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$5.50
IN THIS ISSUE

Optimum crank-arm length for recumbents

Danny Too and Chris Williams tested nineteen subjects using the recumbent-seating position found in earlier studies to permit maximum power output to be developed. Each person pedaled at maximum effort using, in turn, five different crank lengths. (One subject produced over 1 kW.) The recommendations on these lengths of cranks for different races are bound to be followed closely.

Bicycle pitchovers

Fred Matteson is concerned for the safety of bicyclists, particularly when braking on steep descents. His analysis has produced a graph on which each rider can enter her/his body and bike characteristics, and thereby learn on which hills her/his level of braking can be critical.

CDa and Crr measurements

John Snyder has developed two methods of measuring one’s coefficients of aerodynamic drag and of rolling drag. The first uses two hills of different slopes but similar surface, and the terminal coasting velocities and other easily measured data give the coefficients. The second method involves one hill, and two coasting runs down the hill, in one case with a drogue chute. John gives all instructions.

ICMR

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Abstract

The purpose of this study was to determine the crank-arm length that would maximize peak power and minimum power outputs in a recurrent cycling position. Nineteen male volunteers were each tested with five pedal-crank lengths (110, 145, 180, 230 and 265 mm) according to a randomized sequence on a free-wheel Monark cycle ergometer. The 38-second Wingate Anaerobic Cycling test was performed in a recurrent position (75° seat-tube angle, backrest perpendicular to the ground) against a resistance of 85 kgf of the subject’s body mass (5.0 J/cycle kgf/m). Curve estimation with regression analysis revealed that the crank-arm lengths to achieve peak power, mean power and minimum power are 124 mm, 175 mm and 235 mm, respectively.

Introduction

It is well documented that recumbent-human-powered vehicles with aerodynamics fairings, having a smaller drag coefficient and cross-sectional area, are faster than the standard racing bicycle (Kyle, 1982). However, with the current racing bicycles, most of 117.60 kg/hr (72.74 mph), established in 2000 by a single rider (Sam Wittingham) on a Varna recumbent bicycle “Mephisto,” designed and built by Georgiev, it becomes questionable whether a more aerodynamically effective human-powered vehicle can be designed. If future speed records are to be attained, it is necessary to focus not only on the aerodynamics, but also to examine the variables that affect power production in recurrent cycling and the interactions that would maximize it. Investigations in this area of research are rare and power production have included an examination of changes in seat-tube angle (Too, 1993), seat-tube angles. Seat-tube angle was defined by the angle formed between the seat tube and a vertical line (perpendicular to the ground) passing through the crank spindle. Using a 75° seat-tube angle, Too (1994) investigated the effect of three trunk-seat backrest angles (0°, 90° and 120°) on power production. A parabolic trend in peak power and mean power was found with changes in trunk-seat backrest angle, with the largest peak power and mean power reported using the 90° trunk angle.

Based on muscle force-length and force-velocity power relationships, changes in crank-arm length will affect joint angles, muscle length, force, torque and power production in cycling. Since the literature involving traditional upright cycling positions have reported an effect on power output with changes in crank-arm length (Hull & Gonzalez, 1988, Inbar, Dotan, Trousl & Dirix, 1983; Too & Landwer, 2000), it can be assumed that power production will also be affected in a recurrent cycling position with different crank-lengths. Therefore the purpose of this study was to determine the trend in power production with changes in crank-length, and the crank-length that would maximize peak power, mean power and minimum power in a recurrent cycling position.

Method

Nineteen healthy volunteer male participants (mean age = 24.8 ± 4.1 yr.; weight = 81.76 ± 11.84 kg, height = 1.80 ± 0.08 m) subjects were tested with a free-wheel Monark cycle ergometer (Model 814E) at five pedal-crank lengths (110, 145, 180, 230 and 265 mm), as defined by the distance between the center of the crank spindle and pedal spindle. The (normal crank-length for a Monark cycle ergometer is 170 mm). To accomplish this, two adjustable crank arms allowing for manipulations from 0 to 300 mm were used (Too & Landwer, 2000). All subjects were
tested in each of the five pedal crank-arm length conditions, with the order of testing randomly assigned. There was no minimum of 24 hours of recovery between test sessions. For each condition, pedal toe clips were worn, and the subject was strapped to the seating apparatus at the hip and ankle.

The recumbent cycling position used for all test sessions, was defined by a 75° angle between the bicycle seat tube and the horizontal through the crank spindle (see figure 1; Too, 1991). To obtain this seating position, a variable seating apparatus allowing for manipulations in seat tube angle, back angle and seat-to-pedal distance was used and interfaced to a recumbent cycle ergometer (Model 318E). The seat backrest was kept perpendicular to the ground and the seat-to-pedal distance adjusted to 100% of the total leg length of each subject, as measured from the right femur to the ground (Too, 1991). The test protocol involved cycling for 30 seconds. Anaerobic Cycling Test. To initiate the test, the subject pedaled the cycle ergometer with no load. Once the subject had attained a steady-state pedaling rate which had been overcome, the appropriate load (85 g/kg of the subject’s body mass) was instantaneously applied using calibrated load cells. A sampling rate of 50 Hz, interfaced with a Zenith 386 micro-computer, in conjunction with 16 reflective markers on the ergometer flywheel, was used to monitor and record flywheel revolutions during the test. Peak power was calculated from the highest average flywheel speed during any consecutive five seconds, mean power was determined from the mean flywheel speed for the entire 30-second test, and minimum power was calculated from the lowest mean flywheel speed during any consecutive five seconds (which was always the last five seconds). The differences in power variables were calculated using the following equation:

\[ \text{Peak power} (\text{W}) = \frac{\text{liner}}{\text{flywheel revolutions per minute}} (1.615 \text{ meters per revolution}) \times \text{average number of recorded flywheel revolutions} \times \text{five seconds (rpm)/[1/min/60 sec].} \]

Additionally, maximum and minimum pedaling rates were calculated from power for peak power and mean power, respectively. The equation used in this calculation was:

\[ \text{Peak rate (rpm)} = \frac{\text{average flywheel rpm for five seconds}}{3.73 \text{ flywheel revolutions per pedal-crank revolution (crank arm length)}} \]

