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Human Power

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IN THIS ISSUE

Bicycle chain transmissions
Jim Spicer and his associates at Johns
Hopkins have written a paper that will
change minds, and design directions, on
HPV transmissions. To give just one
example: the losses associated with small
sprockets on the rear wheel make "mid-
drives" or counter-shaft gears suddenly
attractive, and possibly hub gears too.
They also find that chain lubrication
doesn't seem to reduce losses: that will be
ever more controversial. (Your editor has
high confidence in the data: he asked Chet
Kyle, IHPVA founder and one of the
foremost researchers in bicycle perfor-
man ce in the world, to look at them before
publication. He had done a proprietary
study on the same topic, and has produced
a broadly similar results.)

Offset rims
Vermon Forbes gives us another of
his careful studies of spoke-wheel construc-
tion incorporating derailleur--chain
brake disks that cause the wheel to be
"dished" (spoke asymmetrically). He
shows that the use of rims that have off-
center spoke holes brings about a con-
siderable reduction in the difference in spoke
tensions that otherwise makes highly
dished wheels prone to spoke failure and
occasionally to collapse.

Rolling resistance
John Lafford has tested, on equipment
of his own design and construction, a
prodigious number of bicycle tires, mostly
of the wide, particularly suited to the
framed wheels of recumbent bikes. He measured
rolling resistance and power loss over a
range of speeds and inflation pressures.

PROJECTWORK

Letters include kind words from Chet
Kyle, comments by Anil Rajanu on
publication of his article on rickshaws in
the last issue (Human Power 49); and
compliments by Anil Schmidt on his article "Velocar variations",
also in the last issue.

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. News and similar items should go to APV News or to your local equivalent. Contributions should be understandable by any English-speaking person in any part of the world, should be in 3x1 (local units optional), and the use two-inch "tabs" should be either avoided or explained. Ask the editor for the contributor's guide (available in tables, e-mail and PDF format). Many contributions are sent out for review by specialists. Alas! We cannot pay for contributions. Contributions include papers, articles, technical notes, reviews and letters. We welcome all types of contributions from IHPVA members and from nonmembers.

On the efficiency of bicycle chain drives

James B. Spicer,* Christopher J.K. Richardson, Michael J. Ehrlich and Joanna R. Bernstein

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Masahiko Fukuda and Masao Terada
Shimano Inc., Product Engineering Division, Sakai Osaka 590-77

ABSTRACT

The efficiencies of bicycle drive trains have been studied and energy-loss mechanisms in these sys-

tems. An analytical study of frictional energy loss along with a series of experimental ef- forts and arrangements of derailleur-type chain-drives systems under a range of power, speed and

lubrication conditions are given to identify loss mechanisms. These me-

surements of mechanical efficiency are compared to infrared measurements performed during driving that show the heating of drive components resulting from frictional losses. The results of this study indicate that chain tension and sprocket size primarily determine chain-drive efficiency.

INTRODUCTION

When this study was performed, it was hoped that through identification of the loss mechanisms primarily

responsible for limiting the efficiency of bicycle chain drives, methods for improving efficiency could be realized

by eliminating or decreasing the vari-

ous losses. While some of the results

will be used to measure chain-drives

performance based on chain contact
ten s, while static measurements of these forces have agreed with mod-

els, efficiency-measurement results

have not appeared in the literature

(Kidd et al. 1996).

In this work, the efficiencies of bicy-

cle chain drives are investigated both

experimentally and theoretically to iso-

late factors associated with loss in

these systems. A computer-controlled
drive-train-testing system was designed to

measure the performance of the

chain ring and rear cassette in a derailer-
type system. This system was used to

measure chain-drive performance under a variety of operating conditions. Assuming that frictional forces degrade the overall efficiency of

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Fig. 1. Experimental schematic of test stand showing elements of the drive assembly
the system, simple analytical models for the losses of chain drives have been developed to estimate and identify the primary mechanisms of frictional loss. These models for drive losses have been used to interpret experimental data. An analysis for this tension can be found in the work by Tordoj (1996) and in the work by Kidd et al. (1989). Since the friction depends on chain tension, there are perhaps two major locations for loss in the drive that should be identified beforehand since the chain tension is large and is transferred from the chain to the sprocket at these locations. These include the surfaces between the inner link bushing and chain pin and between the sprocket tooth, link roller and inner link bushing. Rather than derive in detail the functional form for the losses of chain drives, two separate configurations are examined and are given as follows: Configuration A, \( N_1 = 11 \) Configuration B, \( N_2 = 15 \) Configuration C, \( N_2 = 21 \)

These configurations were chosen to reflect the situation that the offset has a form nearly identical to that given for friction at the pin/bushing interface except that the factor of the offset angle appears in the expressions for off-set losses. Since this angle is small, the frictional effects of offset should be small compared to the pin/bushing losses. Any effect would necessarily appear in the largest offset conditions.

The essential elements of the system were acquired using an electromagnetic brake mounted to the output shaft.

The drive shaft was driven by a variable-speed electric motor system connected to the drive shaft. The drive shaft rotation rate from this system could be varied continuously under manual control. Consequently once the desired rotation rate was set, the rate was not actively controlled and the actual rotation of the drive shaft was measured using a speed sensor. The drive-shaft torque was measured using a non-developer torque meter. The drive-shaft was configured to the geometry found on bicycles with the distance between the front chain ring and rear cassette being adjusted by mounting the entire output-shaft assembly on a translational platform. Mounting ensured that the pin and bushing images of drive components while the drive was in operation. Since frictional losses, noise, thermal effects, and other components, the infrared camera was useful in identifying those components that had the highest temperature rises. The primary component of this system is the infrared camera that operated with an InSb planar array sensitive in the 3-5 μm range. LabView software to control the camera and the image-acquisition board, thermal images of the drive were acquired and stored for analysis and display. For these operations it was important to acquire images of the drive so that the drive component of interest occupied the same position in the infrared image from frame to frame. By acquiring images in this manner, the heating of an individual component, such as a single chain link, could be tracked accurately as a function of time.

