Summaries of articles in this issue; masthead ........................................ 2
The phantom trailer, Andreas Knöck Kemp ........................................... 3
Call for papers: 4th Velomobile seminar ................................................. 4
Measuring drive-train efficiency
Angus Cameron ....................................................................................... 5
Comment on Angus Cameron's article
Jim Papadopoulos .................................................................................... 7
Predicting wheel dish from hubs
Vernon Forbes ........................................................................................... 9
Letter .......................................................................................................... 10
A bicycle with auxiliary hand power
Duhane Lane, John Jones, John Caracutti and Andrea Varju ......................... 11

Technical notes
Correction to “Lower-extremity output in recumbent cycling: a literature review” (Human Power 45, pp 6–13)
Rud Reiser and M. L. Peterson ................................................................. 14
Summaries of papers, Danny Tan .............................................................. 14
Response to questions, Danny Tan ........................................................... 17
Some comments on the effects of “interference drag” on two bodies in tandem and side-by-side
Jim Papadopoulos and Mark Drela .......................................................... 20
IHPVA record wind rules: a participant’s perspective
Paul Buttimer ........................................................................................... 21
Review: Continuation, Eighth cycle-history conference .................................. 22

Editorials
Remembering Gunter Roehl, Dave Wilson ............................................... 23
Indexing and renumbering Human Power
Dave Wilson ............................................................................................. 23
The phantom trailer

By Andreas Konekkamp

The Institute of Electromechanical Engineering (EMK) at the University of Technology Darmstadt is developing the concept and a prototype of the phantom trailer in cooperation with AKASOL. Darmstadt (a student project that produced “Pinki,” a vehicle that won the Tour de Sol three times). The pushing and pulling forces of this trailer will be completely compensated by a self-controlled electric drive (“inverse--over-running brake”).

INTRODUCTION

Situation #1: A family is touring a hilly landscape by bicycle. As long as the path gently follows the river, dad has no problem hauling the bike trailer and two children inside, weighing about 40 kg together. He is quite fit because he bikes regularly. But when the first big hill appears, the enjoyment disappears: dad and the children have to walk, pushing bike and trailer. After the second or third hill his mind is made up: there will be no more bike trips until the children can ride on their own.

Situation #2: Mom takes the children to kindergarten before work at ten o’clock. On the way back she has to buy beverages and groceries. As often happens, the time is a bit short and she needs a bit more. When she reaches home dripping with sweat at a little short and she pedals a bit harder. When the first big hill appears, the enjoyment decreases: she sees the children and starts to pedal only enough to keep going. Here she will be as much interested in the children as in the children’s interest in the environment.

Situation #3: The trailer has many advantages: The bike remains fast and maneuverable, especially on short distances, and takes up little space. Many people are willing to put up with the necessary—more or less moderate—exertion to benefit from these advantages and to achieve fitness.

The trailer, which is carried along only if necessary, expands the transport capacity of the bicycle. Some all short-distance transport tasks are possible this way (see Burwitz et al., 1996). However, in particular hilly terrain, with many stops and starts (traffic lights, crossings etc.), or with considerable head wind, the load work increases significantly. A typical example: a woman (60 kg) riding a bike (15 kg) with a coupled trailer (15 kg) including two children (35 kg) has to expend two thirds more energy to pull that trailer. Many people fear such experiences and are reluctant to use a bicycle trailer.

AN ELECTRICALLY-DRIVEN BICYCLE TRAILER

A bicycle trailer with auxiliary drive offers the chance to avoid the extra work load, so a larger percentage of short-distance transportation could be carried out with bikes (see Neupert, p. 36). For reasons of environmental protection of small children who cannot ride on their own. The share these kind of trips have on the whole automobile usage is enormous: On cloudy days up to 50 % of all car trips are shorter than 5 km. (see fig. 1.)

For reasons of environmental protection, and of ease of operation, only electric drives are suitable. Unlike many electric bikes hav- ing the image of a vehicle for elderly people, this solution preserves the sporting image and the above-mentioned advantages of the bicycle as the towing vehicle. The primary goal of the trailer concept presented here is to replace frequent short-distance trips by car with the environmental-friendlier ride of a bicycle trailer. And possibly, it avoids the purchase of a second car. Furthermore the trailer should be suitable for bike tours.

THE TECHNICAL CONCEPT

As described above, the electric drive in the trailer should not replace the biker’s muscles, but only compensate for the additional load of the transported weight. In addition, problems with the driving dynamics (behavior in curves) may be expected. Here, the drive only performs assistance similar to power-assist bikes. This is done by measuring the tractive force in the drawbar with a sensor and compensating for it.

The trailer is also equipped with an automatically controlled brake so it will follow the bike almost without being noticed—a phantom!

REQUIREMENTS FOR THE PHANTOM TRAILER

Drivetrain

The requirements for speed and maximum gradient should match the performance of a typical bicycle without trailer.

Without headwind, a speed of about 20 km/h should be reached on the flat, or about 10 km/h up a 5 % gradient.

Figure 1. Frequency of automobile trip distances depending on purpose (adapted from Emnid)
Tractive force measurement and brake system control

1. **FOOTNOTES**

1. Considering the frequency of different distances (not the altogether driven distances) seems to be adequate because of environmental and psychological reasons. The emissions after each starting from cold are distinctly higher, the bike-braking system between different means of transportation is made at the beginning of each trip. This applies especially because of the high emission load for the inner city area by the typical alternative for the electric drive: a two-stroke combustion engine. 3. Fail-safe-properties: appearing defects do not lead to a dangerous situation but are intercepted safely.

