Bike". He is also launching the Bike Culture Quarterly, with a subscription of £25.00 (currently £1.00 is about $1.50) to include the 94-95 edition of Encycleopedia. The current edition is available at the bargain price of £8.95 including postage anywhere, from

Open Road, 4 New Street, York YO1 2RA, England

Alternatively, order in the U.S. from
Open Road USA, P.O. Box 1055
Ansonia Station, NY, NY 10023
Phone 212-865-7688
Annual sub. Bike Culture Quarterly: $35
93/94 Encycleopedia: $9 + $2.50 P&P
94/95 Encycleopedia: $23 + $3 P&P

Dave Wilson



The Delaire Rotator dual-recumbent tandem (Apologies! I used the wrong photo in HP 11/2 p. 22 in John Allen's article - Dave Wilson)

International Human Powered Vehicle Association
P.O. Box 51255
Indianapolis, Indiana 46251-0255
U.S.A.
(317) 876-9478