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BIKE TECH

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ERGONOMICS

The Optimum Pedaling Rate

Han Kroon

Any good design of a human-powered vehicle needs serious attention to ergonomic properties, particularly the mutual adaptation of the rider and vehicle. A number of these adaptations are fairly "static," by which I mean that the adjustments are done only once — a chosen arrangement is not varied during a ride. The saddle height (or more exactly, the seat-to-crank-bracket distance), crank length, and body posture are all examples of static adaptations, which have been studied by several investigators. Their results seem to give relevant data to make an optimum setting possible.

Environmental Changes

"Dynamic" adaptations, on the other hand, raise many more questions. Some of these have been raised recently by David Gordon Wilson's paper in the December 1982 issue of *Bike Tech* ("The Performance of Machines and Riders on Hills," *Bike Tech* volume 1, number 4).

As the foregoing remarks imply, I use the term "dynamic" here for those adaptations done during the ride to accommodate to environmental changes. The most prominent dynamic adaptations are gear selection, by which the pedaling rate is determined for a given speed, and the choice between sitting or standing to pedal.

The aim is always to find those adjustments which allow an optimum performance. But at this point one should stop and ask: What's the definition of an optimum in performance, and by what measure is it determined?

In the literature most research on the influence of the pedaling rate is done in terms of efficiency and the related heart pulse rate, power output, and perceived exertion. (Some care with definitions is needed here. Efficiency is not simply magnitude of output. It is the *ratio* of useful output — in this case, work or power — to the input consumed, in this case oxygen and/or food.) And since the relation of these variables to the "optimum" is not yet defined, we first have to become familiar with all these topics.

Highest Efficiency

As early as 1929 it was shown that the efficiency of bicycling is influenced by the pedaling speed. Experiments done in that year by S. Dickinson showed the optimum rate (optimum for efficiency, that is) to be 33 rpm: an extremely low value, one turn every two seconds. More recent results, however, give higher cadences. From these data it appears that the most efficient cadence depends on the power output. An overall picture of this relation is given in Figure 1a. The second horizontal scale gives speeds which correspond to the various power outputs for a cyclist in racing position on level ground, as given by the equation from page 157 of *Bicycling Science* (see references), with $m = 80$ kg, $C_D \times A = 0.3$, and $C_R = 0.007$. Figure 1b gives the corresponding efficiencies determined for the data points in Figure 1a.

Figure 1a shows that with increasing power output the rider has to increase the pedaling rate as well in order to obtain the highest possible efficiency. Even Dickinson's result of 33 rpm fits rather well in the overall relation given by the curved line. (But according to these data John Forester should lower "his" 140-inch gear — cited in his "The Physiology of Human Power Production" in *Bike Tech* Volume 2, Number 2, April 1983) — to a still amazingly high 120-inch gear.)

By the way, the data given in Figures 2.22 and 2.23 of *Bicycling Science (Editor: Figure 2.23 appeared as Figure 1 in Wilson's "Performance . . . on Hills" article in* Bike Tech*)* should be interpreted with reserve since

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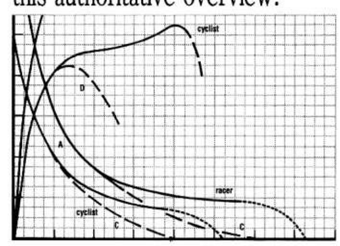

they show no real minimum; the quoted minima are just a result of restricted experimental conditions.

Inefficient Racers

In general the most efficient pedal frequency is on the low side compared to the rates demonstrated by competitive cyclists. On the road these riders' rates are about 100 rpm, and therefore it is often suggested that such data as given in Figure 1 do not apply to them. Hagberg et al. state that "during their training, cyclists make a conscious effort to adapt to high pedaling rates and to become more comfortable and efficient." However, Jordan and Merrill had already undermined this thesis, with respect to efficiency, a few years earlier, by measuring heart rate and oxygen uptake at a rather high work load (75% of maximum) with five world-class racers. They found the lowest rate tested (60 rpm) to be the most efficient. So why do racing cyclists pedal at those high inefficient speeds?

The answer should be clear by now: efficiency is not the only true measure to determine maximum performance, or to choose the conditions at which bicycling feels most comfortable. Bicycling at a high efficiency only means that we use as little food and oxygen as possible for a given speed. But who's worrying about food when there's a race to win?

Maximum Power Output

In bicycling the power output is dependent on the crank length and the forces applied to the pedals (which in combination are responsible for the torque), and the frequency at which the pedals are turned round:

$$\text{Power} = \text{mean pedal force} \times \text{crank length} \times \text{pedaling rate}$$

The mean pedal force should be calculated as the integral (over one turn) of the tangential component of the applied pedal force. (For numerically correct results, force, length, and power must be expressed in a consistent system of units — SI or English — and rotation must be given in radians per second, which is 2π times the rate in revolutions per second, or $\pi/30$ times the rpm.)

Suppose that the maximum mean pedal force were constant, not dependent on the pedaling rate. Then maximum power output would be proportional simply to the pedaling speed. While of course this is not the case, it is reasonably close to being true for part of

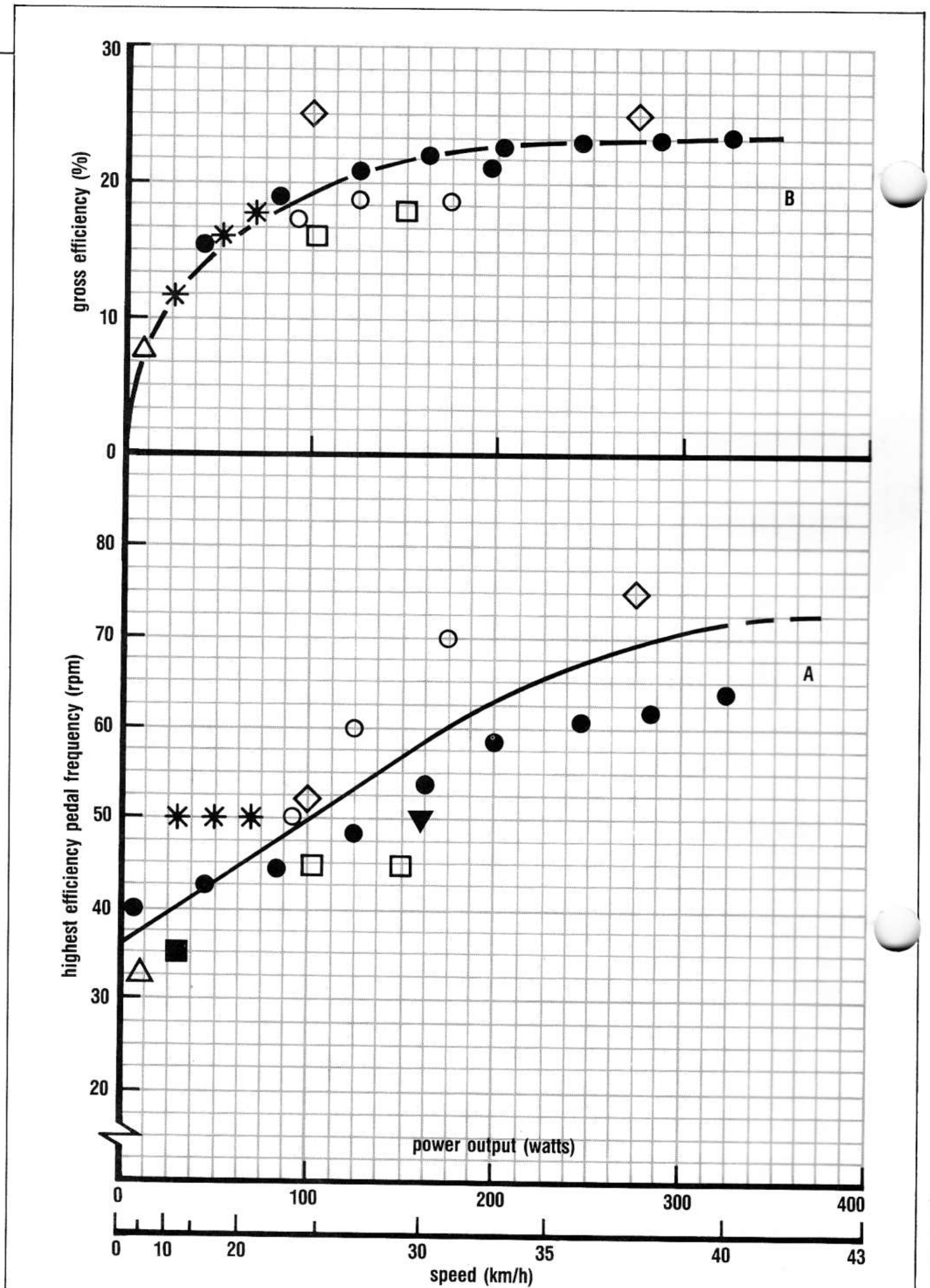

Figure 1: Highest efficiency pedaling rate and corresponding efficiency as a function of power output. The lines are drawn by eye. Symbols: ▼ Åstrand, △ Dickinson, □ Eckerman, Millahn, ■ Hess, Seusing, ○ Pandolf, Noble, ◇ Pugh, ● Seabury et al., ✳ Stegemann et al..

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the upper range of pedaling rates — close enough that this relationship accounts for the behavior of racing cyclists. These riders' rates reach to 150 rpm for short-duration high power outputs. For longer periods the rate will be lower. For example, all one-hour records from 1942–1972 have been done with rates of about 105 rpm.

However, untrained cyclists will not reach that rate even for a low power output (e.g., on an indoor trainer). What's more, the pedal force is not constant but decreases with increasing pedal frequency due to shorter recovery times and increasing losses in the muscle tissues. Here we enter a rather unknown field: to my knowledge only Sjøgaard reports so-called force-velocity curves for bicycle work. Figure 2 shows force-velocity curves (A) based on Sjøgaard's results, for an untrained cyclist (with an 80 rpm maximum) and a racer (with a 120 rpm maximum and a mean pedal force 1.5 times that of the untrained rider).

I have to emphasize that these curves are only examples since their location depends strongly on the subject's condition. That's the reason why the vertical scales have no values.

Muscle Elasticity

The curves show a rather flat section for the higher rates (as long as the maximum rate is not yet reached). This aspect bears a notable contrast to Hill's equation, which describes the force-velocity relation of single contractions.[1] The elasticity of the muscle tissues appears to account for this discrepancy: during repetitive contractions at a high frequency a part of the deceleration work seems to be stored and subsequently released during the following active period. This effect supports the output of power at high pedaling speeds.

By multiplying the force-velocity curve by the pedaling rate we find the corresponding power-velocity curves, which are also given in Figure 2(B). The result is clear: both higher mean pedal forces and higher attainable pedaling rates cause the maximum power output (and so the maximum bicycling speed) to increase strongly.

Although during anaerobic performance an increase in power output may also be achieved by especially high pedal forces, these forces are hard to sustain. In this respect there is a need for force-velocity curves both for maximum output, and also at constant oxygen uptake conditions, which are lower than the rider's maximum, and the duration of performance should be specified.

(In regard to this need, I was not able to tell, from the information given, exactly what level of effort Sjøgaard's results describe. They appear to represent a fairly high level, and so may have a significant anaerobic component, but since his test durations included times as long as 14 minutes the tests must represent work which is largely aerobic.)