**AUTHOR**

Andreas Kinkefeld has studied electrical engineering at the University of Technology Darmstadt (TUD) specializing in electro-mechanical engineering design. Since 1995 he has been working at the Center for International Studies in Technology at the TUD as a consultant supporting engineers in developing environmentally-friendly products. He is also conducting several projects on bicycle trailers.

**CALL FOR PAPERS**

**FORTH EUROPEAN VELOMOBILE SEMINAR**

The fourth European velomobile seminar will be held in conjunction with the world championship for human power, 18-22 August 1999. The seminar is on the first day, Wednesday August 18, and will be in Interlaken, Switzerland. (This will be the first time the HPV championship is to be held in Switzerland, and it is certain to be a very special occasion.) The host organization is Future Bike, and the symposium co-chairs are Andreas Fuchs (<fuchs@isbe.ch>) and a prototype for the Phantom Trailer will be developed.

**Driving and gear forces**

Two hours' driving duration in a gently rolling landscape should be the minimum and twice this is desirable. The range may be increased by extending the battery capacity or by recuperation, i.e., feeding back some of the braking energy into the battery. The above performance should be possible with a load up to 50 kg; with higher loads less performance could be accepted.

**Safety**

The trailer must be safe, especially when transporting children. Besides suitable seats and storage places, adequate safety belts and roll protection are necessary. Furthermore all technical parts (brakes, electric equipment, etc.) and wheels (spokes and wheels) have to be child-proof. The parts as well as the child passengers and transported load must also be protected from rain, loose chippings, or too much sun. Finally the system has to show fail-safe-properties in any case of a defect (failure of the brakes, electrical fault, etc.).

**HANDLING**

During the ride itself the Phantom Trailer obviously does not need any manual control, but in all other situations the handling also has to be safe, simple and comfortable. Relating to this, simple coupling to different bicycles, easy battery charging during the ride, and easy loading and unloading, are required as is the possibility of safe and space-saving storage.

**PRESENT PROJECTS**

Two studies concerning the main problems of the phantom trailer are presently under way: measuring the tractive force within the drawbar, including the steering of the braking system and the design of the drive system and control.

**Measuring drive-train efficiency**

by Angus Cameron

**ABSTRACT**

A simple but effective procedure for measuring the static mechanical efficiency of bicycles is presented which would be suitable for all kinds of high-school science labs, science-fair contestants, and even small manufacturers. Test results from a 21-speed bike showed efficiencies ranging from 92.4 to 98.0% with a chain tension and size and condition of cog, with uncertainties between 0.15 and 0.35%.

**INTRODUCTION**

The measurement of chain efficiency may have started with Prof. R. C. Carpenter at Cornell University in 1887, as reported in the "100 Years Age" section of the journal Nature, 2 October 1997. He is quoted that "frictional loss has been found to be between 1/2 and 3/4 per cent of the total power transmitted."

Although some values of chain efficiency have been published for normal bicycles (see table 1), little information exists about the effects of novel designs incorporating extra idlers, chain tubes, inter-modulated teeth, etc. The techniques described here will allow any curious person who has access to a spring balance and a set of calibrated weights to make highly own measurements.

The term mechanical efficiency is commonly defined as the ratio of the power output to the power input in some mechanism. Measuring power requires knowledge of speed, which makes it a dynamic measurement. Power, however, is difficult to measure without excessive lab resources. Therefore I chose to measure the static efficiency; the ratio of the work out to the work in; where work is defined as the product of a force and the displacement it causes. Static in this sense doesn't mean that there is no motion involved, just that the speed is small and needs to be known.

My test vehicle was a 9-year-old mountain bike equipped with Deore XT components and a lubricated chain that had been lashed through 1/8 inch per inch. My first experiment was to find the friction loss in a simple loop of chain running over the large 42-tooth sprocket. I supported the bike with a sturdy stand with the bottom bracket at table height. After removing the drive chain and setting it aside, I laid a second shorter loop of chain over the chain wheel. Using strong steel hooks (coat-hanger wire) I hung a 6-kg weight on each side of the chain so that they balanced (see fig. 1). Originally I intended to add small brass weights to one side until the friction force was just overcome. At this point the chain wheel should have continued to rotate at a constant speed once given a small push. However, the friction force was far from constant and also a little "lumpy" due to the engagement of the chain with the teeth, making it impossible to tell the exact location of the value of the friction force with any consistency. So I substituted a sensitive spring balance for the brass weights. Using a steady hand I pulled each of the 6-kg weights to towards the floor at a steady slow pace, it was easy to watch the pointer and "eyeball" the average friction force.

When the tension in the chain was 6000 grams the friction force (f) was found to average about 55 grams. Dividing the friction force by the tension and multiplying by 100 gives a relative loss (or inefficiency) of 0.9%. Subtracting this from 100 resulted in an efficiency value of 99.1%.

The reader must excuse my use of mass units (g and kg) rather than the correct force units, the Newton. There are two pragmatic reasons: first, the weights and measuring instruments were calibrated in grams, and second, since efficiency is defined as a ratio of two quantities, the units will always cancel regardless whether in grams or newtons. Encouraged with this result I replaced the spring balance with a Peco electronic force balance and a data logger and made additional readings with weights of 6, 11 and 16 kg. As can be seen in figure 2, the data points fell close to a straight line, showing that friction increases in proportion to the chain tension. More importantly it told me that the technique was producing consistent and reproducible data.

When the efficiencies were calculated they averaged 99.1% and showed a slight increase with an increase in tension (see fig. 3).

