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HUMAN POWER

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HUMAN POWER
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Human Power (ISSN 0898-6908) is published irregularly, ideally quarterly, by the International Human Powered Vehicle Association, a non-profit organization dedicated to promoting improvement, innovation and creativity in the use of human power generally, and especially in the design and development of human-powered vehicles.

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A streamliner as a road vehicle

John Tetz gives us a word picture, and several photographs, describing the joy he gets from riding his very compact fully faired "hard-shell" recumbent bicycle on the highway. Subsequently he responds to questions about the performance and design of this and future vehicles.

Wind-tunnel and track tests of various types of bicycles: faired, partly faired and unfaired

This is a review by your editor of a remarkable series of tests carried out by and for the German bicycle magazine *TOUR, das Radmagazin*. Among the findings were that unfaired recumbents have considerably higher aerodynamic drag than unfaired "upright" bicycles.

Reciprocating-drive recumbent tricycles for young riders with disabilities

Stefan Radloff and John Henshaw of the University of Tulsa give a moving record of designing and adapting recumbent vehicles for young people who previously had very limited mobility. The success they achieved is inspiring.

Steering trailing-arm-angle determination for a three-wheel HPV

Timothy Gorman develops a mathematical model for determining the desired angle of steering configuration to minimize tire scrub and forced side-slip in three-wheeled vehicles.

HP pioneer from France

Lucien Battarel rode his own design of short-wheelbase recumbent bicycle to Lelystad, The Netherlands, for the 1995 HPV championships, and met John Riley, now of Toronto, Canada. John asked him if he would write up his story. It is of particular interest because Lucien Battarel made his first SWB in 1950. It includes many features that we might formerly have called "modern".

Stefan Gloger's PhD thesis

Another ground-breaking development from Germany is Stefan Gloger's doctoral thesis at the Technical University of Darmstadt, reviewed by Theo Schmidt and Andreas Fuchs. They give the English version of the thesis as "The development of lightweight human-powered vehicles". They review a body of work that was extremely wide-ranging, and involved building HPVs that were used for testing, transportation and competitions.

The Bicycle, a book by Pryor Dodge

A new and beautiful book on bicycle and bicycling history is reviewed by your editor. The book is full of wonderful detail photographs and diagrams and of fascinating information. A chapter on HPVs is included.

1997 Buyer's Guide: Recumbent Cyclist News

Robert Bryant's, 96-page buyer's guide for 1997 is his sixth and best. It lists data and photographs for no less than 125 models from 32 manufacturers, given in consistent and useful formats. It makes HPV enthusiasts' mouths water and their chests pubb out with pride.

Encycleopedia 4: The international buyers' guide to alternatives in cycling

This is a beautiful book prepared as a labor of love for, and celebration of, all forms of nontraditional bicycling, including various forms of HPVs. It is accompanied by a video showing several machines in action. It continues a tradition of the highest quality photography and production by Alan Davidson and their team at Open Road.

Letters

Development of small wheels from Ben Brown, toothed-belt transmissions from Theo Schmidt, William Volk and your editor, and Theo Schmidt's response to Clark Higgins.

CONTRIBUTIONS TO *HUMAN POWER*

The editor and associate editors (you may choose with whom to correspond!) welcome contributions to Human Power. They should be of long-term technical interest (notices and reports of meetings, results of races and record attempts, and articles in the style of "The building of my HPV" should be sent to HPV News). Contributions should also be understandable by any English-speaker in any part of the world: units should be in S.I. (with local units optional), and the use of local expressions such as "two-by-fours" should be either avoided or explained. Ask the editor for the contributor's guide. Many contributions are sent out for review by specialists. Alas! We are poor and cannot pay for contributions. They are, however, extremely valuable for the growth of the human-power movement. Contributions include papers, articles, reviews and letters. We welcome all types of contributions, from IHPVA members and nonmembers.

STREAMLINER AS A ROAD VEHICLE

by John Tetz

John Tetz, well-known for his innovative developments in assisted HPVs, sent in the first part of this article as an intriguing comment on the value of fully-faired HPVs even for about-town use. I felt it my duty to suggest that he submit it to the "My HPV" feature of HPV News. However, I also felt that there was technical value in relating John's enthusiasm for his vehicle with some of the design decisions he made. He willingly agreed to respond to the questions, given at the end, that I asked about his design.
—Dave Wilson

John Tetz in his streamliner

Photographs, courtesy of John Tetz

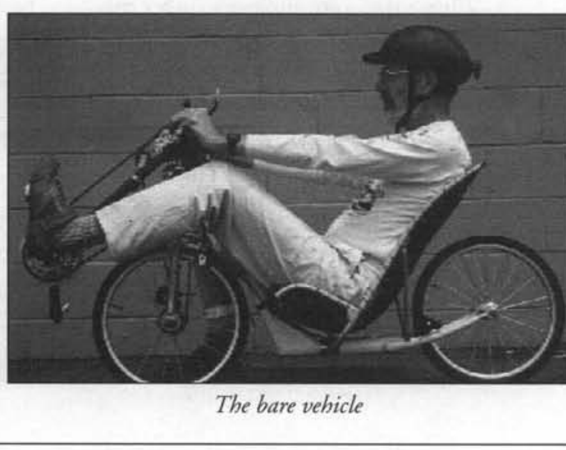
I have to run an errand uptown so I roll the hard-shell out. I open the canopy, unlatch the side door and let it swing down, then step in and settle down in the seat that's about 7 inches (175mm) off the ground. I connect the seat belt, latch the side door and close the canopy. In front of me is the handlebar, gearshift levers, brake handles, high/low-beam light switch and two little push buttons for directionals. Just in front of the handlebars are the FWD 7-speed cogs on the right and the drive gear (on the left side)—a rather attractive machinery look, particularly when the cogs are spinning.

You have the distinct feeling you are in the cockpit of a flying machine. I reset the trip odometer mounted on the single-tube frame, open the nose vents, click my shoes in the pedals, release the brakes, ease out of the driveway and turn onto the road. Within a couple of short revolutions through three gears easily brings the speed up to 15mph/24kmh on the flat road, then I coast the rest of the way to a hard left turn. Touching the brakes and checking for traffic—nothing there. I throw it into the turn, accelerating through three more gears to bring the speed up to 22 mph/35kmh. Then I quit pedaling and let it coast and coast.

The feeling never ceases to be thrilling—pure joy—while I sit back and watch the scenery roll by, coasting the 0.25 miles/400m to a busy intersection where I have to brake hard because the speed is 16mph/25kmh. Ease out on to Main street, flat and extra wide with plenty of room. I poke it up to 22–25mph and again quit pedaling. My legs are not warmed up so I take it easy while looking around, waving to neighbors, and when the speed finally drops to 20mph (which feels slow) I push it back up. A few of these and I have to come to a busy intersection 0.7mi/1.2km down the street. Crossing, I climb a small hill, crest the top and shift into the big chainring and bring it up to 28mph/45kmh. I coast along the flats about 0.3mi/480m where I have to touch the brakes before flinging it into a left turn because the speed is still 21mph/34kmh.

Two lanes have now changed into a four-lane street crossing a center-divided four-lane highway. I'm making a left turn so I go down the center line (there is absolutely no room for a bike on the right side) past the three or four cars that had passed me who are now sitting and waiting behind several others for the traffic light. I'm in front of the cars, not breathing their exhaust, looking up at the cross traffic light. When it turns orange I check for cross traffic and push off hard, quickly accelerating across four lanes just as the cars behind me start to move. I'm out of their way diving into a series of quick left, right, left, right, turns into a shopping center. I pull up to the grocery store and get out of the bike. The cars I passed at the light are still wandering around looking for a parking place. A shopper comes over to me to ask how fast will it go? I say, I just cruised the 2.5mi/4km to get here at about 20mph/32kmh and they notice I'm breathing normally. Of course the next question is what kind of a motor do you have (the most-often-asked question). The lecture begins.

So what kind of a flying machine is this? It's tiny: 72in/1.8m long, total weight 36lb/16.2kg (bike 2/3, fairing 1/3). It's easy to store, to carry on the back of a car and to carry to my upstairs shop. The fairing is constructed using the Burt Rutan moldless technique. The foam is carved down to about <0.25in/6.2mm) and covered with 5.4oz S glass on the outside and 3.7oz B cloth on the inside at the higher-stressed areas, and 1.4oz in the remainder areas. It's about 8% faster than a Lightning F-40 (set up for touring) over a 12-mi/20-km test course with a couple of steep hills, some rolling hills and flat sections.



The bare vehicle

It is not practical to use the fairing when riding with unfaired bikes. They are working to maintain 18mph/29kmh. while I am relaxing at 20–25 mph/32–40 kmh. The slightest down grade and I'm gone. The bike plugs in/out of the fairing in about six minutes so it's easy to choose either the faired or unfaired version to use. The bare bike is a FWD, 36in/900mm wheel base (a bit too short for a streamliner), with 17-in Moulton wheels. It is so small that I can throw it in the back of my 1979 Ford Fiesta. The frame is 0.035in/0.8mm wall CrMo (too flexible for a streamliner) with some carbon tubes used on the boom assembly. It is a proverbial hot rod—pure fun to throw around. It has terrific acceleration, partly due to the low dynamic mass of the wheels, and quite good aerodynamics—only about 8% slower than an F-40 on the 12-mi test course. Gearing is 20 inches to 112 inches, with three chainrings, 7-speed cogs, and a directly-operated two-speed shifter down on the front fork.

The smallness of the fairing makes developing a high-speed aero shape difficult (aesthetically, too—I call it "Tubby"). The nose is quite blunt, then widens at the shoulders at about 77% back which leaves very little remaining distance for contraction. Therefore the tail is cutoff; the widest is 6in/150mm. Combine this with an open cockpit (for ease of entry and exit, visibility, and awareness of sounds and traffic) and a hole to get the feet down: all adversely affect the aerodynamics. I am less interested in maximum speed but in reduced effort (hovering about 0.1hp, 75 watts) in the 20–30mph range. The bike easily gets up to 20–25mph. At 30mph/48kmh the effort increases noticeably but the downhill speeds are still too high for an alternative-transportation vehicle using bicycle-type equipment (tire contact area, braking distances, crash protection). Of course I could use the brakes but somehow I don't (high-speed downhill braking needs improvement).

Is a vehicle this small and low dangerous? My eye height is 34in/850mm (looking up at car-door handles). We have all heard that the lowness of recumbents supposedly makes them dangerous, but I have found this not to be true. I have been using the bare bike and the fairing for 3600mi/5760km without any problems. But I do feel this vehicle is below the limits of practicality for some conditions. As an example: when pulling up alongside cars at an intersection you can't see over the hoods (another reason for smaller cars). I have also heard a couple of complaints from car drivers. They feel I'm so low they might not see me and if they hit me they will be held responsible. The responsibility of my safety

The getting-in process

still comes down to my abilities. But meanwhile motorcycles are also hard to see, so are pedestrians, and kids are as low as I am on or off bikes, and dogs and cats are even lower. Yes, driving a 3,000-pound/1350kg, 100-hp weapon is a responsibility. I remember a large round man in a huge older classic Caddy yell out to me "You're sick". I got a good laugh out of it and wondered how much of the earth's resources he uses each day in that blunderbus.

Also, I live in a suburban area that has room on the roads and slightly less-intense traffic. If I ride in rush-hour traffic I choose more side roads. I would not want to ride the tiny bare bike in dense urban areas along streets lined with parked cars. Even the streamliner is at a disadvantage. I've ridden the Lightning F-40 through cities when on tour or when visiting someone. City riding is basically stop and go every few blocks. You'll never get to use the aero advantage, yet you're having to accelerate a larger mass. Also cooling becomes a problem. Streamliners are at their best running errands to neighboring towns.

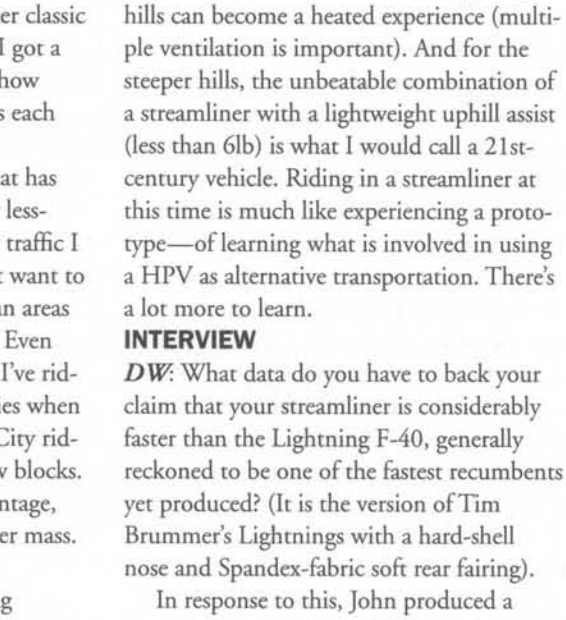
When using a streamliner in other than dense urban areas the above problems for the most part disappear. It looks like a vehicle, drivers tend to treat it as a vehicle and I use more of the road, as does a vehicle. The speed helps a lot. My town speed limit is 35mph/56kmh so when I am at 30mph/48kmh cars do not pass—or if they do, they wait until they have room. On blind curves I will drift into the middle of the lane to prevent dangerous passing, and pull over after the curve. Again this is easier to do at higher speeds.

We all know that a streamliner is faster than a unfaired bike. But how that feels is the commanding issue. I can't say enough about how satisfying it feels to be doing 20mph/32kmh or more, and be using only about one-tenth of a horse power (on many other bikes you're working at 0.2hp or higher, and it's a continuous effort). A streamliner uses so little power and it coasts for so long that I have the reserve to pedal large (for me 0.2hp) amounts of power and not use up my body. My body accepts power bursts followed by a period of rest. It's a great old man's machine. Rolling hills are leveled because you can come into them so fast you climb 'way up, lose a little speed but crest the top at say 15mph/24kmh — generally followed by a sweet downhill and back up to speed. Thrilling! This effect is important because typically there are many smaller hills. On longer hills you come to them less worn down. But climbing long hills can become a heated experience (multiple ventilation is important). And for the steeper hills, the unbeatable combination of a streamliner with a lightweight uphill assist (less than 6lb) is what I would call a 21st-century vehicle. Riding in a streamliner at this time is much like experiencing a prototype—of learning what is involved in using a HPV as alternative transportation. There's a lot more to learn.