**EXPERIMENTAL PROCEDURE**

Four major areas for investigation were identified and were pursued. Time loss was the instrument of efficiency were made over extended run periods (2 hours) to determine whether or not efficiency varied as a function of time during drive operation. Efficiency was measured as the ratio of the torque signals to actual torque values, each of the torque sensors was calibrated using known static loads. By measuring the torque-sensor signals as a function of time, a calibration curve was obtained that returned the applied load to the applied torque.

Figure 2. Measured chain-drive efficiency as a function of time for three different drive configurations (S2-11, S2-14, and S2-21) in the no-cassette condition. The data were run for two hours, but only the first 100 minutes are shown here. Note that efficiency is fairly constant during the entire time period.

These results indicate that configuration A should have 63% more power loss than configuration B. Configuration B should have 28% more power loss. For example, if a test of efficiency indicated a 5% power loss in configuration C, then configuration A should suffer 31.2% loss and B should have a 6.4% loss.

**DESCRIPTION OF THE EXPERIMENTAL APPARATUS**

To assess drive efficiency, a test stand was designed to measure the overall drive efficiency of the chain drive. The drive was configured to the geometry found on bicycles with the distance between the front chain ring and rear cassette being adjusted by mounting the entire output-shaft assembly on a translational platform. Mounting ensured that the pin and bushing images of drive components while the drive was in operation. Since frictional losses, noise, thermal effects, and other components, the infrared camera was useful in identifying those components that had the highest temperature rises. The primary component of this system is the infrared camera that operated with an InSb planar array sensitive in the 3-5 μm range. LabView software to control the camera and the image-acquisition board, thermal images of the drive were acquired and stored for analysis and display. For these operations it was important to acquire images of the drive so that the drive component of interest occupied the same position in the infrared image from frame to frame. By acquiring images in this manner, the heating of an individual component, such as a single chain link, could be tracked accurately as a function of time.

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sured as a function of gear ratio (52–11 etc.) and the effects of offset were determined to test the effects of drive-dependent configuration.

**Power/rate.** Efficiency variations with input power and rotation rate were measured to determine if load or rate-dependent effects were present. **Lubrication.** The effects of lubrication and drive configuration were quantified.

**EXPERIMENTAL RESULTS AND ANALYSIS**

**Time variation of efficiency**

A new chain used for these tests was cleaned using Simple Green™ Bike Cleaner/Degreaser and was lubricated using Generation 4 White Lightning™ self-cleaning lubricant. These tests lasted 120 minutes at 60 RPM 100W for each of the following chain-drive configurations: 52–11 no-offset, 52–15 no-offset and 52–21 no-offset. As shown in figure 2, the efficiency for all long-duration tests showed little-to-no long-term efficiency variations during the tests. The measured efficiencies for these three configurations are as follows: 52–11 no-offset: 91.4%, 52–15 no-offset: 90.2% and 52–21 no-offset: 95.6%. These values represent an average over the duration of the test. As a result of this finding, the subsequent tests were run for no more than 30 minutes to assess efficiency or efficiency variations.

**Configuration**

The next series of tests investigated the effect of chain configuration on efficiency. These tests lasted 30 minutes each and were conducted with the 52–15 combination in the no-offset condition. Consequently, the 52–11 and 52–21 combinations were tested in an offset condition as would occur for a properly configured bicycle. The results of these tests are summarized in Table 1.

First, comparing the results here with those in the long-duration tests, the effect of chain offset can be estimated. These data were obtained with the 52–11 and 52–21 configurations in the offset condition while those in the long-duration tests were taken with no offset. Comparing the data for 60 RPM 100W shows that the offset lowers the efficiency by, at most, 0.5% when measurement precision is considered. Additionally, if the efficiencies are normalized by efficiencies measured in the 52–15 configuration (both sets of data were obtained with no offset), then it appears that the offset has a negligible effect on efficiency.

More importantly, in these mid-duration tests, the efficiencies show a consistent dependence on rear sprocket size where the larger the sprocket, the higher the measured efficiency regardless of the selected power or rotation rate. If the efficiency for 52–21 is 95.2% (as is found for 50 RPM 100W), then the previous modeling predicts a difference in efficiency of 2.6% between the 52–21 and 52–21 configurations.

From the data in the table, the measured difference between the 52–21 and 52–11 combination is 2.7%. These results indicate that the primary mechanism for chain-drive loss could be friction at the pin/bushing interface and enhanced articulation are currently being pursued using noncontacting optical measurement techniques to investigate these effects.

**Lubrication**

In this phase of the study, the chain was thoroughly degreased/de-lubricated using commercially available degreasers (Castrol Wrench Force Degreaser™ and/or Simple Green™ Bike Cleaner/Degreaser) and was relubricated using one of three commercially available lubricants (Castrol Wrench Force Dry Lube™, Pedro's Syn Lube™ or Generation 4 White Lightning™). The results in table 2 indicate that the previous trends for efficiency as a function of configuration and as a function of drive dependent configuration were followed. However, these results also indicate that the actual lubricant used has little effect on the overall performance of the drive under laboratory conditions. Even the precision of the measurement. In addition, the chain used for this experiment was fully degreased and was re-tested for efficiency. This degreasing operation consisted of a five-minute scrub with kerosene followed by a cleaning with Castrol Degreaser. The measured efficiency of the de-lubricated chain for the 52–15 combination at 60 RPM and 100 W was 90.3% and at 200 W was 96.5%. These efficiencies are essentially the same as those measured for the chain in the re-lubricated condition.

**Infrared during chain-drive operation**

Infrared images of the chain drive during operation aid the interpretation of the efficiency measurements that have been presented and also support the models of chain-drive friction by the three-axis accelerometer chain drive devices. Simply put, the chain components responsible for friction should heat if the chain and its components lose energy by heating.