The next question was whether this same technique could be used to find the overall efficiency of the complete drive train. Some human power advocates, the algebra always says yes. Starting with the definition of "work", it can be shown (see appendix 2) that efficiency = 1 - f/F can be found using equation 7. Where f is the friction measured at the rear wheel and F is the equilibrium force required if the system was free of friction. The friction force f can be found averaging the two measured forces, f1 and f2, using equation 7, while F can be found using equation 6. Note that the magnitude of the only the smaller

Table 1. Comparison of single-speed, multi-speed hub and derailleur gearing

<table>
<thead>
<tr>
<th>Speed</th>
<th>1-spd</th>
<th>5-speed hub gear</th>
<th>7-speed derailleur</th>
</tr>
</thead>
<tbody>
<tr>
<td>50W</td>
<td>96.0</td>
<td>90.6 93.4 87.3 94.2 94.1 92.1</td>
<td></td>
</tr>
<tr>
<td>100W</td>
<td>97.3 92.8 95.7 90.9 96.2 96.4 94.9</td>
<td></td>
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</tr>
<tr>
<td>150W</td>
<td>98.1 94.0 96.9 92.9 97.4 97.6 96.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200W</td>
<td>99.0 95.0 97.9 93.3 98.1 98.4 97.8</td>
<td></td>
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</tr>
</tbody>
</table>

**Figure 1.** Odometer measurement and brake system control.

**Figure 2.** Friction on the 42-tooth sprocket.
The chain was then reinstalled on the sprocket using a separate loop of chain (fig. 6). I used 6.5-, 13- and 26-
kg weights because the resulting chain tension was too small to obtain any reliable values.

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Predicting wheel dish from hubs
by Vernon Forbes

ABSTRACT
A number of freewheel widths, hub widths and axle lengths exist. Both the freewheel widths and the center-to-flange measurements are shown to predict poorly the resulting rear-wheel dish. It is suggested that dish is best measured as a ratio.

INTRODUCTION
What factors influence rear-wheel strength? Certainly a straight rear wheel will often choose a 7-speed because it is thought to be less severely dished. Axle length is another variable. Manufacturers have been increasing axle length to make room for wider freewheels. Putting the freewheel further outboard requires an increase in the bottom-bracket spindle length in order to keep the chainstay intact. It is well known that wider bottom brackets are harder to pedal. Ever since the introduction of multi-speed cogs, wheels have had to be dished. A freewheel moves the hub over to make room for it. Cyclists are long familiar with this explanation and more likely to break. What is needed is a way to predict how much a wheel will have to be dished from any hub to be used.

The hubs listed in Sutherland’s 1 were used in this and all subsequent analyses. Only hubs having a 135 mm axle length were used. Among 130 hubs are listed as having a 135 mm axle length only 74 are labeled. Sutherland’s list 31 hubs as 8-speed, 43 as 7-speeds, 9 as 278-speed and 1 as 67-speed. 45 are not categorized. Sutherland’s gives the center-to-flange measurements for both the drive side and the non-drive side. Freewheel width was taken as the distance from the drive-side locknut to the flange center (see fig. 1). An examination of 74 labeled hubs in Sutherland’s was conducted to find out if there were any consistent patterns that constituted 7- or 8-speed spacing. Considerable variability exists as to the width of both 7- and 8-speed freewheels. The following values (mm) were obtained from labeled hubs only. The table below shows the number of speeds (#speeds), the number of hubs analyzed (N), the average (AVG), the lowest and highest values (Range) and the standard deviation (SD). The 68% confidence intervals (CI68) are discussed later.

<table>
<thead>
<tr>
<th>Freewheel width: labeled hubs</th>
<th>Non-drive side</th>
<th>Drive side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-drive side (NDS)</td>
<td>Drive side (DS)</td>
<td></td>
</tr>
<tr>
<td><strong>HUB WIDTH</strong></td>
<td><strong>HUB WIDTH</strong></td>
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</tr>
<tr>
<td>7</td>
<td>8</td>
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<td>8</td>
<td>7</td>
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<td>43</td>
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<td>64.6</td>
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<tr>
<td>48.0</td>
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<td>45-51</td>
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<tr>
<td>15</td>
<td>22</td>
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<td>1.0</td>
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<td>45</td>
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<tr>
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<tr>
<td>1.7</td>
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<td>49.0</td>
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<td>1.0</td>
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**WHAT THE RANGES CLEARLY SHOW IS THAT, CONTRARY TO POPULAR WISDOM, IN MANY CASES A 7-SPEED HUB IS ACTUALLY WIDER THAN AN 8-SPEED HUB.**

As a guide to hub selection.

As a guide to hub selection.

FREEWHEEL WIDTH
We initially set out to establish how much narrower the freewheel spacing on 7-speed hubs is compared to 8-speed hubs of 135 mm spacing.

The straight lines that appear are not regression lines but are lines of constant dish. The addition of hub width can enhance the discrimination of the dish ratio. The addition of hub width can enhance the discrimination of the dish ratio. The most straightforward way would be simply to specify hub width along with the dish ratio. For example, 0.69–59 mm allows us to discriminate between two different-width hubs. We conceptualized the hub’s influence on the resulting wheel strength in the following way. We saw dish as a function of freewheel width impinging on the amount of strength available to divide between different sides of the wheel provided by hub width. What some manufacturers are using are narrow “dishless” hubs these hubs come in different widths. Figure 3 plots the amount of dish (as measured by the dish ratio) against the hub’s width for both seven-speed and eight-speed hubs. The regression lines plot both seven-speed and eight-speed hubs, illustrating how increased dish is often coupled with narrower hubs. This is especially so for eight-speed hubs.