Perceived Exertion

Up until now the opinion of the bicyclists themselves has been left out. But to my thinking we should carefully listen to the talk of our body. There are many examples in which the body chooses that work condition that fits best. For example, the normal walking speed of 5 km/h and the usual 20 km/h speed for cycling agree exactly with the speed for minimal energy consumption per unit of distance.

Perceived exertion depends on both the required performance (cycling before the wind is easier than against it) and the rider's condition (a young rider feels comfortable at 30 km/h, whereas an aged man may not be able to reach 20 km/h). But also other aspects such as pedaling rate appear to influence the perceived exertion.

The most common method of measuring the perceived exertion is based on on scaling. Before the tests the subjects have a look

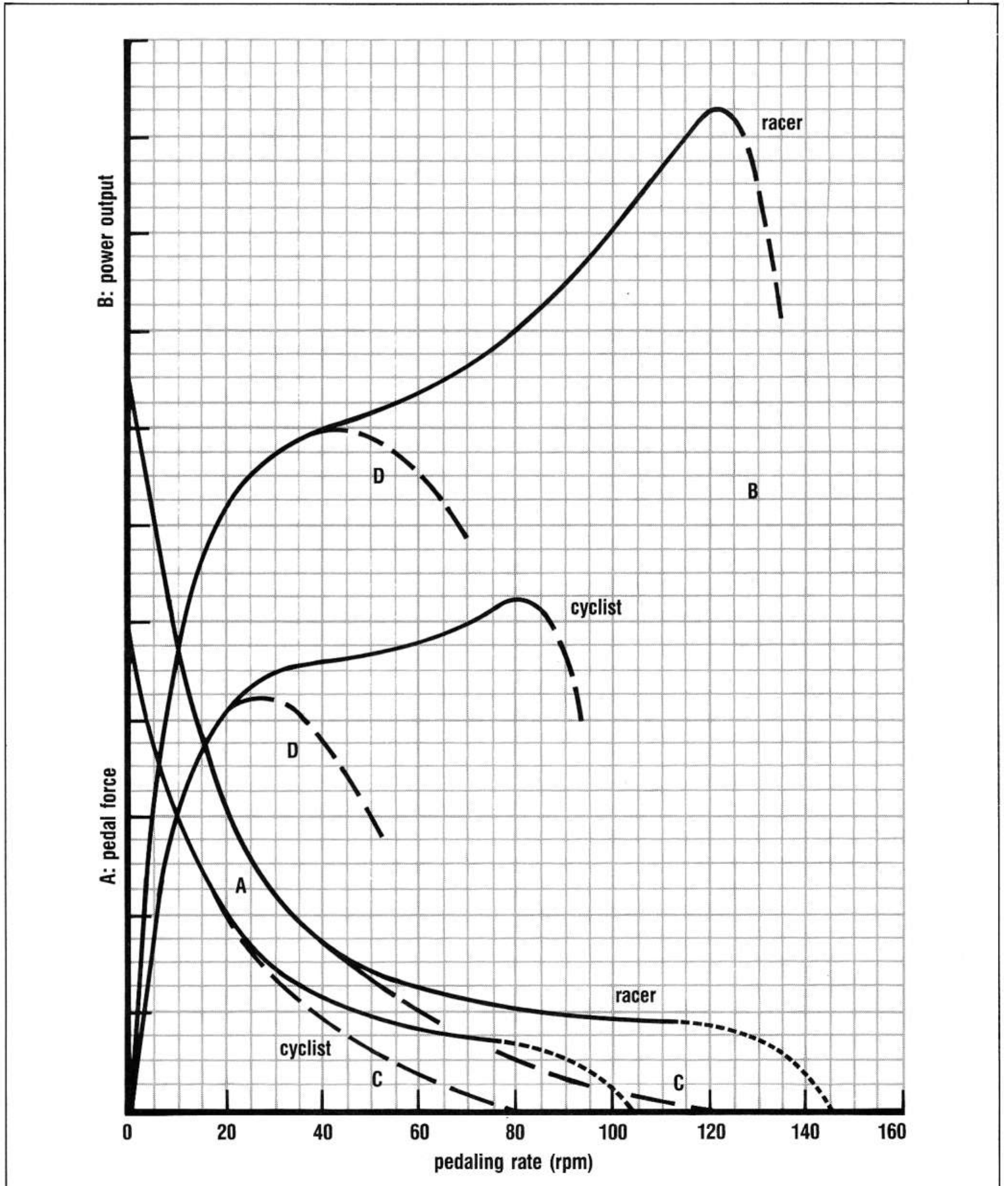

Figure 2: Force-velocity curves (A) and power-velocity curves (B) for a hypothetical racer and an untrained cyclist. Lower dotted curves C and D give force and power that would result if the Hill equation for single contractions were applicable.

[1] *Hill's equation describes a simple hyperbolic curve, also shown on Figure 2, of the form*

$$(P + a)(V + b) = a \text{ constant}$$
$$= b(P_o + a)$$
$$= a(V_o + b)$$

where P is force and P_o is maximum force; V is contraction rate and V_o is maximum contraction rate; and a and b are constants usually about 1/3 the magnitude of P_o and V_o respectively.

at a so-called Borg scale (see below). After every test they assign a number between 6 and 20 corresponding to the perception of the exercise. The result is a perceived exertion rating (PER).

Borg scale:

6		14	
7	very, very light	15	hard
8		16	
9	very light	17	very hard
10		18	
11	fairly light	19	very, very hard
12		20	
13	somewhat hard		

The influence of the pedaling rate on PER for a constant power output is given by Löllgen et al. Figure 3 shows that the PER decreases with increasing pedaling rate, at least at rates between 40 and 100 rpm. So, the higher your rate at a given speed, the lighter it feels. Another conclusion follows from Figure 3. If you have to supply a higher output, not only the PER is higher (which goes without saying), but also the decrease of it as the pedal frequency increases is more pronounced. With increasing power output it is more and more worthwhile to choose a high cadence.

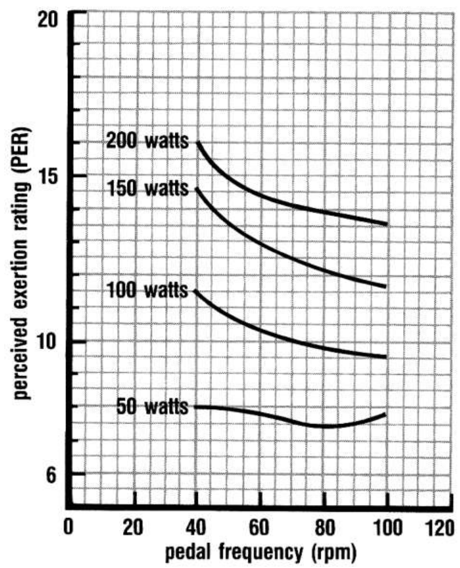

Figure 3: Perceived exertion as a function of pedaling rate. (source: Löllgen et al.)

Since an increasing pedaling rate at constant power necessarily means that the mean pedal force decreases, we may conclude that the perceived exertion should be strongly related to the pedal force. E. Cafarelli (reference 2) demonstrates that this applies more strongly for longer-duration performances. This may be looked upon as a self-preservation system of our body; for higher pedal forces also mean a higher load to muscles and joints, which promotes the development of hard-to-cure injuries. Novice riders in particular are seldom aware of these risks, and they often prefer a high gear which probably gives them a feeling of delivering a high performance.

Preferred Pedaling Rate

Every cyclist who has a gear selection system can freely choose his pedaling rate (within limits, of course). Therefore we have to include data on the preferences of the cyclists themselves, data which also give a reflection of the internal sensation. Figure 4 shows both preferred pedaling rates and natural step frequency in walking. The data originate from Pugh and Dean respectively. The latter have been included since during walking we also have a free choice of our step frequency up to a speed of about 8 km/h. For higher speeds the leg length limits the step length so that the step frequency is forced to increase. The published step frequency had to be halved (one cycle now includes a step of both left and right foot) in order to make it comparable with the pedal frequency. The similarity between walking and cycling rates is striking, suggesting that similar processes govern both means of conveyance.

Climbing: Spin or Stand?

In hill climbing, in particular, we observe two very distinct kinds of cycling: seated spinning; or dancing on the pedals with a relative low pedal frequency. A study by Soden and Adeyefa (very worth reading) on the forces that a rider applies to the pedals, saddle, and handlebars, gives interesting results on this topic. From these results an estimation is given below on the maximum power output for the two conditions. Let's consider a long-duration performance.

By Soden and Adeyefa's assumptions, the mean torque for a seated rider is half the maximum value.[2] Let us also assume that a seated rider's pedal force does not exceed the rider's body weight. At a maximum power output this leads to:

$$P_{max,sitting} = 0.087\ m\ f_{max,sitting}$$

where P is power in watts, m is rider's mass in kilograms, f is frequency of pedal rotation in rpm, and the crank length is 170 mm.

Standing on the pedals permits a pedal force of up to three times the body weight. Here let us restrict the maximum pedal force to two times the body weight. On account of the changed character of the pedal force, now the mean pedal torque (by Soden and Adeyefa's assumptions) is 0.64 times the maximum value.[3] Maximum power is now given by:

$$P_{max,standing} = 0.111\ k\ m\ f_{max,standing}$$

where P, m, f, and crank length are as defined above and k is the ratio of maximum force to body weight, and has a value between 1 and 2. We consider the maximum seated pedaling rate to be 120 rpm, and the maximum standing pedaling rate for long-duration work to be restricted to 80 rpm. With m = 70 we obtain the following maximum power outputs:

$$P_{max,sitting} = 730 \text{ watt}$$

$$P_{max,standing} = 622\ k = 622 \text{ to } 1244 \text{ watts.}$$

So the standing condition enables the rider to perform better, although his physical condition has to agree!

Besides, standing hill climbing makes it easier to get past the "dead points" in the pedal cycle, since the total of the left and right pedal torques shows less pronounced decreases at the vertical crank positions. With respect to the load on joints, standing at a relatively low pedal frequency seems to be less dangerous than sitting of the same cadence and power output, since for standing pedaling the joints are rather fixed during the supply of the high pedal forces. This contrasts with the low-cadence rate, level

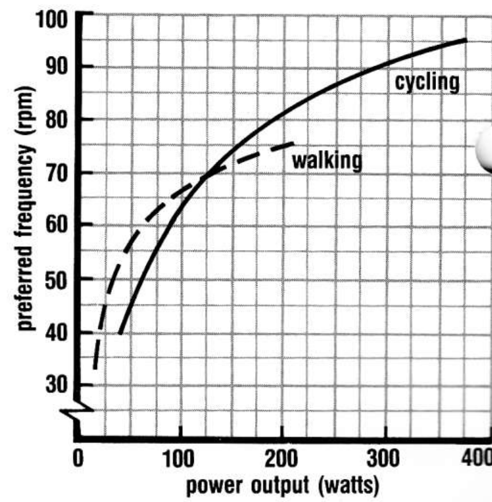

Figure 4: Preferred pedaling rate and natural step frequency in walking as a function of power output. One cycle in walking includes both left and right foot step. (sources: Pugh, Dean)

George Retseck

[2]Soden and Adeyefa's simplifying assumption is that a seated rider varies the pedal force in proportion to the sine of the crank's angle from vertical (so as to push hardest when it does the most good — when the crank is horizontal) and that the force can be regarded as vertical. With a vertical force, the torque-to-force ratio will also vary with the sine of the crank angle, so the net torque will vary in proportion to the square of the sine. For a sine-squared function, the mean value is half the maximum value.