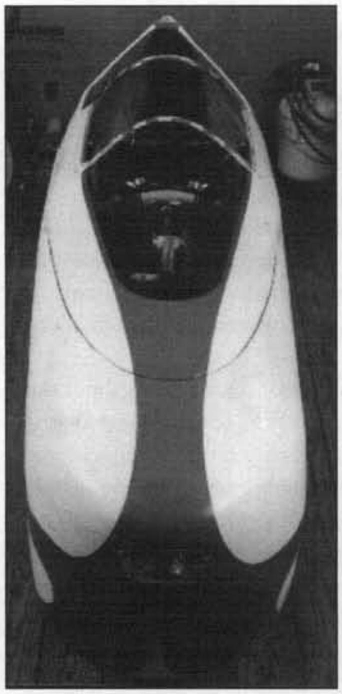
INTERVIEW

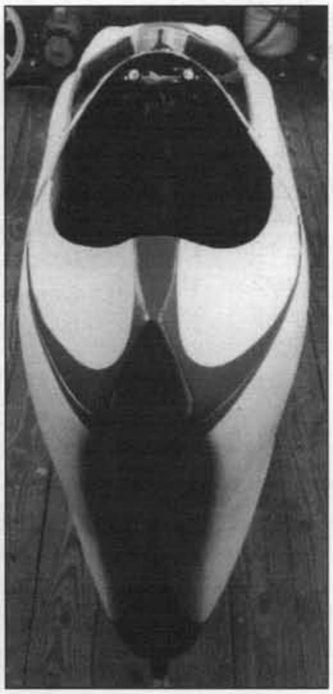
DW: What data do you have to back your claim that your streamliner is considerably faster than the Lightning F-40, generally reckoned to be one of the fastest recumbents yet produced? (It is the version of Tim Brummer's Lightnings with a hard-shell nose and Spandex-fabric soft rear fairing).

In response to this, John produced a table, given below (page 6), of carefully taken data of him pedaling his F-40, his



Nose showing pedaling bulges





Front and rear views

wheel. The F-40 is much better.

DW: Does this weight distribution with FWD give you adequate traction?

JT: I do lose traction on takeoff if there is water or dirt, even with all that weight on the front. This is a common FWD problem. I just take it easy in those conditions. In all other conditions I accelerate at a phenomenal rate. As I mentioned earlier, I generally beat the cars across an intersection at a traffic light. Upright riders haven't got a chance. I believe that this comes from the low dynamic mass of the wheels.

DW: How much snow can you handle?

JT: I might try to ride the bare bike in snow but definitely not in the fairing. The foot hole in the bottom of the fairing looks large, but it restricts how far apart you can place your feet on the ground. Therefore your feet cannot spread out enough to stabilize the vehicle easily. I must work on this. Unclipping one's feet fast enough is another problem.

DW: How is stability in cross-winds?

JT: Part of the instability comes from the short wheel base and part from frame flex. Small steering inputs create noticeable directional changes. I feel that the 36" wheel base is too short for a faired bike. It is fine as a bare bike - no wind problem at all. Being low helps. One is so low that much of the higher-velocity wind is above one.

The F-40 is much better in windy conditions (up to 30mph (13 m/s)): it has a longer wheel base, and the spandex caves in temporarily which reduces the side pressure. It may also give one more time to react.

DW: Does the low seating position give you any sense of insecurity?

JT: As I stated in the article, the eye height of 34in/860mm is a bit low when alongside a car at an intersection. One can't see over the hood. In a city situation this could be a constant problem. Where I live it is only an occasional problem. But I am raising the eye height slightly on the next design.

mountain bike, his bare front-wheel-drive recumbent (FWD) and his FWD in the hard-shell fairing on a 12-mile course of rolling hills with two steep hills, two stop signs, little traffic, about a third reasonably flat. He wore a heart-rate monitor (AVH) to show that his energy expenditure was similar in the various runs. The hard-shell does show a consistent advantage.

DW: How much does your twisting-chain front-wheel drive limit your maneuverability?

JT: There can be adequate turning capability on a twisting-chain FWD. This bike can do a 180-degree turn in about a 15-ft-diameter/4.6m circle. The short 36-in/<1m wheel base helps. Short turning radius is not high on my list. What I have is enough to do 98% of everyday use. So on occasions I might have to pedal back and for me to turn around—essentially a non-issue.

DW: How is low-speed stability on so low a machine?

JT: Low-speed stability is superb. I can easily do 1-to-2mph. Even first-time riders have no problems—and those who have never ridden a recumbent do well.

DW: The bike looks as though the weight distribution might be unusual. How does it turn out?

JT: Weight distribution with me on the bare bike is 51% on the front. That is too much forward bias for good handling on bumpy surfaces. It overloads the front

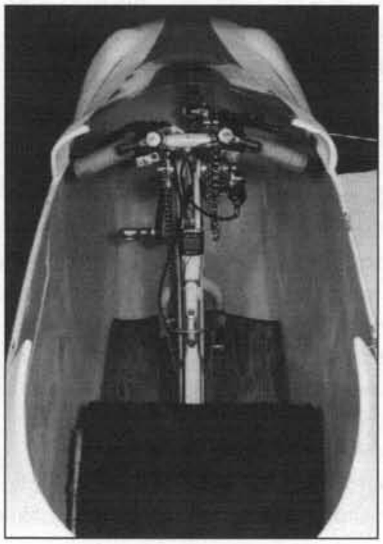
DW: Do you feel that you are visible enough to other road users?

JT: On any bike I ride as though I am invisible. From my experience I believe that the distinctive shape and color of the fairing give an additional safety factor over unfaired bikes. For most conditions I feel much more secure in the hard-shell. The bare bike is another story. I haven't had any problems but a few drivers have voiced their concern that they cannot see me. Yet I have never had a close call. The bare bike is much lower looking and indeed can be harder to see. I feel that it is not sufficiently visible for city streets or busy highways.

DW: Did you build the bike to fit you yourself, or is it adjustable for others?

JT: The bike has a moveable extension on the boom, and a movable seat. But it would take time to set it up for another rider. Chain length would have to be changed. The seat-stay spacers would have to be changed. If the boom is moved in, the cranks would probably hit the tire—absolutely not allowed. I tried to design adjustability into it but the compromises I had to deal with finally got the best of me. So I concentrated more on the other issues.

A hard-shell is not a vehicle that one can just climb in and ride away. It's not for beginners. Starting and stopping is harder because of the difficulty in getting one's feet down. Lack of a visual sense of the near-ground seems to cause balance problems. Speeds are much higher, requiring quicker reaction time. There is no elbow room. One cannot reach into one's pant pocket. At first



View of cockpit

TWELVE-MILE TEST RUN ON VARIOUS BIKES

Dates: Started 26 Feb 1996 to 1 July 1996 (averaged about 2 tests per month.) The course consists of many rolling hills with two steep hills, and about 1/3 semi-flat. Two stop signs; no traffic lights; almost no traffic.

	Bike computer readings				Heart computer readings			
Bike	Dist	AVS	Time	MXS	AVH	TM ABV	TM in	MAX
F-40	11.5	15.9	43:1	44	132	29:0	14:2	148
Mtn bike	—	—	—	54	133	39:0	13:0	150
F-40	11.6	15.4	44:3	47	134	34:0	10:2	152
FWD	10.8	14.2	45:2	37.2	134	33:4	13:0	150
FWD	10.8	14.8	43:5	36.6	132	31:1	12:4	147
Hard shell	11.9	19.9	35:3 brake	42.2	137	29:3	6:10	—
F-40	11.6	15.0	45:5 brake	39				
Hard shell	11.7	20.4	34:3 brake	38.9	134	24:0	10:1	152
F-40 w/new tire	11.5	18.8	36:3 brake	49	139	30:1	6:20	156
F-40	11.8	18.7	37:2	49				
FWD	11.8	17.1	41:3	42.2	133	28:3	—	150
FWD	11.7	17.4	40:3	43.2	137	33:4	7:00	151
FWD	11.8	17.1	41:2	44.7	135	18:1	22:5	151

AVS = average speed, mph MXS = max speed, mph
AVH = average heart rate for entire run
TM ABV = time above lower heart rate zone (75–130bpm) in minutes
TM in = time in zone, in minutes
MAX = observed while climbing, but not recorded by monitor. (Need computer down-load model.)
Hard shell = FWD in hard-shell
brake = braking down steep hill in heavy cross winds

it feels claustrophobic, but after a while there is more than enough room inside. Actually, it feels quite cozy. Many of these disadvantages are replaced by the exotic feeling of moving quickly using very little energy. The narrowness, the tightness, makes sense.

DW: Do you overheat in hot weather, and do you keep warmer in cold weather than on a bare bike? I can't keep my feet warm at 0F (-18C): can you?

JT: I find that a fully faired vehicle can be cooler than a bare bike. First, one is in the shade. Second, one is using less energy. Third, one can coast down the slightest grade where others are pedaling. I mentioned in the article how rolling hills are treated. I have been in several situations riding with others where I can cruise at 20mph/32kmh working in the 0.1-hp/75-watt range where the unfaired riders must put out double the power. With human efficiency between 20 and 25% those riders will be dripping with sweat. Venting is important. I have adjustable vents for my legs, and I need to make vents for my hands and possibly my head, without harming the aerodynamics. Sitting at a stop light on a hot day can be brutal (minimize the window area). But once in motion one is fine.

I ride all winter except in snow or ice. The combination of no wind on one's body and of heat from pedaling makes the ride quite comfortable. I use very thin gloves. A completely enclosed vehicle would be toasty inside. At zero F (-18C) my feet get cold, too. The cleats pull heat out of the bottom of my feet. I'm fine down to 20F. I must make some modifications to my shoes.

DW: Do you feel that the hard-shell fairing is an advantage in a high-speed accident because it gives you protection from road rash and some collisions, or do you feel that it might cause you to slide into the path of a vehicle?

JT: I haven't had a high-speed accident yet. I have gone down several times (most often because I couldn't get my feet down quickly enough at stops because the foot hole was too small at the time) and I just rolled over. One accident at about 14mph/22kmh resulted in the bike skidding with absolutely no injuries to me. I do wear a seat belt, mainly to keep me in the bike. Without it the tendency is to come up and out, breaking the lighter upper parts of the fairing. High-speed accidents are a problem yet to be solved. I think that I would add friction material on the sides of the fairing.

DW: Your HPV appears to be the most compact faired machine yet made. The advantages are obvious. Are there disadvantages?

JT: I think that my vehicle is about the smallest around. The disadvantages are that the short wheel-base causes too much twitchiness at higher speeds. It also requires a blunt nose and a cutoff tail.

DW: You have two equal-size wheels, something I would like to have. You don't seem to have full fenders (mudguards). Any comments?

JT: I also like same-size wheels. I think that it is important to minimize having to carry extras. (Actually I don't carry any tools, parts or pump for my local-area travels. I had to walk home only once in five years.) I don't know of any disadvantages of smaller wheels for this type of HPV. Bigger wheels would handle bumps better, but the vehicle would become bigger. Because of the high speeds, suspension is a must. Road bumps become road shocks at high speed. Suspension eliminates the FWD. That is too bad because, for a low bike, the drive train is easier than for RWD.

I don't have full fenders. The frame down tube does a pretty good job of keeping the water off me. I have plastic on the back of the seat. I am treating this bike as a prototype, and have not yet spent the time to set it up for all-weather travel.

Also I don't have a luggage rack, just a triangular piece of sailcloth attached to the seat and the fairing. This is very convenient for 90% of my cargo. Heavy pieces I tie to the seat side rails.

From what I have learned with this HPV I am designing another with RWD to allow suspension, slightly longer to improve the aerodynamic shape, and slightly higher to give me better visibility.

John Tetz is an engineer, recently retired after 38 years at Bell Laboratories, and having the time of his life. He writes that he just can't stay off his bikes. Jgtetz@aol.com

REVIEW:

WIND-TUNNEL TESTS OF VARIOUS TYPES OF BICYCLES, FAIRED, PARTLY FAIRED AND UNFAIRED IN *TOUR, DAS RADMAGAZIN* (German bicycling magazine)

September 1994, Review (and sketches) by Dave Wilson

This remarkable and valuable article has been the subject of much discussion in the Internet HPV mail list. I would have liked to have reproduced it in full. However, I received no reply to my request to the *TOUR* editors. I am grateful to David Gordon Ullman, designer and developer of the BikeE, who sent me a copy of the original article and an approximate translation by Ralf Stetter, who was visiting Oregon State University from the Technical University of Munich. Oliver Zechlin also posted copies of the two principal results tables in the HPV list, and I have used these.

TOUR arranged to use the huge wind tunnel at Ford's John Andrews Development Center near Köln. It is described as having a test section several stories high, enough for a large truck. The fan providing the flow absorbs two megawatts when producing maximum wind speed. However, the bicycles were tested at much-less-than-maximum wind speeds: 30, 45 and 60 kmh. (Divide kmh by 3.6 for m/s, and by 1.609 for mph).

TOUR obviously conducted the tests with great care and thoroughness. Beautiful photographs accompanied the article, showing riders on racing bikes in full "tuck" (including the controversial Obree position); riders sitting relaxed on unfaired recumbents; and fully faired recumbents that may or may not have contained a rider (the drag would presumably not have been affected). Many photographs showed smoke trails passing over the rider's head or over the fairing to indicate areas of flow separation. The wheels were mounted on sensitive force-measuring platforms.

The data produced in these tests must be about as good as we can expect to get in this type of test. Some very valuable results have been produced. Wind-tunnel tests usually have two significant deficiencies. One is that there is usually no moving ground plane. The airflow passes over a stationary rider at the same relative velocity that the rider would have when riding the machine on the road. However, in the real case the road is stationary and the wheels are rotating. The wind-tunnel tests produce flow that is different to that in actual riding. We hope, of course, that the relative results are still valid. All the machines are tested with the same stationary ground plane (and, incidentally, the same rider); all should be affected similarly; and therefore differences in results should reflect the aerodynamic characteristics of the machines in other important respects.