Examination of figure 3 also reveals that the amount of dish is independent of hub width. For example, two hubs have a dish ratio of approximately 0.69, yet one of them is 49 mm wide while the other one is 59 mm wide. A solution measuring dish that accounts for hub width is problematic. The addition of hub width can enhance the discrimination of the dish ratio. One way to specify hub width along with the dish ratio. For example, 0.69–49 mm or 0.69–59 mm allows us to discriminate between two different-width hubs having the same dish ratio. What is needed is a way to predict hubs along both dimensions simultaneously for the drive side and a 50 mm center-to-flange measurement for the non-drive side. What is needed is a way to predict hubs along both dimensions simultaneously for the drive side and a 50 mm center-to-flange measurement for the non-drive side.

**THE DISH RATIO**

Considering the importance of dish in determining rear-wheel strength how do we measure it? Center-to-flange measurements are more commonly used as a guide in hub selection. The longer the drive-side center-to-flange distance, the stronger the resulting wheel is. Dish, however, is the difference in tension between both sides of the wheel and can be expressed as the difference between the two center-to-flange measurements for each side of the wheel. To measure dish truly we must somehow include the center-to-nondrive side. Using the labeled hubs only, figure 2 plots the length of the drive side (center-to-flange) against the non-drive side, illustrating the versatility of these two measures. The straight lines that appear are not regression lines but are lines of constant dish explained above.

The amount of dish a hub puts on a wheel can be measured by comparing the center-to-flange measurements of each side of the wheel to each other. One such comparison is the dish ratio, achieved by dividing the smaller center-to-flange measurement on the drive spoke center-to-flange measurement on the non-drive side. The dish ratio is defined as the ratio of the smaller center-to-flange measurement on the drive side to the non-drive side. The dish ratio is defined as the ratio of the smaller center-to-flange measurement on the drive side to the non-drive side.

HUB WIDTH
Hubs’ width is the distance between the flanges, center to center (see fig. 1). In an attempt to reduce the effects of increased dish caused by wider freewheels some hub manufacturers are using “dishless” hubs. These are nothing more than narrower hubs. The tendency to use narrower hubs as the freewheel width impinged on the amount of strength available to divide between different sides of the wheel provided by hub width.

While some manufacturers are using narrow “dishless” hubs these hubs come in different widths. Figure 3 plots the amount of dish (as measured by the dish ratio) against the hub’s width for both seven-speed and eight-speed hubs. The regression lines plot both seven-speed and eight-speed hubs, illustrating how increased dish is often coupled with narrower hubs. This is especially so for eight-speed hubs.

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**DISCUSSION**

What is needed is a way to predict wheel strength from a hub: a single number.
The author would also like to thank Dave Wilson for his invaluable comments in the preparation of this paper. The author would also like to thank Adam Corbitt without whom this article would not be possible. The author would like to thank Dave Forbes, University of Missouri, Columbia, MO 65203-4025 USA forforbes@mail.cvm.missouri.edu

ACKNOWLEDGMENTS

Figure 1 is after The Bicycle Wheel by Jobst Brandt and appears with his permission.
Mechanism requires no structural modification of the frame. Instead, users are required to purchase an entire new bike. Riders should be able to learn to ride the new system in a reasonable amount of time (e.g., one day's worth of riding).

The mechanism is robust enough to handle normal cycling conditions. The two requirements of 120° and feet moving 180° out of phase requires some further explanation. Hand-and-foot strokes have been implemented with hand motions similar to the foot motion (cranking), rowing motions with the hand while the feet cranked, or up-and-down motions simultaneously with both hands out-of-phase with the legs. None of these drives is entirely satisfactory. Often the hand motions feel unnatural and the other functions required while riding a bicycle are difficult to perform with the hands. We approached the problem from a different direction and came up with a different method of harnessing hand power on a bicycle that works in conjunction with the legs. In fact, although we might not realize it, we already utilize our upper-body muscles while riding a bicycle. Arm muscles are often used to provide a reaction force against the force of the legs pushing on the pedals. When climbing or sprinting out of the saddle, cyclists often sway the bicycle back and forth. In effect, this is using both the leg and arm muscles to exert a torque on the bicycle. The arms plant the hands on the pedals and pulling up on the frame with the hands. The action described above is a natural motion for experienced cyclists and is potentially the most efficient way for the body to work. Whitt and Wilson state, in reference to the work by Kyle and co-workers: “The power was greater when the arms and legs were cranking out of phase than when each arm moved together with the leg on that side.”

The goal is to mimic the natural action of a cyclist climbing as closely as possible but providing for even greater use of the arms and upper body. The natural action is such that when the left foot pushes down on the pedal, the right hand pulls up and the left hand pushes down. Similarly, when the left foot pushes down on the pedal, the left hand pulls up and the right hand pushes down. The timing of the hands and legs is very similar to that of a cross-country skier doing a diagonal stride.

THE HANDLE-DRIVE BIKE

After much thought, we arrived at a general solution that meets most of the conditions stipulated. We built a prototype, the Handle-Drive bike. Two levers mounted on the stem are moved up and down by the hands as shown in figure 1. The hands grip a handlebar (see fig. 2) which protrudes out from the side of each lever. These handlebars are mounted to give the approximate reach, width, and gripping angle of standard handlebars on existing mountain bikes. The cycle also has the option of gripping along the main levers.

Brakes, rear and front derailleur controls are mounted as shown in figure 2 to allow access even while using the arms to govern the front wheel. A chain is mounted on an assembly that slides up and down the main lever on each side. This chain powers front wheel sprockets on either side of the handlebars, as shown in figure 3. The levers are connected together by a gear such that when one lever moves down, the other lever is forced upwards and vice versa. Note that the system is inherently a two-wheel-drive system. Various attempts have been made in the past to invent a two-wheel-drive bicycle that provides for greater traction. These implementations usually involve a flexible cable driving the rear wheel to the front wheel. Because the handlebars are on opposite sides of the bicycle, it is difficult to move the hand and foot simultaneously. One solution is to use a hand-powered lever to give a range of speeds varying from low (close to the bicycle end of the lever) to high (at the far end of the lever).

