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# BIKE TECH

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PHYSIOLOGY

# FUNDAMENTALS OF THE NEW TRAINING

## by Peter Van Handel, Ph.D.

In many sports, equipment may play a pivotal role in competition. In bicycling, however, training makes an equal contribution to performance, in spite of American cyclists' tendency to endlessly debate the merits of different equipment. National caliber masters racer Bob Zelly once endured such a debate, with the participants suggesting a long stream of equipment improvements for a struggling category 4 racer. Finally, fed up, Zelly ended the discussion by emphatically declaring, "The problem with him is that he just doesn't put enough pressure on the pedals!"

The way you learn to "put enough pressure on the pedals," of course, is by stressing your appropriate physiological systems involved in nutrient intake and delivery, energy production, and waste removal in order to cause your body to adapt. That adaption allows these functions to respond faster and operate at higher levels. Zeroing in on your weaknesses and accurately determining and performing appropriate types and levels of stress is really what elite-level training is all about.

Unfortunately for many athletes, training is a hit-or-miss situation. There is no long-term plan identifying competition "peaks" or off-season "valleys," no organization to the pattern of training and, perhaps most important, no concept of what training is to accomplish or how it is to be conducted. Two basic principles should underlie the development of anyone's individualized training program: PERIODIZATION and SPECIFICITY.

Periodization refers to the long-term plan of training, taper, competition, and rest that athletes follow through their career. Major and minor competition goals are identified, as are testing dates and off-season recuperation periods. The resulting schedule is individual in nature and provides the framework for assigning daily training workloads. The key is to vary the three basic components of daily training, *intensity, frequency,* and *duration,* in such a way that the athlete's physiological systems reach optimal levels of performance in time for major competitive events.

Achieving the optimal levels of training stress, while at the same time providing both the quality rest needed to continue training and the recuperation necessary to prevent injuries from overstress, requires careful consideration of the second basic principle of training, specificity.

Specificity means that although any training will produce physiological adaptations, it will not necessarily produce improvements in performance. Bettered performance requires *quality* training, training that is designed specifically to meet the athlete's competitive

## IN THIS ISSUE



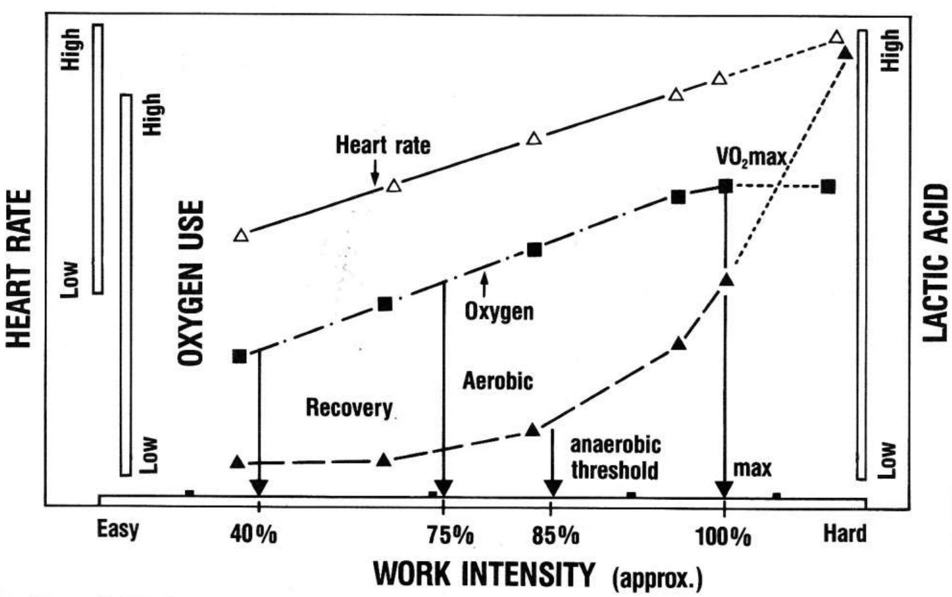


**Figure 1: Heart rate, oxygen use, and blood lactic acid responses to various work intensities. Note the four training paces.**

goals and to overcome any weaknesses (sprinting power vs. pursuiting strength vs. road racing endurance, for example). Specificity can optimize training time, minimize negative aspects such as overstress and injury, and maximize gains in strength, endurance, and power.

When it comes to establishing the specificity of their individual training program, the problem for many cyclists is the unavailability of qualified coaching and, perhaps most important, an accurate means of determining the physiological baseline measurements needed to accurately individualize and monitor a training regimen.

## Physiological Testing

Laboratory and field studies on the physiological responses to work have been conducted on many sports, including running, swimming, rowing, skiing, and cycling. These studies have described the relationship of physiological measures such as heart rate, oxygen use, and blood lactic acid accumulation to intensity of effort. In addition, they have generally quantified the maximal capacities of those measures that are required for competitive success at various levels.

An example of physiological data obtained from a typical test is shown in Figure 1. Note the general pattern of increases in the physiological variables measured, especially at the point where maximal aerobic capacity ($VO_2$-max) occurs. Strictly speaking, the principles of periodization and specificity require that laboratory tests such as this be conducted at key points throughout the competitive year; that the mode of testing be appropriate to the sport (runners should run on a treadmill, cyclists should ride an ergometer, etc.); and, that the data be used to identify weaknesses in physiological function so that recommendations on training can be made.

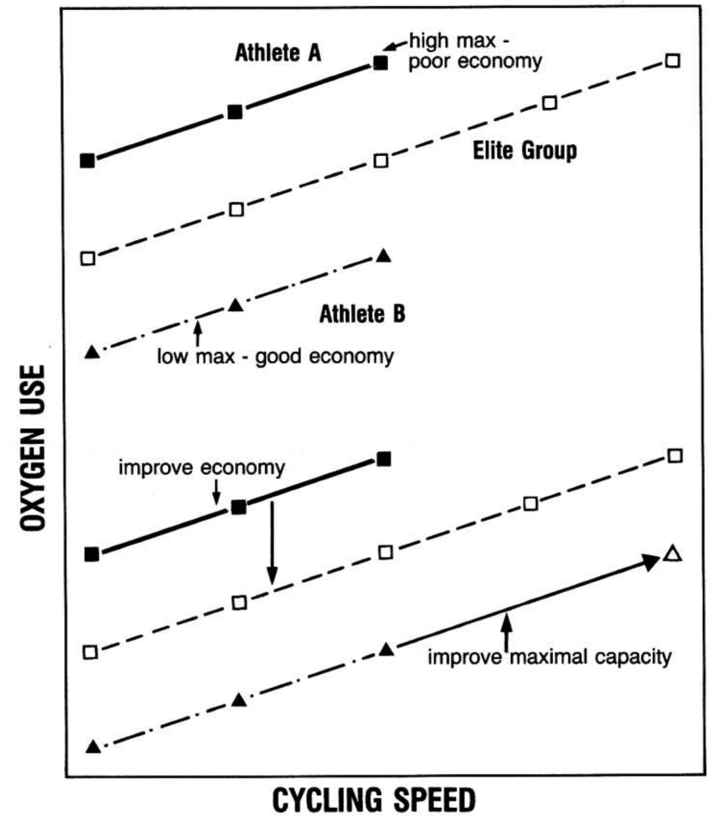


**Figure 2: Comparison of oxygen economy to an elite group for two athletes with different weaknesses. Cyclist A, with a high $VO^2$max, should improve economy. Cyclist B, who already enjoys good oxygen-use economy, should improve $VO^2$max.**

## Targets for Improvement

An example of identifying "weaknesses" is illustrated in Figure 2. In the upper panel, oxygen use for two junior cyclists is compared to the group average of the National Road Team. Compared to the elite senior group, cyclist A has an equivalent maximal aerobic capacity but is also relatively inefficient (uneconomical). In other words, at any speed he requires more oxygen than the average for the senior riders. Cyclist B has a maximal aerobic capacity considerably lower than either cyclist A or the elite group, but uses less oxygen at all speeds; i.e., cyclist B is very economical.

What are the implications of this test data and what recommendations could be made to these two athletes?

It is a well-established fact that endurance events, like many cycling races, are conducted at percentages of aerobic capacity that are less than the individual's maximal aerobic capacity. Let's assume that the elite national team, as an average, can sustain a pace that is associated with efforts of 85 percent $VO_2$max. This pace is indicated on the graph. Cyclist A, even with a maximal capacity equivalent to the elite group, could not sustain this pace because of the inefficiency of his effort. Cyclist B, on the other hand, while very efficient, is also at a disadvantage because of his low maximal capacity. The 85 percent maximum pace of the elite group is actually 100 percent of maximum for both junior athletes.

Recommendations for training these two juniors would be different, as illustrated in the lower panel of Figure 2. Cyclist A would be

## *NEXT ISSUE*

Have you ever wondered how we derived the figures for energy loss due to frame flex that we've used in several *Bicycling* articles? Join us as we separate the hypothesis from the hype.

Drs. Peter Van Handel and David Sanderson will continue our look at the hi-tech rider, with detailed discussions of elite training techniques, plus pedaling style modification using biofeedback.

Shot peening could offer an inexpensive means of making lighter frames. We'll give you the numbers and some insights on the design implications.

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advised to improve efficiency (economy of effort), shifting the oxygen cost curve down and to the right. Good weather riding and certain types of interval work could improve his efficiency. In addition, extra attention should be paid to his riding position and pedaling style. Cyclist B should work specifically to improve maximal aerobic capacity, probably through an increased schedule of carefully monitored interval training.

## Monitoring is Crucial

How important is an easy means of physiological monitoring to the individual cyclist? Far greater than was previously thought. Any given individual's physiological responses to work have a specific pattern; these responses can change with training. That's why athletes train, of course—to change (improve).

Unfortunately, enough variability exists among individuals so that assigning a common work intensity to a group of athletes may be acceptable for some or even several, but is likely to under- or overstress the others. Consider how many athletes are plagued by staleness, burnout, and injury. How many never reach their potential?

In part these problems are due to the inability of coaches to assign proper workouts and recovery sessions because of a lack of individual physiological test results. That is, if a racer has a coach at all.