Table 2. Efficiencies for different drive rotation rates and sprocket configurations (input power 150W)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>52–11 40 RPM</td>
<td>92.8 89.4 84.2</td>
</tr>
<tr>
<td>52–15 40 RPM</td>
<td>94.0 90.5 86.5</td>
</tr>
<tr>
<td>52–21 40 RPM</td>
<td>95.2 92.0 88.3</td>
</tr>
<tr>
<td>52–11 60 RPM</td>
<td>93.6 89.5 85.6</td>
</tr>
<tr>
<td>52–15 60 RPM</td>
<td>95.6 92.8 88.8</td>
</tr>
<tr>
<td>52–21 60 RPM</td>
<td>95.3 92.8 89.0</td>
</tr>
<tr>
<td>52–11 80 RPM</td>
<td>94.0 91.1 87.2</td>
</tr>
<tr>
<td>52–21 80 RPM</td>
<td>94.2 91.1 87.2</td>
</tr>
</tbody>
</table>

**Human Power**

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**Figure 3:** Variation of chain-drive efficiency with the reciprocal of gear ratio.

**Figure 4:** Infrared images of chain drive during operation showing effects of frictional heating.
These data were taken at 60 RPM intensity for positions on a chain of pixel intensity. Chain-drive heating must be performed using the temporal evolution of pixel intensity.

In Fig. 5 the infrared pixel intensity for positions on a chain pin, on a pulley tooth and on the body of the pulley (midway between the bearing and the pulley teeth) are shown as a function of time for different input powers. These data were taken at 60 RPM in the 52–21 configuration. These results clearly show that the chain pin rises in temperature more rapidly than the other locations regardless of the input power and indicate that heating results from frictional losses near the pin.

The data for the chain and the pulley tooth indicate that the component temperature rises with the input power. For the pulley tooth, at 50 W input power, the maximum pixel value is approximately 23 units; at 100 W, 35 units and at 150 W, 65 units. These results are in rough agreement with the loss models presented previously where the frictional losses are directly proportional to the input power.

Unfortunately, the power loss in each of these cases is not proportional to the input power owing to the dependence of efficiency on chain tension. Using measured values for efficiency under the conditions for the data in Fig. 5 (97.2% for 150 W, 94.4% for 100 W and 85.5% for 50 W) indicates that 4.2 W of power at 150 W input, 5.6 W at 100 W input and 7.3 W at 50 W input. Obviously, for a lower power loss, the temperature rise should be lower if the lost power is converted entirely to heat by frictional loss. It would be expected that the temperature rise would be lowest if the 150 W input test since the measured power loss is lowest for this case.

DISCUSSION AND CONCLUSIONS

Tests of efficiency for the derailleur-type chain drive indicate that the overall efficiencies for the transfer of power from the front drive sprocket to the rear sprocket range from 80.9% to 98.6% depending on the conditions of drive operation. Primary factors affecting the efficiency include the sizes of the sprockets in the drive and the tension in the chain.

It was found that larger sprockets provide more efficient transfer of power while smaller sprockets proved to be less efficient. Simple, frictional loss models were developed that gave sprocket-size loss variations that agreed with those variations measured experimentally. Typically, a 2–5% loss difference was measured between the 52–11 and the 52–21 sprocket combinations depending on the drive operating conditions.

Experimental results indicated that the efficiency of the chain drive varied as a function of chain tension. It was found that the efficiency varied linearly with the reciprocal of the average chain tension with the highest efficiencies occurring at high chain tensions and lowest at low chain tensions. For example, the highest efficiency measured in the study, 98.6%, was measured at a chain tension of 395 N and the lowest, 80.9%, at 76.2 N.

It was found that chain-line offset and chain lubrication have a negligible effect on efficiency under laboratory conditions. Calculations of frictional loss resulting from offset indicate that this loss should be small compared to those produced by other mechanisms. This was verified experimentally. Lubrication effects on chain efficiency were tested using three different chain lubricants under a variety of test configurations. These results are in rough agreement with the proposed lubrication model.

The chain pins rapidly heat on the tooth and chain lubrication have a negligible effect on chain efficiency. At low chain tensions and low rotations, the lubrication heating is consistent with heating at the pin-bushing interface. At low chain tensions and high rotations, the lubrication heating is consistent with heating at the chain lubrication and chain lubrication have a negligible effect on chain efficiency. This was verified experimentally. Lubrication effects on chain efficiency were tested using three different chain lubricants under a variety of test configurations. These results are in rough agreement with the proposed lubrication model.

REFERENCES


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The Hopkins group pursues work in pulsed and ultrasonic (feltronosecond) laser-based materials processing and characterization. In contrast, the expertise of the Shimano participants lends towards the design and manufacture of cycling components. All of the authors express their gratitude to the Baltimore Orioles for the use of Camden Yards where many fruitful technical discussions about this work were held.

Figure 5: Variation of infrared emission with time during a calculation for different drive components. At time equal to 0 s, the chain drive was placed under full power loading.

SUMMARY OF EQUATIONS

1. $W_i = \frac{\mu_\psi}{2} \int_{T}^{T+s} \sin(\psi) dp \cdot \left[\frac{\tan(\alpha/2) / \tan(\psi/2)}{1 - \tan(\alpha/2) / \tan(\psi/2)}\right]

2. $P_{\text{Total}} = N_0 \omega_0 W_i /2 \pi$

3. $P_{\text{Total}} = N_0 \omega_0 \frac{\mu_\psi}{2} \frac{1}{N_1} \frac{1}{N_1}$

4. $P_{\text{Total}} = \mu_\psi \frac{1}{2} \frac{\omega_0}{N_0} \frac{2 \pi}{N_1} \sin(\psi) \cos(\psi) - \sin(\psi) \cos(\psi)$

5. $P_{\text{Total}} = \mu_\psi \frac{1}{2} \frac{\omega_0}{N_0} \frac{2 \pi}{N_1} \sin(\psi) \cos(\psi) - \frac{\tan(\alpha/2) / \tan(\psi/2)}{1 - \tan(\alpha/2) / \tan(\psi/2)}$

6. $\% \text{Efficiency} = \frac{2 \pi \omega_0}{100} \times 100$

7. $P_{\text{Total}} = 1.63$ and

$P_{\text{Total}} = 1.28$
Offset rims reduce the amount of dish
by Vernon Forbes

ABSTRACT
Offset rims reduce the amount a wheel is dished. Two offset rims are tested and the results compared to a standard rim. Possible implications are discussed.

INTRODUCTION
"Dish" in a bicycle wheel is a measure of the radius from the center of the rim to the center of the hub. The dish is the ratio of the distance from the center of the rim to the center of the hub over the diameter of the wheel.