RIDING THE HANDLE-DRIVE BIKE

The prototype was built by replacing the stem, handlebars, and front wheel of a standard mountain bike. The standard handlebars were replaced by the Handle-Drive levers linked together and a chain that ran down the left side of the front wheel. A tensioning device maintained tension in the chain. We used a tandem hub with freewheel threads on both sides to accommodate a single sprocket on the right side and a BMX freewheel modified to freewheel backwards on the left side. Although the prototype was quite heavy and somewhat crudely made, learning to ride it and using the Handle-Drive system was surprisingly easy. Using the levers and timing the power stroke of the arms in relation to the legs was very intuitive. One could learn very quickly the action of the arms going up and down—it took us approximately ten minutes or so to get our actions coordinated and to begin to deliver power effectively to the front wheel.

To match the front drive ratio to the rear drive ratio, the driver can synchronize the two drivetrains in whatever way feels most natural. Generally, this will be the action described above: whereby the handlebars are turned on both sides of the bike, and the rider is free to stop powering with his or her hands at any given time (e.g., to maneuver around obstacles or to apply the brakes). In fact, the rider can power with only hands, only legs, both together, or none at all. The levers can still support the cyclist's weight if the cyclist pushes down evenly on both legs at once. A good feature would be to allow a look-out whereby both levers can be locked together in one position. In this case, the bike would essentially ride like a normal bicycle. The point of connection of the chain to the levers is varved along the length of the lever to give a range of travel varying from 0 to 230 minutes or so to get our actions coordinated and to begin to deliver power effectively to the front wheel.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, we feel that the prototype we built has proven that the concept is viable. While this prototype was somewhat crudely made, learning to ride it was very intuitive. One could learn very quickly the action of the arms going up and down—it took us approximately ten minutes or so to get our actions coordinated and to begin to deliver power effectively to the front wheel.

Some drawbacks of the prototype were the play between the two levers because of our crude connection system, and the rather ominous appearance of the long protruding handlebars to pedestrians who happened to pass by. One could learn very quickly the action of the arms going up and down—it took us approximately ten minutes or so to get our actions coordinated and to begin to deliver power effectively to the front wheel.

ACKNOWLEDGMENTS

Our project could not have been completed without the support and support. We would like to thank the following people and organizations (not necessarily in the order of appearance): Pippin Osbourne (Symons), Andy Wong (Rocky Mountain Bicycles), Dave Overgaard (NORCO), John Scott (RNA Bearing Company), Colin Belhumeur (A&M Non-Ferrous Metals), Cliff (Carlton Cycles), Rocky Newton Cycles, Phil and Sue (Dunbar Cycles), Andrew Rawicz, Steven Whitmore, Tim Collins, Gary Houghton, Bill Woods and Fred Herp (School of Engineering Science, SFU), Peter Heliland, Bill Eyr, Steve Chua, Rob Johnson, Dennis Michaelson, and Will Lee.

REFERENCES


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John Jones is the director of the School of Engineering Science at Simon Fraser University and is presently working at Rocky Mountain Bicycles where he designs full-suspension mountain bikes.

Andrea Vargas has a Bachelor of Science degree in Engineering Science and is presently studying to be an agronomist.

*Any correspondence relating to this article should be directed to Dunabe Lamer at <clam@sfu.ca>.
50 mph. The current record of 51.29 mph was set by Jim Glover in a fully-tailed Mouhlin AM7 at the 3rd IHPV Scientific Symposium in Vancouver [Erof HSIFC] on 29 August 1986. Apologies to Jim and all the people who worked on that project.

The entire pedal stroke. With the foot under the pedal, the toe clip may not provide adequate support to the foot-to-pedal interface which could result in reduced power output.

The numerous possibilities for why the cycling position with the hips below the bottom bracket is less powerful than the hips-above positions demonstrate how complex the system is that we are trying to understand. It also shows the need for more research in this area so that improvements may be made in the area of human-powered vehicles.

Additionally, hip orientation was referenced by Too based on seat-tube angle which is slightly different than the line between the hip joint and the bottom bracket. However, these two methods to determine hip-to-pedal orientation should be very similar (within a couple of degrees).


This study examined the effects of changes in hip angle (while keeping the knee and ankle angles the same) on cycling duration and work output. Hip angles were manipulated by a systematic change in seat-tube angle (as determined from a vertical line passing through the crank spindle). Five seat-tube angles were examined: 0, 25, 50, and 75, and 100 degrees. For each seat-tube angle tested, the trunk was always kept perpendicular to the ground, and the seat-to- pedal distance adjusted to maintain the same ground clearance measured in each of the five seat-tube angles. The tests were on a Monark bicycle ergometer, with increasing load or cadence every three minutes until the subject was exhausted. The results revealed a parabolic curve in cycling duration with changes in seat-tube angle from 0 to 100 degrees body configuration (summarized above) and the 75-degree seat-tube angle and the trunk perpendicular to the ground. This same result was found regardless of whether a trained or untrained subject was tested. The 75-degree seat-tube angle is as important as the joint angles. Changes in joint angles affects muscle length and other variables that interact to produce force and power. Changing the seat-tube angle changed the minimum and maximum hip angle during a pedal cycle, but did not change the range of motion.