Changes in crank-arm lengths, the mean ± SD values of peak power, mean power, minimum power, maximum and minimum pedaling rates are presented in table 1. Based on regression analysis the change in peak power, mean power and minimum power with increasing crank-arm length, appears to be best described by a parabolic curve, representing the equation: \( y = ax^2 + bx + c \) (where \( y \) represents peak power and \( x \) represents crank-arm length) as shown in figure 2. The specific regression equations for the various measures of power were as follows:

- Peak power (quadratic trend, \( p < 0.001) = 0.0012x^2 + 2.8x - 972 \) (SE = 11)
- Mean power (quadratic trend, \( p = 0.001) = 0.011x^2 + 3.8x + 513 \) (SE = 5)
- Minimum power (quadratic trend, \( p = 0.002) = 0.0075x^2 + 2.8x - 325 \) (SE = 2)

From table 1, several observations can be made: (1) regardless of crank-arm length, peak power is greater than mean power and mean power is greater than minimum power; (2) peak power is greatest with the 145-mm crank-arm length and least with the 205-mm crank-arm length; (3) mean power is greatest with the 145- and 190-mm crank-arm lengths and least with the 265-mm crank-arm length; (4) minimum power is greatest with the 230-mm and least with the 110-mm crank-arm length; and (5) maximum and minimum pedaling rates occur with the 110-mm crank-arm length. From these results it can be seen that the predicted crank-arm lengths to maximize peak power, mean power and minimum power are 124 mm, 175 mm and 215 mm, respectively.

**DISCUSSION**

Since no literature could be found examining the effect of changes in crank-arm length on cycling performance in a recumbent position, comparisons will be made with the literature on the upright (right side up) position. The parabolic curve observed in peak power and mean power with increasing crank-arm length is consistent with the trend for an upright position reported by: (1) Inbar et al. (1983) for five crank-arm lengths (125, 150, 170, 200 and 225 mm); and (2) Too and Landwer (2000) for five crank-arm lengths (110, 145, 180, 230 and 265 mm). From best-fitting parabolic curves, Inbar et al. (1983) described the peak power and mean power to occur at a crank-arm length of 166 mm and 164 mm, respectively, whereas Too and Landwer (2000) described peak power and mean power to be maximized with crank-arm lengths of 164 and 200 mm, respectively. This is quite in contrast with the predicted crank-arm lengths (124 and 175 mm) to maximize peak power and mean power, respectively. Full power production is greatest with the largest load that can be applied. Although manipulation of load was not examined in this investigation, changes in power are greatest with the predicted crank-arm lengths of 164 and 200 mm, respectively. From best-fitting parabolic curves, the mean power produced is greatest with crank-arm lengths of 166 mm and 164 mm, respectively, whereas Too and Landwer (2000) described peak power and mean power to occur at a crank-arm length of 180 mm and 200 mm, respectively. The parabolic shape of the relationship, a longer crank-arm length would alter the torque on the crank arm (when the same force is applied) and would be analogous to a change in crank length. Biomechanically, this relationship, a longer crank-arm length resulting in a lower "load" experienced by the lower limbs would result in a greater linear velocity at the pedal (when compared to the same pedaling rate with a shorter crank-arm length). This was confirmed when the maximal pedaling rates determined for the different crank-arm lengths of this investigation were converted to maximal linear pedal velocity. The maximal linear pedal velocity was found to increase (although the maximal pedaling rate decreased) with increasing crank-arm lengths, with the greatest rate of increase being predicted with the crank-arm length to maximum power dependent on load and pedaling rate. Since power is a function of both force and velocity, the optimal crank-arm length to maximize peak power would be one where the maximum pedaling rate is produced and maximum power is also produced.

Maximal pedaling rates are increased loads to maximize power, resulting in a decreased pedaling rate. Changes in crank-arm length will affect not only the force-velocity power relationship, but also the muscle force-velocity relationship. The relationship between crank-arm length and pedaling rate is consistent with that expected from force-velocity relationships. Since parabolic curves in power were observed with increasing crank-arm lengths, the largest values for peak, mean and minimum power were found with three different crank-arm lengths, this would suggest that there is an optimal crank-arm length to maximize power is dependent on the type of power examined. Changes in the interaction of crank-arm lengths, pedaling rates and load (as evidenced by parabolic curves for power), would suggest that the optimal crank-arm length for peak, mean and minimum power would change with different loads. Based on the force-velocity-power relationship, increased loads to maximize power, resulting in a decreased pedaling rate, would favor longer crank-arm lengths. Changes in crank-arm length will affect not only the force-velocity-power relationship, but also the muscle force-velocity relationship.
Bicycle pitchover characteristics
by Frederick H. Matteson

SUMMARY
The predicted crank-arm lengths to maximize peak power, mean power and minimum power in a recumbent cycling position, using a resistance load of 85 g/kg body mass, were 124 mm, 176 mm and 215 mm, respectively. This would suggest that for human-powered vehicle competitions of short duration, where maximum peak power is necessary, a shorter crank-arm length is recommended. For competitions of longer duration where fatigue is a factor and the largest mean power and minimum power become important, it is suggested that longer crank-arm lengths be used.

DEFINITIONS
F slope
h height of the combined bicycle- and rider-center-of-gravity on level ground
W total weight of bicycle and rider
B braking force
l horizontal distance from bicycle- and rider-center of gravity on level ground to contact point, P
F = h tan Φ

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The predicted crank-arm lengths to maximize peak power, mean power and minimum power in a recumbent cycling position, using a resistance load of 85 g/kg body mass, were 124 mm, 176 mm and 215 mm, respectively. This would suggest that for human-powered vehicle competitions of short duration, where maximum peak power is necessary, a shorter crank-arm length is recommended. For competitions of longer duration where fatigue is a factor and the largest mean power and minimum power become important, it is suggested that longer crank-arm lengths be used.