[3]For a standing rider Soden and Adeyefa assume that since the rider's full weight is on the pedals (i.e., there is no support from the seat), the rider will apply the full (maximum) value of the pedaling force throughout the whole stroke of each pedal. With the pedal force constant, then, the net torque varies with the sine of the crank angle rather than with the squared sine. The mean value of a sine function (if its value is always considered positive) is 0.64 times the maximum value.

(seated) cycling, in which high loads are applied to slowly moving joints.

Conclusions

A composite picture of the previously-discussed 'optimum' pedal frequencies is given in Figure 5. The definition of only one optimum is not possible, since its choice depends on the rider's needs and circumstances. However, some remarks can be made.

For a low power output you should choose a low pedaling rate (about 60 rpm) which ensures that you are cycling with the highest possible efficiency. With increasing performance one should not only raise the pedal force, but also the pedaling rate, which decreases efficiency but gives better results, because it feels more comfortable and lowers the chance of injuries. The warming-up and warming-down may be employed to become accustomed to these high rates of pedaling.

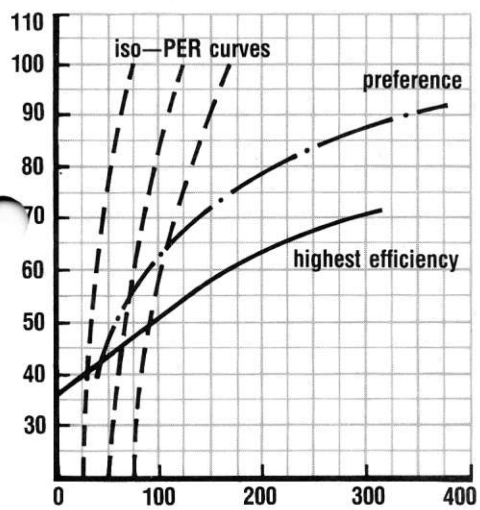

Figure 5: Curves according to the highest efficiency (fig. 1a), preference of the cyclist (fig. 4) and isoPER-curves. An isoPER connects points with equal perceived exertion (source: Stegemann et al.)

Also hill climbing is preferably done while spinning, but since there is a limit to the power output, a large steep slope may force you to do it standing. After all, "dancing on the pedals" relieves your bottom and may be fun in itself.

The conclusion that efficiency is not the final word in the determination of the optimum pedaling rate has its consequences for the optimization of other cycling topics. In my opinion the "static" aspects mentioned in the introduction should also be treated in this manner. The results might amaze us.

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INDUSTRY TRENDS

ISO Proposes New International Bicycle Lighting and Reflectorization Standards

Fred DeLong with
John S. Allen

One of the most important considerations for the use of bicycles as practical transportation is the ability to see and be seen after dark. But in the bicycling community this important area has also been one of the most haphazardly treated. We have had little data on the performance of available equipment, and less on what performance is needed *for the cyclist to see and especially to be noticed by automobile drivers. So we make guesses, which are often dangerously optimistic because we misunderstand what's needed, or because we're reluctant to bother with carrying a full set of lights. With this two-part report on the ISO's proposed standards, described in the context of other standards for cycles and automobiles, we hope to provide a framework in which lighting and reflectors can be better understood.*

Because of the report's length, we present the two parts in separate issues. The first, printed here, explains the nature of the ISO standards and describes the headlight and taillight specifications. The second, to be printed in the next issue, contains the reflector specifications and an analysis of the factors (and pitfalls) involved in making a bicycle show up at night.

After five years of work, testing, and study, the ISO (International Standards Association) Technical Committee 149, Bicycles, is nearing the completion of a new set of standards on lights and reflectors for bicycles. The Committee has issued the portion on reflectors as a Draft International Standard (DIS 6742/2) for its final stage of review and voting by the delegations of the member countries, and is expected to issue the portion on headlights and taillights as DIS 6742/1 later this year.

The new standards are to be used along with existing ISO Standard 4210, Bicycle Safety (see *Bike Tech,* Volume 1 Number 3, October 1982), which has been approved by the ISO's member nations, and which, among other requirements, specifies pedal reflectors, side reflectors, and a rear reflector. For those rare countries which do not require fitting of front and rear lighting to new bicycles, ISO 4210 requires wide angle reflectors front and rear.

The standards will not preclude further improvements in lighting, and will greatly improve the efficacy and durability of lighting and reflector systems worldwide. (Some manufacturers, though, are already producing and selling equipment that meets or exceeds the improved standards.)

The new standards, while voluntary, will be particularly useful in combination with the type of standard used in traffic laws such as those of most states of the U.S.

For example, many U.S. state laws require a white light that can be seen from a distance of 500 feet and a rear reflector that can be seen from a distance of 300 feet when illuminated by the low beams of automobile headlamps. However, nothing is said about the conditions of measurement; to quote Dr. Kenneth Cross, an expert on bicycle accident statistics, "on a clear, dark night, the light of a match can be seen for a quarter-mile."

It would be difficult to specify measurement conditions in much detail in a law which must be enforced on the street without benefit of sensitive equipment or controlled conditions. But bicycle lighting must be more than just visible when it must compete with background lighting or oncoming headlamps, or on curved roads, dips, or hillcrests. Atmospheric haze, mist, or fog, dirty or wet windshields, and other impediments can also prevent recognition of the night bicyclist.

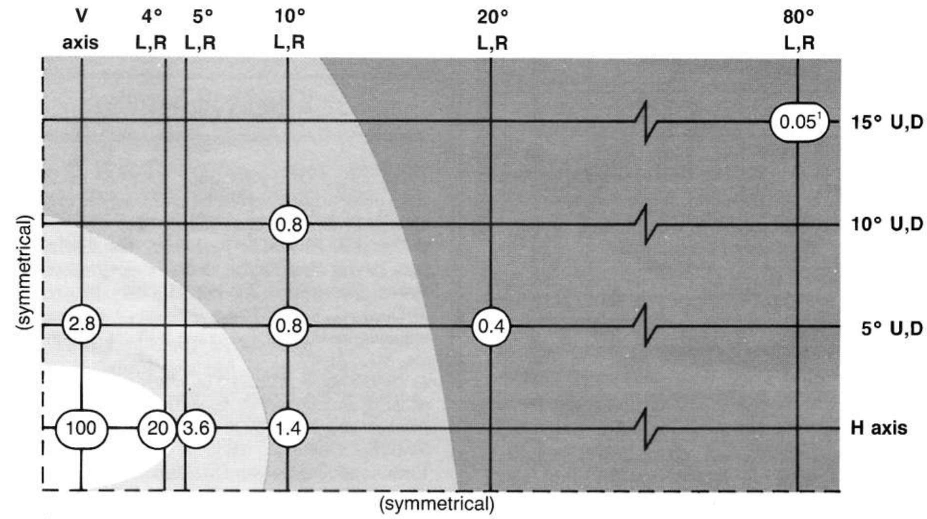
Minimum Photometric Requirements

The new standards, in contrast to U.S. state traffic laws, are industrial product standards which can be implemented by detailed testing procedures. These standards specify photometric (measured lighting intensity) requirements intended to make bicyclists more visible to other road users, and also require sufficient light from a headlamp so bicyclists can detect road hazards immediately ahead.

The minimum requirements set by the new ISO standards can be met by headlamps using the common 6 volt 2.4 watt headlamp bulb with 21 lumens light flux or a 2.5 volt 0.75 amp (1.88 watt) battery headlamp, and by taillights with the common 6 volt 0.6 watt, 3.3 lumen taillamp bulb. (For example, the required headlamp brightness pattern can be satisfied liberally by a net output of five lumens in the right direction. Although substantial losses due to absorption and scattering by the reflector and lens are inevitable, a lamp with a 21-lumen bulb could lose as much as three-quarters of the bulb's light and still accomplish this task.) Other bulbs that exceed these outputs are permissible.

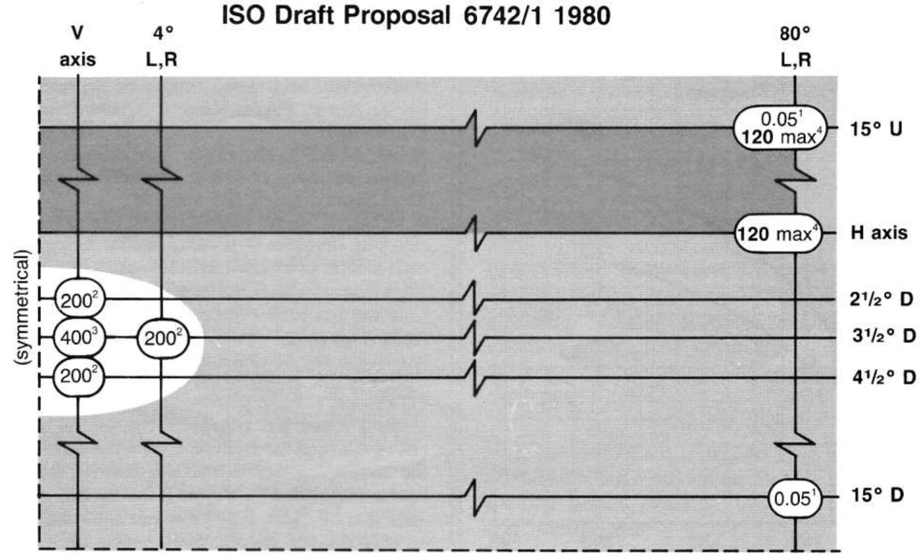
Increased lighting intensity without changing the bulbs is achieved primarily by improvements in lamp housing design and beam pattern. The following comparisons should make it clear just how dramatic the improvements can be.

Table 1: Headlamp Beam Intensity Measuring Points, BS AU 155, 1973



¹Nowhere between 15° U,D and 80° L,R shall the luminous intensity be below 0.05 cd.

Table 2: Bicycle Headlamp Beam Intensity Measuring Points, ISO Draft Proposal 6742/1 1980



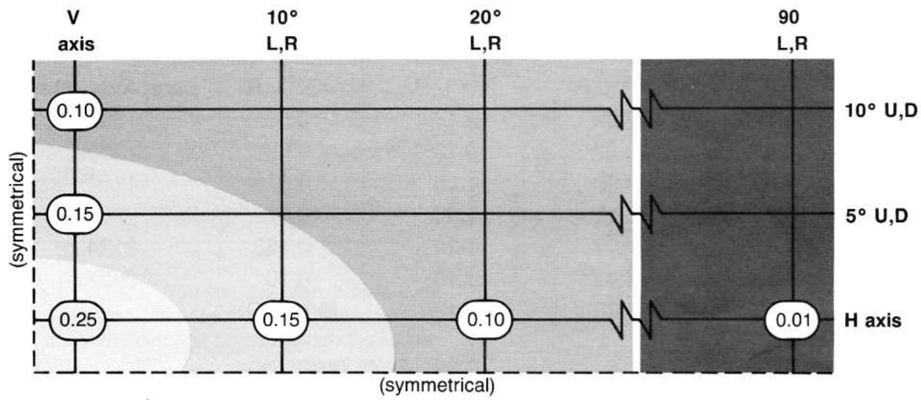
[1]At any point between 15° U,D and 80° L,R, luminous intensity shall be equal to or greater than 0.05 cd.
[2]At or between these points, intensity must be equal to or greater than 0.5 of the maximum intensity.
[3]At this point, intensity must be equal to or greater than 80 percent of the maximum found anywhere in the pattern.
[4]At any point in the shaded zone enclosed by these points, the intensity must not exceed 120 cd.