Figure 1. Wheel cross-section for asymmetric rims (after Brandt) with modifications for asymmetric rims.

One effect a freewheel has is to increase spoke tension on the drive side of the wheel. If an eccentric wheel is used, the spokes will be tighter on the drive side than on the non-drive side. The ratio of spoke tension on the drive side to the non-drive side is a measure of the asymmetry of the rim.

Figure 2. Offset rim: Bontrager Mustang (produced here with permission).

METHODS
Three 26x1.75 32 spoke rims were tested, two offset and one non-offset, for comparison. The offset rims were a Ritchey OCR (Off-Center Rim) and Bontrager Mustang Asym (Asymmetric). The non-offset rim was a Ritchey Singletrack. Each of these rims was built up on a 135-mm-long axle. The wheel was then taken apart and redished the wheel, e.g., the DS was increased by increasing the spoke tension.

Figure 3. Tension differences (dish) for regular and offset rims.

<table>
<thead>
<tr>
<th>Speeds</th>
<th>F/W</th>
<th>Reg</th>
<th>OCR</th>
<th>Asym</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-sp</td>
<td>65.5</td>
<td>59.2</td>
<td>52.8</td>
<td>47%</td>
<td>34%</td>
</tr>
<tr>
<td>8-sp</td>
<td>66.5</td>
<td>60.2</td>
<td>53.8</td>
<td>55%</td>
<td>45%</td>
</tr>
</tbody>
</table>

DISCUSSION
Figure 3 plots dish differences as a function of spoke tension between the drive side and the non-drive side (DS-NDS). The graph plots three lines; one for a Bontrager Asym, a Ritchey OCR, and a standard non-offset rim. A front wheel.
or any wheel with no dish would plot a value at zero. At the higher the number the more vertically dished the hub. Less dish is desirable. What is obvious is that the non-offset rim has the greatest tension differences, for all levels of width. Both offset rims appear to have significant reduction in dish. While both offset sets are based around the standard rim height, there is a difference in the overall rim width. The Ritchey rim is 24 mm wide. With a wider rim you can move the spokes further over to the NDS. While the Bontrager rim is 22.5 mm narrow it has only 0.5 mm more dish than a Ritchey. There is a weight penalty for a wider rim. We measured (and Bontrager literature) the Ritchey OCR at 360 g and the Ritchey Rim OCR at 484 g. Wider rims are stiffer. Overall weaker. In terms of height the Ritchey advertised 12 mm height and the Bontrager advertised 13 mm height. Deeper rims are stronger. Both rims are made from 6061-T6 aluminum alloy.

Offset rims have been criticized by some as being weaker because they lack ferrules, or “spoke sockets” that join the upper and lower parts of a spoke section so the spoke pulls on both sections of the box-section rim. In answer to both these rim concerns we use what the Ritchey literature used to claim a 3-mm reduction in dish. However, this is all highly speculative. The possible effects of bending-moment asymmetry in offset rims are not known. Possible effects include:

- Increased denting during cornering.
- This might result in increased lateral movement of the rim. Any vertical loading will force, or lack of balance. The possible effects of bending-moment asymmetry in offset rims are not known. Possible effects include:


REFERENCES


Rolling resistance of bicycle tyres

by John Lafford

INTRODUCTION

I have been a research and development engineer for many years, and when I started recumbent racing about fourteen years ago, it was only natural for me to want to obtain reliable data on cycling performance. The most important factor in aerodynamics, and I addressed the measurement of aerodynamic drag in the real world by doing coast-down tests. The procedure for this is described in "So you want to build an HPV" ([4], p. 40) if a publication of the British Human Power Club. For an accurate drag result you also need to know the rolling-resistance values for the tyres. As you go faster, the rolling-resistance becomes more important and it is therefore vital to have accurate data on which to base a tyre choice. It was this requirement that led to study and analysis to derive an accurate and repeatable test procedure for measuring rolling resistance.

The testing has all been done with racing in mind. For touring or commuting other factors such as wear resistance, puncture resistance, grip in the dry and wet, and cost, come into consideration for tyre choice.

TESTING PROCEDURE

The tyre-testing procedure involves rolling the tyre/wheel combination along a flat surface and so represents the real case of using the tyre on the road. The tyre is also loaded with a representative weight and starts rolling at a controlled initial speed. The distance that the tyre rolls is inversely proportional to the rolling resistance. The rolling-resistance coefficient is derived from the difference in initial speed and the distance that the tyre rolls.

The speed of rolling in the tests is slow so that aerodynamic forces are negligible and we may use small wheels and tyres. The commercially smooth concrete in my local aircraft factory workshop, and is reasonably representative of a smooth tarmac road surface. In any event, as all the tests are performed in exactly the same place, they all relate to one another.

The power to propel tyres along the road (PRr), is directly proportional to the rolling-resistance (Rr), and the weight of the vehicle plus rider (W), and also the speed of the vehicle (V).

PRr = crx W x V (times a constant for users of various units – ed.)

The power absorbed is the same with either of the two or four wheels (so long as they are perfectly aligned, as the author confirms below – ed.). In the table, the power is computed in watts for the cases of:

1. Vehicle plus rider weighing 185 lb (84 kg) at road speeds of 20 mph, 25 mph and 30 mph (12, 19 and 20 kph, respectively); and

2. Vehicle plus rider weighing 200 lb (91 kg) at road speeds of 30 mph, 40 mph and 45 mph (48, 64, 60 kph and 80 kph, respectively) which is relevant to faired vehicles.

TIME LOST

The time-longest column gives a practical appreciation of the importance of the rolling resistance of the active wheeled vehicle. It is not knowing the test by each of the tyres against the best tyre listed (the last tyre in the list), over a distance of 10 miles, but 16 km. The base time map is taken from a controlled initial speed of 10 miles at 25 mph, and 24 miles at 20 mph.