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of l/h is 0.5 (curves descending to the x-axis), those braking curves coincide and there is an increase to about 14 degrees, the pitchover. This level of braking can be a third of the weight of the bicycle. It would seem helpful to lower the right) and the slope is ten degrees dirty from splashing and sometimes hit curbs, but otherwise seem to be satis-

If you follow the 1b curves down to the x-axis, those angles where tan Φ = b/l, result in a pitch over with no braking. The impor-
tance of figure 2 to the cyclist is not in such calculations, but rather in permit-
ting an understanding of the nature of the problem. In practice one probably
do not know the steepness of the hill precisely. The values of l/h vary with
the position of the rider; the rider can increase l/h by lowering his body or
sliding back on the saddle. Further, the rider can only roughly judge the
amount of braking force. Lastly, the rider can only roughly judge the
precisely. The values of l/h vary with
the position of the rider; the rider can increase l/h by lowering his body or
sliding back on the saddle. Further, the rider can only roughly judge the
amount of braking force. Lastly, the rider can

The density of air, often referred to by the Greek letter
varies considerably with altitude, temperature, and humidity. For the moment,
the most consequential of those four to alter by a known amount is angle. It is hypothesized that a comparison of
terminal velocities as achieved on two unlike hills, with
similar road textures, permits quantifying a bicycle’s unique
characteristics.

In practice, comparing the terminal velocities achieved on
two different hills, as well as the single-hill test that appears
later, should be recognized as a method to approximate the values describing performance.

Reflect for a moment on the constants. Each needs to be known with some assurance as it applies to a specific
coasting event. Knowing if calm wind conditions exist is also

The system’s total mass can be found quickly by standing
on a scale while holding the bicycle and all equipment that
will be carried while riding. Ideally this measurement should
be taken just prior to coasting. Ideally this measurement should
be taken just prior to coasting.

Gravity
Acceleration due to gravity varies only slightly at different
altitudes. In the United States, the acceleration due to gravity is
9.81 m/s\(^2\)

Wind
A length of about 300 mm of spongy tissue paper when
held hanging straight down reveals whether or not calm wind
exists. This deceptively uncomplicated tool demon-
strates sensitivity to subtle movements of air. For the pres-
ent need, a wind-speed-measuring device need only indicate
zero wind velocity (see table 1).

Air density
The density of air, often referred to by the Greek letter \(\rho\),
varies considerably with altitude, temperature, and humidity.
Alternatively, one may use a com-
thread tight to the protractor, the hill's
slope of the road. Then by pinching the
tractor's base becomes parallel with the
moves the device until the inverted pro-
elering through a small dip in the road
effects. Any coasting event should
coasting hold the potential of exerting
in any manner with the vehicle's normal
The assumption that a drogue could be
deployed such that it does not interact
with the vehicle's normal
The following depicts measuring the
terminal velocity twice on a single hill. The
first coasting occurs without changes to the
system. The second coasting is performed while a drogue device is deployed.

### Conditions

CdA drogue = $0.44 m^2$

These relationships permit the com-
parision of a coaching vehicle's unmod-
ified (prime) and modified (double prime)
configurations to give:

\[ X' - b' - y' = X + b - Y = Y' \]

Though there exist various ways to alter a bicycle's aerodynamic prop-
erties, the deployment of a small para-
chute [6], or the attachment of a rigid plate off to the side of the vehicle [7],
represent ideas that have been success-
fully adopted in the past for increasing
total aerodynamic drag in a controlled
manner. It is assumed by this math-
ematical model that any auxiliary source
of drag will not significantly interact with the
normal performance characteristic of the
tested vehicle. A drogue device also implies a more elegant handling.

When $M$ mass $g$ gravitational constant $G$ grade [8] $p$ density $v$ velocity,
the following equation depicts the equi-
librium between aerodynamic drag and
rolling resistance, and grade's effect when
at the steady state,

\[ (0.5)(p)(v^2)(CdA + Mg)(Cr) - (1 - Mg)(G) \]

This equation may be rearranged into:

\[ (0.5)(p)(v^2)(CdA) - (1 - Mg)(G) + Cr(1 - Mg)(G) \]

If a vehicle's CdA changes by a known amount ($CdA'$) then the following also applies:

\[ (0.5)(p)(v^2)(CdA' + Mg)(Cr) - (1 - Mg)(G) \]

If two coastdowns to terminal velocity are conducted, one of which has been modified, and both occur dur-
ing identical weather conditions on the
same hill, permitting cancellation of values that have not changed, then:

\[ (v^2)(CdA) - (v^2)(CdA') = CdA' \]

which, after having been solved for
$CdA'$, reveals the following description:

CdA vehicle = CdA drogue

By solving this equation, a bicycle's CdA may be assessed even if mass, grade, and air density are unknown val-
ues, but are consistent from one coast-
ing device to the next.

### Example B

The following depicts measuring the
CdA of a bicycle coasting to terminal velocity twice on a single hill. The
first coasting occurs without changes to the
system. The second coasting is performed while a drogue device is deployed.

**Conditions:**

- CdA drogue = $0.44 m^2$
- CdA, modified (double prime) = $0.9 m^2$

**Determination of CdA**

\[ CdA = CdA drogue - \frac{(v^2)}{(v^2)'} \]

\[ = (0.5)(p)(v^2)(CdA) - (1 - Mg)(G) \]

\[ = (0.5)(p)(v^2)(CdA) - (1 - Mg)(G) + Cr(1 - Mg)(G) \]

\[ = (0.5)(p)(v^2)(CdA) - (1 - Mg)(G) + Cr(1 - Mg)(G) \]

\[ = (0.5)(p)(v^2)(CdA' + Mg)(Cr) - (1 - Mg)(G) \]

\[ = (0.5)(p)(v^2)(CdA + Mg)(Cr) - (1 - Mg)(G) \]

\[ = (0.5)(p)(v^2)(CdA + Mg)(Cr) - (1 - Mg)(G) + Cr(1 - Mg)(G) \]

**Limitations and Stiffnesses**

The accuracy of determining the
hills' angles, air density, mass, and
velocity values, ultimately control the
quality of the solution. Though simple
design and the suggested instruments
are pragmatic and easily obtained. It is con-
ceivable that by exercising due care any
error brought about by input data could
be made negligible.