The average athlete is never tested for physiological function. Even many elite athletes, who may be tested at one of the few qualified facilities in the USA, often spend the majority of their competitive seasons far from those facilities and the possibility of regular laboratory monitoring. The result? Guesswork, instead of an organized, scientific approach to training and recovery, is the rule rather than the exception.

If most athletes are left to their own resources for monitoring workouts and training adaptions, how could the two junior racers in our example avoid the pitfall of inadequate monitoring? To enjoy widespread use, a means of self-supervision should be simple and economical.

Monitoring oxygen consumption while training is almost impossible. Note, however, that in addition to oxygen use, heart rate and blood lactic acid concentration are also related to speed of cycling (Figure 1). Either of these two variables could be used to monitor work intensity. Heart rate, however, because it can be taken manually or with portable, relatively inexpensive pulse monitors, is definitely more convenient.

## Determining Heart Rate

The simplest (and cheapest) way is to count beats immediately after the exercise task. The "pulse" is located at an artery in the neck or wrist and a count is obtained for 6, 10, or 15 seconds and converted to beats per minute. Unfortunately, there are problems with counting, no matter what interval of time you use.

The longer the count, the less accurate the total is because heart rate decreases fairly rapidly after exercise stops. On the other hand, short counts must be multiplied by a larger conversion factor, magnifying even the small discrepancies that are unavoidable at high rates into large fluctuations in accuracy. For example, a "real" heart rate of 180 bpm has 3 beats per second or:

$$30 \text{ beats}/10 \text{ sec} \times 6 = 180$$
$$18 \text{ beats}/6 \text{ sec} \times 10 = 180$$

A counting error of just 2 beats (for example, one at the start and one at the end of the counting period) is actually multiplied by factors of either 6 or 10. The result is a possible error of 12-20 beats per minute, inadequate accuracy for monitoring elite-level training. It's realistic to expect these errors in heart rate determination, because palpitation of the artery is not the best method for obtaining accurate heart rates, especially for the unskilled.

A number of products are available which measure pulse pressure at the wrist or fingertip and display heart rate on a digital monitor. The monitor can be worn on the wrist like a watch or mounted on the bike itself. These heart rate monitors vary considerably in price and quality and care must be taken that the display values are "real."

In general, monitors that employ a chest strap transducer give more consistent results than ones which use an earlobe clip. Memory capacity which allows later display of periodic readings is a helpful, though not necessary, feature.

## Training with Heart Rate

For optimal training and recovery sets to be prescribed, heart rate must be associated with work loads which are geared to specific purposes, i.e., increasing maximal aerobic capacity, altering the anaerobic threshold, building base mileage, or maximizing recovery from intense workouts.

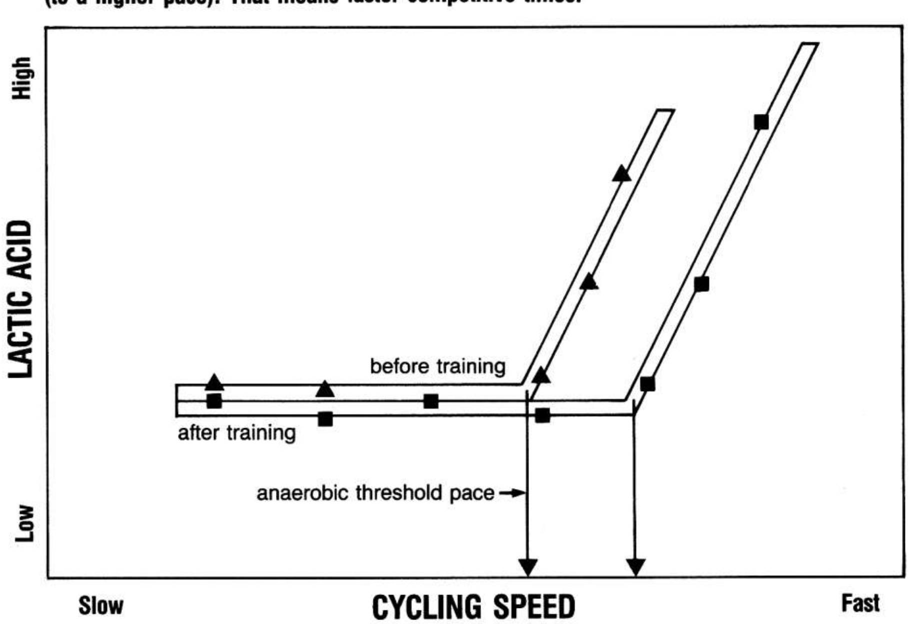
In addition to sample physiological data, Figure 1 also shows the location of four specific training intensities (derived from test results) that correspond to the above work loads. Moving up on a vertical line from these "pace" points identifies the respective value of the physiological variable of interest, in this case heart rate.

Physiological testing quantifies two important values: maximal aerobic capacity, or $VO_2$max; and the "anaerobic threshold," (AT). The former refers to the point where oxygen use can no longer increase in spite of increased work being done; the latter, the location where lactic acid begins to rapidly accumulate in the blood. $VO_2$max is measured by gas analysis, anaerobic threshold by blood analysis. These two points determine four distinct training paces:

**1.** Maximal aerobic training seeks to improve maximal oxygen consumption, or $VO_2$max, and involves interval work (repeated short term exertions interrupted by short rests) at 100 percent of the athlete's current $VO_2$max. Training above or below this pace, while possibly improving $VO_2$max, may not optimally try the physiological system.

**2.** "Tempo" training just at or below the AT is used to raise the percentage of maximal

**Figure 3: Training at the anaerobic threshold pace can move the threshold to the right (to a higher pace). That means faster competitive times.**



aerobic capacity where the AT is located. This pace can range from 75-95 percent of $VO_2$max, and, ideally, *should be determined independently of $VO_2$max*. Training below the AT does little to raise the threshold.

**3.** Training at 55-70 percent of $VO_2$max (labeled "Aerobic" in Figure 1) creates the cyclist's mileage base. This pace will not significantly improve $VO_2$max or AT, but will condition muscles and joints and prepare the body for efficient nutrient metabolism. The percentage chosen varies with the fitness of the athlete.

**4.** A pace which equals roughly 40 percent of $VO_2$max (labeled "Recovery") is not a conditioning tool, but rather, an appropriate exertion for "active" recovery. Although higher levels of function are not directly caused by such a low level of effort, the increase in metabolic function above sedentary rate actually speeds up the rebuilding and/or recovery of the systems stressed in previous efforts. It is imperative that recovery is sufficient before new, high-level efforts are attempted.

It is apparent from Figure 1 that all of these paces are associated with a particular heart rate. If an athlete is tested simultaneously for $VO_2$max, blood lactate, and heart rate, making those associations is simple. For serious training, *laboratory determination of $VO_2$max and anaerobic threshold is the preferred method.* In this case, heart rate monitoring is only needed for just that, monitoring training effort during those periods between regular laboratory testing.

But what happens if the athlete tries to do without laboratory determination of his physiological thresholds and trains by "feel?" Depending on the duration of a particular athletic event, the body functions at greatly varying capacities. As shown by Figure 1, note that: 1) the athlete can ride (or run, swim, etc.) at speeds faster than that required to achieve maximal oxygen use but the maximum does not increase; and 2) that heart rate may go higher than that associated with maximal oxygen consumption and blood lactic acid accumulation will accelerate, but oxygen use will not rise above its maximum level. In most cases the tendency is to train *above* the work loads required to raise either maximal capacity or anaerobic threshold. That's a practice that often leads to overtraining and poor results. Rather than suffer those calamities, it's better that athletes diligently train using carefully monitored estimates of their maximal thresholds until the time they can afford either the time and/or the money required for lab tests.

## Estimating Thresholds

While the "anaerobic threshold" pace is clearly identified by the sudden rise in blood lactic acid levels and aerobic maximum by a leveling off of oxygen use in spite of increased speed, there may be no clear indication of these changes by corresponding alterations in heart rate response. In other words, there is no simple formula to convert heart rate into an individual's maximum aerobic and anaerobic threshold points. It is possible, however, to make *estimations* of those points through some generalizations based on performance.

Competitive events of about 8-10 minutes duration are conducted at paces of 100 percent aerobic maximum. Races of shorter duration are conducted at paces much greater than that of aerobic maximum, while those of longer duration proceed at rates equal to or less than 100 percent of the aerobic maximum, depending on distance. These "rules" can be applied in the following manner to specific training goals:

TRAINING MAXIMAL CAPACITY — Improving maximal aerobic or anaerobic capacities (Figures 1 & 3) requires training at paces which require maximal oxygen consumption. Lactic acid levels are high and repeats (intervals) are completed at this pace. It is NOT NECESSARY to train at faster paces to improve maximal aerobic capacity or tolerance to blood lactic acid. Overtraining characterized by overstress, staleness, and injuries is all too common in sports and due, in the past, to intense training beyond that needed for optimal adaptation.

As indicated above, maximal efforts of approximately 8-10 minutes duration can be completed at paces which require 100 percent of maximal aerobic capacity. Therefore, the pace for interval training repeats and the associated heart rate can be estimated from a steady-paced yet maximal effort covering approximately 4-5 miles. Average "pace" in miles/hour, etc. is calculated from the time and distance covered. Heart rate is obtained at the end of the ride.

Key points to remember are: 1) The test should be a steady-paced but "all-out" effort over the distance (i.e., don't pace with submaximum work with a sprint at the end); 2) Head or tail winds and drafting will give falsely high or low results; and 3) Wear clothing and use gear normally used in training.

Interval repeats over any distance up to about 6 miles and with any length of recovery can be done at this pace to improve both maximal aerobic capacity and lactic acid tolerance.

TRAINING THE ANAEROBIC THRESHOLD — The pace at which lactic acid begins to accumulate is highly related to competitive performance times in many events conducted at less than maximal intensity. In other words, faster competition times are related to higher anaerobic thresholds and the pace athletes can sustain for medium-length events is very close to the pace where lactic acid begins to accumulate. Training at the anaerobic threshold is used to move the point at which lactate accumulates to the right; i.e., to a faster pace (Figure 3). Everything else being equal, the higher the anaerobic threshold, the faster the pace which can be held over long distances.