The time lost is derived from aerodynamic-drag values obtained in coast-down test results (see reference below) using my own racing recumbent. Data from the test will predict the power required to ride along a level road at 25 mph and 24 mph. The difference in these two values was 28 watts for my recumbent with an average tyre that were tested at one time. The best was good enough to ride 10 miles at 24 mph in 25 minutes. The time-longest column is calculated by proportion of the power absorbed where

a. the tyres are good just because the three numbers raise a host of questions.

b. Because the measurement was taken at low speed, then the high-speed calculations should have a disclaimer.

c. John Lafford’s comments are entirely relevant to faired vehicles. The power absorbed must be called “Rolling resistance of small-diameter tyres”. My questions relate primarily to accuracy and mechanistic considerations on his own tests.

8. For additional rolling-resistance data, see reports in the following publication.

Cycling Plus, issue 62 (Feb. ’97)

“Winter tyres”; Cycling Plus, issue 68 (Mid-summer ’97) “Road tyres”


9. Thanks are due to the following for the loan of tyres for testing: Hilary Stone, Richard Grigsby, John Kingdon, and rahul, an Indian-Canadian Tylers, Dillipoloe (Nokian tyres).

John Lafford <jalafford@aol.com>
John Lafford is an engineer who has been building and racing recumbents for 14 years. He is interested in all the technical aspects of cycling with emphasis on efficiency of operation. He has built two- and three-wheeled recumbents, both faired and unfaired, and also works on powered-assisted bikes and trikes. He also takes part in time-trial events using a cross-shaped frame design of bicycle produced by his own Arrow Bicycle Company.

(Editor’s note: discussion of contributions is always welcome in letters to Cycling Plus, Richard Grigsby, John Kingdon, and rahul, an Indian-Canadian Tylers, Dillipoloe (Nokian tyres).)

Note on Lafford’s testing method

by Jim Papadopoulos

It is always heartening to see evidence of a great deal of careful testing. Unfortunately, I was unable to find anything to support the claims of saving 0.0019–0.0033.

1. Has he taken care to eliminate some of the “obvious” errors one might expect in this kind of low-speed, “coasting to rest” test? Low-speed rolling is strongly affected by small invisible dips (in the roadway). In the Hallway at Cornell, for example, there was an invisible dip that would clearly accelerate a rider. His results lose force if either (a) the paths differ from time to time or (b) in going down and up, some wheels “stall” while others just manage to “creep” a rise and travel much further. Also, I wonder how the wheel is balanced and guided as it comes to rest. The normal way is to make a tricycle, but then there is an issue of drag from the support wheels (particularly if they are faired) that could perhaps be subtracted, but only if it was known with high accuracy. In my own researches I had to cope with the invisibility of the initial support wheels as they loaded support wheels, but never got around to it. Finally some comments about conditions:

a. Wind speed. A measurement was taken at low speed, then the high-speed calculations should have a disclaimer. Kyle had there is a speed effect, Kev had there is a speed effect, Kev

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ACKNOWLEDGMENTS

The author thanks David Gordon Wilson for the introduction to the preparation of this article, Helen Studios in Columbia, MO, John W. Stephens of Garden Grove, CA, and Jean Seay of U. of Oklahoma, for their assistance in the preparation of this figure.

Figure 2 is after The Bicycle Wheel by Jobst Brandt and appears by courtesy and with his permission. The author thanks him for his comments in reading an advance copy of this article.

Figure 3 is after The Bicycle Wheel by Jobst Brandt and appears by courtesy and with his permission. The author thanks him for his comments in reading an advance copy of this article.

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<th>Tyre name</th>
<th>Size</th>
<th>psi</th>
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*1 bar = 14.5 psi
*2 compared with the time using the tyre (at the same power input) with lowest Crr, the last entry in the table

**Tyre name** Size **Tyre test** **Rolling resistance power absorbed** Unfair ed wgt = 185 lb/84 kg / Faire d wgt = 200 Lb/91 kg

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**Rolling resistance of tyres - test data**

Generally available recumbent tyres

Rolling resistance of tyres - test data

*Pres- Rolling 20mph 25mph 30mph 30mph 40mph 50mph over 32kmh † 40kph 48kph 48kph 64kph 80kph 10 mi. ‡

Test Prr Prr Prr Prr Prr Prr 25mph

Unfaired wgt = 185 lb/84 kg / Faired wgt = 200 Lb/91 kg

‡ compared with the time using the tyre (at the same power input) with lowest Crr, the last entry in the table

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**Recommended Tyres for Rear Wheels** for comparison. Very good performance at reasonable price.
• What was his load? “Representative” probably means it was 45 kg, but it would be nice to know for sure.

None of this is meant as direct criticism of Lafford’s careful efforts, but rather as an invitation to discuss some vitally interesting issues!
—Jim Papadopoulos

Reply to note by Jim Papadopoulos, approximately in the order of his questions,

Tires tested. The number of tyres tested is approaching 480 and I have tested tyres of all sizes. The article was focused on small-diameter tyres as they are of particular interest to HPV riders. I included three good 700C tyres of good value.

Repeatability
1. If I ran a tyre up the track and it ran 20” 3’” (say), and then I repeat it straight away and follow the exact same piece of the floor, then it also will run 20’ 3”. If the direction is a bit off then the distance will be slightly different due to the slight imperfections in the floor.

2. If I were to repeat the test on that tyre on another day, then I might not include these as they are more expensive and less durable. There are many 700C tyres a whole lot worse.

The Moulton data are for the line tread, touring tyre, not the high-pressure slick.

I am not looking to repeat other people’s results. It would be relevant only if I had the same tyres that they had used.

The test wheel/tyre is fitted to a tri-cycle. The two other wheels are perfectly aligned, I know their rolling resistance coefficient and they are only lightly loaded. Even so, their rolling coefficient and load and drag components are taken into account.

The weight on the test wheel is 66 lb. This is representative for three 20” wheels.