Note: all intensities given in candelas.

Table 1 shows the headlamp intensity in candelas of the previously recognized British Standard AU-155: 1973. Table 2, by way of comparison, shows the headlamp intensity requirements of the new proposed ISO standard. Intensity at the center of the ISO headlamp beam must be at least 400 candelas, four times the British requirement. The ISO standard specifies that the center of the beam be aimed downward 3.5 degrees toward the road surface (41 feet ahead of the bicyclist, for a lamp 30 inches above the road surface). Within angles one degree above and below center (between distances of 32 and 57 feet) and four degrees to the left and right of center (about three feet to either side at a distance of 41 feet), the ISO standard requires intensities at least 50 percent of the maximum. Compare this with the British requirement at four degrees left and right for only *five percent* as much light: 20 percent of a maximum which is already only 25 percent as great!

The stated requirements relate to the bicyclist's ability to see the road ahead. British and ISO requirements relative to the ability of other road users to see the bicyclist's headlamp are, by contrast, identical: between the four points at 80 degrees right and left, ten degrees up and down, intensity

Table 3: Bicycle Taillamp Beam Intensity Measuring Points, BS 3648, 1963 (revised 1967)



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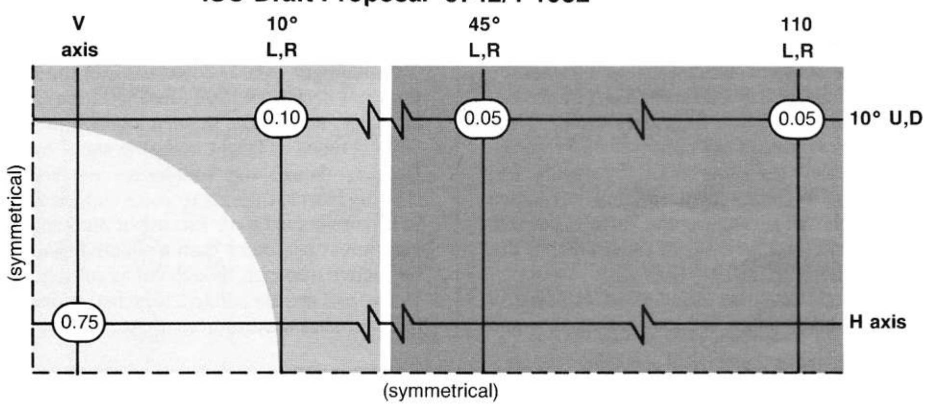
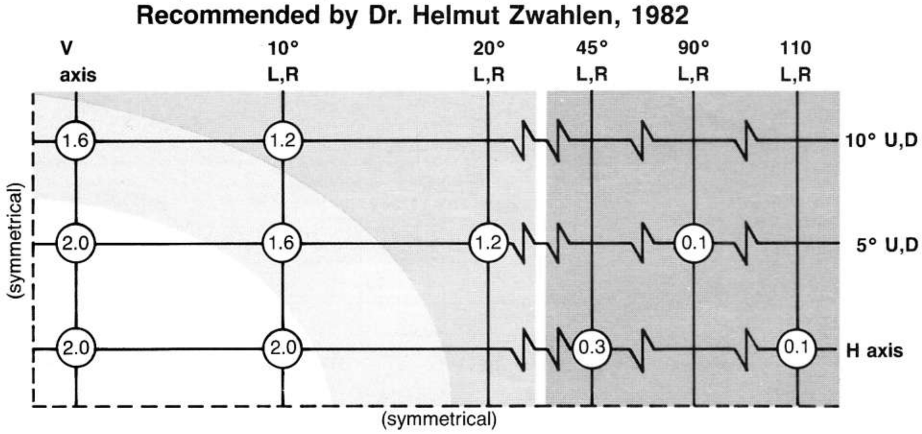


Table 5: Bicycle Taillamp Beam Intensity Measuring Points as Recommended by Dr. Helmut Zwahlen, 1982



Note: all intensities given in candelas.

Note: The shading on these diagrams is not *part of the specifications, but is added as an aid to visualizing typical brightness patterns that would satisfy the given requirements in a simple, straightforward way.*

These are by no means the only patterns that will satisfy the requirements. The specifications generally designate brightness only at certain points, so a beam pattern with darkness in the intervening areas (such as a cross-shaped pattern for Table 3) can satisfy the letter if not the spirit of the standard; and the specifications usually give only a minimum required brightness for each point, so a beam pattern can differ from one of these here if it exceeds the requirements by different margins at different points.

In addition, the reader should bear in mind that the range of shades available in print is much narrower than the actual range of the magnitudes specified in the diagrams.

must be no less than .05 candela. This requirement is amply fulfilled by stray light as long as parts of the headlamp assembly or bicycle do not hide the headlamp's lens.

The ISO standard specifies a *maximum* allowable intensity in the area shown in gray in Table 2, which can glare into other road users' eyes. To be sure, no ordinary bicycle headlamp will violate this requirement; though the newer high-powered battery lamps might if their beam pattern were poorly chosen. Table 7 shows SAE (Society of Automotive Engineers) standards for automobile headlamps in the United States, allowing a comparison of permitted glare. Automobiles are allowed to glare more; the ISO glare limits for bicycle headlamps probably are more in line with European standards for automobile headlamps, which require a sharper cutoff in the low-beam pattern; further comments are in the notes with the Table 7.

Bicycle taillamp comparisons reveal a range of brightnesses even greater than bicycle headlamps. Table 3 gives minimums required by British Standard BS 3648: 1963 (revised 1967); Table 4, those required by the proposed ISO standard; and Table 5, those recommended by lighting expert Dr. Helmut Zwahlen based on his research at Ohio University, Athens, Ohio. Directly behind the bicycle, the British standard specifies 0.25 candela, the ISO standard 0.75, and Dr. Zwahlen 2.00. (By way of comparison, a typical car taillamp has an intensity of 8 candelas — See Table 8.)

Away from the center of the beam, differences are even more pronounced. Note that test points for the British standard (see Table 3) are in a cross-shaped pattern. You can see a result of this if you aim some British taillamps — such as the common Berec battery lamp — at a blank wall. The lamp's mirror and lens were clearly designed to meet the standard by placing the most light in the cross-shaped measuring pattern, with less light in diagonal directions which could be just as important.

At ten degrees right and left and up and down, the ISO standard specifies (see Table 4) that intensity must be 0.10 candela, and at larger horizontal angles it must be 0.05 candela, just as for the headlamp. No area specifications, such as for the headlamp, are given, but the decreasing angles between the center of the pattern and the outer test points relative to the horizontal are designed to assure a full-coverage beam pattern. The ISO standard also requires a projecting part of the lens of the rear lamp, or a window in the top of the housing, so the rider can look back and see whether it is working.

Dr. Zwahlen's recommendations define the beam pattern differently from the ISO standard: by specifying a larger number of points. However, the ISO standard and Dr. Zwahlen's recommendations are comparable at points ten, 45, 90, and 110 degrees right and left.

Table 6: Bicycle Taillamp Luminous Intensity (Tests made by Dr. William Venable for ANSI Technical Advisory Group for ISO TC/149; intensities in candelas)

	Location from Beam Center (on horizontal axis)				
	0°	10° L,R	20° L,R	45° L,R	Lens Area, mm²
1950 Soubitez	0.0125	0.09	0.11	0.06	390
Soubitez, age unknown	0.61	0.32	0.13	0.06	1350
1950 JOS	0.86	0.08	0.05	0.025	1134
1979 Taiwan make	0.16	0.12	0.06	0.07	962
1978 Schwinn Union	1.30	1.07	0.19	0.155	2124
1978 Schwinn Soubitez	1.26	0.47	0.18	0.10	2827
British test on "standard production taillamp" reported to ISO TC/149	1.58	0.25	0.12	(90° L,R) 0.082	
German test of Varta sealed beam taillamp-reflector combination	11.36	2.5	0.83	(45° L,R) 0.36	(110° L,R) 0.30

At the extreme angles of 110 and 90 degrees, and at the central focused spot, the ISO standard comes close to meeting Dr. Zwahlen's recommendations, but at intermediate angles, the ISO standard requires as little as one-twelfth as much light as Dr. Zwahlen. The ISO standard represents a compromise — the highest level upon which the ISO delegates could agree based on the amount of light that a lamp housing of reasonable price and complexity can extract from the standard bicycle generator-driven 0.6 watt bulb — and with a red lens, which further reduces the light output.

Performance of Commercial Taillamps

Now, let's see how some actual, commercial taillamps stack up against the various standards. As part of the USA's American National Standards Institute Technical Advisory Group's contribution to the ISO's work on bicycle lighting, Dr. William Venable of Hunter Laboratories, in Virginia, was kind enough to measure the light output in the horizontal plane of several of my own bicycle taillamps (Table 6). Also shown are independent results for a British taillamp and for the Varta Super sealed taillamp made in Ireland and West Germany.

Considering that they all use 6 volt 0.6 watt bulbs, the range of variation in light output of these taillamps is all the more remarkable: twenty to one at the center of the beam pattern.

The worst of the lamps fail to meet even the weak British standards at one or more of the test points. The 1978 Schwinn Union and Soubitez lamps meet the ISO standards; the 1950 JOS comes close: good taillamp designs clearly predated the ISO standards. The Varta lamp is in a class by itself. At only one angle does it fall below Dr. Zwahlen's stringent requirements, and not by much; in the center spot of its beam pattern it is more than five times as bright as he requires, and easily as bright as the standard car taillamp, which uses a much more powerful bulb. This center spot is especially intended to prevent the lamp's being drowned out by the light from oncoming car headlamps.

Table 8 gives intensities of automotive rear lamps as required in the USA by the Society of Automotive Engineers (SAE). Note that the minimum taillamp intensities are approximately the same as Dr. Zwahlen's, and that the recommended taillamp intensities are in the same range as the Varta's; but that the brake and turn signal requirements are far higher.

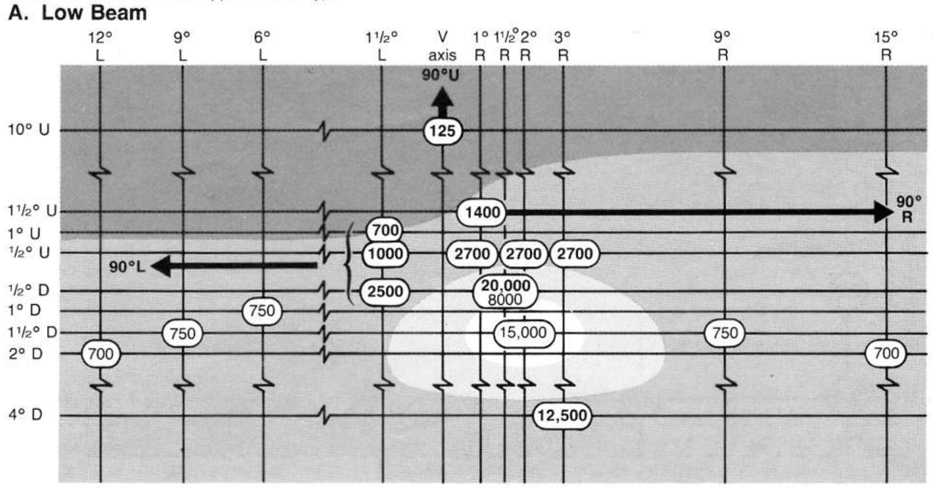
It might even be asked whether some of these upper limits are excessive; stop and turn signals must be visible by day as well as by night, and the noticeable result is to degrade the dark adaptation of following drivers at night.