This change where the fatigue is felt. In an upright position (e.g., seat-tube angle of 25 degrees), the stress occurs more on the quadriceps, hamstrings, and gluteal region. The 75-degree seat-tube angle apparently distributes the stresses more evenly over the quadriceps, hamstrings, and gluteal region, thereby reducing the stress on the various muscle groups. The 75-degree seat-tube angle apparently changes the points at which the various muscle groups are active and inactive during a pedaling cycle (although there is no change in the pattern or duration of activation). This was based on another study I had published (titled: The effect of hip position/configuration on EMG activity during cycling). This has major implications regarding efficiency and force and power generation.

Conclusion: The optimal mean hip angle that maximizes cycling duration and work output with incrementing workload is 77 degrees, with a minimum of 77 degrees, a maximum of 100 degrees, and a range of motion of 41 degrees. This was found with a seat-tube angle of 75 degrees with the trunk perpendicular to the ground, and a seat-to-pedal distance of 100% of leg length (as measured from a standing position from the greater trochanter to the ground). The current record was set by Danny Too, D. (1991). The effect of hip position/configuration on anaerobic power and capacity in cycling. International Journal of Sports Biomechanics, 7(4), pp. 359-370.

This study was, in essence, the same as the previous investigations. The protocol detailed above that was testing was that testing was done anaerobically (with a 30-second all-out power test, using a resistance based on body mass) and the complete protocol of aerobically. This information is more appropriate for those constructing HPVs to set new speed records, as opposed to distance/endurance records.

The purpose of this investigation was to determine the effect of systematic changes in hip position/configuration, while maintaining an upright trunk orientation, on cycling peak anaerobic power and anaerobic capacity. Seventeen male recreational cyclists (age 21-32) were each tested in four hip positions (25, 50, 75, and 100 degrees), as defined by the angle formed by the seat tube and a vertical line. The seat-tube angle apparently distributes the stresses more evenly over the quadriceps, hamstrings, and gluteal region. The 75-degree seat-tube angle apparently changes the points at which the various muscle groups are active and inactive during a pedaling cycle (although there is no change in the pattern or duration of activation). This was based on another study I had published (titled: The effect of hip position/configuration on EMG activity during cycling). This has major implications regarding efficiency and force and power generation. To fully address the issues in this area calorically (with a 30-second all-out power test, a resistance based on body mass) and the complete protocol of aerobically. This information is more appropriate for those constructing HPVs to set new speed records, as opposed to distance/endurance records.

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The results of this study would suggest that, although a reclining position (120-degree trunk angle) may be more comfortable, it is not effective in power production. The reason? A reclining position where the feet are above the hips forces the cyclist to overcome not just the ergometer resistance, but also the resistance of hip, knee, and ankle angle, and this would be to cycle in a completely inverted position. In this position, it would be more effective to pull on the pedals, using gravity and the weight of one’s legs (than to push against the pedals to overcome the weight and gravity). A neutral position would be to have the feet equal to the ground, or (depending on the height of the bike seat) one leg weighting against pushing the pedals (60-degree trunk angle) would be more effective than a position where one has to overcome gravity. This clearly explains why reclines (especially those where the pedales are the same height) are not effective in climbing hills. This study dealt with peak power production in a 30-second test because another study that I had conducted aerobically (90-minute test) with the same results as to trunk angles revealed no significant difference between all three angles. An EMG study, examining possible differences in muscle recruitment between a 90-minute aerobic exercise and trunk angles revealed no differences in muscle timing, patterns, or duration among muscle activity. All quantitative data were not available, and may have supported the “overcoming leg weight” explanation of why the 120-degree trunk angle was less effective.

Denny Too: (1994). The effect of body position/configuration and orientation on cycling peak power output. In C. R. Ky, J. S. Kyle (eds.), Fourth International Human Powered Vehicle Scientific Symposium Proceedings (pp. 59-65). Cycling Research Association, Word, Canada. This study is a really a compilation and pre- sentation of the data from previous studies on measurement of squat position (as presented as experiment 1) and manipulation of trunk angle (presented as experiment 2). The study found no significant differences for the results and discussion.

Too, D. (1994). Comparison of joint angle power production during upright and recumbent cycle ergometry. In J. A. Hoffman, A. Chapman, J. J. Eng, A. Hodgson, T. E. Milner, & J. A. Sanderson (eds.), Proceedings of the Ninth Biennial Conference and Symposium of the Canadian Society for Biomechanics (pp. 184-185). Simon Fraser University, Burnaby, British Columbia, Canada. This study compared the 75-degree seat- tube-angle recumbent-cycling-position with the standard upright-cycling-ergometer position. With both hip, knee, and ankle angles, the data were compared, as was peak power and average power during the 30-second power test. All subjects were tested in both the recumbent and upright positions. The up-angle data was selected on each subject’s body mass. The recumbent position was found to result in significantly greater absolute and relative power (relative to body mass) in peak power and average power, when compared to the upright position. Only the minimum and maximum hip angles between the upright and recumbent position were significantly different. There were no significant differences in the maximum, minimum, and range of motion of the knee and angle between the recumbent and upright position. This would suggest that differences in cycling efficiency between the upright and recumbent position were attributed to differences in hip and knee angles. There are other factors and variables to consider, including the interaction between muscle-force-length, and force-velocity-power relationship, since there apparently is an interaction between crank-angle length, load, and cadence.