There are several conceptual con-
cerns. First is the model's presumption
that a precise single CdA, unlike, minor
velocity variations in a road bed and
other transient phenomena exhibit little or no
influence. The rate of velocity
increase becomes

\[ b' = m \times \sin(angle) \]

\[ = 10.64 m^2/s \times \sin 2.86 degrees \]

\[ = 10.64 m^2/s \times 0.05 \]

\[ = 0.53 m^2/s \]

\[ = 1000 kg \times 0.81 m^2/s \]

\[ = 1.18 kg/m^3 \]

\[ = 10.64 m^2/s \]

\[ = 10.64 m^2/s \times 0.05 \]

\[ = 0.53 m^2/s \]

\[ = 1016 kPa \]

\[ = 16 m/s \]

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\[ = 0.53 m^2/s \]
Construcation of a drogue parachute suitable for HPV experimentation is an easy project. Using scissors, cut the two side creases and the bottom fold of a large, plastic lawn-and-leaf bag (2.4 micrometer thickness) to obtain two equally-sized panels of material. Set one aside; the other will serve as a rectangular parachute canopy. To each of the two sides of the cord, then can be attached, via a fishing-line swivel, to a handle. A circular hole cut in the center of the rectangle helps stabilizes the parachute when it’s open and filled with moving air. The coefficient of aerodynamic drag of any drogue device is defined as:

\[ C_dA = \frac{F_d}{\frac{1}{2} \rho V^2 A} \]

where:
- \( F_d \) is the force due to aerodynamic drag,
- \( \rho \) is the air density,
- \( V \) is the air velocity,
- \( A \) is the area of the parachute.

In order to determine the product of coefficient of drag (Cd) and area (A) of either CdA or as they exist separately:

A dimensional analysis reveals

\[ C_dA = \frac{F_d}{\frac{1}{2} \rho V^2 A} = \frac{\text{N}}{\text{kg/m}^2 \cdot \text{m}^2} \]

Thus, a drogue device's CdA may be learned by finding representative values for: air velocity, air density and the force due to air resistance. If connected to a land vehicle traveling through still air, a drogue device's air velocity equals the vehicle's ground speed. Estimating air density occurs by applying the prevailing air temperature and air pressure to the ideal gas law.

The force is found with a little more effort. A spring-scale may be adopted as a hand hold when attached to a small parachute's shroud lines. While riding aboard a tandem bicycle or an automobile, a passenger holds the open parachute by the scale's handle into a non-turbulent region of air flowing past the vehicle. The resulting drag causes an SI-unit instrument to display a reading in newtons (N). If the parachute described herein must not be used to slow an over-speeding vehicle.
Efficiency of bicycle chain drives: results at constant velocity and supplied power
by Claire L. Walton and John C. Walton

The paper by James B. Spicer et al., (2000) presents very useful and relevant information for further understanding of HPV transmissions. Its conclusions concerning the effects of lubrication, rotation rate, and tension on efficiency are highly valuable. We believe this contribution will be viewed as even more significant when the data are presented from a slightly different perspective.

The testing apparatus was set up to maintain the rpm of the front chaining and the power applied to it at constant levels. A single 52-tooth sprocket was tested. This leads to the observation that the largest rear wheel sprocket is most efficient. Though correct, this result is not necessarily widely applicable. When applied power, crank rpm, and chaining rpm are scaled, and the output power is applied to the rear wheel, we then see the same information with different data. This testing apparatus was set up to maintain the rpm of the front chaining and the power applied to it at constant levels. A single 52-tooth sprocket was tested. This leads to the observation that the largest rear wheel sprocket is most efficient. Though correct, this result is not necessarily widely applicable.

In order to address this question we take the measured data (specifically the linear fits from Spicer et al., (2000)) and present the results in a revised format. The experimental results are not changed: they are merely presented differently using simple algebraic manipulations. The power supplied to the wheel, \( P_w \), and by the chain, \( P_c \), are given by:

\[
P_w = 2\pi r_w 0 \omega_s \quad \text{Eq. 1}
\]

\[
P_c = 2\pi r_c 0 \omega_c \quad \text{Eq. 2}
\]

The difference in power from the loss of efficiency in the chain:

\[
P_c = \frac{1}{2} P_c \quad \text{Eq. 3}
\]

\[
P_s = P_m - P_c \quad \text{Eq. 4}
\]

Substituting the equations for power and simplifying:

\[
2\pi r_w F_w \omega_s = 2\pi r_c F_r \omega_s \quad \text{Eq. 5}
\]

\[
T_c = F_r x \omega_s \quad \text{Eq. 6}
\]

In order to eliminate variables we take a ratio of the chain tension from the use of two different sprockets (11 and 21-tooth) while keeping power supplied to the rear wheel constant:

\[
\frac{21}{T_{11}} = \frac{11}{T_{21}} \quad \text{Eq. 7}
\]

A similar equation is used for the 15-tooth sprocket. The linear fits of chain tension versus efficiency from the different sprockets in figure 3 of Spicer et al., (2000) provide relationships between efficiency and tension for each sprocket. We assume that efficiency is independent of chain speed (as reported by Spicer et al., 2000) and that most of the chain loss is associated with the rear sprocket. Figure 3 of the paper indicates that at equal tension, larger sprockets are more efficient. It follows logically that most of the loss in chain efficiency occurs in association with the rear sprockets which are all much smaller than the 52-tooth chaining.

Solving the system of equations provides an estimate of the chain efficiency for the case of constant vehicle velocity and applied power to the rear wheel. The alternative data presentation is shown here in figure 1 with efficiency for each sprocket size given as a function of the chain tension in the 11 tooth sprocket. For example, when the tension in the 11-tooth sprocket is 0.006 — 167 Newtons, the efficiencies are 92% for the 11-tooth sprocket, 90.5% for the 15-tooth sprocket, and 88.5% for the 21-tooth sprocket — assuming the same vehicle velocity and power to the rear wheel for all three sprockets. The corresponding tensions and efficiencies for the 15 and 21 tooth sprockets are calculated using equation 7. The lines are truncated approximately at the limits of the experimental data. Over most of the experimental range the smaller sprockets give greater chain efficiency. The lines appear to converge at high tensions, with all three sprockets giving high efficiency.

The surprising and counterintuitive result is that the smaller sprockets have greater estimated chain efficiency at constant velocity and applied power than the larger sprockets. Therefore, the increased efficiency from the higher chain tension is more important than the loss of efficiency from having the smaller sprocket. Clearly more experimental data using different chaining and sprocket combinations will be required to answer questions on chain efficiency definitively.