The second deficiency of wind-tunnel tests is that the riders were required to stay as still as possible so that the instruments would give consistent and repeatable readings. This is justifiable in this type of test. In practice, riders and their machines are moving, sometimes jerking, in response to rider and road inputs, and the air flow might be significantly affected. More important, however, particularly for unfaired machines, is the enormous effect of the rider's whirling legs. These must disturb the air flow very greatly. It has always seemed strange to me that we streamline, for instance, the brake calipers that are already largely in the "stagnation-point region" in front of the fork crown, while relatively huge knobbly knees and muscular legs are thrashing around behind them in the full air flow. We need some adventurous individual or team to run some coast-down tests on a similar range of machines to those tested here, with the rider's legs stationary in various positions, and rotating (with the chain disconnected) to find the effect of leg rotation plus some additional wobble. Such tests could complement the *TOUR* results.

But the Tour team carried out its own realistic tests on bicycles being ridden on the Olympia velodrome at Büttgen to compare with those in the wind-tunnel. The instrumentation was provided and operated by Ulrich Schoberer, a highly respected experimentalist.

THE MACHINES AND THE RESULTS

Ten bicycles were tested: five were recumbents (see figure 1). Each was top-of-the-line in its class. The non-recumbents included a mountain bike, ("Heavy Tools Equipe R2"); a road-racing bicycle ("Cadex"); an aluminum-frame triathlon ("Principia SC 650"); a time-trial bike ("Davinci"); and a Moser track bike using the position in which Graeme Obree won the world hour record. All except the Moser had Spengle disk rear wheels and Spengle tri-spoke front wheels. The Moser had an Ambrosio disk rear wheel and a radial-spoked front wheel. Every machine was mounted by one rider, Axel Fehlau of the German Vector team (and brother of Gunnar Fehlau, author of *Das Liegerad*—the recumbent) in the wind-tunnel tests, and ridden by him in the velodrome runs.

The recumbents included a Peer Gynt LWB Avatar-like machine; a Radius 16V SWB with a high bottom-bracket position; a very low SWB, the "Aeroproject" in which the chain goes almost diametrically across the front wheel giving limited steering capability; the "Flux", having an almost identical layout but with a streamlined faired compartment behind the seat; and Bram Moens' fully faired record-breaking "M5 Carbon Low Racer".

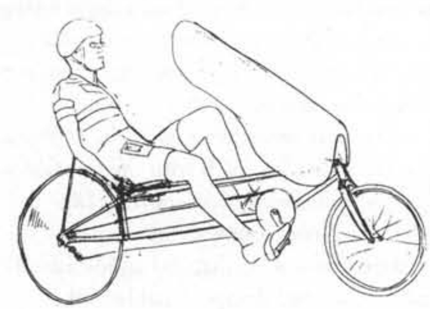


Figure 1. Partially-faired long wheel-base recumbent

The aerodynamic resistances of these bicycles were measured as the product of the coefficient of drag multiplied by the frontal area in sq.m., and are given in table 1. The frontal area should not change with speed; however, the coefficient of drag can change because of changes in the flow pattern ("Reynolds-number effects"). The values are given at 45 and 60 kmh. The values at 60 kmh are usually a few percent lower except for the M5, which went up by seven percent. A very small change in vehicle position, angle etc. could produce changes greater than these differences.

The results showed data that were expected and some that were surprising.

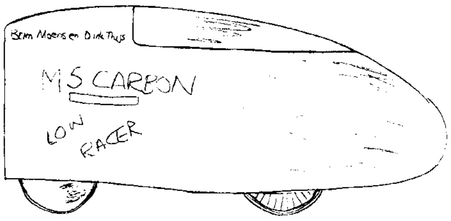


Figure 2. Sketch of Bram Moens' fully faired M5 Low Racer

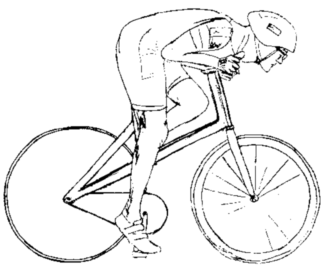


Figure 3. Moser bike

TABLE 1. TOUR WIND-TUNNEL TESTS: RESULTS

Type of bicycle km/h	CwA (m^2) 45	CwA (m^2) 60	frontal area A (m2)	Cw 45	Cw 60	Drag (N) 45	Drag (N) 60
M5 Low Racer, faired	0,044	0,047	0,348	0,16	0,16	4,6	7,8
Flux SWB, rear fairing	0,194	0,187	0,348	0,56	0,54	18,1	31,2
Aeroproject SWB	0,236	0,236	0,320	0,74	0,74	22,4	39,5
Moser bike	0,214	0,236	0,420	0,51	0,49	20,1	34,0
Principia set low	0,235	0,231	N.A.	N.A.	N.A.	21,88	38.1
Principia normal setting	0,264	0,260	0,403	0,66	0,65	24,8	44,0
Cadex road-racer	0,252	0,242	0,460	0,55	0,53	23,8	40,1
Radius V16 SWB	0,282	0,279	0,398	0,71	0,70	26,6	46,3
Radius PeerGynt, unfrd.	0,415	0,402	0,563	0,74	0,71	28,9	66,4
Peer Gynt, front fairing	0,436	0,428	0,585	0,75	0,73	40,9	71,0
Mountain bike	0,391	0,385	0,573	0,68	0,67	37,1	65,4

Moens' M5 Carbon Low Racer had by far the lowest CdA at 0.044. The largest was not the mountain bike (0.391) but the LWB Peer Gynt (0.415). A Zzipper front fairing was also fitted to the Peer Gynt but gave an even larger CdA: 0.436. In the later velodrome tests it was found that a slight change in angle of the front fairing could make a large change in drag, giving a drag considerably below that of the bare machine.

The next-lowest drag (after the M5) was given by the Flux SWB with the rear fairing (0.194) followed by Moser's track bike (0.214). The Aeroproject, like the Flux without the rear fairing, had almost identical drag to the Principia triathlon bike (0.235-6) set at its lowest handlebar level. However, Axel Fehlau found that he couldn't pedal the bike for long at this setting on the velodrome, and at more-normal handlebar height the drag was 0.264. Between these two results were that of the Davinci time-trial bike (0.246) and of the Cadex road-racer (0.252). The SWB Radius 16V, like the Peer Gynt LWB, had a drag higher than all the "regular" bicycles, at 0.282, except for the mountain bike, 0.391.

Thus the surprising finding: unfaired recumbents (with riders) have higher aerodynamic drag than unfaired regular bicycles.

These findings were confirmed in the velodrome tests (table 2). Ulrich Schoberer fitted torque-measuring cranks and presumably a rotation readout, and so obtained mean power (watts) put in to the pedals by the rider. Measurements were made at 30, 45 and 60 kmh. Some drag forces, such as those from bearing friction and rolling friction, increase only slowly with speed; the power losses would therefore be a little more than proportional to speed. Aerodynamic friction from laminar-flow boundary layers (the flow right against the surfaces) is approximately proportional to speed, and from turbulent flow is proportional to the square of the speed. The power losses would then be approximately proportional to speed squared and speed cubed, respectively. The M5 took 50 watts to go at 30 kmh (Axel Fehlau had difficulty keeping the speed down to that level because the power required was so low) and 200 watts at 60 kmh, indicating that much of the aerodynamic drag was from laminar flow. (Laminar flow is usually desirable because of its low-drag characteristics.) Most of the other machines took much more than four times the "30-kmh" power to travel at 60 kmh, from which it may be inferred that most of their drag was from turbulent flow. The Flux and Aeroproject required about six times the power, and others were in the same range. In some cases Fehlau was being asked to put out over a kilowatt of mechanical power, and it would be expected that in these circumstances he would be "throwing the bike around" in his efforts to reach the required outputs. Thus we can conjecture that a wobbling bike needs about fifty-percent more power to propel it than would a steady bike. (This is more evidence in favor of my favorite method of breaking the speed record: do it on rails).

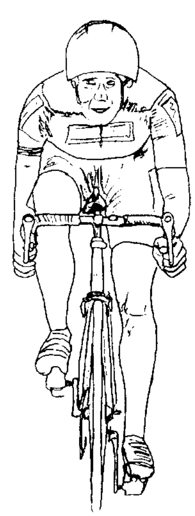


Figure 4. Front view of Cadex road racer

CONCLUSIONS

These results are of very great interest for recumbent builders and users, and will presumably come as a shock to many.

1. Unfaired recumbents, long and short wheelbase, under-seat and above-seat steering, have higher drag than the best diamond-frame bicycles.

2. A tail-cone type of fairing (including a streamlined luggage compartment) is enough to reduce recumbent drag by around 20 percent and to bring it down below that of unfaired road- and track-racing bikes.

3. Front fairings on recumbents can reduce the drag by around ten percent. However, a small change in angle can also produce an increase in drag over that of the bare machine.

4. We hope that *TOUR* or another group, could fill in the gaps in its very valuable tests by measuring the drag of recumbents with partial front and rear fairings,

TABLE 2. PEDALLING POWER (WATTS) REQUIRED IN TESTS AT A VELODROME

Type of bicycle	30km/h	45km/h	60km/h
M5 Low Racer, full fairing	50	106	200
Flux ultra-low SWB, rear fairing	95	263	572
Aeroproject low SWB	107	305	671
Moser bike	109	311	685
Principia SC 650 triathlon	119	346	768
Davinci time-trial	121	355	790
Cadex road-racer	127	373	832
Radius 16V	127	374	834
Radius PeerGynt, front fairing	136	405	908
Radius Peer Gynt	148	447	1007
Mountain bike (Heavy Tools)	152	460	1038

such as some Lightning Cycle Dynamics models and such as the Delaire Rotator, for instance.

Review by Dave Wilson

LETTER

Development of small wheels (Ben Brown)

Development of small, efficient wheels is a worthy goal in the field of HPVs because of their clear advantages in terms of weight, packaging and aerodynamics. The comparison of rolling resistances of small wheels vs. more-common large bicycle wheels is an important step in this process. Therefore, I was interested in Ian Sims's article "Greenspeed Tyre Testing" (Human Power, vol. 12:13, Winter-Spring 1996). Unfortunately, the author's test method does not allow a valid comparison among varying tire sizes.

Ian reports that he used a 4.5-inch-diameter drum as his test "road surface" because it was simple, inexpensive, and could be directly driven by an available motor. The problem is that running a 27-inch tire on a 4.5-inch drum is much like running a 4.5-inch tire on a 27-inch drum in terms of the contact patch shape and distortion of the tire body, which accounts for much of the frictional loss. We would expect that measured rolling coefficients on the small drum would be substantially higher than on a flat road, and that the differences among various tire diameters would be deemphasized by this test procedure. The former is confirmed by a calculation of the rolling-resistance coefficient of 0.008 for Ian's best test case (20 watts at 30 kph and 294 N load), which is two or three times the value typically reported for good road tires. The latter hypothesis is consistent with Ian's finding that, based on this test method, small wheels are as good as, or better than, the large. I would love to believe this conclusion, but it is counterintuitive and contradicts the theory and data that have been developed over many decades.

I am hopeful that, with the hard work of Moulton and others, small wheels with appropriate suspensions will allow our HPVs to be smaller, lighter and more efficient than they are today. But I'm afraid that Ian Sims' tests do not provide valid confirmation of the superiority of small wheels at present.

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Reciprocating-drive recumbent tricycles for young riders with disabilities

by Stefan E. Radloff and John M. Henshaw

ABSTRACT

A two-year project focused on the design and development of a three-wheeled human-powered vehicle for children with disabilities. The goal of the project was to design and construct vehicles that are usable by a wide range of children who cannot ride conventional bicycles or tricycles, providing both therapy and independence. The vehicles were designed for rehabilitation and recreation of children with spina bifida, cerebral palsy, or similar conditions. The tricycles feature recumbent seating and are powered by reciprocating leg motion. A first-generation design focused on proving the concept and design, while a second-generation tricycle simplified the first vehicle. Both vehicles have proven successful over several years of use.

INTRODUCTION

Children with disabilities present a challenge to the designer of human-powered vehicles. Yet it is a challenge well worth the effort, since such children can benefit greatly from the physical and spiritual rewards inherent in human-powered vehicles, just as the rest of us do. This paper describes a two-year project to develop tricycles for children with neuromuscular disorders such as spina bifida and cerebral palsy.

Spina bifida is a birth defect in which the embryonic spinal cord does not form correctly during the early development of the fetus. Closure of bone and muscle around the spinal cord is thus also impaired. Common symptoms of spina bifida are hydrocephalus (fluid buildup in the brain), weakness, loss of feeling, or paralysis of the legs, and possible loss of bowel and bladder function. Treatment includes surgery with continuing exercise and physical therapy. Spina bifida is one of the most common birth defects, occurring in about one in a thousand births.

Cerebral palsy is caused by an injury to the brain before, during, or shortly after birth. The injury can be caused by high blood pressure or diabetes in the mother, an infection, or a difficult delivery in which the baby's brain is injured. Cerebral palsy damages the area of the brain that affects movement and muscle coordination, causing problems ranging from mild awkwardness to severe physical disability. Treatment primarily includes physical, speech, and occupational therapy. Like spina bifida, about one in one-thousand children is born afflicted by cerebral palsy.

The recipient of the first tricycle, Kramer, is an active boy with spina bifida. He was seven when he received his tricycle. Kramer has limited use of his legs. He has no feeling in his feet, and wears leg braces to keep his feet pointed forward. Kramer can walk, and even run short distances, but he tires easily because some of the muscle groups in his lower legs are underdeveloped.

Despite many attempts on several tricycles, Kramer lacks the coordination in his legs to perform the rotating motion required to power a conventional tricycle or bicycle. Kramer's parents had purchased several tricycles for Kramer, including an expensive tricycle custom built especially for Kramer that is powered with combined arm and leg power. All of these tricycles proved to be ineffective. As a result, Kramer's attempts at fun and exercise frequently ended in frustration.

If Kramer represents the upper bound of disabilities that can benefit from the type of tricycle described herein, the recipient of the second-generation tricycle, Jamie, can be considered the lower bound. Jamie, who has cerebral palsy, was 8 years old when she received her tricycle. Jamie has never been able to walk or otherwise move under her own power (she lacks the arm strength to move her own wheelchair), and requires side support to maintain an upright seated position. Unlike Kramer, who was already physically active, the only exercise that Jamie received was boring and repetitive physical therapy. Jamie's doctors and physical therapists felt that the rehabilitative benefits of a tricycle that Jamie could actually ride would be significant.

While Kramer could exert 356 N (80 lbf) with both legs from a recumbent position, Jamie could exert only 89 N (20 lbf). These values were determined with a simple test - with the kids sitting sideways in a doorway in a recumbent position and pushing as hard as they could on a vertical bathroom scale. The door frame and a cushion on one side provided back support while the opposite frame provided a solid surface on which to place the scale.