It should be noted, however, that the eye does not easily perceive small differences in intensity; so a brake or turn signal must be several times as bright as a stop signal to be distinct; though the conclusion is obvious that the bicyclist who is to be as conspicuous to drivers behind a car turning or stopping at night must use more than a simple taillamp. Reflective material, though not as reliably effective can greatly add to a bicyclist's conspicuity *most* of the time.

Table 7: Automotive Headlamps — SAE standard J597C   Comments by John S. Allen

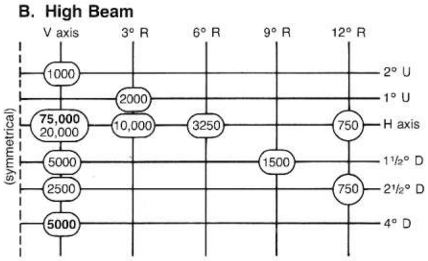
This standard specifies both minimum intensities and maximum (because of glare) intensity limits. Values for maximum limits appear in bold type.

A. Low Beam



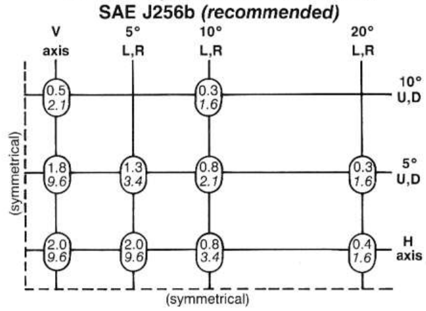
Note: The maximum permissible stray light is 125 cd — comparable to the 120 cd of the bicycle lighting standard — only at more than ten degrees above the horizontal: principally to avoid backscatter. Requirements at lower angles above horizontal are considerably less stringent. Perhaps the more stringent limit for bicycles is partly in order to allow for bicyclists' encountering each other more closely on paths; however, the SAE low beam characteristic is widely criticized among knowledgeable drivers for not providing a sharp enough cutoff at the horizontal. European headlamps are reportedly much better at providing illumination where it is needed while not blinding the oncoming driver; these headlamps are, in fact, imported into the United States in considerable quantities for custom installation, though this is at least moderately illegal.

B. High Beam



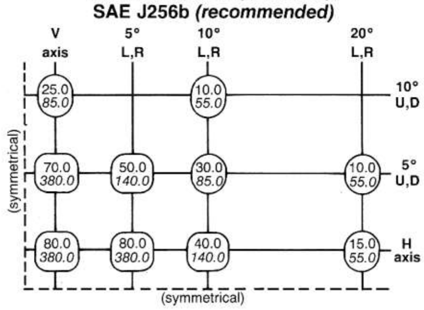
Note: These figures are for single-unit headlamps. Low-beam values for dual-unit headlamps (one unit operating) are the same; some combined high-beam values for dual-unit headlamps (though not the maximum at the center of the beam pattern) are moderately higher. In all cases, these values represent only the headlight or headlights at one side of the car.

Table 8: SAE Taillights, Stop, and Turn Signal Standards Comments by John S. Allen
A. Taillamps SAE J585 (minimum); SAE J256b *(recommended)*



Note: Maximum not to exceed 18 cd anywhere above the horizontal axis. The values given are for one-compartment lamps. For double or triple compartments, slightly lower values are permitted for each compartment.

B. Stop Signals and Rear Red Turn Signals SAE J587, J588 (minimum); SAE J256b *(recommended)*



Note: Maximum intensity shall not exceed 300 cd. Two- and three-compartment lamps need be only slightly brighter together than one-compartment lamps, but the intensity of a stop or turn signal must be five times (in center of beam) or three times (farther from center) as great as that of a taillamp if combined in the same compartment. SAE specifications for yellow turn signals are roughly 1.6 times as bright at all points, but allow a maximum brightness of 750 cd.

Taillamp Construction

A look at the construction of bicycle taillamps clarifies the reasons for variation among them. In order to have a bright center spot, the lamp must have a parabolic mirror behind the bulb and/or a carefully designed focusing lens. The worst of the lamps have neither. A parabolic mirror is preferable to a lens alone, because it saves light that would otherwise be wasted behind the bulb, and because a lens used with it can easily be tailored to spread the beam to place controlled amounts of light at angles away from center.

Generally, the larger the lens area, the better the control over the beam pattern. The tiny 1950 Soubitez lamp's lens is barely larger than the bulb! For the larger lamps, variations in the position and shape of the bulb's filament are of less importance.

The Varta lamp takes a more refined approach to accurate filament placement and precise optical design. It is a sealed bulb-mirror-lens assembly, so alignment is factory-controlled. However, in case the filament fails, a rider needs to carry along an entire lamp (and its built-in retroreflector) except for the fender-mounting bracket, rather than just a spare bulb.

As the tests show, lamps of common commercial design can easily meet the proposed ISO standard; a more refined design can far surpass it and rival standard automotive taillamps, even while consuming only the standard 0.6 watts. The positioning tolerance of lamps and filaments was one of the issues raised by French delegates to the ISO committee; also due to the increasing availability of more efficient halogen cycle bulbs, there is some additional room for improvement in light output even without the higher user cost and inconvenience of sealed-beam assemblies.

The editors wish to express special thanks to Jay Townley and Gene Szymski of Schwinn Bicycle Company for their help reviewing information for this article.

Summary of Additional Requirements of Draft Proposal 6742/1, Bicycle Lighting

(Comments by Fred Delong)

Headlamp and Taillamp Markings:

type of bulb and generator (or battery) for which they are designed, the name or identification of the manufacturer, and the notation "ISO STD. 6742/1."

Generator Markings:

rated voltage and amperage, name of manufacturer, and "ISO STD 6742/1."

Battery Performance:

must conform to IEC Publication 86; for nickel-cadmium batteries, to IEC Publication 285. Headlamp intensity must not fall below 100 candelas when tested with fresh batteries (less than four weeks old) at 20 degrees Centigrade and 60 percent humidity, for a continuous 30-minute period once per day, five days per week, for four weeks (total operating time ten hours).

Generator Performance:

Speed		Voltage, percent of rating	
km/h	mph	min.	max.
5	3.1	50	117
15	9.3	85	117
30	18.6	95	117

Notes: after one hour at 15 km/h, voltage must not fall below 85 percent of rating.

Vibration Test:

one hour at 750 cycles per minute, 3 mm displacement, mounted as on a bicycle. (In each cycle the testing machine raises the lamp mounting bracket 3 mm in roughly 0.03 sec., then releases it to be snapped back down against an anvil by a spring tensioned to 265–310 N (i.e., roughly 60–70 pounds.)

Temperature Tests:

after being "cooked" for two hours at 50–55 degrees C (122–131 degrees F), bulbs must operate at an ambient temperature of 23°C (73°F) for one hour at 117 percent of rated capacity. Generator must comply with the specifications in the table above after two hours at 50–55 C.

Water Spray Test:

six hours, shall function successfully.

Chemical Resistance:

lens must not show any effect beyond slight local surface crazing when wiped with 70 percent n-heptane, 30 percent toluene mixture.

DESIGN

The Evolution of a Hand-Powered Tricycle

Bill Warner and L. Chris Hager with John S. Allen

Editor: Recent developments in human-powered vehicles are of interest not only for their own sake, but also because they create a larger frame of reference for questions about design. The recent HPV issue of Bike Tech *was written with these goals in mind, as is the following article on hand-powered tricycles.*

Side view of the Trike 324.

Christopher Harting

Tricycle design has always been a combination of technology and black art. Designing a practical tricycle powered by arms alone is an even trickier business. This article will detail some of the technical issues that one faces in bringing fast, fun, safe cycling to a group new to the sport — the physically handicapped. With a good hand-powered tricycle, persons who used to settle for wheelchairs can enjoy cycling at speeds comparable to casual cyclists.

Even in the early days of cycling, the advantages of hand power were apparent. U.S. Patent Office files are brimming with crank-driven wheelchairs, hand-powered machines, hand- and foot-powered machines, and others which defy description. We also have photos of hand-powered trikes from many third-world countries, where transportation is dominated by the bicycle, and the superiority of a trike over a wheelchair can make the difference between mobility and isolation.

A good trike needs three qualities: good steering, good brakes, and good gears. What's more, the machine must be designed to meet the special needs of its rider by providing the right seating position, good handling, a stiff, efficient frame, and reasonable cost. Over the past few years, New England Handcycles has evolved a design which has proved successful in production, and in use by people with a wide variety of handicaps.

The Trike 324

Our "324" tricycle (three wheels, 24 speeds) is a sports, recreation, and transportation machine designed to provide speed and mobility similar to a regular bicycle, but is powered by arms alone. It has two 27-inch aluminum rims at the rear, and a 20-inch BMX aluminum rim at the front. Using standard bicycle derailleurs, its two-stage drive system provides 24 speeds. A Sturmey-Archer drum brake on the front wheel provides good braking in all weather conditions. Steering, pedaling, and braking are all done by hand without letting go of the crank handles.

The riding position is similar to that of a more upright foot-powered recumbent bicycle or tricycle, and the large seat is much akin to the seat on many recumbents. For riders who use crutches, a bracket is provided to hold the crutches during riding. For those who use a wheelchair, the trike's seat height can be adjusted to make transferring from the chair to the trike easy.

The design evolved from a 15-speed trike purchased from Dan Gould of Missoula, Montana. Starting with a 100-pound prototype designed by a local paraplegic named Ron Grisamer, Gould constructed a practical trike, and went on to refine the design in chrome-moly steel. I (Bill Warner) rode over 1,000 miles on Gould's machine, and came to realize that it needed a number of further improvements.

Evolutionary design is best when there is good communication of design ideas, something that has not been common with hand-powered trikes. Today's designs are generally basement-shop models which often repeat mistakes painfully well-understood by others who have been there before. The following is an overview of the issues a trike designer faces, and the solutions found by New England Handcycles.

The Major Design Issues

Steering and Stability — To be safe and fun, the trike must be easy to control. Most hand-powered trikes built in the past have suffered from a serious flaw in steering geometry — we call it the "tiller effect." Since most designers use a conventional head tube angle close to vertical, the hand pedals usually end up *behind* the steering axis (see drawing). This seems innocent enough, but in fact introduces a very dangerous positive feedback that leads to instability.

Since centrifugal force tends to make the rider lean to the outside of a turn, he will actually end up moving the tiller *farther to the outside* if he leans on it in an effort to steady himself. This will sharpen the turn and easily flip the trike.

The solution is to put the pedals *forward* of the steering axis. Then *negative* feedback leads to excellent stability. (Dropped handlebars of a conventional bicycle are ahead of the steering axis, achieving the same effect. However, much of the reason why is different — and it is instructive as an aspect of bicycle design that you can't take for granted when you move to three wheels. Because a bicycle leans in turns, its cornering forces are mostly "downward" within the plane of the bicycle. Centrifugal force on the handlebars is minimal. But when a bicycle rider leans forward on conventional bars, the rider's weight does help hold the bars in the straight-forward direction.)