Currently I have two papers related to crank-angle length in review for publication: 1. Too, D., & Landgraf, G. The effect of pedal crank length on angle and power production in upright and recumbent ergometry. Submitted to Journal of Sport Sciences. 2. Too, D. The effect of pedal crank length on joint angle and power production in recumbent-cycling-ergometry. Submitted to Ergonomics. I am currently analyzing data for a paper, comparing the power production between and across subjects. Hopefully within the next 2 months, I will have some data to present. Denny Too: Table showing differences depending on crank length (CL)

<table>
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<tr>
<th>CL (mm)</th>
<th>110</th>
<th>145</th>
<th>160</th>
<th>180</th>
<th>205</th>
<th>230</th>
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In summary, the recumbent position demonstrated that changes in cycling trunk angles may affect peak power and mean power production and cycling effectiveness, but also happens to maximize aerodynamic drag, may not necessarily maximize cycling performance (as defined by maximum velocity or minimal time to cover a pre-set distance). The optimal cycling position may change with the subject’s build, but differences in changes in crank-angle length. The same subjects were used for all test conditions in the upright and recumbent.

The effect of body position/configuration and orientation on cycling peak power output. In C. R. Ky, J. S. Kyle (eds.), Fourth International Human Powered Vehicle Scientific Symposium Proceedings (pp. 59-65). Cycling Research Association, Word, Canada. This was an investigation to compare power production between an upright (UP) and recumbent (REC) cycling position with chair heights of 90, 120, 150, 180, and 210 mm. The chair height was randomly assigned, with a minimum of 24 hours between sessions. A 12-minute warm-up and post-hoc tests revealed that peak power at the 90-degree trunk angle was significantly greater than that at the 120-degree angle. It was concluded that changes in cycling trunk angle may affect peak power and mean power production.

The interaction between crank-angle length and cycling performance is much more complex, since changes in crank-angle length may affect knee angles. There are other factors and variables to consider, including the interaction between muscle-force-length, and force-velocity-power relationship, since there apparently is an interaction between crank-angle length, load, and cadence. It was concluded that changes in cycling trunk angle may affect peak power and mean power production. The results of this study would suggest that, although a reclining position (120-degree trunk angle) may be more comfortable, it is not effective in power production. The reason? A reclining position where the feet are above the hips forces the cyclist to overcome not just the ergometer resistance, but also the resistance of hip, knee, and ankle angle, and this would be to cycle in a completely inverted position. In this position, it would be more effective to pull on the pedals, using gravity and the weight of one’s legs (than to push against the pedals to overcome the weight and gravity). A neutral position would be to have the feet equal to the ground, or (depending on the height of the bike seat) one leg weighting against pushing the pedals (60-degree trunk angle) would be more effective than a position where one has to overcome gravity. This clearly explains why reclines (especially those where the pedales are the same height) are not effective in climbing hills. This study dealt with peak power production in a 30-second test because another study that I had conducted aerobically (90-minute test) with the same results as to trunk angles revealed no significant difference between all three angles. An EMG study, examining possible differences in muscle recruitment between a 90-minute aerobic exercise and trunk angles revealed no differences in muscle timing, patterns, or duration among muscle activity. All quantitative data were not available, and may have supported the “overcoming leg weight” explanation of why the 120-degree
Danny Too: First, my experiments do not show or prove that “high-BB” bikes (SWBs) are slower climbers than low-BB recumbents (many LWBs). The subjects, in general, were recreational cyclists. Do you recall what you referred to as ‘upright’ and ‘recumbent’ in your papers? I do have one question regarding your claim in the paper ‘The effect of body orientation on power production in cycling.’

Q. Question: King Gary wrote: “Thou too’s experiments were probably very accurate, I don’t believe they prove ...”

A. Answer: Thanks for pointing the summary of what’s readily available in the marketplace (e.g., 165, 170, 175-mm crank). I am using extreme (short and long) crank-lengths to observe the trend in performance that occurs, and to understand the mechanisms involved. It appears that it is not so much the length of the cranks that is important, as it is the angles of the lower extremities in producing power.

The difficulty with using the same individuals for repeated tests over a period of time is the training effect that would occur. The data with different crank-lengths would be confounded by the improvement in performance due to training. It would then be difficult to separate performance differences with different crank-lengths are attributed to crank-lengths, a training effect, or both. To control for the training effect, the crank-angle-length test sequence needs to be randomized across subjects (i.e., a different crank-angle-length test sequence for each subject). The pull-back stroke is a very powerful stroke on the above three styles of cycling require different body configurations from the rider.

Danny Too: Yes, it is very possible that a 10 mm variation in hip-joint height (or lean angle) could make a difference for people riding the same bike to experience different levels of exertion for the same height. A 50 mm variation in crank-angle length is probably not significantly affecting the type of cruising position that the cyclist would be in. However, it may be a more important factor affecting the type of cruising position that the cyclist would be in. However, it may be a more important factor affecting performance.

Q. Question: Akash Chopra writes: “ ...It is not only different in trunk orientation, but also to a certain extent, to the sit position (because the ischial tuberosities) producing a much smaller amount of variability. "I have come upon another puzzling observation. I tested my heart-rate monitor using a high-bottom-bracket (BB215 mm above seat bottom) recumbent’/mag trainer and an upright bike on a mag trainer. On the ‘bent trainer at 150 bpm I was starting to feel uncomfortable and was at my aerobic threshold at 160. I then rode the up- right bike on the same trainer at 150 bpm, I did not understand the performance difference. Could it be that the ‘bent position constrained my diaphragm and reduced my cardiac output? I ‘bent’ a bike on a high bottom bracket and an upright bike on a mag trainer. I do not see what form of recreational cycling they used most often. Do you have any data on experienced, off-s chilld cyclists, track cyclists, or other? I ask because I think the position that a person uses for cycling might influence the optimal cycling position and the above three styles of cycling require different body configurations from the rider.”

Danny Too: I wonder if a variation of seat/crank position for upright bikes must have been in trivial compared to the relatively direct comparison of each such set of data showing the exact angle-of-the-seat (or ischial tuberosities) producing a much smaller amount of variability.