The results of these tests suggested that a reciprocating drive system might be appropriate for riders like Jamie and Kramer. Reciprocating-drive (linear-drive) human-powered vehicles have been around for a long time[1] but have never received wide acceptance, for a variety of reasons. The standard rotating drive system has proven relatively efficient, simple, and durable. One aspect of rotating-drive systems that is not usually considered is the significant coordination that is required to make the rotating leg motion necessary to propel a machine by this technique. As noted above, Kramer was unable to make this motion, yet he could exert significant force in simple "reciprocating" fashion. For Jamie, whose disabilities were much more daunting, it seemed advisable to keep the drive train as simple as possible. Thus, it was determined to pursue reciprocating-drive systems for these vehicles.

The recumbent position likewise suggested itself, as it improves leverage in force generation and lowers the center of gravity of the rider and vehicle. The stability provided by a three-wheeled vehicle was also deemed necessary. Four-wheeled concepts were discarded as needlessly complex and heavy.

DESIGN GOALS

The primary design goal of this multi-year project was to develop a tricycle that was usable by the widest possible range of children with neuromuscular disorders. Children such as Kramer and Jamie afflicted with either spina bifida or cerebral palsy represent a significant number of these children.

Despite their wide range of disabilities, we determined early on with the bathroom scale-test described above that Jamie and Kramer could perform a simple pushing motion and apply significant force with their legs, particularly in the recumbent position. It was this ability that was used to power both generations of tricycles. Combined with leg power, recumbent seating allows for the use of a high percentage of the rider's available power.

Several other important goals were also considered as part of the design process. Safety was a primary concern, especially with respect to stability and braking. The vehicle was to be as lightweight and portable as possible. Their tricycles needed to be adjustable so that both Kramer and Jamie would not quickly outgrow them. It was also important that the design not be a custom fit, that is, the tricycle needed to be ridable by a wide range of disabled and able children. When possible, standard bicycle parts were used to help minimize machining and repair costs. Effort was also made to minimize overall cost of the finished product. Finally, it was important to make using the vehicle fun. For Kramer, fun was synonymous with fast, and for Jamie, fun would be simply the ability to move under her own power.

FIRST-GENERATION DESIGN

After considering several reciprocating-drive mechanism concepts, a final concept was chosen for the tricycle as shown schematically in figures 1 and 2.

The first-generation tricycle is a recumbent design, allowing Kramer to push against the seat back as he applies force to the pedals. Pedal force is transmitted through the cable crank and a cable to a one-way-clutch mechanism. When force is no longer applied to the pedal, a return spring pulls the cable and returns the pedal to its starting position. From the one-way clutch, force is transferred via a chain through a five-speed hub to the rear axle. The return spring is necessary because spina-bifida and cerebral-palsy children, while possessing excellent leg-extension strength as described above, often have difficulty retracting their legs for the start of the next stroke.

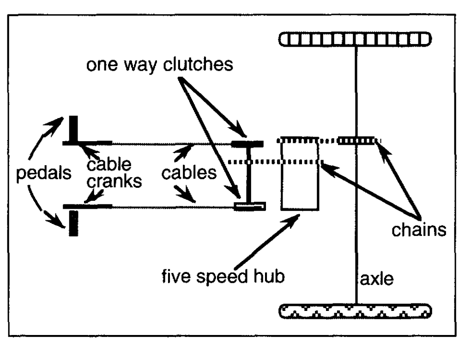

Figure 1. Top view schematic of first-generation tricycle drive train

An important feature of the drive-train mechanism is that the two pedals are not linked together. The pedals can be pushed independently, or both can be pushed at the same time. The five-speed hub is internally geared, allowing stationary shifting as well as providing the low gear ratios to climb hills and high ratios for higher speeds.

Finally, the first-generation design includes custom pedals that secure Kramer's unfeeling feet against slipping, and also allow Kramer to get his feet in and out of the pedals quickly and safely without assistance. The tricycle was constructed using a welded frame of straight-gage carbon-steel tubing, and with as many standard bicycle parts as possible to reduce cost and allow for easy maintenance. Specifically, the standard parts include the 20-inch wheels, handlebars, internally geared hub, front drum brake, chain, crank arms, recumbent seat, and drive cog. The cable crank, pedals, and one-way clutch were custom made. For ease of use and because of the configuration of the frame, a single drum brake mounted on the front wheel was used to brake the tricycle. Drum brakes provide smooth, reliable braking action, and are easier to mount and less susceptible to fading in wet conditions than conventional caliper brakes. For seating, a standard aluminum-and-nylon-mesh re-cumbent bicycle seat was used. A simple frame manufactured from square aluminum tubing both attached the seat to the frame and allowed front-to-rear changes in the position of the seat. The first-generation prototype weighed about 23 kg (50 lbf), and had a total materials and assembly cost of about $1700, including design, development, construction of the test model, and testing.

FIRST-GENERATION TESTING

Before constructing the first-generation prototype, a preliminary test model was constructed by modifying an industrial-grade, adult-size tricycle (of the type often seen in factories). The test model or "mule", shown in figure 3, proved that the proposed drive mechanism worked. The design team observed Kramer extensively while he rode the test model, both outdoors and indoors on a modified set of bicycle rollers. These tests proved to be important in modifying the design of the final prototype that was delivered to Kramer. Tests of force exerted versus leg position showed that Kramer could apply the least amount of force to the pedal when his legs were the least extended.

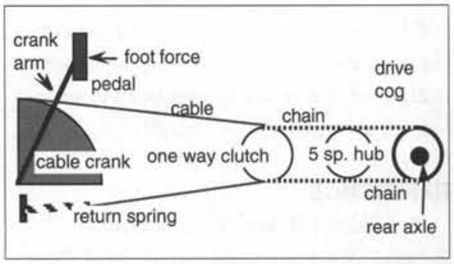

Figure 2. Side view schematic of first-generation tricycle drive train

Figure 3. Kramer rides the first-generation "mule" (a converted industrial tricycle) used to prove the concept.

Figure 4. Kramer on the first -generation trike.

Thus, a varying radius was added to the cable crank, allowing for increased leverage as Kramer's leg is extended, while decreasing the amount of force required in positions where Kramer is weaker. At the beginning of the stroke the 76-mm (3.0 in) cable-crank radius provided a short moment arm; at the end of the stroke the cable-crank radius and moment arm increased to 127 mm (5.5 in). Also, the ideal design, placement, and travel of the pedals were determined using the test model. Seat position, location of the handlebars, crank-arm length, and head-tube location were also established using the test model.

Once the design was finalized, the first-generation prototype was constructed and then tested, as shown in figure 4. Testing of the prototype showed that Kramer was able to ride the tricycle not only on level pavement, but up the rolling hills in his neighborhood. He could also ride "off road" on grass and up a standard building-access wheelchair ramp. Kramer instinctively pushed both pedals at the same time when starting from a stop to achieve maximum torque, and then switched to alternating-foot pedaling as he sped up to achieve a maximum level-ground speed of around 4.5 m/s (10 mph). Since receiving his tricycle, Kramer has ridden it on family outings of 5 km (3.1 miles) and more. (His favorite trip includes a pit-stop at the ice-cream parlor.) According to his parents, he keeps up "pretty well" with his older siblings on their two-wheelers.

SECOND-GENERATION TRICYCLE

Jamie, the "lower bound" (with respect to her physical disabilities) of the intended riders for these tricycles, was the recipient of the second-generation tricycle. The design of the second-generation tricycle is shown schematically in figures 5 and 6. Once again, however, the intent of this design was not a custom fit for Jamie, but simply an improvement over the first generation. The main areas to be improved were: weight reduction, simplification of the drive train, reduction of steering input motion, a steeper head tube angle, an improved seat attachment, and finally, a further reduction in the amount of custom hardware required to build the tricycle. The second-generation design includes a simplified drive-train mechanism. The mechanism is conceptually similar to the first, but the much smaller one-way clutches and pedal-return springs are incorporated into the bases of the custom crank arms. The changes reduced the number of separate components in the drivetrain, resulting in a simpler and lighter mechanism. The overall weight of the second-generation prototype is 16 kg (36 lb), a 7-kg (15 lb) weight savings over the first generation. Much of this weight savings is in the drive train. The second-generation design also included a custom-designed seat for Jamie with side supports, as well as a redesigned steering mechanism. In the second-generation design, the seat is modular, that is, a standard recumbent seat can be attached to the frame, or a custom fitted seat can be used if necessary for riders like Jamie.

The second-generation tricycle included a major modification to the steering. The first-generation tricycle steers conventionally with flat bars connected rigidly to a steering tube. Because of the long wheelbase, this requires a relatively long stem to bring the bars back to the rider. The long stem in turn requires significant "bar motion" to execute, for example, a 90° turn. This did not prove to be a difficulty for Kramer, who has very good upper-body strength and flexibility. However, in test rides on Kramer's tricycle, Jamie had a great deal of difficulty steering. She could rotate the bars somewhat, but not enough to execute simple steering maneuvers. This was mainly due to her lack of upper-body flexibility. Thus, the steering for the second-generation tricycle was redesigned, as shown in figure 7. The handlebars and steering tube are mounted in a vertical tube attached to the frame about mid-way between the seat and the front wheel. (By moving the steering tube much closer to the rider, it was possible to use a much shorter stem.) The steering tube is connected to the fork via a horizontal linkage. This linkage is connected by ball joints to both the bottom of the steering tube and the right blade of the fork. Thus, when the handlebars are rotated, the linkage translates the motion into a rotation of the fork. For Jamie, this meant much less steering motion was needed to control her tricycle than on Kramer's first-generation design.

The first time that Jamie rode her new tricycle was the first time in her life that she had moved herself under her own power. She was ecstatic beyond words, and there wasn't a dry eye among those who attended this "test ride". Jamie was able to ride the tricycle on flat, paved ground for long distances (hundreds of yards), maintaining a walking pace of 2–3 miles per hour. She was also able to steer the tricycle acceptably, executing figure-eights, U-turns, and other maneuvers on a parking lot. It was all her mother could do to separate her from the tricycle when this first test was finally over.

SAFETY

Although the primary goal of these tricycles was functionality and ridability, safety was a significant concern. Several safety features were incorporated into the design of both tricycles. First, the three-wheeled design adds stability from tipping, especially at low speeds or when the tricycle is not in motion. The recumbent seating provides a

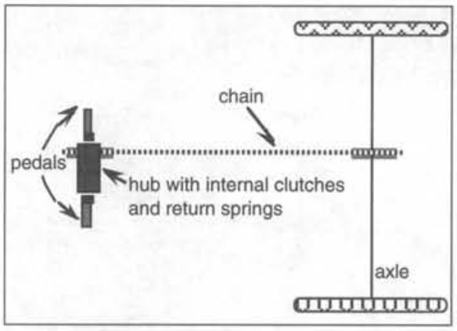

Figure 5. Top view schematic of second-generation tricycle drive train.

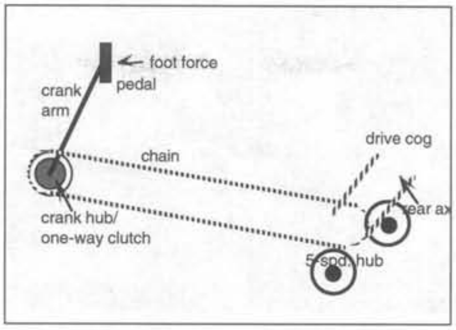

Fig 6. Side view schematic of second-generation tricycle drive train

lower center of gravity than an upright design. This is important for riders with disabilities who may also lack coordination and balance. The low center of gravity increases the stability of the tricycle. A single front-wheel brake has proven effective on both machines. The recumbent and relatively aft position of the rider relative to the front wheel help make this a stable situation.

Because of the drive-train design, these tricycles cannot roll backwards. Like a conventional bicycle with a rotating crankset, for these tricycles to roll backwards the pedals must also rotate backwards. However, since the range of motion of the tricycle pedal is limited to about 90 degrees by mechanical stops, the tricycle cannot roll backwards more than a single pedal stroke's distance. This feature prevents the rider from rolling backwards if he or she tries to ride up a hill that proves to be too steep, and also makes it easier to get on and off the tricycle.

Jamie's tricycle includes a specialized seat to provide her with the necessary back and side support. The seat consists of a formed steel frame and hand-sculpted polyethylene foam cushions covered in a Lycra fabric. The seat was custom-designed and fabricated in cooperation with Jamie's physical therapist and includes several belts to help keep her in the correct recumbent position. (As noted earlier, this custom seat is modular and can be replaced with a standard recumbent seat depending on the needs of the rider.)

DISCUSSION

The prototype tricycles successfully met or exceeded the goals of the project. Most important, functioning tricycles were provided to two children with disabilities. Neither was previously able to ride a bicycle or tricycle. Jamie's first time on the tricycle was also her first experience at self-locomotion. The tricycles have provided each with independence, fun, and exercise that they previously did not have. This type of tricycle should benefit a wide range of disabled children, filling a need that has previously gone unmet.

Both Kramer and Jamie ride their tricycles frequently, and to date neither has experienced any significant problems. Kramer has now ridden his tricycle regularly for over three years, while Jamie has ridden hers for two. Kramer's trike has made several trips to the repair shop for various component failures, including most recently the failure of the custom-machined gear that connects the five-speed hub to the rear axle. For prototype machines, both have held up well under the rigors of use.

Several concepts were considered for a third-generation vehicle. Different frame designs have been examined, especially one that provides for easier mounting and dismounting. Kramer climbs right on his tricycle, and has no trouble swinging his braced leg right over the top tube. Jamie, on the other hand, will probably always require assistance getting on her tricycle, regardless of frame design. However, riders with less ability than Kramer, but more than Jamie, have revealed a weakness in the frame design. Such children can walk, and are thus relatively independent, but they often have difficulty getting their leg over the top tube when mounting the tricycle. Thus, a new design, currently in production, features a scooter-style low-slung frame that does not require raising the leg nearly as high when mounting or dismounting.

Finally, as it is in many projects, cost is an issue that could still be improved. Estimates of manufacturing costs for the second-generation design indicate that it could be produced in small lots for about $1200 per tricycle.