—Jim Papadopoulos

TECHNICAL NOTES

Power requirements for laid-back recumbents
Report and coment by Dave Wilson, with translation help from Jan Limburg and Ellen Wilson

This is an interpretation of the high points of an article by Bert Hoge and Jeroen Schasfoort in HPV nieuws no. 4, 1999, the magazine of the Netherlands NVHPV. Its topic is the use of an SIHM instrumented crank (giving torque) on a “regular” racing bike and on five recumbents. All of the recumbents were of the very-laid-back variety, having seat-back angles with the horizontal of down to 15 degrees (see photos). All of them had the bottom-bracket considerably above the lowest part of the seat. I believe that this is important because whirling legs normally give a high drag, and having them in the “forward shadow” of the body must reduce this drag. The authors write, “A smaller frontal surface gives less air resistance and higher speed. It can be achieved by increasing the height of the bottom bracket above the lowest point of the seat to about 270 mm (10.6”), and reducing the seat height to about 250 mm (9.8”).” (These are approximately the relevant measurements of the M5 Low Racer.) All six bicycles were ridden by one tester, Dries Baron, weight 90 kg (186 lbs), height 1.86 m. (6’1”), almost a midget by Dutch standards. Ten circuits (2 km total) were made for each test point. All bicycles used Continental Grand Prix or IRC tires pumped to about 8 bar pressure (116 psi). Two speeds were chosen: 30 and 40 kmh (18 and 25 mph), and the cadence was kept to about 88 rpm. The temperature was about 15° C, 59° F. The measurement accuracy was reckoned to be ±2% (see graph, figure 1).

The racing or “road” bike was ridden in the “touring” position, which I believe meant that the hands were on top of the handlebars, rather than the rider being in a full crouch. All of the

recumbents required less power to propel them than did the “regular” racing bike in this configuration. The reduction appeared to be a function of how low the rider was (see photos). The lowest power of the unfaired recumbents was needed by Bram Moens’ M5, which at 40 kmh took 225 W, while the racing bicycle required 380 W input. The fully-faired M5 required less than 130 W at the same speed. (Table 1)

These results can be compared with the aerodynamic drag measured in the “Tour” tests of stationary bikes in the wind-tunnel and on bikes being ridden on a velodrome, reviewed in Human Power, 12/4, spring 1997. There is a general qualitative agreement, although only the faiured M5 and the regular bikes were common to both tests. The LWB “Peer Gynt” with low bottom-bracket was found to have a higher drag than that of a regular racing bike with the rider in a full crouch. Because of the difference in the rider positions on the racing bike, the principal interest in the results shown here is in the differences among the recumbents, and in the accuracy of actual power measurements taken on different bicycles with the same rider on the same circuit with similar tires. These are very valuable data. Thank you, Bert Hoge, Jeroen Schasfoort and the NVHPV!
—Dave Wilson

Table 1: Power required to propel bicycles

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<th>Bicycle type or name</th>
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<th>Expected increase in speed*</th>
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<td>336</td>
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*Relative to racing bike

Figure 1. Power (watts) required vs. speed (kph).

—Photos and chart courtesy HPV reviewers; prepared for Human Power by JW Stephens

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Figure 2. Bicycles tested.

—Photos and chart courtesy HPV reviewers; prepared for Human Power by JW Stephens

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Figure 2. Bicycles tested.
My propeller theory by E. Eugene Larabee

In 1978 I developed a useful form of propeller theory based on the work of Hermann Glauert (1926 and 1938) and Sidney Goldstein (1929). It was successfully applied to the propellers of the Chrysalis and Gossamer Albatross human-powered airplanes in 1979, and (in reverse) to windmills for US Windpower, Inc. in 1980.

It is related to lifting-line theory as developed by Ludwig Prandtl and his associates at Göttingen during World War I. In this induced velocity is developed parallel to the blade lift direction and perpendicular to the relative velocity of the blade section with respect to the air mass as shown in figure 1. The flight (or axial) velocity, the rotational velocity, and the induced velocity combine to produce the resultant velocity.

The induced velocity is caused by lift on each blade section due to bound circulation according to the Kutta-Joukowski Law. Strangely enough, if the induced velocity is small enough compared to the axial velocity it can be shown that the induced loss of the propeller is minimized if the virtual slip velocity is radially constant, corresponding to a minimum loss of energy is as if the screw surfaces passed over by the propeller were solidified into a solid figure and this were displaced backward in the non-viscous fluid with a given small velocity. Since the induced displacement velocity is exactly twice the virtual slip velocity.

I calculated the radial bound circulation distributions for minimum induced loss by a process suggested by Glaeser in 1938. The distributions are functions of the advance ratio and the number of blades as shown in figure 2. They correspond to elliptic span loading for a wing. Apparently these circulation distributions are slightly in error, as suggested by Goldstein in 1929 and by my former student, Mark Drela, in 1982. In any event they were good enough to form the basis of a Fortran code written by Hyoung Bang in 1978 to define the blade chord and pitch angles for the Chrysalis and Gossamer Albatross airfoils, on which they had not only minimum induced loss but also minimum profile drag by choice of blade section. You lift coefficient at the design point. They were propellers of highest efficiency in Glauert’s words.

At the relatively low advance ratios of these propellers they are characterized by narrow outer blade chords and wide inboard ones with strong twist, having almost true geometric pitch, as shown in figure 3. The same is true of the US Windpower windmills generated by a later Fortran code HELICE, written by Susan Elsa French at MIT. In the case of windmills the displacement velocity is against the wind direction and the more curved portions of the blades are downwind. They were intended to leave a minimum hole in the air for a given power output for the average wind speed of a windfarm of many windmills.

Since then Prof. Mark Drela has developed his own XTOR code which is a finite-element adaptation of Goldstein’s 1928 paper. XTOR was used to design propellers for the Monarch and Daedalairus airplanes.

French’s HELICE code was rewritten in Pascal as ELICA by Robert S. Grimes in a form suitable for IBM PCs in 1982. Both Prof. Ernst Scholer and I have used ELICA for many years personally. I published my algorithms in 1980. I am told that AeroElectron uses a form of them to design propellers for their airplanes including the Pathfinder, which holds the altitude record for propeller-driven airplanes.

—E. Eugene Larabee, professor emeritus, MIT
1800 Avenue of Science
Long Beach, CA 90815 USA
November 1999

The Feet On! an pedal-powered museum exhibit

By Michael Elsasohn

A bicycle is a relatively simple mechanism. A frame holds two wheels. A chain runs from the chain-ring to the sprocket attached to the rear wheel. Turn the pedals and the bike moves. So how do you get those pedals to power a television or an organ, to light up light bulbs or create a vacuum, to blow 300 ping-pong balls around inside a chamber, or a moving sculpture which consists of twelve bicycle wheels mounted on the wall?