Cranking and Steering Interaction — Since cranking and steering are done with the same mechanism, some interaction between the two is inevitable. This is kept to a minimum by using a short crank spindle. Again, placement of the cranks forward of the steering axis is important, since this allows the rider to apply a *side force* on the crank assembly to counteract the *rotational* steering forces which result from hand cranking. As the rider becomes more adept, this compensation becomes automatic, and wobble disappears.

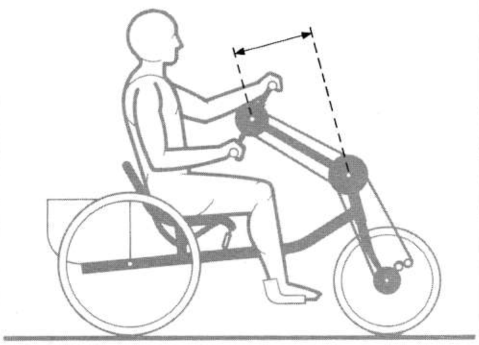
Fork Rake — Fork rake has a dramatic effect on stability, but with a trade-off between low and high speeds.

At low speeds, too little rake will give the steering assembly a strong tendency to flop sideways, because such a motion will allow the frame to descend. For neutral steering the frame must stay at a constant height.

But high-speed stability requires some amount of trail (i.e., the wheel's contact with the ground must trail behind the steering axis' intersection with the ground) so that "castering" behavior will help keep the wheel pointed straight; and trail always requires a rake less than that for neutral steering, and consequently makes the steering tend to flop sideways.

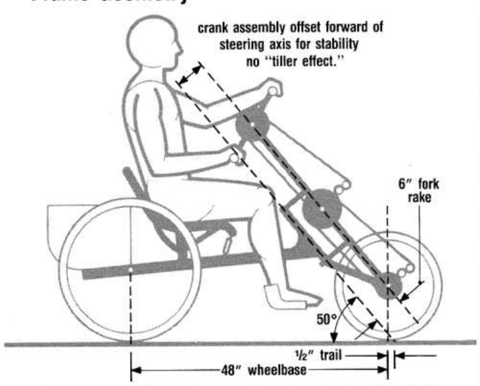
In the Trike 324 we chose a rake (six inches) that creates about 1/2-inch of trail.

Centering Spring — A centering spring stabilizes the steering at low speeds, since the 1/2-inch of trail and the weight of the steering assembly do cause some tendency for the wheel to flop sideways. This would



The tiller effect. When the crank assembly is behind the steering axis, it swings toward the outside in a turn, and any weight applied to it causes oversteering.

Frame Geometry



George Retseck

be no problem in a bicycle, but the trike steering must occasionally hold itself straight "no hands" at low speeds, for the rider to turn the rear wheels by hand, wheelchair fashion (to back up, or to climb a very steep slope where the front wheel's traction is reduced).

The spring pulls rearward on a pair of chains, attached to either side of the fork crown, so that whichever side swings forward encounters the tension of the spring. This arrangement concentrates the centering effect when the wheel is near center, and provides little resistance when the wheel is moved beyond about 45 degrees, so that the rider doesn't have to fight a spring to make sharp turns.

Frame Rigidity — Any flex in the power transmission system means that some of the rider's energy that is put in never gets to the drive wheel. On a hand-powered trike this problem is complicated by the need for the pedals to move from side to side for steering. A good design provides rigidity, either through tubes with a large cross section, or by triangulation. However rigidity is provided, it is a crucial quality that many early trikes lacked. The Trike 324's main tube is of 6061-T6 aluminum, 2-inch O.D. and .063-inch wall thickness; and the highly stressed front fork assembly is triangulated for stiffness.

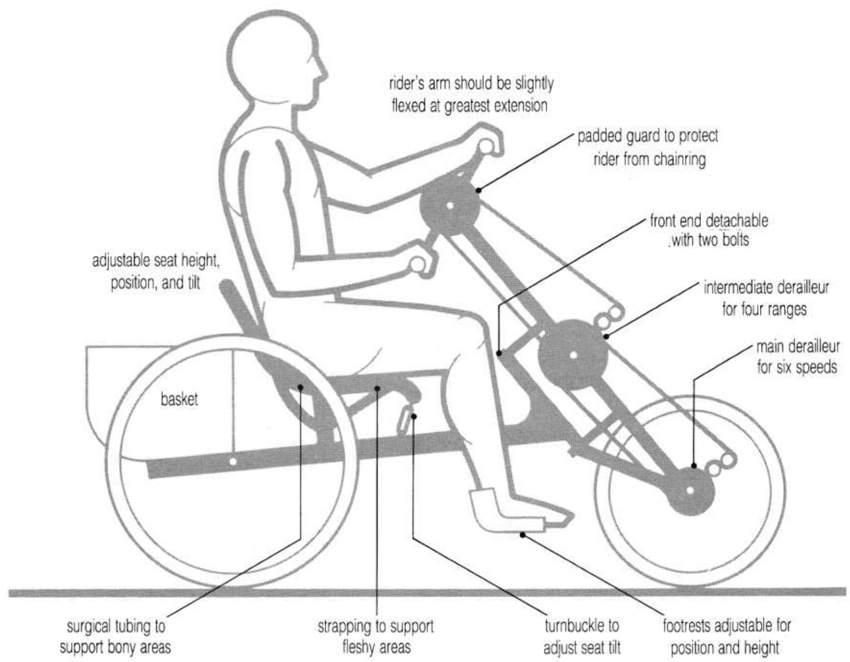
Seating — A good seat for a hand-powered trike must distribute pressure evenly, because a handicapped rider often lacks the large muscles that do this cushioning in an able-bodied person. A hard plastic seat just won't do, and vinyl or other cushioned seats do not allow proper air circulation. The Trike 324 uses nylon webbing to provide a lightweight, breathable surface for the more fleshy parts of the rider, and stretched gum-rubber surgical tubing below the rider's bony areas to distribute pressure and provide some shock absorption.

Rider Position — The rider should be high enough for good visibility, and should not have to lean forward when pedaling. Riders who have poor sitting balance find that tilting the seat back is helpful. By moving the seat forward, the proper rider-to-cranks positioning can be maintained.

Gearing — With the limited power of arms, gearing is crucial. Gears on the Trike 324 range from 10 to 75 inches. The two-stage gearing uses two rear derailleurs. A single chainwheel at the handcranks drives an intermediate freewheel whose pawls are removed. The innermost cog drives a second chain which runs to the front wheel and its derailleur. SunTour freewheels with 38-tooth cogs give the necessary wide gear range. The two-stage drive eliminates the need for a long, floppy chain, and the two gear clusters eliminate multiple chainrings near the rider's face, a potentially saw-blade-like hazard. The Trike 324 includes a cushioned bumper around the small single chainring to provide additional crash protection.

Braking — The Trike 324 uses a unique backpedaling braking system developed by Dan Gould and Art Anderson, also of Missoula, Montana. Since the chains run through derailleurs, a normal coaster brake is not workable, and a different means of activating the brake is used.

Miscellaneous Design Features



The system uses a cam and cam-follower arrangement coupled to the crank spindle by a roller clutch. When the rider backpedals, the roller clutch engages, rotating the cam backwards. The follower rides up, tensioning the brake cable. The cam limits the maximum cable tension. The brake can be released by backpedaling beyond this peak of the cam, at which point the cam snaps back to the rest position. This last maneuver is needed if the rider stops with the brake on — he can't pedal forward (the brake is on!), so the only way to release the brake is to back-pedal. To offer a large leeway between applying the brake and releasing it, the cam maintains its maximum height for a "plateau" extending through an angle of 100 degrees before it drops back to the released portion.

The brake can be left on, useful as a parking brake when getting on and off the trike. As an additional benefit, the brake goes on when the trike rolls backward. (There is a release for backing up.)

An independent caliper brake, operated by a lever on the steering column, is provided for additional safety.

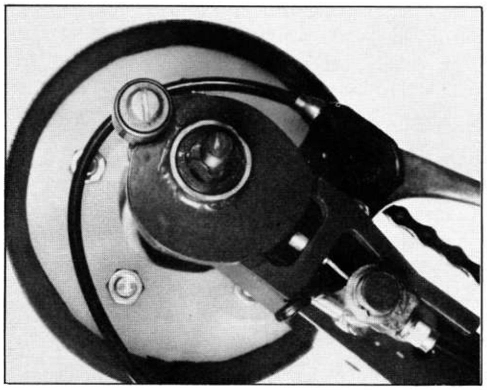
Most high-performance foot-powered tricycles, like the Trike 324, have two brakes on the front wheel. On a trike, skidding the front wheel does not precipitate a fall, as on a bicycle; furthermore, weight transfer during hard braking is such that rear brakes would contribute little. For these reasons, the added difficulty and expense of mounting two rear brakes and equalizing their power is not justified.

Frame Materials and Construction — Our earlier trikes were made from brazed steel. The new machines use an all-aluminum frame of TIG-welded 6061-T6 aluminum, achieving a ten-pound weight reduction. After welding, the entire frame is heat-treated to relieve stress and return the material to its rated tensile strength.

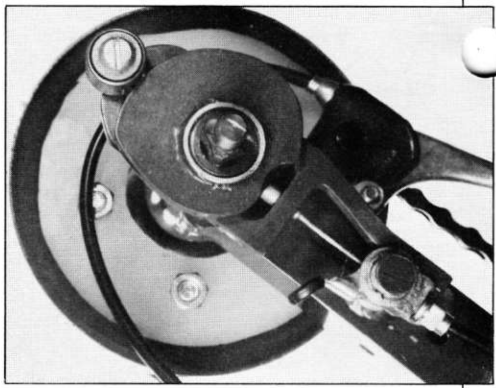
TIG welding is an expensive cross between industrial technique and black art. It takes 15 hours to weld the present frame; much of this time with torch in hand, the rest repositioning pieces of the frame in jigs as it is built up. A custom jig might cut the time down somewhat, but we have taken another approach to cutting manufacturing costs: we are prototyping a trike with tubes epoxied into cast aluminum lugs. We will be able to use tubes made of stronger, non-weldable aluminum alloys, achieving either an increase in frame strength or a weight reduction despite the additional weight of the lugs; we may add design improvements at the same time.

Ease of Assembly — The front end of the trike is designed as a self-contained module, with no cables to connect to the main frame. Since all setup and adjustment of drivetrain, steering, and brakes is done at the factory, the owner simply has to put a few pieces together and start riding. The only parts which need be added are the front end, seat, footrests, rear wheels, and basket. These all bolt on simply; no adjustments are needed. The buyers of our trikes often have had no contact with bikes, so the ease of assembly is welcome.

Flat Tire Repair — Tire repair can be more difficult for a handicapped person, so Mr. Tuffy® tire protector strips are used to prevent penetration of puncturing objects to the tubes. A pump and patch kit can be carried, however, and it is possible to ride the trike a short distance on a flat tire.



Brake cam in rest position. When the crank spindle is rotating forward, the cam rests in a detent. (One crank has been removed for clarity.)