Identifying this pace may be difficult without actually monitoring blood lactic acid levels. Much attention has recently been given to the "Conconi Test"[1] which purports to associate a deflection in the heart rate response to a certain level of exercise (i.e., a nonlinear curve) with the sudden increase in blood lactic acid that characterizes the anaerobic threshold. The Conconi Test is illustrated conceptually in Figure 4.

It essentially requires a ride which gets progressively more difficult at regular intervals. Heart rate is monitored during each steady-

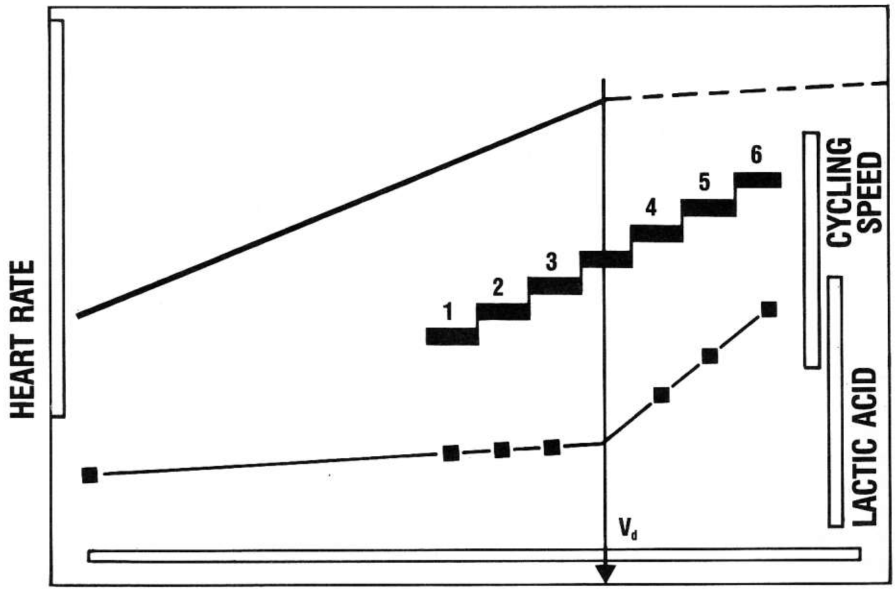



**Figure 4: The "Conconi Test" purports to show that a "break" in the linear rise of heart rate occurs at a pace (the "velocity of deflection") that is directly related to a rapid rise in blood lactic acid level (the anaerobic threshold).**

1) *Conconi, F.J., Applied Physiology, 52(4):869, 1982.*

state work session and is plotted versus cycling speed. According to Dr. Conconi, the heart rate will, at some point, begin to flatten out. In other words, it will not increase in direct proportion to increased speed as it had at less intense work levels. The pace at which this occurs is stated to be the same as the pace where blood lactic acid suddenly increases. This pace or speed is defined by Dr. Conconi as the "velocity of deflection" ($V_d$).

Notice that in Figure 1, I have not shown a "deflection" or curve in the heart rate response to work. While this is not the forum to discuss the relative merits of the Dr. Conconi's conclusions, research and testing done at the Olympic Training Center in Colorado Springs, Colorado, raises questions about the Conconi method. At this point we do not feel entirely confident that the suggested association between heart rate and lactic acid deflections can be seen for all athletes under all testing situations. We either do not see a curve in the heart rate response to work, or cannot match the pace where this does occur with the pace where blood lactic acid actually increases rapidly according to blood analysis. Until more studies are completed, care should be taken when assuming that training is being done at the anaerobic threshold unless it has been measured directly via blood analysis.

An alternate to the Conconi method of estimating the anaerobic threshold pace and training heart rate is to complete a 25-mile time trial, again at a steady but maximal pace with no reserves left for a sprint. As described above, pace is calculated from the time and the distance covered. This choice of distance is based upon the observations that in competition, overall average pace or speed for many events is close to the speed at which the anaerobic threshold occurs in testing situations. Once again, it is important to consider environmental conditions because oxygen use, blood lactate levels, and heart rate responses are markedly affected by wind and road conditions. Training rides of approximately 15 to 30 minutes can be made at this training pace.

AEROBIC TRAINING AND RECOVERY — Quality rest and "easy" training are equally as important as quality interval (maximal aerobic) and anaerobic threshold training sessions. "Aerobic" training refers to those long rides at less than maximal intensity, usually at a pace which requires 55-75 percent of aerobic maximal capacity. Note that these rides are longer and less intense than the anaerobic threshold rides. Their purpose is to give the athlete the conditioning base needed to ride for long periods of time. Note, though, that aerobic training will not directly improve maximal capacity, since the physiological systems are not stressed at that level. Pace and heart rate are based on percentage calculations of the maximal levels previously determined.

Riding at a pace substantially lower than what we've labeled as "aerobic," while not directly contributing to maximal capacities, may play a critical role in permitting any athlete to achieve maximal capacities. Putting in some very easy miles on rest days (as well as increasing the number of rest days) is becoming a common practice among American racers. Elite racers from several Eastern bloc countries log regular recovery rides at relatively low heart rates (about 120 bpm), usually "spinning" in "small" gears. While various names can be applied to this training, it is essentially what we would call "active" recovery. While some work is being done, it is of very low intensity and is basically used to help the athlete recover from previous intense workouts in preparation for future sessions. In Figure 1, I have indicated this is done at about 40 percent of maximal aerobic capacity, though the actual level may vary. Again, the pace should be adjusted for environmental conditions.

The relative proportion and amount of training done at each intensity depends upon the individual's program, including time of the season and the immediate goals of the training. It is important to recognize that as adaptations take place, both physiological measures and training paces are altered. The most obvious marker is that competitive performances improve. Periodic re-evaluation of training paces, goals, etc. must be made if optimization of work is to continue.

## Summary

Heart rate responds to exercise like many other physiological variables; it increases in rough proportion to the stress imposed until a maximal level is attained. Training status, age, genetics, and environmental factors all affect this relationship. Heart rate is easily monitored and can serve as a marker for training stress provided it is accurately recorded and certain criteria are established, including true maximal levels.

There is no doubt that extensive field and laboratory testing is preferred to the indirect estimates described in this article. Athletes willing to invest thousands of dollars and a major portion of their life in athletic training should consider applying a part of this investment to sports science and medicine. The gains made possible by the knowledge provided from accurate physiological tests far outweigh their costs.

*Peter Van Handel received his Ph.D. in exercise physiology from Kent State University. As the Senior Sports Physiologist on the staff of the United States Olympic Committee, Dr. Van Handel is involved on a day-to-day basis in the laboratory evaluation and training recommendations for elite-level athletes from many sports, including cycling.*

■ In future articles, Dr. Van Handel will discuss: periodicity, or the seasonal time framework on which is overlaid the various types of training discussed in this article; each of the major types of training (maximal aerobic, anaerobic threshold, aerobic, and recovery) in greater detail; and how to modify a training regimen according to an individual's competitive needs, as well as other factors such as climate, current level of performance, etc.

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**SPECIAL REPORT**

# The U.S. Patent System

## Guide for the Inventor and Cycling Technical Enthusiast

Robert G. Flower

The patent system is either a curse or a blessing, depending on who you ask. Originally, patents were devised to safeguard the rights of an individual inventor, while allowing the invention to be sold openly in the marketplace. In theory, everyone would benefit: the inventor is rewarded for cleverness, while the public at large is able to buy a better product.

But in practice, the patent system has grown into a maze of legalisms, some say, where the small inventor gets lost and only big corporate interests know how to get around. In fact, the patent system is relatively simple to understand—provided you have the right map. And so the purpose of this article is to unfold that map, or at least the part of the map that relates to bicycles and bike components.

The good news is that recent changes in patent law make the system much more accessible to "ordinary people" (i.e., non-lawyers). Inventors will be happy to know that the process of obtaining a patent has been streamlined; for small businesses the fees are reduced to only one-half those charged large companies. And you can cut the cost even further: instead of paying a patent lawyer $1500 to $3000 for a complete patent filing, you can handle the process yourself for as little as about $450. Or you can follow a middle path, do much of your own legwork, and hire a lawyer only for specific tasks as needed.

Even if you have no interest in obtaining a patent, you can still use the patent files as a vast technical libaray. The nitty-gritty details of many inventions are available nowhere else except in the patent literature. If you're wrestling with a design problem—adhesive-bonding of aluminum to carbon-fiber, for example—the solution may available to you for no more than the $1.50 cost of a patent. How do you find it?

With the new CASSIS on-line computer system, now available in more than 60 libraries (see "Access Guide"), you can search the entire U.S. patent database in a few minutes. Hundreds more libraries contain the books needed to do a manual search; the cost is next to nothing. Why bother? Consider, for instance, that it's perfectly legal to copy and sell, in certain circumstances, the devices and processes described in patents. So if you're a designer or tinkerer, chances are good that you'll learn some new tricks by reading up on patents in your field.

### Law of the Land

The patent system is based on the same legal principle that led to the great land rush in the midwest more than a century ago. The basic idea, crudely put, is: "If you get there first and put up a fence, you own it." In the real estate business, this ruthless approach was outlawed years ago. But you can still get away with it in the patent system.

The big difference, of course, is that patents deal not with physical land, but with the invisible terrain called "intellectual property," or ideas. Nevertheless, the inventor seeking a patent must accomplish two tasks much like those facing the early land claimant. The first is to prove that the territory to be claimed does not belong to someone else. In a patent, this is accomplished in the *specifications*: a technical description of the invention must be given in such minute detail that any reasonably skilled person could build a working model. This means that *"secret" mechanisms are not allowed*; the inventor must reveal the very soul of his invention to the world. The specifications must also state how the invention is *different* from all other similar inventions (called "prior art"). For this reason, patent specifications are a gold mine to anyone seeking to learn the state of the art in any given field; the technical specifications must be accurate and to the point to be legally acceptable. By reading the specifications for about a half-dozen current and perhaps related patents in any field, you can learn what works, what doesn't, and why.

The inventor's second task is to draw a "boundary line" to define the territory he wants exclusive rights to. This is accomplished in the *claims* section of the patent. Claims provide almost no technical information, but they're the legal meat of the patent; like a real-estate property survey, patent claims stake out the territory in question.