NOMENCLATURE

- \( r_w \) = wheel radius, m
- \( \alpha_1 \) = rotation rate, rev/s
- \( F_w \) = propulsive force, N
- \( r_c \) = effective sprocket radius, m
- \( T_w \) = chain tension, N
- \( \zeta_s \) = chain power loss factor or efficiency

REFERENCE


AUTHORS

The Spicer article on bicycle-drive efficiency is interesting, and the research appears to me to have been well-conducted. The conclusion that “most of the chain loss is not converted to heat (that is, went into vibration instead) is interesting, as are the conclusions that loss is not much greater with an unlubricated chain or with chainline offset (though I think the loss es with offset would be greater with older types of chain with flat side plates which do not engage and disengage smoothly). The conclusion that larger sprockets increase efficiency is expected from theory.

Spicer used two torque-measuring devices, one attached to the crank and the other to the rear wheel. At the high efficiencies typical of chain drives, this approach to measurement is somewhat prone to error, because the measurement of interest—the difference between the actual power and 100%—is a small difference between two large quantities.

One way around this problem is to use a single measuring device to measure a torque difference. Implementation of this approach is simple with a unidirectional transducer, and the motor at the input of the drive-train may be applied directly to the brake.

Figure 2. Efficiency of 11, 15, and 21-tooth sprockets at constant vehicle velocity and power to the rear wheel.

Figure 3 (left) and Table 1 (above) provided by James B. Spicer for his article in Human Power 50. "On the efficiency of bicycle chain drives" are reproduced here for the convenience of readers of the technical notes submitted by Claire C. Walton, John Walton, and John Allen.

![Figure 2](image-url)
at the output, where it cancels except for the difference due to power loss. At this point, a torque is positioned by a frictionic force in the motor and brake cancel, and so do the measurement errors. Assuming that a reasonably accurate measurement of the motor torque is taken, the approach promises a high degree of accuracy for a high-efficiency system.

Spicer's conclusions suggest some what more difficult in the case of a bicycle chain drive, with its step-up ratio. The torque-combining system must combine the forces that convert the sliding friction of the stationary torque-combining chain drive into viscous friction (as also happens, for example, with the pivots of phonograph tone-arms when subjected to the vibrations transmitted from the stylus to the record). There is another, real and serious problem, however, and it also occurs because the torque-combining chain is not in motion. Chord factors average out in a chain drive that is in motion, not in motion. Chord factors average out in a chain drive that is in motion, not in motion. Spicer never tested for how much friction is reduced by eliminating one or both derailleur pulleys. And would largerv bearings, with their smaller chord factor, increase efficiency by reducing vibration as well as bearing friction?

BICYCLE STABILITY AFTER FRONT-TIRE DEFLATION

Dave Wilson (reporting partly for Andy Oury)

Drawings by author, 2000.11.13

THE PROBLEM

On three occasions I have had front tire blowouts, or at least rapid loss of pressure, that have resulted in my having been thrown off my bicycle with some violence. One was when riding a Mouton road bike as a bus was about to pass, one was on an Atari LWB recumbent, and one on a CLWB recumbent, when I narrowly avoided being hit by a large truck. A friend told me about someone who was in, fact, killed after his front tire burst, causing him to be propelled into the path of a car. A photo intended to be humorous in Bicycling (January 1, 1987) showed two of the same symptoms on the same bike, probably kept in the Davis Double Century just after their front tire deflated (almost certainly before affecting sharply at a corner during a mountain descent, thus overheating the rim). The caption stated that as they hit the curb, they arched like a famous breakfast cereal (“snap! crackle! pop!”). The reporting from dead bicyclists is zero, and the reporting of and examination of bicycle accidents is so perfunctory they are likely to be considered a considerable number of deaths and serious injures are the result. This is the basis for taking the instability following front tire deflation. Therefore this has to be regarded as a serious problem.

OUR STUDY OF THE PROBLEM

In the summer of 1998 I wrote about flat-tire instability to a list [Internet discussion list] then called HIB, for “Hardware bicycle science”, moderated by Jim Papadopoulos (the name is now shortened to “Bicycle science” and it is moderated by Sheldon Brown). No one ever reported previous studies of this problem apart from one described by Doug Milliken, who wrote a letter “Flat-tire directional performance” to Human Powered News (1987). He tested a motor-cycle fitted with pro- prietary run-flat tires on the rear wheel. The tires had a flap of rubber on the outside of the tire that fitted tightly over the rim and acted as a bead-reten- tion system. One with a small flap did not hold the bead when the tire was flat, and the bead fell into the “well” in the rim. The tire flopped around, causing the motor-bike to go unstable, even though the tire was on the rear wheel. The second tire with a wider flap held the beads in place. With this tire, Milliken found that he could run the bike at high speed (80 km/h) and could perform various maneuvers without problem. He thought the result that the big-meat tires would probably be tubeless.

I wrote also to the HPV list, and sev- eral writers on this and on the BBS list have found reported valuable experiences and suggestions. Some reported similar occurrences to mine, including Dave Langhorne of the British Human Power Club, who had had “instant crashes” from front-tire flats on regular bikes (“upworn”, in his words) and on recumbents, and Joshua Putnam, who considered the problem serious enough to buy a bike that never let the air completely out of the front tire when trying out a new bike. Bill Volk wrote, “I too find the situation to be unacceptable— I run my inefficient-thom tubes because of my fear that a blowout at high speed would be a disaster. Why can’t some manufacturer find a way to do in even at no inflation? And perhaps a rubber strip that is placed around the rim, under the tube, that supports the bike tire and prevents me from being hurt… I had Performance semi-slick 26” tires that fit so snugly that you could safely ride no inflation. That should be the standard.” Presumably because of a tight-fitting tire, Ed Deean of Fools Crow Cycles, faced with difficult choices, rode five miles (8 km) on a flat front tire. He had IRC “Roadlites” with Sun M14 rims. Similarly Andy Milstein of Princeton had no trouble riding with a flat front tire. It was a Tioga Comp Gool, measured by Mark B. of Wheel Life Cycles to be 46-mm wide, on a Sun CR-18 20 x 1.75” rim of about 27-mm with tuned tires. The tire was a 29-mm BTMS BE-21, one of my early suspensions, and a concern of Larry Black, was that a wide tire would narrow rim might have a considerably greater tendency to “pop” alternately left and right.)