Brake cam in operation. Backpedaling engages the roller clutch, which rotates the cam and causes the follower to pull the brake cable. The maximum braking motion is reached at about 90 degrees of backpedaling; the braking tension then remains constant for the next 100 degrees.

Sheldon Brown

Rider Performance

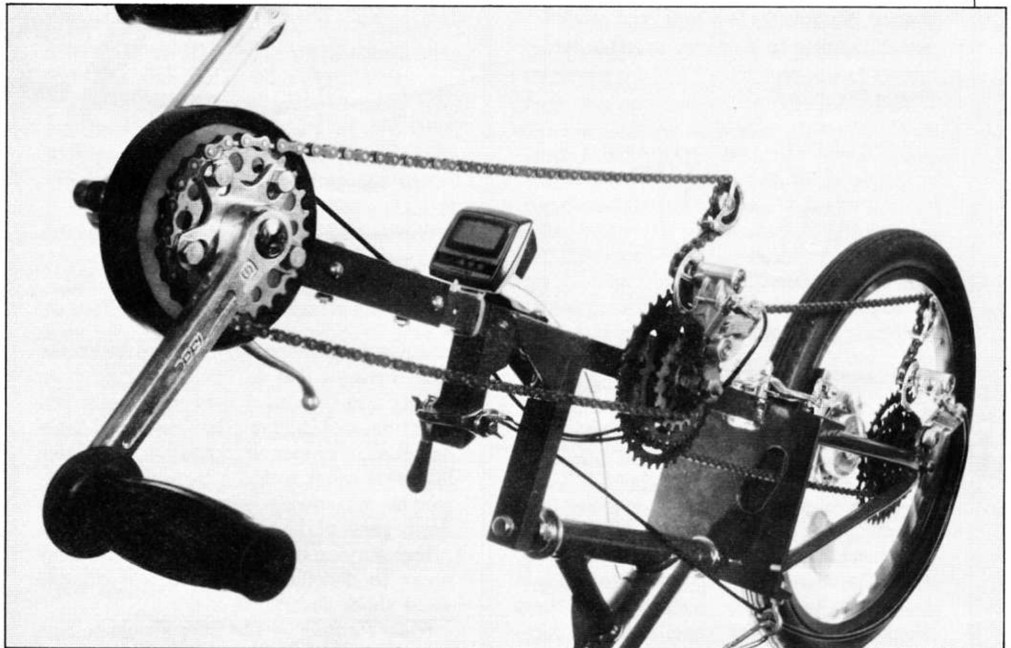
Trike riders maintain a cadence similar to cyclists — about 70 to 90 rpm. A triker can peak at about 180 rpm in a sprint!

Rory McCarthy of Bath, Maine, rode his handcycle in the Pepsi Challenge held last year in Central Park in New York, and ticked off 155 miles in 19 hours of riding. The crowd was amazed at his performance; Rory got more cheers than former Olympian John Howard, who did 475 miles. Rory will be back this year to break 200 miles.

Another determined triker, Charlie Pugh of Chocorua, New Hampshire, rode his trike from his home to Boston, 121 miles away, in one day, averaging over 9 mph on the difficult, hilly terrain.

Bill Warner rode his trike in the Boston Marathon, completing the 26-mile course in 2:07. Bill also completed a recent 10K race in 28:31, averaging over 13 mph.

A typical rider on a handcycle can sprint to 18-21 mph, grit his teeth and average 12 mph on level ground, and relax at 8-10 mph for touring. Downhill, wind resistance holds the trike to 35 mph, though stability is not a problem even at this speed.



The front end of the Trike 324, showing the two-stage drive. Also note the drum and caliper brakes, auxiliary brake lever, and centering spring chain. The Cat-Eye cyclometer is optional.

Trikes of the Future

Future trikes will add some important innovations. Many of our riders can't use crutches, and depend entirely on their wheelchair for indoor mobility. (Try taking the trike into a bathroom!) But it's inefficient to bring a wheelchair along when going for a ride on the trike — it's 40 pounds of extra weight!

The solution is a "split-apart" trike, which converts to a wheelchair. On a trike, the rider should be forward of the rear wheels to provide front-wheel traction. In the wheelchair mode, the rider has to be just about even with the rear wheels to get proper power input, and to keep the overall length reasonable. Thus a good trike/wheelchair combination would need a mechanism to change the rider position in the different modes.

Trike add-ons have been made for wheelchairs, but they seldom work well; some have tiller steering, some have mushy frames, and at best they have too little traction on the front wheel, since the rider position is dictated by the wheelchair, not by the trike add-on. This marriage of trike and wheelchair is a challenging design problem that we are actively working on.

Finally, many people need hand and foot power on the same trike. Single amputees, for example, have one good, powerful leg that simply goes along for the ride on the Trike 324. A trike with dual power would reach a much broader market than the arms-only version. What's more, if the machine were designed in a modular fashion, a whole line of trikes — hand-powered, foot-powered, and hand/foot-powered — could be based on one frame design, cutting costs, and broadening the market.

We're looking for good design feedback, and *low cost* approaches to make the trikes of the future practical today.

Bill Warner
L. Chris Hager
New England Handcycles, Inc.
228 Winchester St.
Brookline, MA. 02146
617/277-3035

Arms Race

There will be a special category for arm-powered racers at the IHPVA's Human Powered Speed Championships this year. The championships will be held in Indianapolis from September 30 to October 2, 1983. For more information on this event, contact Bill Warner, 228 Winchester St., Brookline, MA 02146, 617/277-3035, or the Indiana chapter of the International Human Powered Vehicle Association, 340 Ripple Rd., Indianapolis, IN 46208.

Trike 324 Specifications

Head tube angle	50 degrees	Helps bring cranks to rider.
Effective fork rake Trail	6 inches 1/2-inch	Neutral steering.
Crank bracket offset	6 inches	Provides negative cornering feedback; also allows rider to compensate for power input/steering interaction. Pedal position forward of steering axis is crucial.
Wheelbase	50 inches	Short wheelbase is desirable for maneuverability.
Track	28 inches	Designed to fit through most doorways. Wide enough for good stability.
Weight	44 pounds	Basket adds 5 pounds.
Frame material	6061 T-6 aluminum heat treated	TIG welded; full stress relief, then heat treating.
Front freewheel	14,17,21,26,32,38	Provides six speeds.
Intermediate freewheel	14,20,28,38	Provides four ranges.
Chainring	25 t Regina	9.7 to 71.4-inch overall gear range.
Intermediate chainring	28 tooth	
Derailleurs	SunTour VGT	Handle 38-tooth cogs.
Rear rims	Weinmann concave	Strong rims needed for side loads.
Front rim	Araya aluminum	20 × 1.75
Main brake	Sturmey-Archer internal drum	Provides excellent braking in all weather conditions.
Brake control	roller clutch activates cam/follower system	Works by backpedaling.
Emergency brake	Weinmann caliper	Emergency brake is totally independent of main brake.
Paint	Dupont Imron Metallic	
Seat adjustments	7 inches height 7 inches front/back 25 degrees tilt	Good rider position is very important for power input and comfort. Accommodates riders 4 foot 6 to 6 foot 6 inches.
Cruising speed	8-12 mph	Comparable to a casual cyclist.
Sprint speed	15-21 mph	
Maximum speed	35 mph	
Cruising range	40+ miles	
Price	$1900	Less than many custom bicycles, and for a considerably more complex machine. Future price reductions are anticipated, with more efficient manufacturing techniques.

SHOP TALK

Odd Tire Sizes and Compatibilities

John S. Allen

One interesting outcome of a worldwide comparison of tire sizes is that despite different markings, several tire sizes are accidentally compatible with sizes from different countries — either identical, or so close as to lie within normal manufacturing tolerances. This article may help if you must replace tires on a bicycle which has wheels of an unusual size.

When using tires that might be slightly off-size, make substitutions carefully. If a tire is a millimeter or two oversize it will tend to pull out from the rim at one or more spots; if it is undersize, it will tend to pull in. Try more than one tire if necessary, to take advantage of sample-to-sample variation.

In Table 1, the sizes on the left are the ones less obtainable in the United States.

Among the tires listed in the left column, the American sizes are obsolete; yet you will still sometimes find a Columbia bicycle from the 1950s or earlier equipped with rims in one of these sizes. Since these are hook bead rims (like the current 1.75- and 2.125-inch rims), you must make sure the overhanging edges are not sharp enough to cut the 1¼-inch tires, which are made for straight-side rims. If there is a problem, you may have to fill the rim flanges with silicone seal.

The Swedish sizes are very slightly different from the equivalent British sizes. Since they are marked the same, this substitution has probably been made unawares many times.

The Dutch sizes are part of Holland's sensible ordering of sizes but unavailable in the United States; these sizes just happen to be close to some of the French sizes stocked by Mel Pinto, Inc. The Dutch sizes sometimes carry French markings, so this substitution too may have been made unawares. A look at a recent Vredestein-Paragon tire catalog suggests that these sizes may in fact have been merged with the French sizes.

The compatibility which is probably most useful to an American mechanic is between the British 24 × 1⅜ and the French 600A. These are so close as to be the same size for all practical purposes. Yet this fact is largely unrecognized, because of the different markings.

Strange Swedish and German Sizes

In my listing of national tire size groups in *Bike Tech,* February 1983, I mentioned that I left out a few sizes because they didn't fit the pattern. Some are given in Table 1, indicated with an asterisk. The remaining ones of which I am aware are shown in Table 2.

The smallest, wheelchair front wheel sizes are common, but the others are the ones American mechanics will have the most trouble replacing. These sizes are probably the survivors of entire systems of sizes established by various manufacturers in the early days of bicycling. The tides of international trade and the rises and falls in bicycling's popularity probably drove many tire size systems to extinction, except for sizes which had been unusually popular or served a special need. Two examples are the sizes common on wheelchairs, and the fat Swedish sizes for heavy-duty cargo tricycles.

The process through which some tire sizes survive and others disappear is remarkably like that of Darwinian evolution of species, because it responds to similar pressures.

In addition to these odd *sizes* of the familiar beaded types of tires, there are also entirely different *types* of tires which are rare or extinct — for example, the genuine clincher tire, with a wide, wireless bead that hooked under the rim flange. These may still be in use in Japan: their dimensions are listed in the Japanese bicycle industry handbook, if you need to know about them.

Same Markings, Different Sizes

Another outcome of these evolutionary

Table 1: Accidentally Compatible Sizes

Rare or Obsolete Size				More Common Size		
Swedish	27 × 1¼*	(32-631)	and	British	27 × 1¼	(30-630)
Swedish	28 × 1⅝*	(44-623)	and	700C or	28 × 1¾	(47-622)
American	26 × 1.375*	(32-599)	and	British	26 × 1¼	(32-597)
Swedish	26 × 1½*	(40-585)	and	650B or	26 × 1½	(40-584)
American	24 × 1.375*	(37-548)	and	British	24 × 1¼	(32-546)
French	600A	(37-541)	and	British	24 × 1⅜	(37-540)
Dutch	22 × 1⅜	(37-489)	and	French	550A	(37-490)
Dutch	22 × 1½	(40-482)	and	French	550B	(40-484)
Dutch	20 × 1⅜	(37-438)	and	French	500A	(37-440)
Dutch	16 × 1⅜	(37-339)	and	French	400A	(37-340)
Dutch	16 × 1⅜	(37-339)	and	German	16 × 1⅜A*	(37-337)
Dutch	14 × 1⅜	(37-286)	and	French	350A	(37-288)

Note: Numbers in parentheses are the size designations used by the European Tire and Rim Technical Organization (ETRTO) and adopted by the International Standards Organization (ISO). The smaller number is the overall width of the tire's cross-section (in millimeters) and the larger is the diameter (in millimeters) of the bead seat: the shoulder where the edge of the tire sits inside the rim (which should be the same as the inside diameter of the innermost part — the bead — of the tire.) These numbers allow direct comparison of tire-rim compatibility, unlike nominal sizes which require one to know the height of the tire.