### Access Guide to the U.S. Patent System

A quick review of the tools you need to access the patent system:

— **CASSIS**: a new computer-searchable database containing U.S. patents with their class and subclass numbers. This is probably the fastest way to extract useful information from the patent system. CASSIS will identify all patent numbers on any given topic, inventor, or assignee. CASSIS is available only at the Patent Depository Libraries (see below), but a telephone call can arrange your search in many cases.

— **PTO (Patent and Trademark Office) Publications**: Probably the first place to start investigating a patent question is one of the following official publications of the U.S. Patent Office:

**Patent Office Gazette**: contains one drawing and the main claim of every patent issued, in numerical order indexed by class/subclass, plus new PTO rules and miscellaneous notices. Published weekly. If you want to keep an eye on who is patenting what, just scan the index of the **Gazette** every month or so.

**Annual Index of Patents**: issued yearly in two volumes: **Titles of Inventions** and **Patentees.** Best for access to patents more than a year old.

**Index to Classification** and **Manual of Classification**: These two loose-leaf books are the keys to the classification numbering system (see sidebar). The **Index** is arranged alphabetically with cross-references, and the **Manual** is arranged numerically. A third volume, **Classification Definitions**, gives the final word on what each class/subclass covers.

**Rules of Practice in Patent Cases** (the PTO's rules of practice) and **Manual of Patent Examining Procedure** (the "Patent Examiner's Bible"): answer most questions about official procedure, and are essential for those who handle their own patent cases.

**Attorneys and Agents Registered to Practice Before the U.S. Patent and Trademark Office**: contains geographic and alphabetic listings of all patent attorneys and agents. Thus, you can quickly find those located near you. To find an attorney/agent near the main Patent Office (a good idea for preliminary search purposes), look under Washington, DC, or, in Virginia, ZIP code 22202.

The PTO publications listed above are available in most medium- to large-sized public libraries, Patent Depository Libraries (see below), government bookstores, and by mail from: U.S. Government Printing Office, Washington, DC 20402, phone 202-782-3238.

— **Main U.S. Patent Office**: the best place to physically search the patent files: all 4.5+ million U.S. patents are there, arranged by subject matter (e.g., all patents showing bicycle derailleurs are grouped together), along with several million foreign patents and extensive technical literature. You can talk with the patent examiners who handle your specific subject area, and make instant photocopies or order a complete copy of a patent to be mailed several weeks later. Physical location: South 26th Street and US Route 1, Jefferson Davis Highway, Crystal City, Arlington, VA. Telephone 703-557-3158.

— **By mail**: Copies of patents may be purchased for $1.50 each, and all official PTO business may be transacted by mail. Address: Commissioner of Patents and Trademarks, Washington, DC 20231.

— **Patent Depository Libraries**: a group of 66 libraries throughout the U.S. which maintain special collections of patents (on paper or microfilm), plus PTO publications (listed above), and the CASSIS computer-search system. Call your local library or PTO Arlington for a list.

— **Statutes and Regulations**: The federal laws concerning patents are listed in Title 35 of the U.S. Code (abbreviated "35 USC" in legal citations). The PTO's administrative rules dealing with patents are given in the U.S. Code of Federal Regulations, Title 37, Part 1 (37 CFR 1). Both are widely available in libraries.

Two final points: while a patent is pending (i.e., applied for but not yet issued), the Patent Office will not disclose *any information* about it; the inventor's name, the invention, and even the fact that a patent was applied for, are secret, unless the inventor releases this information himself. Since it takes anywhere from one to three years for a patent to issue, this is a big information gap. (One can learn about pending patents *indirectly* by searching foreign patent files, and looking for patterns among names, inventions, and dates. This tedious method will be easier when more foreign patent files become computer-searchable.)

But once a patent *is* issued, the entire Patent Office file becomes public. You can read all the lawyer's letters arguing back and forth about the merits of each claim in the patent, and often gain insight about the weakness or strength of the inventor's position, or the Patent Office's bias. The patent "wrapper," as these files are called, may also contain test data and other valuable technical information not published in the patent itself, or anywhere else. You can browse through the wrappers only at the Arlington main office, but you can order copies from anywhere else by mail.

## Bicycle Patent Classifications

Every U.S. patent is assigned a unique "class" and "subclass" designation. There are about 300 classes and 66,000 subclasses. Thus, it's essential to identify the specific class(es) and subclass(es) which define your field of interest.

Where do bikes fit in? One patent agent I talked to thought there may be more patents on bicycles and related vehicles than on any other type of invention. In general, bicycles fall within Class 280 (Land Vehicles), which contains more than 1000 subclasses. The most important bicycle subclass (Subclass 200, Occupant-Propelled Land Vehicles) itself contains more than 125 sub-subclasses, with up to seven additional levels of nesting of the categories. The list below is just a sample. These pertain only to patents on the bicycle *itself.*

| Class | Sub-Class | |
|---|---|---|
| 280 | — | Occupant-propelled Land Vehicles |
| 280 | 201 | ...Combined with pump |
| 280 | 202 | ...With carrier |
| 280 | 203 | ...Sidecar type |
| 280 | 204 | ...Trailing vehicle |
| 280 | 205 | ...Single axle or wheel |
| 280 | 206 | ...Occupant within wheel |
| 280 | 209 | ...Parallel-connected cycles |
| 280 | 210 | ...With propulsion means |
| 280 | 211 | ...Steering by driving |
| 280 | 212 | ...Added or stored energy device |
| 280 | 218 | ...Inching or step-by-step |
| 280 | 220 | ...Moveable occupant support |
| 280 | 230 | ...Plural power application |
| 280 | 236 | ...Reversing and power-ratio change |
| 280 | 239 | ...Three tandem wheels |
| 280 | 240 | ...Interconnected steering means |
| 280 | 241 | ...Belt or chain |
| 280 | 242R | ...Hand-propelled |
| 280 | 252 | ...Reciprocating power application |
| 280 | 253 | ...Oscillating lever |
| 280 | 259 | ...Rotary crank power |
| 280 | 263 | ...With steering |
| 280 | 264 | ...Combined with brake |
| 280 | 265 | ...Foot steered |
| 280 | 266 | ...Seat or body steered |
| 280 | 267 | ...Two-wheel controlled |
| 280 | 270 | ...One-wheel controlled |
| 280 | 281 | ...Frames and running gear |
| 280 | 282 | ...Polycycles |
| 280 | 287 | ...Extensible and knock-down |
| 280 | 288 | ...Rear forks |
| 280 | 289 | ...Attachments and accessories |

Components and accessories for bicycles can fall into an even wider range of classifications, as follows:

| Class | Sub-Class | |
|---|---|---|
| 224 | 30R | Attached carriers |
| 116 | 166 | Bells |
| 192 | | 6R Coaster brakes |
| 280 | 7.1 | Convertible |
| 74 | 594.1 | Cranks and pedals |
| D12 | 111 | Design |
| 280 | 152.1 | Dust and mud guards |
| 272 | 73 | Exercising devices |
| 310 | | Generators |
| 322 | 1 | ...Systems |
| 74 | 555.1 | Handlebars |
| D8 | DIG | 8 Handle or grip design |
| 116 | 137R | Horns |
| 308 | 192 | Hub ball bearing |
| 362 | 72 | Lights |
| 315 | 76 | Generator-bulb systems |
| 322 | 1 | Generator control |
| 310 | | Generator per se |
| 362 | 382 | Supports |
| 362 | 193 | Wheel-driven generator |
| 70 | 233 | Locks |
| 70 | 225 | Wheel |
| 29 | 428 | Frame-making methods |
| 29 | 700 | Frame assembling |
| 308 | 23.5 | Pedal-crank bearings |
| 440 | 30 | Propelled marine pedomotors |
| 211 | 17 | Racks |
| D12 | 115 | Rack or holder, design |
| 350 | 97 | Reflector |
| 297 | 195 | Seats |
| 280 | 1.11 | Simulations |
| 135 | 7 | Umbrella for |
| 301 | 5 | Wheels |
| 280 | 160.1 | Guards |
| 280 | 158.1 | Scrapers and cleaners |

**EXCERPT**

# Patent It Yourself

David Pressman

*If you want to apply for a patent and save money by doing some of the work yourself, you need a good source of advice. David Pressman's new book,* ***Patent It Yourself****, fills the bill better than many of the other DIY patent books on the market.*

## What is Patentable?

Any definite physical difference at all will suffice to satisfy the novelty requirement. For example, suppose you've "invented" a bicycle which is painted yellow with green polka dots, each of which has a blue triangle in the center. Assume that no bicycle has never been so painted before. Your bicycle would thus clearly satisfy the requirement of novelty.

Rarely will an investigation into your invention's patentability reveal any single prior invention or reference that could be considered a dead ringer. Of course, if your search does produce a dead ringer reference — that is, any reference showing all the features of your invention and operating in the same way for the same purpose—then your patentability decision can be made immediately. Your invention has been "anticipated" by a prior invention or conception and is thus definitely unpatentable.

The PTO will consider your invention novel even if two or more prior-art items (actual devices or published descriptions) *together* account for all of your invention's physical characteristics. For your invention to be considered as lacking novelty, and thus subject to rejection under Section 102 of the patent laws, *all* of its physical characteristics must exist in a single prior-art other reference.

For example, suppose you now invent a bicycle made of one of the recently-discovered super-strength carbon fiber alloys. The bicycle per se is old, as is the alloy, but you're the first to "combine" the two old concepts. Your bicycle would clearly be considered to be novel since it has a new physical feature: a frame which is made, for the first time, of a carbon fiber alloy. But, remember, just because it's novel, useful, and fits within a statutory class, doesn't mean the bicycle is patentable. It still must climb the steep slope of unobviousness.

## Patent Unobviousness

We're now entering what is probably the most misunderstood and difficult-to-understand aspect of patent law, i.e., whether your invention is unobvious.