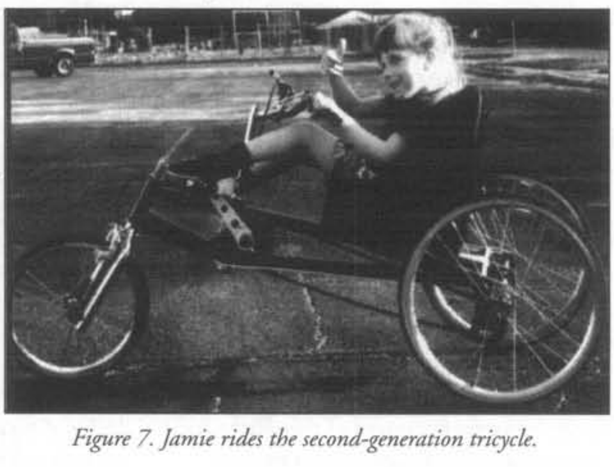

Figure 7. Jamie rides the second-generation tricycle.

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STEERING TRAILING-ARM-ANGLE DETERMINATION FOR A THREE-WHEEL HPV

by Timothy J. Gorman

ABSTRACT

The purpose of this investigation is to develop a mathematical model for determining the desired angle of steering trailing arms with respect to the steered wheels' primary axle in three-wheeled vehicles. This angle will minimize tire "scrub", or the forced sideslip through the turn. It was also necessary to quantify the amount of power loss in a system whose trailing arms in their unturned state are parallel to the central vehicle plane, thereby justifying the need for this accommodation. In both cases, mathematical models were developed to describe the geometry of the vehicle's subsystems and their role in affecting the performance of the vehicle system as a whole. Approximate sample values were introduced for the descriptive variables in these equations to illustrate the salient points being made quantitatively. The results of the power-loss calculations on our sample geometry yielded values in the most extreme cases of over one watt of power loss per steered wheel, amounting to potentially 1% of total power input. This indicates a definite need for some form of accommodation. The calculations for the geometry of a compensated system show that an optimum trailing-arm angle does not exist in practice, at least for the system analyzed here. Using the closest available value results in a steering angle 98% of optimum, compared with 93% in an uncompensated system, depending on the curve size. The benefits of and ease in determining and implementing this design modification are such that it should be considered by designers using a three-wheel configuration in their vehicles. In vehicles where even small amounts of energy loss are crucial (e.g. HPVs), this design characteristic may be essential, both for the benefits of energy savings and reduction in tire wear.

1.0 Optimized steering geometry

Three-wheeled vehicles have performance characteristics which are very different from vehicles with two or four wheels. Similarly, not all three-wheelers are created equal. Each design has performance characteristics all its own. A fairly conventional three-wheeled configuration is used here as a model to demonstrate optimal steering-mechanism geometry. In this model, the steered wheels are on the front of the vehicle, with the driven wheel on the rear (figure 1). The use of the reverse configuration, namely steering wheels rear and driven wheel forward, is not recommended without understanding the dynamics involved.

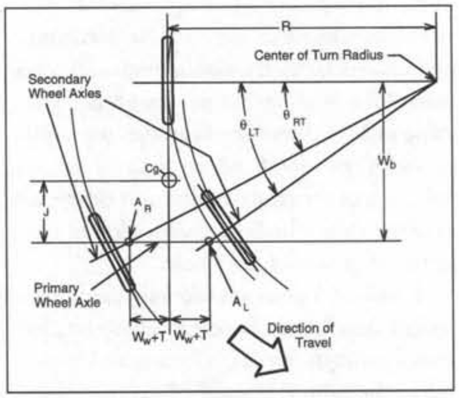

Figure 1. Geometric diagram for three-wheeled vehicle in a turn

Utilizing an appropriate compensation mechanism is required. Nonetheless, these equations will function in such a design. In either configuration, the steered wheels are mounted on two short secondary axles, with separate trailing arms, and pivot on vertical axes at A_L and A_R. The distance between A_L and A_R is $2W_W + 2\,T$ (see section 3.0 for the exact definition of the variables W_W and T). The wheelbase length is W_b. The angles with respect to the driven wheel axle that the right and left steered wheel secondary axles, respectively, should attain in an optimally compensated system through a left-hand turn are θ_{LT} and θ_{RT}.

The ideal geometry will minimize "scrub". This is the tendency for the tire to slide sideways a small amount for each increment of distance traveled forward while in the turn. Negating such additional factors as overall sideslip, eliminating scrub requires that the plane of each wheel lie tangent to an arc whose center is the center for the curve of the road itself. Each of the three wheels would consequently lie tangent to concentric arcs, their axles pointing to this common center point, as in figure 1. In essence, to minimize energy loss, the planes of the steered wheels need to "toe out" slightly. Otherwise, the result is a "snowplow" effect similar to what one does when stopping on skis. The angle of the wheel with respect to the motion of the body mass causes a certain component of the forward momentum to translate at a right angle to motion, and thus be lost

$$\theta_{RT} = \text{Arctan}\left(\frac{W_b}{R+W_W+T}\right)$$

Eq. 1: Optimum outside (right) wheel-axle angle in turn

$$\theta_{LT} = \text{Arctan}\left(\frac{W_b}{R-W_W-T}\right)$$

Eq. 2: Optimum inside (left) wheel-axle angle in turn.

through the heat of friction between the tire and the road. Isolating the outside (right) and inside (left) steering wheels, their optimum angles with respect to the central axis of the vehicle can be expressed in equations 1 and 2.

These formulae are derived through simple trigonometric evaluation of the vehicle's geometry in the turn. Using sample values for the dimensions of a typical three-wheeler, we perform calculations of these formula for various turn radii. Figure 2 illustrates the relationship between these two angles through the turn range. Clearly, there is a definite discrepancy between the optimum steering angle for each wheel, increasing as the turn radius decreases. In a system in which this difference is not compensated, the resulting geometric offset is made up in "scrub".

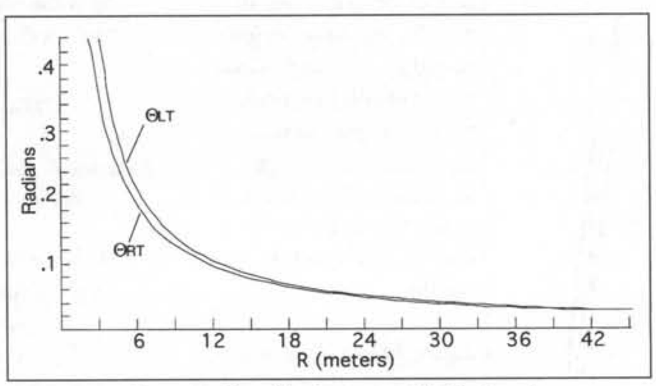

Figure 2. Plot of optimum outside (θ_{RT}) and inside (θ_{LT}) wheel angles.

2.0 Calculating power losses due to tire scrub

The amount of power loss in a system whose trailing arms are perpendicular to the secondary axles of the steered wheels is determined by the "degree of scrub" (θ_D) for each wheel. This can be defined as the angular offset between the optimal turn angle of a properly compensated system and that of a system whose wheels stay parallel to each other. In the uncompensated system, the distance between the points where the tie rods connect to the trailing arms remains the same throughout the turn. Energy is lost from the system through the lateral velocity vector V_L (see figure 3). Calculating V_L requires that we know both the forward velocity V (in meters/second) and θ_D, according to the vector analysis in equation 3:

$$V_L = V\sin\theta_D$$

Equation 3

For each wheel, finding θ_D is a matter of determining the difference between the optimum wheel angle and that achieved with perpendicular trailing arms, using equation 4:

$$\theta_D = \frac{\theta_{LT} - \theta_{RT}}{2}$$

Equation 4

This equation assumes that the total angular differential will be evenly distributed between both steered wheels, and automatically establish an equal θ_D between them. Under realistic conditions, this will necessarily not always be the case. However, as one wheel establishes a more optimal line, reducing scrub, the other will always go farther away, increasing scrub losses by a comparable amount. This equation may not model the system for all possible variations in left-to-right wheel-angle deviation, but will be adequate for the purpose of this investigation. A rough assessment of the total power loss in the entire system is the quantity sought.

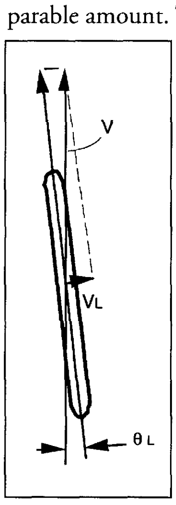

Figure 3 (left). Force-resolution diagram for uncompensated wheel.

The quantity of power loss per steered wheel can be estimated through the use of the base equation 5.
This calculation assumes no resistance to motion, and thus no power loss, in any force vector that proceeds in the plane of the wheel. The velocity vector perpendicular to the plane, V_L, will attempt to drag the wheel sideways. This friction-generating vector multiplied by the force required to drag the tire against the pavement gives us the power lost through this vector, in watts. The frictional force is determined by the proportion of the normal force M on each steered wheel, in kilograms, converted to Newtons and multiplied by the sliding frictional coefficient of rubber against pavement, μ_K. The value of M is determined through the application of equation 6, which analyzes the distribution of the entire vehicle and rider mass over the three wheels by the location of the center of gravity of the whole.

Equation 5 does not take into account weight-distribution factors that may be generated through centrifugal forces and body roll in the turn. It is assumed that as weight increases over one wheel, it will decrease comparably on the other, equalizing the full-system value. Nor does it accommodate such variability caused by swerving or wheel wobble. Rather, it gives us an averaged approximation, as if these forces were not present. For the purpose of these calculations, this will be adequate. More precise evaluation of these other forces become more crucial in the more detailed aspects of steering-system design.

$$P_L = \frac{M\mu_k V_L}{9.81}$$

Equation 5. Total single-wheel power loss (in watts) by uncompensated turned wheels:

(M is the wheel load (kg), and μ_k is the coefficient of sliding friction.

$$M = \frac{W_b M_T - W_b J}{2W_b}$$

Equation 6. Calculation of individual wheel load for three-wheeled vehicle.

(M_T is the weight of the vehicle (kg); J is the distance from steered wheel axle to center of gravity, and W_b is the wheelbase length.

To arrive at a general equation for power loss, we first incorporate equations 1 and 2 into equation 4, and equation 4 into 3. We then incorporate the resultant along with equation 6 into equation 5 to arrive finally at equation 7, the general equation for power loss from uncompensated turned wheel (for both wheels, multiply by 2):

$$P_L = \frac{V\mu_k(W_b M_T - W_b J)\sin\left(\frac{\mathrm{Arctan}\left(\frac{W_b}{R+W_w+T}\right) - \mathrm{Arctan}\left(\frac{W_b}{R-W_w-T}\right)}{2}\right)}{19.62W_b}$$

Equation 7

To analyze equation 7, we introduce values descriptive of the geometry and weight of a typical three-wheeled recumbent-type vehicle with rider (variables W_b=1.07m, W_w+T=0.46m, M_T=90kg, and J=0.4m). For the sliding frictional coefficient μ_k, an apparatus was constructed to measure the friction of a typical high-pressure bicycle tire against concrete. This test yielded an average value of 1.2. A full analysis requires that we evaluate equation 7 across a full range of both velocities and turn radii. The data in table 1 give the total power loss for each steered wheel and are shown graphically in figure 4. From the data, it is apparent that power losses maximize at lower turn radius and increase with speed. This makes logical sense as, from the discussion in section 1.0, the differential between optimum θ_R and θ_L also increases at lower radius. The values shown at very low radius and very high speed would in all likelihood never occur, because the chances of there being a steering system that would allow this kind of dynamic turn are slim.

3.0 Calculating optimized trailing arm angle to minimize energy loss

Modifying trailing-arm angle is a common technique that has been used extensively in the design of vehicles to minimize the amount of energy loss from tire scrub in turns. Developing the proper mathematical model to describe this system and to determine the optimum value is another matter. The methodology used here is presented in some detail so as to permit duplication and adaptation to related projects.

Before proceeding with a mathematical analysis of this system, it is first necessary to understand the principle behind the solution. As was stated previously, minimizing drag necessarily requires that we minimize the potential difference between the optimum angle of each wheel plane with respect

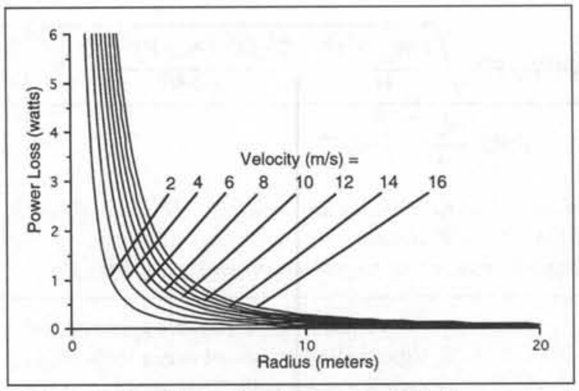

Figure 4. Plot of power loss for steered wheels of uncompensated steering system for various turn radii and velocities.

to the curve, and the actual angle. From figure 1, and from the data in table 1, we've shown that as the outside (right) wheel establishes its turn angle, the inside (left) wheel's angle must be greater by a quantifiable degree. If the trailing arm that forces each wheel to rotate about the vertical pivot at A_L and A_R (see figure 1) is perpendicular to each wheel's secondary axle, each wheel turns to the same degree. However, if this trailing arm is at some angle to the wheel's shaft other than perpendicular, each turns at a different rate. As each wheel rotates, the angle between each trailing arm and the tie rod which is controlling it gets closer to or further from 90 degrees. The wheel whose trailing arm is closer to 90 degrees to the tie rod will have a slower instantaneous rate of rotation at that point than the other.

Figure 5 shows a diagram of the geometric model which we will use to create our mathematical model. Before we create and analyze a mathematical model of our system, we will make no assumptions about whether our trailing arms should be angled inboard or outboard of the rotation points A_R and A_L, but in figure 5 they are shown angled inboard. Neither will we make any other assumptions about what the optimum dimensions of the rest of the geometry will be. Therefore, our mathematical model must be made to accommodate a wide range of possible variations in geometry. For the sake of simplicity, we will only analyze the geometry for the condition of the tie rods and trailing arms being located forward of the steering wheels' axle. The calculation where this mechanism is located between the front and rear wheels is similar in concept. Furthermore, our calculations model our system on the assumption that the tie rods and trailing rods lie as well as articulate within a single plane. Finally, the equations model the system on the assumption that the tie rods are equal in length and translate horizontally to the left and right along a straight line as the means of translating force from the steering controls to the system. These calculations will accommodate the condition where force is translated through the use of a rack-and-pinion mechanism at the tie-rod connections. For the variable T, simply enter the dimension for half the rack length.