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with each beat) and heart rate (i.e., cardiac output = stroke volume × heart rate). For every given cardiac output, the greater the stroke volume, the lower the heart rate. This is the reason why endurance athletes have a lower resting heart rate. For the same cardiac output at an endurance level, there will be a greater stroke volume with each heart beat (when compared to a sedentary individual) and hence a lower resting heart rate (which translates into less heart beat, and work for the heart over the course of a lifetime).

In a supine position, venous blood flow is facilitated, and work output during rest and exercise is much more easily, fills the heart more, resulting in a greater stroke volume, and hence a lower heart rate for any given cardiac output (when compared to an upright position). The maximal heart rate also appears to be less in a supine position than when you are in an upright position. Therefore, your heart rate at 160 bpm in a supine position may be at the same percentage (e.g., 90% of your supine maximal heart rate) as your 173 bpm heart rate in an upright position (e.g., 90% of your upright maximal heart rate).

As for whether the ‘best’ position constituted my diaphragm and reduced my lung capacity and upright position opened up the ribcage and diaphragm?

It is possible. A study by Faria et al. (1978) and comparing a top-bar and drop-bar cycling position (on an upright), reported the maximal oxygen uptake for the drop-bar position to be greater than that attained for the top-bar position. The drop-bar position was described as sitting semi-upright on the saddle with the hands resting on the uppermost portion of the handlebars, while a drop-bar position was described as sitting in the saddle while assuming a deep forward lean, with the hands resting on the drop portion of the turned-down handlebars. The differences in maximum oxygen consumption was attributed to (1) the activity of a larger muscle mass (greater use of the arms, shoulders and gluteal muscles) in the drop-bar position; and (2) the greater forward body angle in the drop-bar position which appears to relieve the weight of the arms and shoulder girdle from the body’s weight.

This reduced weight plus the suspended chest is believed to ease chest expansion, thereby enhancing pulmonary ventilation potential and possibly decreasing the energy requirement for respiration. So reduction of lung capacity and constriction of your diaphragm in a recumbent position is a possible explanation for a decreased work capacity. However, I have not seen any literature that has examined the accuracy and validity of this statement and explanation. It is also unknown as to whether the greater heart lean in the drop-bar position altered angles and allowed a more mechanically advantageous position to produce force when compared to the top-bar position.

If you are interested in references related to heart rate, stroke volume, cardiac output, oxygen consumption, pulmonary ventilation and exercise between supine and upright position, e-mail me and I will send you an attached text file reference list.

**Some Comments on the Effects of “Interference Drag” on Two Bodies in Tandem and Side-by-Side**

Mark Drela and Jim Papadopoulos (Editor’s note: This was contributed to a mailing list “Harcode bicycling science” organized by Jim Papadopoulos, and has been edited and reproduced here with Jim’s permission. Jim opened the discussion by commenting on existing data in a book to pairs of HPVs, including bicycles and riders, and Mark gave his explanation of the theoretical back

As case 7 would apply to A being the seat tube and B the rear wheel. Case 6 would be for A as a forward fork knob and a seat stay close to a wheel disk, or for B being a leg adjacent to a frame member (the latter with the tubes connected by a membrane).

In the last two items, the major problem is likely to be with the boundary layer on the surface rather than on the cylinder.

—Mark Drela (drela@orville.mit.edu)

**IHPVA RECORD WIND RULES: A PARTICIPANT’S PERSPECTIVE by Paul Buttimer**

In late July 1998, Team Varna, consisting of builder George George and rider Sam Whittingham and Paul Buttimer, traveled to a track in Blainville, Quebec, Canada, to attempt to set new records in various categories as recognized by the IHPVA. (For those interested in Team Varna’s results, and a description of the venue, see the article “Record-breaking tandem racing” — Mark Drela — Human Power 1999)

The biggest consideration in choosing our dates was the weather. Historically, the Blainville area enjoys in late July, weather that most commonly develops during the summer, and the conditions, and humidity that is lower than at other times in the summer. However, in this particular year, the Blainville area was affected from unusually high and consistent wind conditions (El Niño after-effect?), with only occasional windows that were within...
 editorial

Gunter Rochelt

Gunter Rochelt, well known to HPV enthusiasts for his remarkable prize-winning aircraft Solar I, Muscular I and II, Schneiderair, has re-attempted in the spirit of the Codex Atlanticus, Leonardo da Vinci's idea for human-powered flight.

REVIEW

CONTINUATION: REVIEW OF THE EIGHT CYCLE-HISTORY CONFERENCE Hans-Erhardt Lessing presented The evidence for the earliest bicycle! The first human-powered aircraft to carry a passenger. Human Power was done in 1994, and it was rather crude ("A poor thing, but mine own—"

HUMAN POWER NUMBERING AND INDEXING

There are 12 other enjoyable chapters—not reviewed here because we are short on space.

The Scottish school of cycle design, by Loren Hufsteadler; The cycling new woman, by Bronwen Edwards; Some steps in the history of women's racing, by John Hufstedler; "In a word, bicycle": By John Hufstedler; "A pedanti-

Pinkerton; The social impact of cycling as a technology-based sport, by Ros D. Petty; Some thoughts on the future of cycling competition, by Rüdiger Rabenstein; The beginnings of trans-Atlantic bicycle racing, by Andrew Rochelt; Is it about a bicycle? By Valerie Hawkins; Piet Pelle op

Some facts about the history of doping in technology-based sport, by Ross D. Petty; The beginnings of trans-Atlantic bicycle racing, by Andrew Rochelt; Is it about a bicycle? By Valerie Hawkins; Piet Pelle op

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