**Misconception:** *If your invention is different from the prior art, you're entitled to get a patent on it.*

**Fact:** *Under Section 103 of the patent laws, no matter how different your invention is, you're not entitled to a patent on it unless its difference(s) over the prior art can be considered "unobvious" by the PTO or the courts.*

Most people have trouble interpreting Section 103 because of the word "obvious." Most patent attorneys, patent examiners, and judges can't agree on the meaning of the term. Many tests for obviousness have been used and rejected by the courts over the years. The courts have often referred to "a flash of genius," "a synergistic effect (the whole is greater than the sum of its parts)," or some other colorful term. One court said that unobviousness is manifested if the invention produces "unusual and surprising results."

Because it's helpful to understand how a bureaucracy operates when you're dealing with it over significant issues, let's examine how a patent examiner proceeds when deciding whether or not your invention is obvious. First, they make a search and gather all of the patents that they feel are relevant or close to your invention. Then, they sit down with these patents and see whether your invention, as described in your claims, contains any novel physical features which are not shown in any reference. If so, your invention satisfied Section 102, i.e., it is new.

Next, they see whether your new physical features produce any unexpected or surprising results. If so, they'll find that the invention is unobvious and grant you a patent. If not (this usually occurs the first time they act on your case), they'll reject your application (sometimes termed a "shotgun" or "shoot-from-the-hip" rejection) and leave it to you to show that your new features do indeed produce new, unexpected results. To do this, you can use as many reasons as you feel are relevant. If you can convince the examiner, you'll get your patent.

If a dispute over unobviousness actually finds its way into court (a common occurrence), however, both sides will present the testimony of experts who fit, or most closely fit, the hypothetical job descriptions called for by the particular case. These experts will testify for or against obviousness by arguing that the invention is (or is not) new and/or that it does (or does not) produce unexpected results.

Inventions which *combine* two or more elements known in the prior art can be held patentable, provided that the combination can be considered unobvious, i.e., it is a new combination and it produces new and unexpected results. In fact, most patents are granted on such combinations since very few truly new things are ever discovered. So let's examine some of the factors used especially to determine the patentability of "combination inventions" (i.e., inventions which have two or more features which are shown in two or more prior-art references).

An example of where the law would consider it obvious to combine several references is the case where, as discussed, you make a bicycle out of the lightweight carbon fiber alloy and, as a result, your bicycle is lighter than ever before. Is your invention "unobvious"? The answer is "No," because the prior art implicitly suggests the combination by mentioning the problem of the need for lighter bikes and the lightness of the new alloy. Moreover the result achieved by the combination would be expected from a review of existing bicycles and the new lightweight alloy. In other words, if a skilled bicycle engineer were to be shown the new, lightweight alloy, it would obviously occur to him to make a bicycle out of it since bicycle engineers are always seeking to make lighter bicycles.

However, if the references themselves show or teach that they *should not* be combined, and you're able to combine them, this militates in favor of patentability. For example, suppose you make that bike out of the carbon-fiber alloy and a reference says that the new carbon-fiber alloy should only be used in structural members which aren't subject to sudden shocks. If you're able to use it successfully to make a bike frame, which is subject to sudden shocks, you should be able to get a patent.

To take an example out of our current bicycle experience, one of Gary Klein's major claims to the patentability of the oversize-tube, welded aluminum frame is the "surprising" result that a lighter, more rigid aluminum frame (results to be expected and, therefore, not patentable claims) is, contrary to conventional bicycle wisdom, more comfortable than a frame of lower rigidity.

*David Pressman is a member of the Pennsylvania, California, and Patent and Trademark Office bars. His experience in the patent profession covers more than 25 years, including work as a corporate patent attorney, a magazine columnist, and an instructor at San Francisco State University. When not writing, he practices as a patent lawyer in San Francisco.*

*This article is excerpted with permission from David Pressman's October 1985 book* ***Patent It Yourself: A Complete Legal Guide for Inventors*** *($24.95). Nolo Press, 950 Baker Street, Berkeley, CA 94710, phone 415-549-1976.*



## READER'S FORUM

# MORE STURMEY CONVERSIONS

There's a simpler adaption than Nick Ackermann's mating of a threaded Shimano three-speed bellcrank to a Sturmey S5 5-speed hub (*BIKE TECH*, Fall 1986). Shimano now makes an unthreaded bellcrank, which is secured to the hub axle by a lockbolt [Shimano #3219027 - Editor]. Just drill out the bellcrank's axle opening slightly to use it on the S5. Use a Shimano cable and shift lever.

The Sturmey 5-speed hub is by far the best gearing system for stop-and-go urban cycling. I've found the original S5 the most reliable version, when used with a sturdy bellcrank and dual trigger controls. All parts which wear are interchangeable with their counterparts in newer models, and the S5 internals fit Sturmey 3-speed hub shells. Enough of the now unavailable S5's are still kicking around to meet the demand from tinkerers like Nick and me.

Don't worry about finding old S5s—the new S5/2 and alloy-shell versions are entirely acceptable when used with positive shifters. The AT5, a drum-brake version with an alloy shell, has been introduced recently. For the all-weather utility rider, it is unequaled in its combination of high performance with high style and light weight.
John S. Allen
Waltham, MA

The article "Testing of Bicycle Rim Brakes" in your Fall 1986 issue confirms what we've been telling the industry since 1981 regarding the stiffness of caliper arms.

But the author is totally wrong in recommending shortening the free length of the caliper arms "as with centerpull brakes." Centerpull brakes are rarely found on good bikes because they're so weak and flexible. Their true "free" length is the combined length of the lower caliper arm and the bridge or crosspiece, measured from the frame mounting hole to the pad/rim interface. This total length is the same as or slightly longer than for a sidepull. Centerpull parts are usually flimsier. Finally, the arm pivot studs bend outward and upward when braking—a hopelessly bad design.

Edward Scott
Scott/Mathauser Corp.

# THE BIOMECHANICS OF CYCLING

by David J. Sanderson, Ph.D.

Bicyclists have always been tinkerers, striving to improve the mechanics of translating bipedal leg power into forward rolling motion. And even though the safety bicycle, popularized in the late 1800s, hasn't changed radically in almost 100 years, there has been a constant stream of incremental refinements that have made cycling faster, easier, and safer. Recent years have seen a flood of new bicycle technology, especially in the utilization of non-traditional materials.

But almost all of these improvements have been made in the efficiency, convenience, or reliability of bicycle hardware, and mechanics constitutes only part of the equation relating two-legged power to two-wheeled motion. What about the biomechanics involved?

Unlike bicycle componentry, the position of the rider and the mechanics of pedaling have changed little over the last 100 years. Are we unjustly overlooking a more effective riding style because of tradition? Since circular pedaling is not necessarily a natural motion in our recent evolutionary heritage, are human beings even equipped to recognize more effective pedaling motions, if, indeed, there are any?

This series on the biomechanics of bicycling will attempt to address these and other questions, as well as pose some new ones for future research. Our first article presents an abridged historical perspective on research into the biomechanics of bicycling, as well as some data typifiying the mechanical features of riding a standard 10-speed "racing" bicycle. Some of the comments are appropriate for any bicycle that is being ridden at a steady rate on a smooth surface.[1]

*1) The scientific study of cycling has its beginnings in the last part of the nineteenth century with the publication of the landmark work - **Bicycles and Tricycles** by Archibald Sharp in 1896. Among other topics, Sharp discussed the strength of bicycle frames, the dynamics of riding, and the forces applied to the pedals. Despite this promising early beginning, little more creative work was done on the mechanics of bicycling for the next 75 years. In the last 20 years, however, there has been renewed interest in studies on the biomechanics of cycling as shown by the work of: Hoes, Binkhorst, Smeekes-Kuyl, and Vissers (1968), Dal Monte, Manoni, and Fuchi (1973), Whitt and Wilson (1982), Daly and Cavanagh (1976), Gregor (1976), Lafortune (1978), Soden and Adeyefa (1979) and Davis and Hull (1981) to name only a few.*