Calculating the optimum angle for the trailing arm must proceed through a number of steps. It is possible to derive a single formula to find the desired value but, having done this, it was found that no single optimal value for θ_S exists. Furthermore, it would deny us the opportunity to check our accuracy as well as the legitimacy of our process. Though we may derive useful values as the end product of such an equation, it does us little good if values for interim variables are fictitious in a practical sense. Despite the fact that numbers don't lie, it must not be forgotten that these numbers represent real dimensions and angles on a potentially viable vehicle design.

First, we calculate the length of the tie rod for some described geometry. In order to cover a wide range of possible variations,

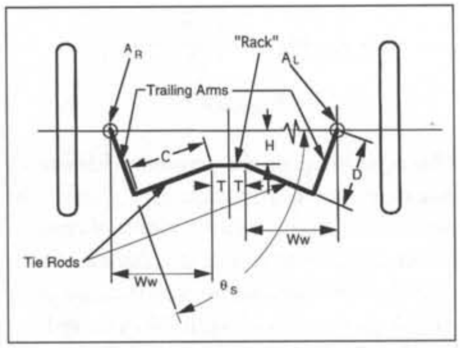

Figure 5. Geometry of steering mechanism

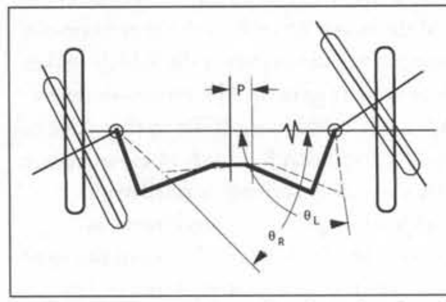

Figure 6. Rotation of the left-side and right-side wheel in a left turn

we analyze the straight-wheel geometry as one of two four-bar linkages whose sides are D, W_W, H and C. This quadrilateral is then treated as two triangles sharing a common side. This line segment, if it could be seen, would pass from the center of the vehicle at the intersection of the primary axle to the connection point of the tie rod and trailing arm. The law of cosines is used to define the characteristics of these two triangles, resulting in equation 8:

$$C=\sqrt{D^2+W_W^2-2DW_W^2\cos\theta_S+H^2-2HD\sin\theta_S}$$

Equation 8

This equation gives the length of tie rod (C) based on trailing-arm length (D), distance from central tie-rod connection to vertical pivot (W_W), distance from central tie-rod connection to primary wheel axis (H), and initial trailing-arm angle θ_S.

Second, we must isolate the optimum angle which the right wheel axle must establish through a left-hand turn. This formula is based on equation 1, modified to reflect the trailing-arm angle rather than the individual steered-wheel axle. The characteristic angle used, $\theta_{R(opt)}$ is the new angle established between the right trailing arm and the primary wheel axle in the turn, as shown in figure 6. This is a simple right-triangle solution which results in equation 9.

Table 1. Total power loss per steered wheel (watts) in a turn, in a system with parallel trailing arms

	Velocity (m/s)							
Radius (m)	2	4	6	8	10	12	14	16
2	0.679	1.356	2.037	2.716	3.359	4.074	4.753	5.432
4	0.203	0.407	0.610	0.813	1.017	1.220	1.424	1.627
6	0.093	0.186	0.279	0.372	0.465	0.558	0.651	0.745
8	0.052	0.103	0.155	0.207	0.259	0.310	0.362	0.414
10	0.034	0.067	0.103	0.138	0.172	0.207	0.241	0.276
12	0.024	0.048	0.072	0.096	0.121	0.145	0.169	0.193
14	0.017	0.034	0.052	0.069	0.086	0.103	0.121	0.138
16	0.014	0.028	0.041	0.055	0.069	0.083	0.099	0.110
18	0.010	0.021	0.031	0.041	0.052	0.062	0.072	0.083

$$\theta_{R(opt)}=\theta_S-\text{atan}\left(\frac{W_B}{R+W_W+T}\right)$$

Equation 9

This equation gives the optimum characteristic right trailing-arm angle $\theta_{R(opt)}$ based on initial trailing arm angle θ_S, radius of curve to central plane of vehicle (R), distance from central tie-rod connection to vertical pivot AR (W_W), wheelbase length (W_B), tie-rod length (C), and half rack length (T).

Our third step involves the calculation to find the lateral offset P of the central tie-rod connecting point(s) when the vehicle makes its turn (see figure 6). The process of deriving this calculation is similar to that done to establish equation 8. In this case, we analyze only the right-hand-side quadrilateral's change in shape as the wheel turns, as reflected in the change in length of the same diagonal. The quadratic equation is then utilized to solve for P, yielding equation 10 (below).

The fourth step requires that we calculate the reaction movement to the left-side four-bar linkage that the offset P causes. This will determine the left-side wheel rotation about A_L. Once again, we use the two-triangle methodology similar to that used in deriving equations 8 and 10. We solve the resultant equality for our desired value, θ_L, through the use of the quadratic equation. By this we arrive at equation 11 (above, right).

Finally, we must find out what the optimum left-wheel rotation $\theta_{L(opt)}$ should be so that we can compare it with the values derived from the analysis of equation 11. Equation 12 gives us this value. Like equation 9, it is a right-triangle solution of the steered wheel's geometry in the turn, but is based on equation 2 rather than equation 1.

$$\theta_L=\text{Asin}\left(\frac{C^2-D^2-(W_W-P)^2-H^2-2D(W_W-P)\sqrt{\left(\frac{W_W-P}{H}\right)^2-\left(\frac{C^2-D^2-(W_W-P)^2-H^2}{-2HD}\right)+1}}{-2HD\left(\frac{W_W-P}{H}\right)^2-2HD}\right)$$

Equation 11. Reaction rotation of left-side wheel based on trailing-arm length D, distance from central tie-rod connection to vertical pivot A_L, WW, distance from central tie-rod connection to primary wheel axis, H, tie-rod length C, and central tie-rod-connection laterial offset P.

$$\theta_{L(opt)}=\theta_S+\text{Atan}\left(\frac{W_B}{R-W_W-T}\right)$$

Equation 12. Optimum characteristic left-trailing-arm angle $\theta_{L(opt)}$ based on initial trailing-arm angle θ_S, radius of curve to central plane of vehicle (R), distance from central tie-rod connection to rotational axis AL (W_W), wheelbase length (W_B), and half rack length (T).

4.0 Analysis of optimization calculations

A full assessment of this system requires that we cover a broad spectrum of possible solutions for trailing-arm angles. This not only provides us with the greatest opportunity of finding a solution but also a better idea of what is happening dynamically with variations in geometry. For our ultimate goal, namely finding the optimum trailing-arm angle θ_S, we will choose a range from 0.8 radians (45.8 degrees) to 2.6 radians (149 degrees). With any luck, our solution will fall within this range, for outside of it we run the risk of two problems. First, we might run out of available rotation room. As the inside (left) wheel rotates, the trailing arm gets closer to parallel to the tie rod pushing on it. When this state is reached, the wheel assembly will not rotate any further. Second, it may become too difficult to steer. The momentum of the vehicle traveling along a straight path attempts to keep it moving along that path. Steering the vehicle involves imparting some lateral force on the road surface which will cause the mass of the vehicle to deviate from that straight line. This force is transferred from the driver's arms through the steering controls to the steering mechanism and finally to the wheels. The trailing-arm length provides a certain amount of torque around the vertical pivots A_R and A_L and an inordinately large or small trailing-arm angle reduces the effective length of this moment arm. The consequent effect would be an increased component of the force of the road being translated to the driver's arms. The actual quantity of this force and the amount which is allowable is the subject of a different paper, but suffice it to say, it is a consideration which should have some bearing on the final configuration which is used.

$$P=D\cos\theta_{R(opt)}-W_W+.5\sqrt{(2W-2D\cos\theta_{R(opt)})^2-4(H^2-C^2+D^2+W^2-2DW\cos\theta_{R(opt)}-2HD\sin\theta_{R(opt)})}$$

Equation 10. Central tie-rod connection lateral offset (P) based on trailing-arm length (D), distance from central tie-rod connection to vertical pivot A_R (W_W), distance from central tie-rod connection to primary wheel axle (H), and optimum characteristic right trailing-arm angle.

The wide range of possible solutions for θ_S should also be assessed over a wide range of possible curve radii. This would ensure that the solution which we arrive at will operate effectively through the full range of wheel turn. Furthermore, it would give us an adequate representation of the dynamic functionability [funtionality] of all the components in the system at the extremes of motion. We will use a range from 2 m (a sharper curve than a tight right-hand urban corner) to 30 m. The latter value is not the greatest radius one might encounter, but as we will see, when steering around very gradual turns of higher radius, the amount of wheel-assembly rotation is so minute that trailing-arm angle makes little difference towards accommodation.

Table 2 gives solutions for tie-rod length C in a sample steering system, calculated using equation 8, across the full range of θ_S. In this steering system, W_W (tie-rod lateral dimension) = 460 mm, W_b (wheelbase dimension) = 1070 mm, D (trailing-arm length) = 120 mm, T (half "rack" length) = θ, and H ("rack" to primary wheel axle dimension) = 120 mm. Also in table 2 are values for the optimal right-wheel assembly rotation $\theta_{R(OPT)}$,calculated using equation 9, through both our θ_S and R (curve radius) ranges. These values for C and $\theta_{R(OPT)}$ are used in equation 10 to arrive at the values for P in table 3. The table position for values of P in table 3 correspond to the table position for values of $\theta_{R(OPT)}$ in table 2 used in the calculation. Likewise, these values for P and those for C in table 2 are used in equation 11 to calculate values for θ_L found in table 4. Finally, we use equation 12 to calculate the values for $\theta_{R(OPT)}$ in table 5.

Isolating the desired solution for θ_L is a matter of comparing the values from table 4 with those in table 5. Where corresponding positions in the two tables have values which are similar, the value for θ_S is most optimum for that curve radius. For this sample steering-system configuration, a value of 2.4 for θ_S is closest to optimum.

One might notice that at higher turn radius, there is little variation between the optimum and reaction values for θ_L. As previously mentioned, steering-system accommodation has little effect because steered-wheel angle deviation in the turn is so slight.

4.0 CONCLUSIONS

Results from the analysis of energy loss indicate that the amount is significant enough to merit the use of some design modifications to compensate. When turn radii are small, power losses can amount to as much as 1 watt per steered wheel. In a human-powered vehicle operating on around 200 watts, this amount of power loss is potentially 1% of the total output. At higher radii, power losses are measurable, if small. Even if this energy loss is intermittent, in such a relatively low-powered system, any power losses which can be avoided should be.

The calculations presented for use in determining trailing-arm angle indicate that a single, optimum trailing-arm angle may or may not exist for all turn radii for a particular steering system configuration. For this example, an angle of 2.4 radians (137.5 degrees) was arrived at, though a value of somewhat less (2.3 radians) would be more optimal and can be determined either through interpolation of the existing data or through a subsequent calculation. At this angle, wheel rotation is approximately 98% of optimal, as opposed to 93% for an uncompensated system (corresponding to a value of 1.8 in tables 4 and 5).

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Table 2. Numerical data from equations 8 and 9

θ_S (rad)	C(cm)	θ_R (opt) (rad)					
	R (m)	2	4	7	10	20	30
0.8	37.79	0.39	0.57	0.66	0.70	0.75	0.77
1.0	39.56	0.59	0.77	0.86	0.90	0.95	0.97
1.2	41.66	0.79	0.97	1.06	1.10	1.15	1.17
1.4	43.96	0.99	1.17	1.26	1.30	1.35	1.37
1.6	46.35	1.19	1.37	1.46	1.50	1.55	1.57
1.8	48.73	1.39	1.57	1.66	1.70	1.75	1.77
2.0	51.01	1.59	1.77	1.86	1.90	1.95	1.97
2.2	53.11	1.79	1.97	2.06	2.10	2.15	2.17
2.4	54.99	1.99	2.17	2.26	2.30	2.35	2.37
2.6	56.58	2.19	2.37	2.46	2.50	2.55	2.57

Table 3. Numerical data from equation 11

θ_S(rad)	P (cm)					
R(m)2	2	4	7	10	20	30
0.8	2.15	1.51	1.00	0.74	0.39	0.27
1.0	3.17	2.04	1.30	0.95	0.49	0.34
1.2	3.96	2.44	1.52	1.10	0.57	0.39
1.4	4.50	2.69	1.65	1.19	0.61	0.41
1.6	4.80	2.80	1.70	1.22	0.62	0.42
1.8	4.89	2.80	1.68	1.21	0.61	0.41
2.0	4.78	2.69	1.61	1.15	0.58	0.39
2.2	4.50	2.49	1.47	1.05	0.53	0.35
2.4	4.10	2.23	1.31	0.93	0.47	0.31
2.6	3.57	1.91	1.10	0.78	0.39	0.26

Table 4. Numerical data from equation 11.