Bill Volk mentioned that Sutherland’s Handbook for Bicycle Mechanics had a good section on fits between different brands of rims and tires, but my edition did not have this section, and I could not get an answer to my letter to Sutherland asking about standards of fit. John Allen, prominent bicycle expert and author, sent me a copy of his Japanese Industrial Standards D 9421, “Rims for Bicycles”, giving a tolerance of +1.5 mm for rim circumference, and calling for the retention of rubber or some other “inch” tires were all at least “good” fits on the rim. Now, it seems from my experience and that of many people who input to me, that it is not by chance that one gets a tire that is a tight fit on a rim and that will therefore probably be less likely to pop out in the event of a front-tire blowout.

After considerable efforts to research tire manu- facturers I was told that Vredestein, the Netherlands manufacturer of the tire on the German recumbent on which I had my most recent episode of instabil- ity, was conducting a study on run-flat behavior. However, when eventually I received a courteous response from Mr. U. K. Baueenee, it turned out that he was investigating puncture prevention. I bought a product called “Snake- charm” from Bikewon International, Mammoth Lakes, CA. It was a length of friction cord intended to be fed into the rim—well under the tube to prevent “pinch” flats and presumably to give some run-flat capability. It was produced only for large XTB tires, at least at the time of my purchase. I intend to test it. It would add a considerable amount of mass to a wheel and, I would think, increase the tire width, which would have to wrap around it.

My instinct tells me that the old inch sizes had some specified or customary allowances for build-up and other “inch” tires were all at least “good” fits on the rim. Now, it seems from my experience and that of many people who input to me, that it is not by chance that one gets a tire that is a tight fit on a rim and that will therefore probably be less likely to pop out in the event of a front-tire blowout.

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In September 1998 I added the problem statement on flat-tire stability to my list of graduate-these topics at MIT. Andy Oury, then a senior, responded enthusiastically- ly, and I would think, quite accurately, to his comments, and has allowed me to report some of his results here. We drew up a too-ambitious program in which we

Figure 1. Tire bead off seats: tread flops to side

Figure 2. “Snake- charm” run-flat insert (note rim without bead seats)
wanted to look not only at bead retention but also at the effect of the ratio of tire width to rim width. The tires in particular are usually bulbous, having a pear-shaped cross-section on what seems like a small rim) and of tire sidewall flexure. Andy Oury worked on what the correspondents just quoted was the most important factor, bead-retention experiments.

The experiments

We first thought that we could do a highly controlled experiment by having my troublome wheel, held in a frame, running on the surface of an inverted portable sled. However, the tire did not display the extraordinary alternating dips, left and right, that had thrown me, off my bike, and that had prevented me even from pushing the bike subsequently. Oury found, that for the flopping behavior to occur, he had to rig up a bike to run along a simulated roadway with a similar number of degrees of freedom as has a bicycle when it is being ridden (or pushed).

The simplest way of producing bead retention on the sidewalls of the tire rim after deflation seemed indeed for them to be a tight fit. I have had tires that could be stretched over the wheel rims only with great difficulty. When these were inflated, the tire beads remained in the “rim-well” until the tube inflation pressure was reached around 80% of normal full pressure. They then “snapped” over the rim shoulders with a satisfying click. My experience follows that of Doug Milhiken and Bill Valk: I have never found tire instability with tires that were a tight fit on the rims, and which, therefore, did not flop loosely around in the rim when they became deflated. I confess that I cannot remember if I had a front-tire blowout around 1986, starts with painstaking detective work assembling and correlating the data available such as not-to-scale pictures on vases, coins and reliefs. It is not even clear whether the name trireme (Greek: trierres) actually means three vertically displaced levels of single-oared rowers, whose feasibility the project aims to prove, or single levels of oars manned by several rowers each, which seems to be the more common arrangement depicted by artists. The pros and cons of the different arrangements are described as well as the reasoning which led to the reconstruction plan of the Olympias, which was launched in 1987. However before this, models and even a full-scale floating section were built in order to study the rowing geometry. The ship was built with more or less traditional materials and methods, but not exclusively, as the major interest lay in operational research and not historical ship-building. It took the combined resources of two trusts (one British, one American) to build the Olympias, and also of the Hellenic navy, which owns and operates it. Part II is completely new in this second edition and describes the results of numerous sea trials in the years 1987-1992. The Olympias nearly lives up to its expectations, but its 5- to 5.5-knot average speed was slightly lower than hoped for. Peak speeds over 8 knots were recorded. The total efficiency of the oar system was estimated at about 0.5; rowing the Olympias is hard, difficult, and sometimes unpleasant work, but apparently there is usually no shortage of volunteers, whether civilian or navy. Only the top level of rowers can see their ears, whereas the bottom-level rowers can see nothing in their poorly ventilated and smelly workspace (they are also often dripping on the boat from the upper rowers). The logistics of operation are remarkable all the more so, as the ship’s short journey requires that almost two tons of water be on board each night, brought in by the rowers. Olympias also performs well under two square sails. Combined sail- ing and rowing are highly successful with a bit less effort. The report concludes with a discussion of the results and suggestions for slight improvements. However, it appears that the Athenian trireme project was just about optimal, and the same can be said for the book jacket: “For this second edition, the text has been recast and a number of substantive changes have been made in the light of the sea trials and new research. In addition, there is an entirely new chapter which describes the trials of Olympias in detail, reports the performance figures obtained, and outlines the changes which the ship would wish to incorporate into any second reconstruction. There are nineteen new illustrations, including eleven photographs of Olympias at sea demonstrating features of the design which could be represented only by drawings in the first edition.”

From the book jacket: “For this second edition, the text has been recast and a number of substantive changes have been made in the light of the sea trials and new research. In addition, there is an entirely new chapter which describes the trials of Olympias in detail, reports the performance figures obtained, and outlines the changes which the ship would wish to incorporate into any second reconstruction. There are nineteen new illustrations, including eleven photographs of Olympias at sea demonstrating features of the design which could be represented only by drawings in the first edition.”