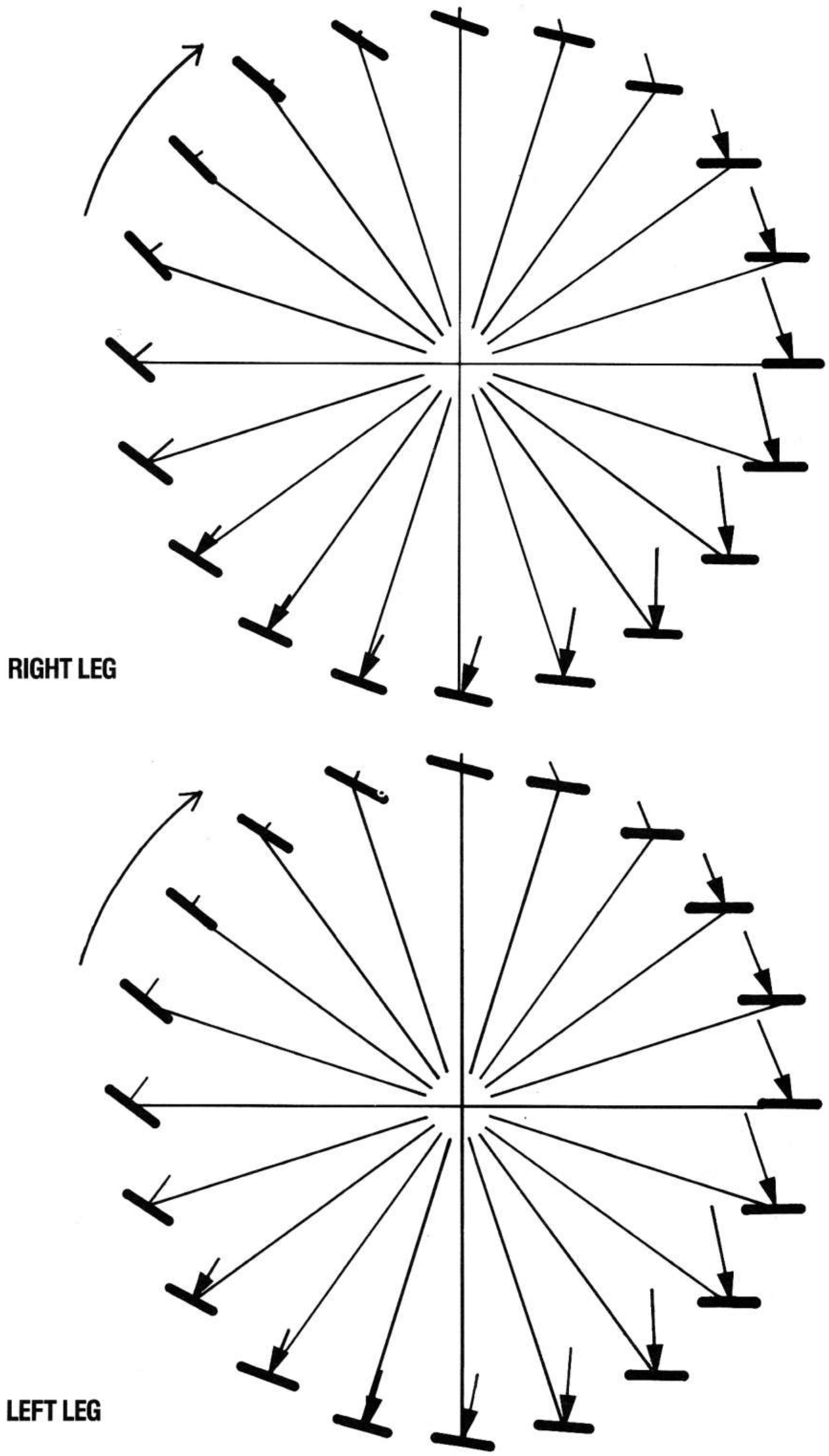


**Figure 1: Pedaling force vector diagrams for the right and left legs of a typical bicyclist. The radiating lines represent positions of the crank, the short bold lines the pedals, and the arrows the resultant force applied at each position.**

## PEDALING ACTION

Many cyclists can describe in elaborate detail how they apply force to the pedals as they ride a bike. Laboratory experience, however, suggests that what they *feel* they are doing and what they are actually doing remain quite different. This is likely the result of the number of links in the human mechanical system, a complexity that makes it difficult for the rider to know precisely what each individual link is doing at a given time.

In the biomechanics laboratory a variety of approaches have been devised for the recording of the mechanical aspects of cycling. The fundamental piece of equipment is the cycle, such as a stationary ergometer (Houtz &

Fisher, 1959), an ergometer modified with new handle bars and seat (Sommerville, Gervais & Quinney, 1985), the subject's own bike with test instrumentation affixed only during experimentation (Hull & Davis, 1981), or a racing bicycle mounted on some platform (Lafortune & Cavanagh, 1983).

A variety of approaches to recording forces have been developed. Sharp (1896) developed a pedal capable of recording the forces applied throughout the pedaling cycle. He was the first to show how the temporal pattern of forces changed throughout the pedaling cycle. Hoes et al. (1968) instrumented a crank and a pedal to record crank torques and the normal component of the pedal force[2]. Lafortune and Cavanagh (1983) reported an ergometer with both pedals instrumented to record the normal and the antero-postero[3] components of the pedal force. Hull and Davis (1981) reported on a three-dimension force measuring pedal but measuring one side only. Finally, Ericson, Nissel, Auborelius, and Ekholm (1985) reported using a Kistler load cell mounted on a pedal to record the three components of the pedal force. Each of these representations has added to the pool of knowledge on the mechanical features of cycling.

Beyond the usual seating position and crankset, an ideal test apparatus should also include pedals modified so that the forces applied can be recorded during active pedaling, typically using some form of computer acquisition system. With such a setup, the scientist could stipulate a set of riding conditions (power output, pedal cadence, and gear ratio), and then record the variables of force magnitude and force direction, crank angle, and pedal angle as the cyclist rode the test bike.

An example of such data is presented in figure 1. This rider is pedaling at 100 rpm with a power output of about 230 watts.[4] In this figure, the radiating dotted lines represent the position of the crank at 18-degree intervals throughout one complete revolution; that is, from one TDC (top dead center) to the next. Positioned at the end of the crank is the pedal, the short bold line. The angle of the pedal with respect to a vertical line is called the ankling angle. The resultant forces that are applied to the pedals are shown by the bold arrows in the figure. The length of the arrow is proportional to the magnitude of the force and its orientation shows the angle at which the force is applied.

Pedaling a bicycle has been considered to occur in two phases: a propulsion phase during which the forces are applied in the same direction of rotation of the crank, usually considered to be the first 180 degrees of crank rotation, and the recovery phase, usually considered to be the second 180 degrees. When examining the pedal force diagram (figure 1), it is important to remember that both legs are moving in synchrony, but 180 degrees out of phase. That is, as the right leg is moving down the left leg is moving up.

Only that portion of the resultant force which is perpendicular to the crank and in the direction of rotation of the crank results in a propulsive or positive torque. It is the torque, then, that makes the wheels go around and the object, for example, in road racing or endurance cycling is to apply the greatest amount of positive torque with the greatest ease. A negative torque would have a retarding effect.

## CONSISTENT FINDINGS

There are a number of interesting observations that can be made with these data presented in figure 1. The magnitude and direction of the applied force varies throughout the complete cycle. This was first shown by Scott in the late 1800s. Using a crudely designed force-measuring pedal, he showed that during cycling the forces applied to the pedals vary throughout the pedaling cycle. He presented data for a selection of conditions including racetrack and uphill riding. The pattern of force application was remarkably similar for the diversity of conditions studied. More recent and more sophisticated methods of recording the pedal forces have verified the major characteristics that Scott identified almost 100 years ago.

The fact that the orientation of the resultant force varies throughout the pedaling cycle has important implications. As was stated above, only the component of the resultant force that is perpendicular to the crank and in the direction of rotation provides positive torque (figure 2). This component has been termed the effective component. The remaining force is lost or unused. Examining figure 1 again, the force applied near TDC is small and almost parallel to the crank, and thus provides only a very small positive torque. As the crank continues to rotate, the orientation of the force alters so that a larger fraction of the total force is perpendicular to the crank. The best orientation appears just before the crank is at a position of 90 degrees after TDC where the torque becomes maximum. After that the orientation becomes increasingly less useful so that near BDC (bottom dead center), the pedaling force, while remaining large in magnitude, is again almost parallel to the crank and its resulting positive torque small.

Generally, most studies of the patterns of resultant pedaling force and crank torque for the complete pedaling cycle report that the peak torque, or greatest propulsion, appears near 90 degrees after TDC, while the peak pedal force occurs a few degrees later. The rate of rise in force, the maximum force applied, and the mean force during the recovery phase all vary with pedaling cadence and power output.

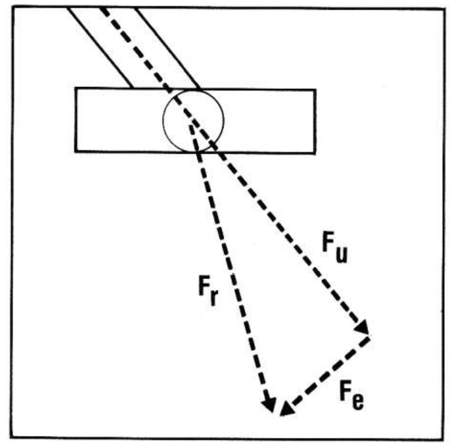


**Figure 2: The two components of the resultant pedaling force ($F_r$): the effective force ($F_e$), which is perpendicular to the crankarm and provides propulsion; and the unused force ($F_u$), which makes no contribution to propulsion, but does increase frame flex.**

A number of recent investigators have used the ratio of the effective force to the resultant force as a measure of the effectiveness of the pedaling style. Patterson, Pearson, and Fisher (1983) called this the Force Effectiveness Index; Lafortune and Cavanagh (1983) labeled it the Index of Effectiveness; and a somewhat different computation but similar philosophy was presented as the Performance Index by Hull and Davis (1981).

If such an index has a value of 1.0 then all the applied force is perpendicular to the crank. These indices provide a useful means by which the mechanical pedaling action of a wide variety of riders can be compared without references to absolute strength. The index becomes, in essence, a measure of a rider's pedaling effectiveness. Unfortunately, there has been little to verify the validity of any of these indices on a large group of riders and, thus, their usefulness remains scientifically untested.

We might note informally that leg strength testing of elite cyclists has not necessarily been a good indicator of actual on-the-bike performance, leaving open the possibility of high pedaling efficiency as a co-determinant performance factor, along with anaerobic threshold, etc.

It is further evident from figure 1 that there are differences between what the left leg is doing and what the right leg is doing. Such asymmetries in cycling, while perhaps surprising, are not uncommon. Daly and Cavanagh (1976) computed an index of work asymmetry as the ratio of the work done by the right leg to the work done by the left. Their data showed that work asymmetry was a characteristic of cycle riding and while apparantly unrelated to leg dominance, it did vary in response to changes in pedaling cadence. Asymmetry in force was also reported by Gregor (1976) over a range of pedaling cadences and power outputs. This evidence has important implications for any re-

*2) A normal force in this case would be perpendicular to the pedal surface.*

*3) The antero-postero components of the pedaling force would be, respectively, the fore and aft forces acting on the pedal.*

4) The data presented in these illustrations were derived from research done by Sanderson and Cavanagh at The Pennsylvania State University.

search which assumes symmetry, because an unaccounted for asymmetry may lead to erroneous conclusions.

## A FEW SURPRISES

Considering the forces applied during the second 180 degrees of the cycle (the recovery phase) reveals some interesting surprises. The cyclists appear to be pushing *down* on the pedal, thus requiring each leg to raise the other through this sector. When asked, most cyclists say they definitely pull up with their leg during the recovery phase. However, there are many examples in the scientific literature beginning with the early data of Sharp (1896) reporting the opposite. Hoes et al. (1968), Daly and Cavanagh (1983), Davis and Hull (1981), Cavanagh, Lafortune, Valiant, and Burke (1983), and Cavanagh and Sanderson (1986) all have reported negative (retarding) torques during this portion of the pedaling phase. These data have been recorded on both recreational cyclists and elite competitive cyclists suggesting that this is the standard riding style. However, it should be remembered that all of these data were collected from riders who were maintaining the same cadence; i.e., not sprinting or hill climbing. Under non-steady state conditions the pedaling action may well be quite different.