θ_S	θ_L					
R(m)2	2	4	7	10	20	30
0.8	1.038	0.973	0.918	0.889	0.848	0.833
1.0	1.295	1.195	1.127	1.094	1.049	1.034
1.2	1.539	1.412	1.333	1.297	1.251	1.235
1.4	1.777	1.625	1.538	1.500	1.451	1.435
1.6	2.013	1.836	1.742	1.702	1.652	1.635
1.8	2.251	2.048	1.946	1.905	1.853	1.836
2.0	2.494	2.260	2.151	2.107	2.054	2.036
2.2	2.750	2.471	2.354	2.308	2.253	2.235
2.4	3.064	2.691	2.561	2.512	2.455	2.436
2.6	**	2.921	2.767	2.714	2.654	2.636

Table 5. Numerical data from equation 12

θ_S	θ_L (opt)					
R(m)2	2	4	7	10	20	30
0.8	1.41	1.29	0.96	0.91	0.86	0.84
1.0	1.61	1.49	1.16	1.11	1.06	1.04
1.2	1.81	1.69	1.36	1.31	1.26	1.24
1.4	2.01	1.89	1.56	1.51	1.46	1.44
1.6	2.21	2.09	1.76	1.71	1.66	1.64
1.8	2.41	2.29	1.96	1.91	1.86	1.84
2.0	2.61	2.49	2.16	2.11	2.06	2.04
2.2	2.81	2.69	2.36	2.31	2.26	2.24
2.4	3.01	2.89	2.56	2.51	2.46	2.44
2.6	3.21	3.09	2.76	2.71	2.66	2.64

HP PIONEER FROM FRANCE

by Lucien Battarel

(John Riley of Toronto met Lucien Battarel riding his SWB 'bent "Sliperette 3" at the IHPSC in Lelystad, The Netherlands, in 1995. John asked him if he would let us have his story. He replied (in French) "I would be most honoured to be ... read by all IHPVA members. I've written out the history of my "Sliperette nos. 1, 2 & 3" for you to translate into English. The photos of me with no. 1 were taken in 1950. [Other] photos are of no. 2, with a slightly aged builder, his face deformed by semi-facial paralysis due to radiotherapy but still an enthusiast, taken in Lelystad in August 1995. Sliperette 1 now has a motor and is no longer an HPV! Shame! Greetings to you and all the youngsters around you who favour the 'bent". Tony Perret and Stewart Dennison of Bikefix/Biketrader, London, did the translation. We appreciate all these contributions - Dave Wilson)

I was born in Algiers in 1921 and eventually studied at the local agricultural college. WWII intervened, and I spent three years, between 1942-5, as part of the victorious allied armies. In 1946, armed with a notion of cycle aerodynamics, I tried Mochet's Velocar. I found it heavy, uncomfortable and ungainly. In 1948, with a diploma in refrigeration engineering, I moved to Nantes. I dedicated my free time to building a bike of my own design. I was lucky in meeting a builder of classic bikes who had no preconceived ideas. With my designs we used all the normal elements of cycle building except for the lugs: we relied mainly on mitre-tube brazing.

My first recumbent, Sliperette 1, was finished in 1949. The photos are from summer 1950. It had the following characteristics:

Front and rear wheels – 400A x32mm
Wheelbase – 1000mm
Overall length – 1420mm
Seat height – 500mm
Bottom-bracket height – 600mm
Transmission – 52/13 by chain: 3.17mm by12.7mm
Three-speed Sturmey Archer hub with ratios of 0.75–1.00–1.33
Front suspension, by leading links using rubber loops in tension;
Rear suspension using swinging fork compressing an inflated ball;
Caliper brakes with circumferential constraints.

Sliperette 1 showed excellent road qualities: I used it for touring from Dijon to Annecy by Lausanne and Chamonix passing over the cols of St. Cergue, Forclaz and Aravis. The gears were too low for me to pedal at speed on the long descent. The heavy rear wheel coupled with the barely damped pneumatic rear suspension made the non-suspended parts rebound on the cobbles. A few years later she was equipped a two-stroke 49-cc engine and hub brakes. The pneumatic ball had been replaced with a silent elastomer block. With little interest in HPVs she remains a reminder of 1950.

Sliperette 2 was undertaken in spring 1980 to overcome the imperfections present in the first prototype. I had the following objectives.

- Using lighter wheels of the same size by using light-alloy rims, specially drilled for 36 spokes, built on cartridge-bearing hubs. Flaurait was good enough to find butted spokes.
- Lightening the frame by using high-strength steel tubes, cylindrical or tapered, double butted, of reduced thickness except at the ends to be joined.
- Lightening the front suspension by making the links of duraluminum. [or duraluminium?]
- Lightening the rear suspension by using tapered tubes.
- Lightening the rear wheel by using a single-speed hub with a unique 13-tooth fixed sprocket without a lock ring.
- Lightening the transmission by adopting a narrow (2.38-mm-pitch) chain.
- Lightening the non-suspended parts by using a triple-link mechanism at the axis of articulation.
- Damping the rear suspension by replacing the compressed-air chamber with annular-rubber Neiman bungs working in tension, slowly returning the received energy.
- Widening the gear ratio by giving the Sturmey Archer two input sprockets of 12 and 30 teeth, and an output sprocket of 26 teeth giving the secondary transmission two speeds. The primary transmission used a 46-tooth chainring on a three-arm spider.
- Lightening the bottom bracket with a hollow axle and steel-alloy cranks.
- Lightening the seat by using a duraluminium frame and shaft.

Lucien Battarel on Sliperette 1 in 1950. Both wheels had suspension; the chain ran in tubes

Battarel on Sliperette 2 in 1995, with the now-engined Sliperette 1

Lucien Battarel on Sliperette 2 in 1995 in Lelystad, The Netherlands

- The duralumin handlebars however had to be changed for steel ones to cope better with the pull of the arms. The seat is now made of soft polypropylene supported from behind by two tapered steel struts. On the front the seat has an adjustable attachment so that the distance to the pedals can be altered.
- Lighting is operated by a series of batteries, the dynamo abandoned due to its incompatibility with high speeds.
- The general dimensions are unchanged. By lowering the seat and removing the rear-suspension rings, the bike can be put in a box 1.15m long, 0.65m high and 20cm wide.
- The weight in full working order is still 14kg. Such is the price paid for the comfort of suspension.

To avoid manually changing from the 12-tooth to the 30-tooth sprocket, to go from "mountain" gears to "flat" gears, and to humour my aversion to derailleurs, I planned to swap the Sturmey 3-speed [hub] for their new Sprinter 7 with gear ratios in steps from 100 to 278%.

Protecting the chain in a rigid PVC tube proved a touch noisy: I replaced it with a tube in soft plastic PVC.

I use my Sliperette 2 less due to my advancing years, except for comfortable touring. I still have the memory of a lovely mountain stage from 1951. I climbed from Briançon (1321m) by the col of Lautaret (2058m) suffering for 28km to enjoy the 88km descent to Grenoble (214m) several times going over 80kph using my biggest gear on the occasional flats.

The integral fairing did not lend itself to touring. I never made it, but in the fifties I drew an outline and during building made a model out of cardboard, transparent film and modelling clay. It would not shock anyone today.

Sliperette 3 was ordered from me by a young customer amazed at the recumbent position, and he insisted on the pneumatic rear suspension. Built to a budget, it has a slight problem with the rigidity of the frame. Equipped with an ergonomic moulded seat it is ridden near Cannes on the Côtes d'Azur. It has an offset front wheel which means it 'dives' in hard braking. It was also built in 1950.

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Book reviews

"ENTWICKLUNG MUSKELKRAFT-GETRIEBENER LEICHTFAHRZEUGE"

by Dipl. Ing. Stefan Gloger

Reviewed by Theo Schmidt and Andreas Fuchs

Pubished by Reihe 12, Nr. 263, VDI Verlag, Duesseldorf, ISBN 3-18-326312-2
In German, price: DM 118.-

This is Stefan Gloger's PhD thesis published as a 188-page paperback by the "Verein Deutscher Ingenieure". In English, the title would be "The Development of Lightweight Human-Powered Vehicles". The HPV-research at the Technical University of Darmstadt is probably the most professional and most extensive ever done and this thesis marks the end of Gloger's work there, which had commenced in the late eighties.

The vehicles used during the investigations, DESIRA-1 and MULTILAB, are well known to many European HPV-riders since Stefan Gloger competed in numerous HPV races. Outside of Europe, the his work and that of his professor, W. Rohmert, may be known due to their papers in the proceedings of the first and second European Seminar on Velomobile Design.

The book begins with an overview of the different perceptives of practical HPV design. The well-known technical criteria are passed by and the work concentrates on human factors: the use, safety, acceptance and perception of HPVs. To do this, many students are questioned according to well-defined rating systems. The students are also subjected to numerous tests on stationary apparatus and various configurations of fully instrumented HPVs. The monitoring includes heart rate and the electrical activity of several muscles.

The first major investigation is an ergonometer comparison of a recumbent cycling position between circular and linear pedalling mechanisms using a modified (not linear) freewheel clutch mechanism. For 100-W output, the average total physiological efficiencies are measured as about 30% for circular pedalling and 15% for pedalling with the specific linear mechanism.

Investigations of optical and accustical perception and sight through various windscreens follow. The best windscreen is one of polycarbonate with a hydrophobic (non-wetting, drop-forming) coating outside, which is also scratch resistant, and a hydrophilic (film-forming) coating inside. This windscreen works well in rain. A wiper is required at night, but not by day.

Using MULTILAB, a universally adjustable recumbent, various steering geometries are investigated.The most favored short-wheelbase configuration has a nearly vertical steering axis with nearly 60mm trail (wheelbase 1100mm, wheel diameter 400mm). Regarding steering configuration, above-seat steering is preferred to under-seat steering, with side- lever above-seat steering in the middle.

The next major test is on wind stability. For this, the fully faired two-wheeler DESIRA is fitted out with various skirts and subjected to side blasts from a large fan and a stationary, much more powerful airplane, while driving by at various speeds. The fan blast did not give any usable data. For the experiment with the airplane, Gloger writes (shortened): "With this second experiment, (inexperienced) tester J.E. had an accident with vehicle damage, so that his subjective impressions are not usable due to his emotional load. The impressions of the experienced tester S.G. are interpretable: all side-area enlargements to the basic configuration are negative. The worst configuration is with additional side area high and forward. The differences are however small." In spite of this relatively inconclusive result, Gloger gives following recommendation based on his personal experience: vehicles should have generous side area forward and low and little side area behind the rear wheel. The center of mass should be nearer the rear wheel than the front. This gives predictable handling in sudden side gusts.

A further investigation is on driver comfort with regard to suspension, ventilation and shielding. Gloger concludes that fully faired vehicles can be designed to provide sufficient ventilation for driver comfort, even when climbing in summer. This short summary, like those above, does not do justice to the thoroughness of the investigations. For example, sweating was measured exactly by weighing the testers before and after!

A next section is devoted to safety. As only 8.5% of cycling accidents are due to motor vehicles, there is a great potential for increasing passive safety with the MAYBUG principle: glancing deviation of forces in collisions (hard, smooth shell), protection from objects and road surface, getting rid of kinetic energy by sliding on the road. No experiments are offered in this direction, but active safety principles are also discussed: lighting, braking, predictability, driver comfort.

The rest of the book is devoted to technical specifications of DESIRA-2, conclusions, and a very comprehensive literature list (the fact that none of the papers of one of the reviewers is listed could be responsible for a slight bias in this review!).

Comment: as with most scientific investigations, a great deal of work is required to produce a small amount of useful data. Gloger's very thorough investigations have several highlights and some surprising results, such as the unusual steering geometry found to be best. In general, there is not much new in the sense that the author's and others' previous work is found to be nearly optimal, there are no recommendations for radical improvements, but rather many small suggestions which in their sum should allow the design of good vehicles. Not all may take the view that fully-faired two-wheelers have the best chance of successful market penetration. Against the objective advantages well-known and undisputed to insiders are the subjective prejudices of most other people. For example, many people perceive such vehicles wobbling slowly uphill or shooting quickly downhill as highly unsafe and undesirable, and it will require many Glogers and some star designers as well to promote a shift in attitude. It would be unfair to reproach Gloger for not expanding the conceptual scope of the investigation; on the contrary he has been very successful at expanding the narrow path of most PhD work into something of public interest and getting his work published in a readable and attractive book. It is however hoped that this work can be continued by other students to include other concepts such as multitrack vehicles. The investigation of linear pedalling should also be expanded to include other mechanisms: this alone would be enough material for a single PhD. A major accomplishment of Stefan Gloger is that he has shown us how to conduct a successful interdisciplinary investigation and that he has us all thinking!

TRANSLATED TEXTS FROM THE BOOK

Keywords: Acceptance, safety, vehicle-usage, ergonomics, stress-perception, handling characteristics, suspension geometry, environmental conditions.

Abstract: In order to improve human-powered vehicles and to transform them into lightweight vehicles with weather-protection, payload capacity and better passive safety, a systems-analysis was performed, considering human factors, traffic planning, design and mechanical engineering. Knowledge gaps in the fields of drive-train, rider modes of perception, suspension geometries, steering design and environmental conditions such as sidewind, vibrations and heat research, were filled by experiments on the road and in the laboratory.

Several physical parameters were measured and the test riders rated their subjective impressions. The conclusions from these investigations were used to design the prototype-vehicle DESIRA-2.

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Other vehicles resulting from this work are DESIRA-2 and the modular DESIRA. The latter is a vehicle to be distributed in kit-form: first, one buys a basic vehicle, to which additional parts may be added at a later time for incremental costs. Now, Stefan Gloger is looking for a producer of the modular DESIRA. Additionally, he is willing to consult professionally on HPV projects.

Dr. Stefan Gloger, Steinackerstr. 14, D-64285 Darmstadt, Germany.

(IHPVA members can also purchase Gloger's book from him directly for about 1/3 price, as long as stocks last.)

The HPV-research at the technical university of Darmstadt is now the responsibilty of the university's solar-vehicle group:
AKASOL, c/o Institut für Elektromechanische Konstruktion, Merckstrasee 25, D-64283 Darmstadt Germany.
See: http://www-emk.e-technik.th-darmstadt.de/~akasol/efahrrad.htm

THE BICYCLE
by Pryor Dodge

published by Flammarian, Paris & New York
(reviewed by Dave Wilson)

"The Bicycle" is a large, handsome history book, full of beautiful close-up and full-machine color photographs. The jacket photograph alone is a masterpiece, showing a ten-speed oscillating-crank drive of c. 1905, with every important detail clear. (This is a drive that people continually "re-invent".) Almost every page also carries delightful thumb-nail illustrations, some quirky, some amazing, always informative.

The book has a wide sweep, starting with running machines and ending with HPVs (full-page photos of Mike Burrows and Mark Drela, and small shots of the Cheetah and others) and a review of modern bicycling groups, resources and the like. The history is accurate in general. Most books on bicycling history are not. Derek Roberts, founder of the (Southern) Veteran-Cycle Club, has published a book called "Cycling history - myths and queries", and every new book purporting to give something on bicycling history is followed by Derek's correction sheets added to his own book. I believe that the list will be short for this book.

There are minor errors. Pryor Dodge is "a classical musician and aspiring Argentine-tango dancer", not a historian nor an engineer. Most of my quibbles concern what seem to be anachronisms. Bangladesh is referred to for a period before the nation was formed. The Ariel bicycle of 1872 is stated to have been made "completely of steel": steel was still an expensive and rather exotic metal at that time. The frame of Rene Olivier's bicycle of 1868 is claimed to have been drop-forged, a highly unlikely procedure. The sketch generally suspected of being fraudulent of something like a modern bicycle by a pupil of Leonardo da Vinci is accepted as fact. The author will irritate Scots, Welsh and some Ulster people by constantly referring to Britain as "England".