That was the challenge facing Tom Caskey, science exhibit designer at the Southwestern Michigan (community) College Museum near Dowagiac, MI. Caskey designed and, with some assistance, made the exhibits for the museum’s “Feet On! The Power of Pedaling” exhibit, which ran from March 9 to June 12, 1999. He said he and other museum staff members came up with the idea for the exhibit.

Among the challenges in creating it was a budget of less than $1,000. So many of the pieces, such as bicycles and exercise bikes, were purchased at a Goodwill store (which sells second-hand goods) and at rummage sales. Some items were donated.

A lot of creativity was used. For instance, a hammer was purchased at Goodwill, but the exhibit also used a metal trash can, garden hoses, a bellows from a previous museum exhibit and a bicycle pedal mechanism. The squirrel-cage blower that moves the ping-pong balls around came from a furnace. “I had a blower...,” Caskey said in explaining how he came up with the idea. “What are you going to do with a blast of air? I wanted something so that as people walked in the door, they could see a lot of action.”

But the 300 ping-pong balls blown around in the clear plastic-walled chamber did more than just move around. There were 294 white balls and six red ones. What were the odds of getting all the red ones to land in the six “pock- ets,” which was half of an egg carton? “...about the same as winning the lottery,” the accompanying sign stated.

Caskey said he didn’t expect anyone would beat the odds during the life of the exhibit, which taught visitors probability—and that it was unlikely they will ever win a lottery.

The device that shot a spark across a gap, to show that air is an insulator and the absence of air isn’t, presented the opposite problem. Caskey adapted an old refrigerator compressor to act as a vacuum pump, to remove the air from inside a clear plastic dome.

In order to be powered by one or two people sitting on a couch.

The pedal mechanisms were two former exercise cycles, with the chains running to flywheels, and V-belts running from there to a generator. To prevent one or two strong ped- alers from “overpowering” the system, Caskey hooked up an electromagnet brake designed for trainers, which acted on a disk on the generator shaft, making it impossible to “blow up” the television.

The other two pedal-powered exhibits were four light bulbs—the harder one pedaled, the more bulbs lit up—and a sculpture consisting of twelve bicycles wheels mounted on a wall, linked by ropes and chains, so that pedaling made the wheels rotate.

Caskey said a challenge in creating the pedal-powered exhibits was that they had to accommodate, in one exercise cycle, everyone from little kids to football-player-sized men. “It’s got to be responsive for both.”

To accommodate various-sized rid- ers, Caskey made super-long banana stools for some of the exhibits.

The mechanisms of the pedal-powered exhibits for the most part were exposed, so visitors could see how everything worked. “These are purposely made kid-understandable,” said Caskey, whose museum job is part-time.

The “Feet On!” exhibit was located in the part of the SMC Museum, to paraphrase from its fiber, devoted to hands-on science and technological exhibits that investigate scientific principles and the technological world that surrounds us.

The sign at the entrance read: “This exhibition is an exploration of energy transformation. The exhibits demonstrate how your energy is converted into other forms with interesting outcomes. You use chemical energy (namely food and drink) to feed your muscles—they are energy transformers. Your mus- cles allow you to move and give you the ability to move different things.”

Making the exhibits pedal-powered was a means to make them “hands-on,” or more correctly, “feet-on.” “You’re really involved,” Caskey said.

The 59-year-old Caskey, whose back- ground includes product and graphic design, making dielines and building a house, recently earned a master’s degree in science education at Western Michigan University and wants to get a doctorate in the same topic.

The “Feet On!” exhibits illustrates Caskey’s goal of making science learn- able by being fun, not just by learning facts. “You can learn physics and sub- tlety and have fun...,” he suggested, “or you can think science is dumb stuff.”

The Feet On! exhibit was located in the part of the SMC Museum, to paraphrase from its fiber, devoted to hands-on science and technological exhibits that investigate scientific principles and the technological world that surrounds us.
Michael Eliasohn read readers of France and became enthusiastically German student, and later he settled in recumbents he had built. His biography shows that Eliasohn Mochet sponsors a cup for the absolute highest hour record for human-powered vehicles regardless of type. (I believe in late 1933 or early 1934)”. It is interesting to note that the book isn’t a dry history book but rather a living document (written a little strangely in the “historical” present tense), and it isn’t precise about every- thing about which we’d like to know more, but I’m sure that we’ll hear again from the author. Every enthusiast for HPV’s should read this book. Reviewed by Dave Wilson.

LETTERS

Supplement to “Velocar variations” by Arnfrid Schmitz

A “key” picture for this article in HP 49 (winter 1999-2000) was unfortunate- ly lost between France and the USA. Here it is, with our apologies. It was published in the French sports press to illustrate the fact that the French recumbent- breaking Velocar of 1933, but states, Schmitz, no one knew anything about the Mochets. But Schmitz read about the prizes and about those papers in the French bicycling magazine Le Cycle, and became excited by the potential. From then on the book becomes partly autobiographical, as he describes how he tried building recumbents, partly for others and partly for himself and his son. (He had some difficulty persuading him to ride the machines.) But the details of his and his family’s HPV activities often take a minor role because Arnfrid Schmitz gives insightful details of many others. For instance, the complex charac- ter of the late Wolfgang Greben comes alive: he is given a great deal of credit for promoting bicycle and HPV racing in Europe, as well as having a few facts exposed.

Henry Lemoine, in the pursuit race. Photographed passing a champion, Faure, was a young well-known track cyclist of the time, but he was certainly far from being a champion. Here he is photographing a champion, Henry Lemoine, in the pursuit race. I want to make another comment on an aspect of bicycling that became more obvious during my riding various bicycles as I was working on the arti- cle: riding in a dead straight line is impossible while pedalling, whether on an upright or a recumbent. We ride in a way that isn’t natural for us when we have wet tires on a dry road or when we ride in snow. What is wrong with our sup- posedly perfect machines if they don’t want to go straight? Is it because we use our legs alone and don’t balance with our arms as we do when walking or running? What do you think? Arnfrid Schmitz, Quatrain Gallus, Lioux, Gordes, F84220 France, 24 March 2000

Human Power: the forgotten energy (ISBN: 95361741.6) by Arnfrid Schmitz, with Tony Hadland

Of course, the US was in the war, so there was nothing about him in the first nine chapters. These are devoted to a fuller re-telling of the history of the early efforts to streamline bicycles and to produce recumbents than I have previously read anywhere. Here are some examples of what was referred to in many of which I was unaware.