Nonetheless, these published data are contrary to the opinion expressed by a long history of cycling "authorities" suggesting that pulling up on the pedals could result in as much as a 30 percent increase in pedaling efficiency. If potential changes in economy of riding were in fact that large, then surely at least the elite racing cyclists would pull up from successful experience. Unloading the pedal during the recovery phase requires the cyclist to overcome two forces, the weight of the leg, which gravity is pulling down against the pedal, and a force due to the inertial effects - the tendency of the limb mass to resist the motion of the pedal. This second force would be present whether or not gravity existed.

So, why don't cyclists develop the technique necessary to provide propulsive force during the recovery phase of pedaling? The answer perhaps lies in an understanding of the energy cost of pulling up on the crank. Consider these three scenarios as outlined by Sanderson and Cavanagh (1986):

—If downward forces are recorded on a pedal, this can be interpreted to mean that the rider is recovering this leg with the aid of the opposite leg.

—If the pedal is unloaded, then the rider is recovering the leg by the action of that leg's own muscular effort.

—If there is a pulling-up force on the pedal, then not only is the leg being recovered by muscular action on that same side, but the muscular action is in excess of what is needed for recovery and results in propulsive forces (figure 3).

It is possible that each of these will involve different physiological costs. It has historically been assumed that negative torques in recovery are undesirable. Because of the previously cited evidence that some of the best cyclists *do not* normally pull up during fast, level, steady-rate riding, it might be assumed that it is *not* physiologically economical to do so. This issue obviously needs much further study before it can be resolved.

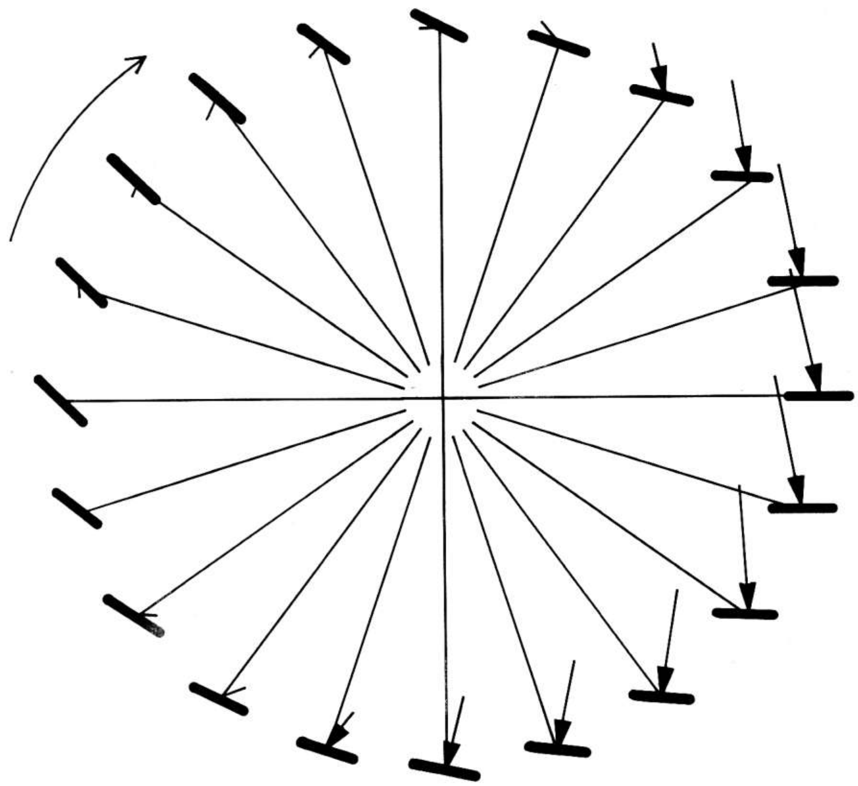

**Figure 3: Theoretical pedaling force vector diagram for pedaling with net propulsive forces exerted during recovery.**

One last point to explain here concerns the ankling angle. It has been thought for some time that at the top of the pedaling stroke the cyclist should drop the heel to facilitate a push across the top of the stroke. At the bottom of the stroke the cyclist should drop the toes to pull across the bottom of the stroke. From figure 1 it is evident that this does not occur. The pedal appears slightly angled down at both points. In fact, there seems insufficient flexibility at the ankle joint when the pedal is at top dead center for the cyclist to perform as suggested in the early literature. A more likely pattern might be to encourage cyclists to use the cleat to allow them to push forward across the top of the stroke and to deliberately pull back along the bottom. This may be the motion writers have referred to when discussing the benefits that might accrue from "ankling" in order to "pull up" during recovery.

## FUTURE RESEARCH

In this article, I have tried to present a summary of some of the information on the biomechanics of cycling as we know it today. These data are presented in the context of some of the research that has been developed since the 1800s. Additionally, where scientific evidence and popular notion have separated, I have identified some of the issues. There are indeed many questions that require thoughtful examination in the future:

—It has long been assumed that cyclists will self-select an optimum pedaling style. This has not yet been conclusively proven. In fact, there is some evidence that optimum performance can be enhanced with proper training. Thus, new pedaling styles might yet be developed if we can assess present styles as well as possible new ones. In a second part to this article some of these developments will be discussed.

—Another issue that needs examination is the question of the economy of pedaling and what constitutes an appropriate cadence. There are some physiologically-based data which show variations in an optimum pedaling rate determined by the intensity of the cycling. There is very little known about how the mechanics change in response to variations in power output. Patterson et al. (1983) have shown that their Force Effectiveness Index decreases with increases in cadence at a particular power output. Redfield and Hull (1986), on the other hand, have proposed that a mechanical mechanism related to joint moments may be the controlling factor. This hypothesis will have to be examined in the future.

—The general enthusiasm for the added leverage of extra-long crankarms is matched, unfortunately, only by the sad consensus that increases in crank length even as small as 2.5 mm can seriously damage the knees or other joints and/or muscles of professional athletes (Hinault and Fignon, for example). Even if articulated crank systems ("Prototypes", Bike Tech, Summer 1986) allow the possibility of altering effective crank length non-symmetrically throughout the pedal cycle, is there a hidden physiological cost? If, for example, such a system requires slower cadence and higher muscle tension, will overall mechanical gains be negated by decreased blood circulation and subsequently lowered aerobic capacity?

—There have not been many publications on the effect of different types of chainrings on the mechanics of cycling. For example, non-circular chainrings are purported to improve the matching of the muscle/anatomical rider with the structure of the bike. And even within this sub-category there is a further division between those who increase the radius of the chainring in order to coincide with sections of the power stroke with the greatest effective force (Durham), and those who increase chainring radius at the *end* of the power stroke in order in slow crank rotation and translate some of the inertia of the leg mass into propulsion (Shimano).

While there would seem to be an intuitive rationale for both schools of thought, there has only been limited attention paid to them and primarily, it seems, by the manufacturers. This area may well provide some interesting data on the matching of the rider and the bike, especially given the recent technological advances shown in bicycle design. While it is not clear that we have reached a limit in that development (Kukoda, 1985), the next stage of development may be the better matching of the rider and the bike.

—The recent rise in popularity of recumbent cycling has not be met with a similar rise in interest in these bicycles from the biomechanist. In which ways do the typical recumbent positions differ in their requirements from the conventional bicycle?

In summary, then, there is yet a whole field of research on the biomechanics of cycling to be examined. These issues cover some of the fundamental muscle mechanics of riding to the improvement of elite performance. We'll explore some of the work already done in these areas in our next article, and move on to propose some new research in later articles.

Author David J. Sanderson received his Ph.D. in biomechanics from The Pennsylvania State University. While there, he worked with Professor Peter Cavanagh on the Elite Athlete Program for both running and cycling. Their work (condensed into a chapter of Science of Cycling, Burke, ed., Human Kinetics Publishers, 1986.) was instrumental in the U.S. Olympic team's training for the 1984 Olympics. Sanderson and Cavanagh also did research comparing in-shoe pressure distribution recorded in both running and cycling shoes for a major bicycle components manufacturer. Sanderson is currently setting up a biomechanics laboratory at the University of British Columbia and will continue his research in the bicycling field.

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**SOUND OFF!** Have an opinion you'd like to articulate? A better mousetrap or an easier way to accomplish something that you'd be willing to share with your fellow *Bike Tech* readers? We want *Bike Tech* to become more of a forum for new ideas, partisan opinions, and other beneficial dialogue between our readers. Send your letters to the Editor, *Bike Tech*, 33 E. Minor St., Emmaus, PA 18049.


Materials • Mechanics • Physiology • Engineering • Aerodynamics

BIKE TECH

Bicycling Magazine's Newsletter for the Technical Enthusiast

STATEMENT OF THE OWNERSHIP, MANAGEMENT AND CIRCULATION OF BIKE TECH REQUIRED BY ACT OF OCTOBER 23, 1962: SECTION 4369, TITLE 39, UNITED STATES CODE, FILED, OCTOBER 1, 1986. BIKE TECH is published quarterly at 33 East Minor Street, Emmaus, PA, 18049, publication and general business offices.

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**SPECIAL REPORT**

# THE 1986 IHPVA CHAMPIONSHIPS

## The Technological Evolution Continues In Vancouver

### Frank Berto

I attended the Speed Championships of the International Human Powered Vehicle Association (IHPVA) during Expo '86 in Vancouver, B.C. This was the 12th Championship, but it was my first close look at the HPV scene. Although a human-powered championship was held for the first time for watercraft, I concentrated on my natural habitat, the road. There were six races in the land championships:

1 - A 165-mile road race from Seattle to Vancouver.
2 - 200-meter sprints with a flying start.
3 - 400-meter head-to-head sprints from a standing start.
4 - A 15-km criterium with a LeMans start.
5 - A 35-km criterium.
6 - A one-hour maximum distance time trial.

Gardner Martin's Easy Racers team overpowered the competition. Professional bike racer Fred Markham provided the horsepower for two Easy Racers HPVs: the fully streamlined Gold Rush, which had just won the Du Pont Prize for the first HPV to exceed 65 mph; and an Easy Racer recumbent bicycle with a deep front fairing and a cloth body cover for the rest of the bike and rider. They won five of the six events. Four flat tires in the Seattle to Vancouver race ruined Easy Racers' chances for a sweep, and proved once again the futility of lightweight tubulars in states without bottle bills.