On the other hand, I learned a great deal of interesting background and detail. I did not know that there was strong antipathy in Germany towards velocipedes. Or antipathy between users of tricycles and bicycles in 1882 in Britain, based mainly on class differences. The Bicycle Touring Club had 16,000 members in 1885, mainly in the US and Canada. Colonel Pope funded instruction in road engineering at MIT and Harvard. The Tour de France was started as a result of the Dreyfuss affair, by one of two rival newspapers - printed on yellow paper. Hence the yellow jerseys.

All this and much more is fascinating to me, and it has to be to you. This lovely and informative book is equally at home on the shelves of the HPV enthusiast and on the coffee tables in elegant homes. It will spread knowledge of and goodwill towards our craft.

1997 BUYER'S GUIDE RECUMBENT CYCLIST NEWS

(reviewed by Dave Wilson)

This is Bob Bryant's sixth and by far the best of his annual eagerly anticipated buyer's guides. It is packed with information that is presented in useful and readable forms. It has a glossy cover and pages of company advertisements. At the beginning a summary page of 1997 recumbents lists 32 manufacturers, mostly US and UK, and about 125 individual models listed by price in the short-wheelbase (SWB), LWB, CLWB, tandem, and trike-quad categories. The details of these models are given in the inside pages: generally 23 lines of information on each model, from the gear range to the seat and frame material, three-to-six listings per page depending on photograph availability and advertisements. Where full information couldn't be obtained, photographs and comments are given where possible, for instance of several German makes and models. Other sections have homebuilder ideas, recumbent accessories and upgrades, and "contacts, parts and supplies".

The Buyer's Guide is an impressive testament to the vitality of our industry. The products are a long way from the "sameness" of automobile offerings. BG is essential reading for anyone contemplating buying a recumbent. That person will get guidance on the relative advantages and disadvantages of the various wheelbase lengths, above-seat and underseat steering, slung and padded seats, and so on. Its pages make one's mouth water. BG is both promoting an industry and is bringing about competition, to the benefit of all. Bob and Marilyn Bryant are to be praised and thanked.

The buyer's guide is sent as part of the subscription to *Recumbent Cyclist News*, published six times per year, $30 for third-class mailing, $42 for first-class mailing, in the US, and $60 for foreign airmail. P.O. Box 58755, Renton, WA 98058-1755, USA; DrRecumbnt@aol.com

ENCYCLEOPEDIA 4: THE INTERNATIONAL BUYERS' GUIDE TO ALTERNATIVES IN CYCLING.
by Alan Davidson and Jim McGurn
Published by Open Road, Ltd.

(reviewed by Dave Wilson)

This beautiful book is a celebration of the vigor and enterprise of cycling of all forms—except the strictly traditional. The editors look for useful unusual examples of different cycles. They present a short essay on each device and on its originator(s). High-quality colored photos adorn every page. There are 147 pages devoted to city bikes, portables (folders), family bikes (tandems and trailers and other means for involving children), touring, load-carrying, velomobiles, racing, recumbents, and mountain bikes, plus accessories and mobility aids. It comes with a good video of several of the machines in action, which is very helpful for someone thinking of buying without having (usually) a chance to try it out first.

Encycleopedia could be described as a coffee-table book. That would be a tribute to its quality, not a disparagement. It is expensive to produce. The authors/editors make it refreshingly clear that it is produced as a partnership with the manufacturers. They help to shoulder part of the cost. It is not, therefore, Consumer Reports for alternative bicycling. We rely on the integrity of the editors that they would not invite the participation of anyone making a shoddy product. Their enthusiasm for the machines and devices that they have included is obvious, and their reputation and integrity are in no danger. It is not intended to be a comprehensive book. Some manufacturers are listed one year, others in another year, still others, perhaps making magnificent machines, not at all. Life is short, space is limited: let us glory in what we have here presented to us.

Encycleopedia 4 and the video, including postage, are 13.50 pounds in the UK and $22.00 in the US ($22.80 in Canada and Mexico): sales@bikecult.demon.co.uk, or (US) dylan@bikeculture.com and many other agents. A German edition is also available.

LETTERS

TOOTHED-BELT TRANSMISSIONS

from Theo Schmidt

I have been using toothed belts everywhere I could, because they work so well and don't require lubrication. I use a type called HTD (High Torque Drive) made by Continental and companies like Uniroyal and Gates, which use round teeth and can apparently handle greater forces than the old.fashioned trapezoidal-tooth design. These come in metric sizes with 3, 5, 8, and 14-mm pitches. I use the 3 and 5-mm sizes.

The 3-mm size is really thin and flexible, so you usually need a wide belt (25mm) to transmit human-type torques (the limiting factor is always the smaller cog.). The 5-mm pitch is more robust and I use this where width and cost is a factor, as then a 15-mm-wide belt is usually sufficient. I am not certain which is more efficient, the wide thin belt or the narrow thicker belt. The Continental belts are made of rubber with a Kevlar or somesuch tension member. Gates also makes a belt called Poly Chain GT with a polyurethane/Kevlar combination. I havn't used this, but according to their catalog, this is superior to Power-Grip and even metal chain in power density, i.e. in torque transferable to a cog of a fixed diameter and fixed width at a fixed speed. The tooth shape of this belt is similar to that of metal cog-wheels. It comes in 8 and 14-mm pitch. Other makes use a polyurethane/steel combination.

The smaller cogs are easily made oneself by buying a length of aluminium profile with the required number of teeth and parting/turning down on a lathe. The biggest job is attaching or even making the flanges, which are necessary on the smaller cog, unless a stationary guide or an idler with flanges is used.

The larger cogs are also easily made from plywood (which must be very accurately sawn or turned, e.g. on an electric drill) and attached to pedal cranks. They don't always require teeth or flanges. If teeth are required, they are easily made by waxing the belt, applying runny epoxy putty to the disc, and wrapping the belt around, thus casting the teeth in two stages. If you do this, you have to get the diameter just right so that the teeth meet. Or use two discs of different diameters: one is the "chainwheel", the other the flange, and insert a few nails as occasional teeth.

I have used such drives extensively on boats (advantage: no rust) and hybrid vehicles (advantage: no oil) and they work well if you design more or less by the book (available from the manufacturers). This means getting the relationships among belt dimensions, belt tension, torque, and small-cog diameter right. This is a bit more tricky than using chain, and such drives have the disadvantage of not being able to part the belt or use derailleurs or oval chainwheels. Also, practically no eccentricity is tolerable, unless a powerful belt tensioner is used. The efficiency is probably comparable to chain, but slightly less in average conditions.

The major disadvantage of using belts is that each job requires a certain belt and you end up with an expensive collection of different lengths, widths, and even pitches. The manufacturers don't help by inventing new systems every few years, which are incompatible with each other.

CVT BELTS

I used to drive a DAF 33 car, which had two independent CVT belt drives for each rear wheel. This was better for traction than either a differential or a locked differential. Also you couldn't get stuck if a belt parted, not that this ever happened to me. I later had a DAF 46, which unfortunately had a single belt and a differential. Both these cars were really easy to drive and had very good mileage (under 5 liters gasoline per 100 km). The belts were controlled by a kind of mechanical analog computer consisting of centrifugal weights, springs, and vacuum cylinders with valving.

I think this system was ideal for cars and it is unfortunate that the power-mad public didn't take to such vehicles, forcing DAF to discontinue making cars. I believe they still make trucks, but without CVTs. I think the system is probably just a bit too inefficient for an HPV application, mainly at the extreme ratios which would be required.

I have seen the Conrad CVT unit: this is a tiny high-speed device of no use at all except with high-speed motors.

Theo Schmidt <tschmidt@mus.ch>

from William Volk

There is a study that compared motorcycle toothed belts to chains — and showed belts to be a bit more efficent (anyone know of the details?).

The real issue isn't ideal conditions, but a toothed belt with some hub transmission vs. bike chain (as dirty as a typical bike's) with derailleur gearing.

I know it's been suggested that you could build a derailleur-based toothed-belt design, but I think it isn't as simple as it seems. I think you would destroy the belt when engaging and disengaging it. You would need a complex mechanism to remove and apply tension to the belt during shifting as well as some clutching of the cogs.

I do have a idea for a totally toothed-belt transmission that might work. You basically mimic a synchromesh transmission. Have a series of toothed belts and "cogs" on two shafts. Have a synchro engage a particular cog (on the shaft) for a particular ratio. I've seen that done for chain-driven applications (the "Bike Car" from the '70s had a four-speed like this). You would mount this somewhere between the chainring and the rear cog, à la an intermediate gearing, which might be a good thing for a laid-back geometry. The key to this is that the toothed belts and cogs always remain synchronized, and therefore in "synchromesh".

William Volk <bill_volk@qmail.lightspan.com>

from Dave Wilson

I fitted a toothed-belt drive to my Moulton (with a Sturmey-Archer FM hub gear) 25 years ago, and it was pretty good (pp 288–9 in *Bicycling Science*). I wish that I had persisted with it. Theo Schmidt is correct when he stated that the smaller cog is

the limiting one. I used a 25-mm width but did get some belt slipping when I stood on the pedals up hills. A higher belt tension would have helped. I cast the front cog in a rubber mould using polyester resin and a worn-out TA aluminum chainwheel. That larger cog was quite light and worked well.
Dave Wilson <dgwilson@mit.edu>

Theo Schmidt's response to Clark Higgins

Clark Higgins wrote: "I'll bet that all your objections could be resolved with about 3 ozs. of integrated circuits."

Clark Higgins, you are quite correct. However, 85g of Power MOSFETS are still quite expensive. A 100-amp controler chip doesn't consist of a single device, but of hundreds of smaller MOSFETS on a single wafer all connected in parallel. By the time you add the peripherals it makes a few hundred dollars. Cheap controlers like those used for electric model aircraft may have the required amperage on paper; in practice they only last a few seconds, because the surge protection is missing. But I agree with you: recuperative braking certainly is nice.
Regards, Theo

EDITORIALS

New beginnings

We apologize for the long delay in the publication of this issue. By the time that it reaches you much of it will be a year late. We have had some problems within the IHPVA and with its relations with HPV groups worldwide. A prestigious international reorganization committee of twelve has been carrying out long and remarkably harmonious discussions almost entirely by e-mail, presided over with great competence and sensitivity by Carole Leone. As I write this in February 1997, agreement is almost complete and the final touches to the committee's recommendations are being made. If the IHPVA board accepts the recommendations we should be able to look forward to a new and vigorous lease of life for the HPV movement. We will owe a debt of profound gratitude to a group of dedicated people who have devoted a great deal of their spare time deliberating in what seems to me to be an extraordinary demonstration of how the new electronic technology can solve very difficult problems. These problems were slated for discussion in 1995 in Lelystad, but a quorum of the IHPVA and of the other organizations could not be assembled for various reasons. High travel costs, individually paid, were an important factor. But it is doubtful that more than a start could have been made at resolving complex issues in a one-evening meeting.

Meanwhile the IHPVA board gave *Human Power* a degree of at-least-temporary independence, allowing us to resume publication before any new arrangements to the overall organization are brought about. Moreover, I was allowed to accept an offer from Jean Seay, who earlier edited and produced *HPV News*, to take over layout, production and possibly distribution. This will be a great relief to me. I hadn't entirely realized what an effort layout was until I took over that task a few years ago in order, I thought, to improve the publication. Small errors had crept in because of the difficult communications that resulted from the editor, the layout person and the production group being in three widely separated states. With the arrival of e-mail and the Internet, those problems should be negligible. Jean Seay has much more experience at publication production than I, has better hardware and software, and a great deal of energy and enthusiasm. I look forward to a new era for *Human Power*.

The longer-term future depends on you, our readers, and on the new organization. Various models for future arrangements have been suggested and discussed. We are ready for anything!

Warmth from the UCI

Les Earnest of Stanford negotiated articles of alliance between the IHVPA and the USA Cycling Federation in 1980 that were ratified by both organizations in August of that year. The new parent body representing (conventional) competitive cycling is the USA Cycling Board (over the USCF, NORBA and USPRO), and it is ready to negotiated new articles of alliance proposed again by Les Earnest, who is that wonderfully valuable person: someone holding an official position in competitive cycling but who appreciates the virtues of unconventional HPVs. We hope that whatever new body arises from the IHPVA will act swiftly to accept his offer of diplomacy.

Meanwhile Peter Ross of Britain (manufacturer of a successful line of HPVs and a valuable member of the reorganization committee) received a very warm response from someone in the world cycling governing body, the UCI, to a letter suggesting that the IHPVA or its succeeding organization and the UCI discuss possible collaboration in some areas.

We have everything to gain from such communications and collaboration. I have been persuaded by reasonable people that it is unreasonable to complain that cycling's governing bodies have established rules in the past that outlawed recumbents and faired machines. They had and have every right to set their own rules. We can and should try to see how we could come closer together.

Germany leads?

Two reviews in this issue show how much recumbents and HPVs have been accepted among regular German bicyclists and academics. Another sign is an article in the July/August 1996 edition of "aktiv Radfahren" ("Active bicycling") reported on the hpv@ihpva.org list by Brian Passingham. Fifteen pages were devoted to recumbents, starting with the top ten recumbent questions, answered by Gunnar Fehlau (author of *DAS LIEGERAD*—the recumbent). Then there were longer reviews of three recumbents and shorter reviews of ten others. Brian reports that the article closed with an anti-recumbent piece, apparently for an appearance of balance, by someone who stated that the seating position was like that required of patients by gynecologists; that recumbent riders act as members of a cult; and that if recumbents were any good they would have succeeded long ago.

In the same month a magazine for bicycle dealers in the US, *American Bicyclist*, had an article by Joshua Ramos "Don't let prejudice squelch recumbent service." It started "What do most bike mechanics do when someone wheels in a knee-high mile-long two- or three-wheeled lawn chair of a recumbent and asks for service? Traditionalists may start snickering or make themselves scarce. The curious gather 'round to see just what kind of ingenuity went into the design. Enthusiasts want to try it out...." The author concludes, "there's a lot of hope that the situation will improve, especially as more progressive shops embrace these unique cycles for the advantages they offer.... Welcome the unusual.... Nourish this market, and let it enrich the shop's business."

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