“In Berlin the first international race for streamlined bikes takes place.” (I believe that was in 1932.) “Charles Mochet sponsors a cup for the absolute hour record for human-powered vehicles regardless of type.” (I believe it was published in the French sports press in February 20, 1934. This was the very moment that a recumbent was recognised as legal by the Union Cycliste Internationale.

The rider of the Velocar, Faust Paire, was a young well-known track cyclist of the time, but he was certainly far from being a champion. Here he is photographing a champion, Henry Lemoine, in the pursuit race. Photographed passing a champion, Faure, was a young well-known track cyclist of the time, but he was certainly far from being a champion. Here he is photographing a champion, Henry Lemoine, in the pursuit race. I want to make another comment on an aspect of bicycling that became more obvious during my riding various bicycles as I was working on the article: riding in a dead straight line is impossible while pedalling, whether on an upright or a recumbent. We ride in a way that isn’t natural for us when we have wet tires on a dry road or when we ride in snow. What is wrong with our supposedly perfect machines if they don’t want to go straight? Is it because we use our legs alone and don’t balance with our arms as we do when walking or running? What do you think? Arnfrid Schmitz, Quatrain Gallus, Lioux, Gordes, F84220 France, 24 March 2000

EDITORS

Ronald van Waveren (translated by Ellen Wilson)

I’d like to introduce myself to you. I am Ronald van Waveren, 48 years old, father of two young children and, for four years, chairman of the NVHPV (the Dutch HPV association).

In comparison with many other HPV associations in the world, the NVHPV has grown considerably in the last few years. This however is thanks to our recumbent-friendly infrastructure—our country has more than 25,000 recumbents here at this time. It is estimated that there are more than 25,000 recumbents here at this time. The NVHPV has almost 1600 members, and recumbent owners and riders rep- resent the largest percentage of mem- bers. Originally this was an organiza- tion made up of recumbent designers and builders, following the American example. But since the recumbent has now been made available as a serious commercial product through diverse factories, the number of recumbent owners has increased proportionately within the membership. The NVHPV wants to be in the limelight, but its objective should be to stimulate the development and promotion of the use of HPVs in general. And this is con- strained by our allegiance to the race.

We organize activities such as presentations at fairs; competitions in the summer and “warm-up days” in the winter; NVHPV annual meetings in association with a number of smaller, state-run events; and a large interna- tional recumbent-promotional event called Cycle Vision. It is on the topic of this last event that I’d like to ask for your attention. Cycle Vision, for the fourth successive time, will be held early in June, on the weekend of the third and 4th, 2000. It will again be located in Leijstad, on the govern- ment’s testing grounds for highway vehicles. There will be many activities on this area. A single tent of 1000 m² can hold all the displays of new products of Dutch and foreign recumbent companies.

There will be many activities on this area. A single tent of 1000 m² can hold all the displays of new products of Dutch and foreign recumbent companies. Under the same “roof” there will be presentations and demon- strations, and a simultaneous second-hand market. If one is interested in a certain vehicle, new or used, one can take test rides on a special adjoining parking lot. Announcements of all events, together with cool music, are broadcast over loudspeakers.

International competitions will be held on the 2700 m-track with adjec- tive accommodations. One can enjoy criteriums, 200 m sprints, “devil-take-the-hindmost” drag races, one-hour time trials and a six-hour race. Cash prizes totalling NLG10,000 (over 4500 US dollars or €50) will be given out at all distances for common vehicles and pro- ominently suitable road and in this international framework a real effort was made in an earlier Cycle Vision to break the world hour record (over 80 km/h).

For this attempt, foreign teams, among them those from Germany, Belgium, the USA and the Netherlands, participated when weather conditions allowed. New this year are the single-day criteriums such as “Thys’ Row- Bike”, “Plevos’ “All-Weather” (Allwded- er) and Challenge’s “Hurricane”.

Cycle Vision is easily accessible by train from Schiphol Amsterdam airport to Leijstad. A bus for Harderwijk will take you to Leijstad airport, and a Cycle Vision shuttle bus will take you the last 3 km. There is also adequate parking.

For those who want to visit the event for both days there are overnight camping sites at “The Opplerie.” Leijstad also has hotels, B&Bs etc. The price of admission is only NLG7.50 per day. In 1998 Cycle Vision was attended by more than one hundred visitors, attracted 3000 visitors and more than 100 competitors. In 1999 there had 1000 m² of exposition space, a recumbent-clothing style show; a toddlers’ activity area; a chil- dren’s recumbent trial.obstacle course; 2000 m² of adult recumbent trial.obsta- cle course with all of the Netherlands’ available recumbents; and the awards for a large design competition, the Bike 2000 Construction Content (likewise an NVHPV initiative). See www.ligfiets.net for more information.

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We Europeans, realizing that to the European continent is not within the reach of every non-European, nervertheless invite all HPV enthusiasts from every part of the globe to take part as competitors or spectators in Cycle Vision 2000, a sensational feast that is a true bike revival. Cycle Vision is an initiative by the Dutch HPV association that has become an annual happen- ing, which you as an enthusiast cannot afford to miss.

Editor’s note: Delays to the publication of this issue means that Ronald van Waveren’s description of Cycle Vision has come too late to persuade readers to travel there this year, but we hope that a record number will visit this wonderful event next year.

Best Wishes,

Dave Wilson

Praise from IHHPA’s founder.

Chester R. Kyle

I just got my copy of Human Power, and I must say that I was pleasantly surprised. The photographs, graphics, design, etc. Congratula- tions. Keep up the good work.

Best Wishes,

Chester

Frisco Faure passing Henry Lemloine in a UCI-sanctioned pursuit race at the Voeltdroms d’Hiver in Paris, February 1934.

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