Reviews


The Athenian Trireme is a comprehensive report on the reconstruction and testing of a Greek trireme with 170 rowers, probably the largest and most successful such project in recent times even if the object of interest dates back to several hundred years BC. These Greek warships were numerous and very successful in their day, but none survive, as they were uninkable and were thus never preserved in bottom mud as were some other ships. It may also be characteristic of the time that a great deal was written about the battles in which these ships were used, but almost nothing about the vessels themselves. Well known is their technique of ramming and holing other ships with a protruding and strengthened bow. Part I of the book, which was originally published in 1986, starts with painstaking detective work assembling and correlating the data available such as not-to-scale pictures on vases, coins and reliefs. It is not even clear whether the name trireme (Greek: trierres) actually means three vertically displaced levels of single-oared rowers, whose feasibility the project aims to prove, or single levels of oars manned by several rowers each, which seems to be the more common arrangement depicted by artists. The pros and cons of the different arrangements are described as well as the reasoning which led to the reconstruction plan of the Olympias, which was launched in 1987. However before this, models and even a full-scale floating section were built in order to study the rowing geometry. The ship was built with more or less traditional materials and methods, but not exclusively, as the major interest lay in operational research and not historical ship-building. It took the combined resources of two trusts (one British, one American) to build the Olympias, and also of the Hellenic navy, which owns and operates it. Part II is completely new in this second edition and describes the results of numerous sea trials in the years 1987-1992. The Olympias nearly lives up to its expectations, but its 5- to 5.5-knot average speed was slightly lower than hoped for. Peak speeds over 8 knots were recorded. The total efficiency of the oar system was estimated at about 0.5; rowing the Olympias is hard, difficult, and sometimes unpleasant work, but apparently there is usually no shortage of volunteers, whether civilian or navy. Only the top level of rowers can see their ears, whereas the bottom-level rowers can see nothing in their poorly ventilated and smelly workspace (they are also often dripping on the boat from the upper rowers). The logistics of operation are remarkable all the more so, as the ship’s short journey requires that almost two tons of water be on board each night, brought in by the rowers. Olympias also performs well under two square sails. Combined sailing and rowing are highly successful with a bit less effort. The report concludes with a discussion of the results and suggestions for slight improvements. However, it appears that the Athenian trireme project was just about optimal, and the same can be said for the book jacket: “For this second edition, the text has been recast and a number of substantive changes have been made in the light of the sea trials and new research. In addition, there is an entirely new chapter which describes the trials of Olympias in detail, reports the performance figures obtained, and outlines the changes which the ship would wish to incorporate into any second reconstruction. There are nineteen new illustrations, including eleven photographs of Olympias at sea demonstrating features of the design which could be represented only by drawings in the first edition.”
Ratcatcher short-wheelbase recumbent bike. Several years ago he was hired by Giant of Taiwan, one of the largest bicycle manufacturers in the world. His influence is therefore already major and is likely to increase.

Mike’s book on bicycle design has been eagerly awaited. When Open Road Publishers failed recently we were concerned that we would not get to see it, but we are fortunate, at least on the American continent, that AlpenBoo’s has picked it up. It is a stubby bound paperback of 160 pages, on bright-white stock, with some color “centerfolds” of “Mike’s favourite bikes.” All the photographs are clear and good, BW and color, as are the diagrams. There are also several excellent cartoons by Jo Burt and Geoff Apps.

The book starts with a gracious foreword by Richard Ballantine, paying tribute to Burrows’s many characteristics, including some that he has recently learned: diplomatic and gentle advocacy, which increase his effectiveness as something close to a revolutionary. Then we plunge into what I can only describe as a即便是 in his many innovations, which I cite as examples. For instance, the monoblades and cantilever wheels. They are well written (or well edited by Tony Papadopoulos), and I am working on the chapter on the future of bicycles. I realized that just about everything that I hope to see in future bikes, like drive-able cantilevers that one can change rapidly when one has a flat or when one wants to put on a studded tire (as on the day of writing), and all-enclosed transmissions, and disk brakes, have been worked on by Mike Burrows. The man is a master and his book is a “must read.”

—Dave Wilson

**Guest Editorial**

**Your next vehicle: a velomobile?**

Joachim Fuchs

Velomobiles are fully faired recumbent vehicles for everyday use. Many people consider that they have the potential to play an increasing role within different types of human-powered vehicles. In addition, they could give a positive contribution on our future traffic. Or, more precisely: can fully faired everyday recumbent riders replace cars and normal bicycles? This article gives a view over the recent developments in Europe.

First of all, velomobiles are human-powered vehicles that differ from normal bicycles in function and appearance. There are many types, produced as prototypes and in small scale manufacturing. Velomobiles are fully faired recumbent cycles that are constructed for everyday use and provide full rain protection. The fairing also gives better protection against accidents for the driver.

An important question is: Why should I use a velomobile, and what are the advantages compared to a bicycle on the one hand, and a car on the other hand?

An obvious example of the difference between the rider of a velomobile and that of a normal bicycle is that users of velomobiles wear almost the same clothes in summer and winter. This is one main argument for velomobiles: there is no need for a look outside in the morning. No shapeless rain suits hinder one’s pedaling. In addition, both women and men can ride in business suits if they wish.

This implies that there must be good ventilation, an important factor in velomobile design. Because of the absence of direct wind, adjustable air flaps are integrated in the fairing. The air stream within the fairing is moderate compared with that on an unfaired bicycle. Therefore, the rider learns to moderate the flow of his own body. My own experience shows that one rides less in a well-ventilated velomobile even in summer. In contrast, on a normal bicycle one is getting “blown dry” by the wind and sweating starts immediately after riding. This is unpleasant when riding to work regularly. Properly mounted air flaps within a fairing can avoid this effectively.