Table 2: Odd, Noncompatible Sizes

American	27 × 1½	(40-607)
Swedish	26 × 2.25	(62-561)
Japanese	25 × 1⅜	(37-655)
Swedish	24 × 1½	(40-531)
Swedish	24 × 2	(50-503)
German	22 × 1⅜	(32-498),
Swedish	22 × 1⅜ × 1¼	
Swedish	20 × 2	(54-428),
Italian	20 × 1⅝ × 1½	
Swedish	17 × 1¼	(32-357)
French	315 × 55T	(57-251)
Dutch	11 × 1¾	(47-222),
Italian	11 × 1¾	
Swedish(?)	10 × 1⅝	(44-194),
Italian	10 × 1¼	
German	8 × 1¼	(32-135)
Dutch	8½ × 2	(54-110)
German	7 × 1¾	(47-93)

processes is that different sizes often carry the same markings. So watch out! Only the recent ISO two-part markings (such as 37-590) are ultimately to be trusted.

North American bicyclists and mechanics should be especially aware of the problem with Schwinn 24 × 1⅜ and 26 × 1⅜-inch (37-546 and 37-597) tires: these have a larger bead seat diameter than British tires with the same inch markings. Probably thousands of bicyclists have ruined British 26 × 1⅜-inch (37-590) tires trying to get them onto Schwinn rims!

What is less well known is that the Schwinn bead seat is the same as for the British 1¼-inch size. This compatibility is useful: for example, some bikes such as the Univega Nuovo Sport 20 and the Fuji S-10-S in their smallest frame sizes are equipped with 26 × 1¼-inch (32-597) tires. For riding on bad surfaces or if a 26 × 1¼ tire is unavailable for emergency replacement, a Schwinn 26 × 1⅜ will fit.

Schwinn 24 × 1⅜-inch tires are common on wheelchairs, with nice Weinmann aluminum 24 × 1¼ rims. On the Fuji Junior 24 × 1¼-inch (32-546) tires are used, and they are distributed by Fuji. Aluminum rims in this size have been only sporadically available from bicycle parts distributors in North America, but if you're willing to go to the trouble of ordering rims from a wheelchair supplier, you can put together nice wheels for small riders. Often, perfectly good used rims are available; the spokes give out first on wheelchairs, and few wheelchair dealers rebuild wheels.

LETTERS

S & M Seats, and Other Design Questions

Time to renew, eh? That I'll do happily! *Bike Tech* is all I had wished for, and shows commendable signs of becoming even more. I've used many items you've published in my daily work. Got a few things on my mind:

If, as is claimed by David Gordon Wilson (*Bike Tech*, December 1982, page 5), champion riders never pull upward on their toe straps, then how come we must endure rock-hard "S&M" seats that "prevent power loss?" I've never seen any proof whatever that comfortable seats steal power, but I hear folks say that all the time. If softer seats do steal power, I'd appreciate a well-reasoned argument as to how this loss occurs. I feel that this is a serious matter, as lots of the letters to the medical departments of bike mags seem to be aimed at problems caused by inadequate seating. My own mountain bike has a Kashimax seat which is (I'm told) a "real power stealer," but I sure don't feel robbed, and my humble tail is in better fettle than it has been in years. In such matters, I think it is very important to separate the needs of the typical recreational or commuter bikers from those of the racers, just as one does not speak of Indy car seats in your family sedan or even sporty car. It is my opinion that one reason more folks don't use bikes for serious transportation is because the seats are so uncomfortable. The same goes for the hand and wrist positions leading to numbness. By now this problem should have been worked out, as it has been in so many other fields of endeavour.

In articles concerning the "power" input to a bike by the rider, I'd greatly appreciate the discussion utilizing the terms commonly used by engineers in other areas. That is, a distinction between horsepower and torque. It seems to me (from many years of auto racing) that much confusion arises from this lack of distinction. The Wilson article mentioned is a prime example. Gears adjust your torque curve. It's different for a bike than for a car, for the bike's "motor" can deliver great torque at dead stall if the pedals are horizontal. In any case "power" isn't a very useful term. I'm sure that Wilson knows this, and I'd like to see his comments on this matter with respect to gearing, crank length, cadence, and oxygen efficiency, or whatever else makes sense.

As a recent convert to mountain bikes (well, I did ride lots of klunkers as a kid in the woods in New Jersey) (yes, New Jersey has woods) I have felt a great need for a chain case. From what I can read, the main reason chain cases have not been popular in this country is because they have a wimpy *image!* From riding my old Humber for 16 years commuting and not once having to deal with the chain other than to oil it (66,000 miles!) I can attest to their effectiveness. Yes, that particular chain case is rattly and heavy, but a Kevlar one wouldn't be! Nor would a molded ABS job. For mountain bikes ridden in mud or sandy terrain, it would be a boon to have those delicacies covered up. And from road experience, I'd usually be happy to pay the price of a few ounces for the protection. On Cape Cod, for instance, one trip through one salt-sand puddle after a rain means lots of nitty and truly gritty maintenance. It becomes a *ritual,* and this means that Human is no longer in charge of the Machine, but quite the opposite. I see a lucrative business possibility here.

". . . lots of nitty and gritty maintenance . . . becomes a *ritual,* and this means that Human is no longer in charge of the Machine, but quite the opposite."

The Deal automatic transmission would need a case, too. Don't sneer at this tranny; I've ridden the prototype, and for all but racing it is quite nice. The only thing it doesn't do well is to respond from highest gear when asked to "sprint". Very few street bikes are asked to sprint. For commuter riding it's a wonder! In a case, it would be maintenance-free. Oh boy! I realize that the hardcore racers will poop upon it despite the laughable derailleur systems used for so long, but the Deal device is the wave of the future, you just wait and see! (I'm assuming that the production model will be well made and detailed. If it isn't, then someone else will have to do it. But the days of the fussy, fragile, slow-shifting derailleur are coming to an end, I think.) Oh, not tomorrow, but soon enough. I mean, isn't the SA 5 speed hub nice in the city? Think of not having to shift at all!

The mountain bikes are seen more and more around here used as city bikes. I've accosted many riders to see why they prefer them. The answer is always the same: "They stand up to city streets," and "I don't have to watch the road as much." I quite agree, and add that when touring, the wonderful roadholding makes scenery easier to enjoy and at the same time reduces "shoulder fear". On Cape Cod, for instance, a trip onto the sandy shoulder (often to escape deliberate auto harrassment) with a standard skinny-tired bike will likely result in a header. With a mountain bike, you just blast along as usual. Ours are Univega, a sort of Cafe Racer type mountain bike, but very fine in most ways, especially at about half the price of a Fisher or Breeze model. I and virtually everyone to whom I've lent the bike agree that it is *so* much more pleasant to ride than the usual machine. Many have already traded in their standard bikes, despite the high price at this time of real mountain bikes. (By "real" I mean under 30 pounds, ready for the road. Ours are 25). The Univega needs a lower granny and will get one soon. And a chain case, too. *Lah* dee Dah!

Thats all folks. Keep up the good work! Test a Deal tranny soon! I'm still working on that commuter bike, too. I'll keep you posted.

Jay Baldwin
Soft-Tech Editor, *CoEvolution Quarterly*
Sausalito, California

Tilt!

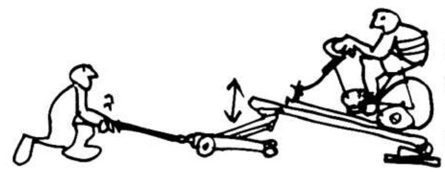
It is surprising that, in the discussion of hill climbing in the December 1982 issue, neither Wilson nor Miller considered the effect the grade has on the rider's position relative to the bike and to gravity.

It may be that standing is in part an attempt to reestablish the normal relationship between the rider's center of gravity and the crank axis, and that, since it is difficult to spin for any length of time standing, it is not worth providing any gears low enough to do so.

Also, the rider may be trying to restore the balance that is lost as his or her weight moves farther over the rear wheel. Friends who ride Mount Washington tell me that the front wheel often leaves the ground on the steeper sections. It's ironic that the very qualities considered desirable in a frame for climbing will aggravate this problem!

It would be interesting to try a bike built to maintain the rider in a level position on a steep grade, by means of a small front wheel and extended rear triangle or whatever, to see if the rider would still be more comfortable standing.

An easier line of experimentation would be to mount a load-applying training bike of some kind on a hinged plane which could be raised or lowered (by a garage jack under the free end, for instance) to see how the rider would adapt, and how the output would be affected.



Steven Lindblom

All this would seem basic enough that I wonder: has someone already done it?

Steven Lindblom
Henniker, New Hampshire

Pedaling Rate and Muscle Chemistry

The sidebar to the David Gordon Wilson article ("The Performance of Machines and Riders on Hills") in the December 1982 issue raised the question of why skilled cyclists normally (i.e., not on hills) pedaled at much higher rpms than would be expected from the peak efficiency point. While (to my knowledge) no experiments have been done to address this question directly, there is much existing evidence which suggests some answers to this question.

There seem to be two primary mechanisms that can be deduced. One involves the blend of fuels required by the muscle tissue to produce the necessary tension. Glycogen is increasingly demanded in preference to fatty acids as the tension required increases. When it is depleted, the muscle is relatively unable to utilize "pure" fatty acid to generate tension (this is the condition known as "the bonk"). Further, the amount of oxygen required to oxidize fatty acids to produce each unit of ATP is greater than that for glycogen. Thus if efficiency is determined by power and oxygen uptake measurements, there will be a bias toward glycogen utilization.

The other mechanism involves fiber recruitment within the overall muscle. That is, slow-twitch, fast-twitch fatigable, and fast-twitch fatigue-resistant fibers deplete their glycogen supplies at different rates. Near-maximal tensions require fibers from each of these populations to contribute to the overall tension developed. The fast-twitch fatigable fibers are unable to supply the required tension for very long, since these fibers will deplete their glycogen at the highest rate.

The circulatory congestion resulting from high-thrust, low-rpm pedaling may of course also contribute to fuel or oxygen deficiencies, or to local acidosis as lactic acid accumulates.

Perhaps these factors will help explain why cyclists are well advised to maintain high pedal rpms. One of the latest compilations of muscle experiments is: *Human Muscle Fatigue: Physiological Mechanisms,* Ruth Porter, Julie Whelan, editors, Ciba Foundation Symposium 82, Pitman Medical, London (1981).

Frank P. Miles
Ann Arbor, Michigan

Let Us Hear

We'd like *Bike Tech* to serve as an information exchange — a specific place where bicycle investigators can follow each other's discoveries. We think an active network served by a focused newsletter can stimulate the field of bicycle science considerably.

To serve this function we need to hear from people who've discovered things. We know some of you already; in fact some of you wrote articles in this issue. But there's always room for more — if you have done research, or plan to do some, that you want to share with the bicycle technical community, please get in touch.