When riding uphill, passive ventilation does reach its limit, on a regular bicycle and in a velomobile, because the speed of the vehicle is not enough to produce a sufficient air flow. The question is often asked: “Is it possible to ride uphill in a velomobile?” Velomobiles are around 15 per cent heavier than upright bicycles if the rider is included in both cases. The speed loss uphill can therefore never be larger than this 15 per cent. On small or moderate gradients uphill, the lower air resistance of the velomobile compensates for this disadvantage. Velomobiles normally have a smaller effective frontal area (which governs the air resistance). This is the reason for the higher speeds that can be reached with some velomobiles. Higher speeds are attractive especially for riders that are used to physical exercise and have fun riding with their own power. Those people who like riding at 1.5–3 m/s (5–10 mph) will not feel a difference. With a little more power input, riders who are not very sportive become astonished when they can ride at 15 m/s, 30 mph, for some time. This is indeed possible with “sportive” velomobiles.

There are, naturally, many different kinds of velomobiles. Most velomobiles are tricycles. They are stable, anyone can ride them immediately, and they have good luggage capacity. Two-wheels are ridden by sportive people because they can normally go faster and can lean in turns. Examples of such velomobiles in Europe are Aeolos and Desiro. In everyday use, the handling is very important. Getting in and out should not be hindered by the fairing. This is the precondition for switching from a bicycle to a velomobile: it should be practicable for short distances (buying bread rolls on Sunday morning…). A velomobile that exhibits its advantages only in rainy weather would not find many users, because the additional problem to park such a velomobile is a problem at least in urban cities in Europe. To some extent, one can say that velomobiles combine the advantages of cars and bicycles. As bicycles, velomobiles can be used on roads on which cars are banned. Often, everyday distances can be covered through a nice landscape whereas car drivers have to use boring main roads. Besides that, velomobiles are economic even though they are expensive when purchased. This is especially the case if velomobiles are often used and if they replace other vehicles. Compact velomobiles can be taken along in a train with a bicycle compartment, at least in some countries in Europe. Some designs can be taken apart to make them easier to stow, which is necessary with most tricycles.

A few people who ride with others (non-velomobile) riders should take
into account that one can chat while pedaling. This can also be useful for communicating with other traffic users, mostly car drivers. A properly constructed velomobile can be pushed along sidewalks and shopping malls. (You will not have a built-in shopping cart!) Most enthusiasts first think of rain protection when the talk is about velomobiles. The Leitritz is especially favored by cyclists that are shyundariders who calculate that it rains only a small amount of time. On the other hand, in practice, people who are interested in velomobiles are likely to use the car next time.

To match the demands of practicability, constructors have to design their products with considerable skill. Protection from cold wind in winter time is as important as from rain. On a normal bicycle, it is often hard to choose the right clothes. After commuting some time, one begins to sweat under the warm clothes. Velomobiles avoid this problem, because one can adjust the air flow and do not have to change clothes. And this is what the feeling when getting in a velomobile is that the head might have to outside the fairing have the disadvantage that the fairing is individually quite variable. Some open velomobiles even if they don’t touch it. Instead, the fairing forms a closed shell every all components mounted to it. Vehicles of that kind have fewer parts and are cheaper to produce. But in the case of damage, it is necessary to repair it skillfully to ensure the shell recovers its rigidity. There are further aspects to take into account, for example eye-level height, which is important in urban traffic. For that reason, the commercially available velomobiles there are some vehicles that were either produced for personal use or have at least the potential for a commercial product. The inventors of prototypes add to the diversity of velomobiles. To give some typical examples, the commercially available velomobiles there are some vehicles that are hanging by a slim financial thread. The temptation to draw some parallels is irresistible: if we want superb publications like those of Open Road to continue, and the less ambitious but replaceable magazines such as Bike-Aide (UK), Recumbent UK, and all the other publications of our national and local HPV associations (in which we hope we may include Human Power), we must support them with subscriptions and with the recruitment of others to join. From the very beginning there have been efforts to associate at Open Road performed the miracles they did in the spirit of missionaries with a vision, at low or zero profit. Many selfless people also invested in a dream, and have lost all their money. We give heartfelt thanks and appreciation to all involved for their all time short period of brilliance, one that shines on us all. One of the reasons to this is that the more adventurous, and the quicker, human-powered vehicles. Enthusiasts would seize each issue of each series and be inspired by the publication of the quality and the publicity of the subjects. We marveled that the most ambitious projects outdo even the best advertising campaigns of macho trucks and SUVs on every other page. Open Road had been going from strength to strength for the better part of a decade, publishing in English and German, with agents in four countries, organizing "Bike Culture Weeks" in velomobile home territory in and near York, UK, and, lately, publishing two superb books.

I had thought that Open Road must have an "angel funder", in the way that the early IHHP had infusions for prizes from Du Pont especially, but it seems that there was none. The speed of the collapse of Open Road, and the large amount of debt at the end are, saddening and sobering. We in the new, reorganized IHHP are far less ambitious, even timid by comparison, and yet we are hanging by a slim financial thread. The temptation to draw some parallels is irresistible: if we want superb publications like those of Open Road to continue, and the less ambitious but replaceable magazines such as Bike-Aide (UK), Recumbent UK, and all the other publications of our national and local HPV associations (in which we hope we may include Human Power), we must support them with subscriptions and with the recruitment of others to join. From the very beginning there have been efforts to associate at Open Road performed the miracles they did in the spirit of missionaries with a vision, at low or zero profit. Many selfless people also invested in a dream, and have lost all their money. We give heartfelt thanks and appreciation to all involved for their all time short period of brilliance, one that shines on us all. One of the reasons to this is that the more adventurous, and the quicker, human-powered vehicles. Enthusiasts would seize each issue of each series and be inspired by the publication of the quality and the publicity of the subjects. We marveled that the most ambitious projects outdo even the best advertising campaigns of macho trucks and SUVs on every other page. Open Road had been going from strength to strength for the better part of a decade, publishing in English and German, with agents in four countries, organizing "Bike Culture Weeks" in velomobile home territory in and near York, UK, and, lately, publishing two superb books.

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Human Power 11:4 (Fall/Winter 1998) Numbering system for Human Power since we are not able to publish on a regular, pre-defined schedule. Adding up all the issues we could find back to issue 1, we numbered the next issue #46. After a long time number indexing was added, so if you have a number, we re-numbered that Human Power 1988–89 issue #47.

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Human Power 11:2 (Spring/Summer 1998)

Human Power 11:1 (Winter 1997–98)

Human Power 10:4 (Spring 1997)

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