The finals for the 200-meter sprint was a repeat of the duel between builders Gardner Martin and Don Witte for the Du Pont Prize. Gold Rush went 57.59 mph on the final run to edge out Witte's Allegro, which went 56.43 mph. My personal opinion is that the upright position and lighter weight of Gold Rush allowed Markham to deliver more power in the last sprint.

Both HPVs went about 8 mph slower than their Du Pont speeds, because the Vancouver course was at sea level and didn't have the very slight downhill grade and tail wind allowed in the Du Pont runs.

Based on my observations and builders' comments in Vancouver, I conclude that to be competitive in the IHPVA speed trials you should adhere to these recommendations:

*Minimize frontal area.* The lower limit seems to be about 4.5 square feet for a rider lying on his back in a tricycle with the wheels in front of and behind the rider. Allegro epitomizes minimum frontal area design.

*Maximize the power output of the rider.* This often conflicts with the first recommendation. Glen Brown, who has been involved with the HPV scene for years, commented that the rider's backside has to be above the pedal spindle for good pedalling efficiency.

It's quite probable that an HPV using leg *and* arm propulsion would have more human power available than one powered by the legs alone. The problem is to enclose the rowing type mechanism and the rider within an acceptable frontal area. On the same theme, it's important that the rider gets enough practice time to be familiar with the HPV.

*Consider ground effects.* None of the HPVs with open bottoms went much faster than 40 mph. There are two schools of thought. You can either barely clear the ground with a flat surface (like Allegro), or you can provide for smooth air flow under the shell (like Gold Rush). In either case, it's very important to seal the openings where the wheels come through the shell.

*Minimize overall area and resulting skin friction.* This ties in with the first two recommendations. Putting the rider in a sitting position increases the frontal area a bit, but it also shortens the length of the HPV. That reduces overall area and surface drag. Laminar-86 and Gold Rush are good examples.

*Minimize overall weight.* Physiology texts have documented that, for very short periods of time, athletes can produce power outputs much greater than their normal, long-term capabilities. To take advantage of this on the IHPVA top-speed course, the HPV has to accelerate quickly just before reaching the 200-meter speed trap. Obviously, heavier HPVs accelerate more slowly, a fact that either requires more power for the same top speed or predestines a lower potential top speed.

*Use disc wheels.* Some people seem to think that wheels inside the shell don't count. That would only be true if the inside of the shell were under vacuum.

Here are some additional minor recommendations:

*Use strapless pedals* in recumbents where the feet hang from the pedals.

*Use a jackshaft,* rather than a huge chainwheel, to provide the necessary gearing. Along the same lines, use an 11- or 12-tooth final sprocket to keep chain speed down. Don't worry about chordal action. The Moulton HPV successfully used a 10-tooth sprocket, and they had a 9-tooth in reserve.

*Provide a very low mechanical advantage on the steering,* especially on tricycles. Bicycles need fairly quick steering to allow the rider to correct for crosswind gusts at HPV speed. Tricycles are more stable in cross winds, but at 50 mph you can still run off the course very quickly. On the down side, with low mechanical advantage it's hard to steer a straight line when you're putting out maximum power in the last sprint. I thought that the tricycles that steered one front wheel and drove the other were ingenious.

Within these suggestions, there's lots of room for diversity— witness the differences between Gold Rush and Allegro. There were nearly one hundred HPVs at Vancouver, but only about a dozen were able to exceed 50 mph. Let's look at nine of them to show how different designers tackle the same problems.

• GOLD RUSH (57.6 mph). Gold Rush is a tall, narrow two-wheeler. An aluminum-framed Easy Racer recumbent bicycle lurks beneath the Kevlar shell. The total package weighs just 31 pounds, which is extremely light for an HPV. Gold Rush is wildly successful testimony that it's possible to design a very efficient HPV with minimum frontal area that also puts the rider in a position which permits peak power development. In comparison, I think many of the tricycles suffer trying to meet this requirement.

In Gold Rush, Fred Markham sits in the standard recumbent position and the shell is designed around his dimensions. The frontal area is almost exactly five square feet. Gardner Martin worked hard to reduce drag where the wheels come out of the shell. Gold Rush is so air-tight that Markham was running out of oxygen by the end of the run.

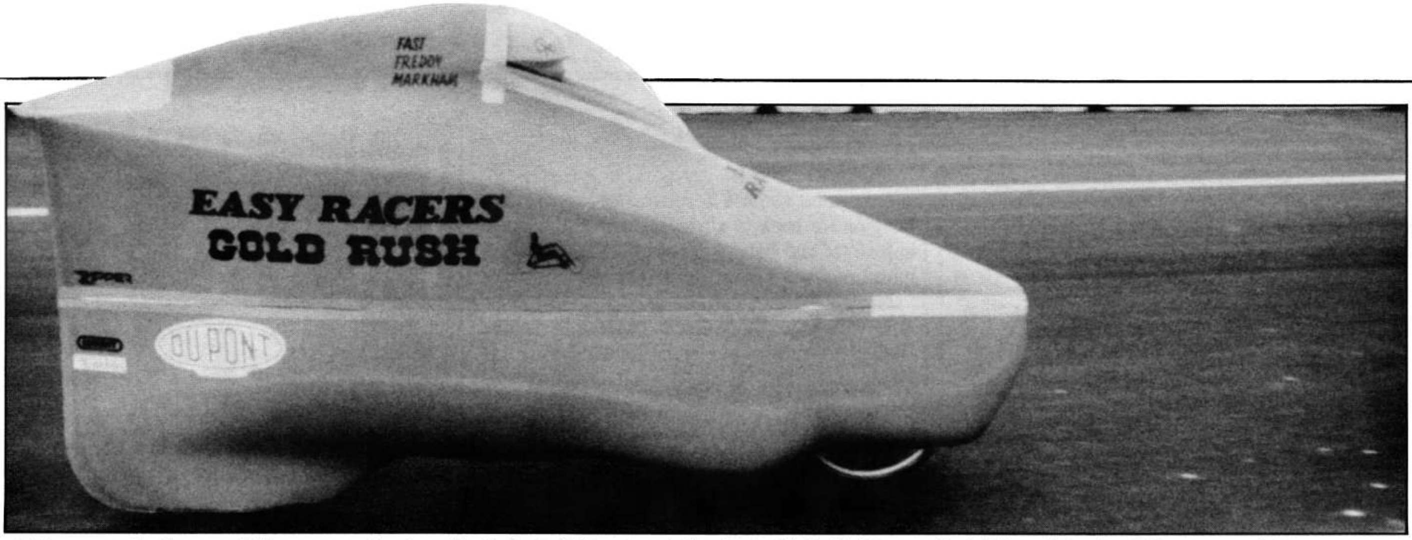
Like all of the completely enclosed two-wheelers, Gold Rush is a handful in a cross-wind, but not so much that it can't compete on a circular course. Markham showed what was possible by winning the 400-meter standing-start sprint, the 35-km criterium, and then reeling off 41.8 miles to set a new one-hour HPV record. Markham rode the more easily mounted cloth-bodied Easy Racer to victory in the LeMans start 15K criterium.

Martin uses a computer simulation developed by Danny Pavish that calculates the top speed of the Markham/Gold Rush package, correcting for altitude, course slope, and tail wind. It assumes that Markham puts out one horsepower in the final sprint through the traps. Martin predicted 57 mph for the Vancouver course and that's what they achieved.

• ALLEGRO (56.4 mph). Allegro is almost purely a straight-line racer. It's a tricycle with the steering and the power going to the single front wheel. The two rear wheels sit behind the rider's head, instead of alongside, to minimize width. The result is an 11-foot-long, airfoil-shaped white torpedo which clears the ground by less than an inch. Designer Witte adjusts the ground clearance to match the roughness of the course.

Allegro weighs 60 pounds and has a fixed 90 × 14 gear. A 120-rpm cadence produces 60 mph. Acceleration isn't very sprightly. The rider lies on his back with his head raised about a foot to get a knot-hole view of the course through his legs.

Although Allegro isn't at home on the road, it was comfortably averaging almost 41 mph in the one-hour contest when a flat forced them out of contention.




▲ **The overall winners at Vancouver, Gardner Martin's Gold Rush and "Fast Freddy" Markham, clock 56 mph in the 200-meter sprint.**

• LAMINAR-86 (54.4 mph). I was very impressed by Laminar-86, which made its first run at Vancouver. The builder, Wayne Kirk, didn't have a rider, and had to ask around Vancouver until he found a local racer to pilot Laminar-86. With very little practice, Laminar-86 went 54.4 mph. Kirk and company will be tough in 1987!

Laminar-86 is full of novel ideas. It's very small (like Gold Rush, just large enough to enclose a normal-size adult in a sitting position) to minimize skin friction. One front wheel of its narrow-track tricycle configuration is driven, while the other steers. The brake is on the rear wheel. The drivetrain is through a jackshaft, which allows the use of regular bicycle components. Laminar-86's smooth shell is a true monocoque, without major internal framework. Kirk hot-wired a large block of Styrofoam to make an airfoil-shaped male mold for the shell.

• VECTOR-007 (54.3 mph). At the first IHPVA meetings, there were all kinds of different configurations. Then there was a period where all of the winning HPVs were either Vectors or Vector clones. The Vector is a tricycle whose rider lies almost flat on his back. The two front wheels steer; the rear wheel is driven with a long chain.

• PRESTO (54.0 mph). Most of the HPV tricycles have stability problems at high speeds because the steering is so sensitive and the hard-working rider can barely see where he is going. Presto neatly avoids most of the problems by transmitting steering efforts hydraulically. The mechanical advantage of the system is adjustable.

• BIOTEC VISION (51.6 mph). This HPV had a very light, efficiently constructed shell hanging from a Bill Boston frame. The rider inserts himself through the frame, under the top tube and over the bottom tube.

• MOULTON AM-7 (51.1 mph). Alex Moulton came over from England to compete. One of his Moulton AM-7s was equipped with a deep front fairing with a cloth skirt behind. It came second in the 160-mile Seattle-to-Vancouver race that preceded the IHPVA finals. Not too shabby for a standard configuration bicycle.

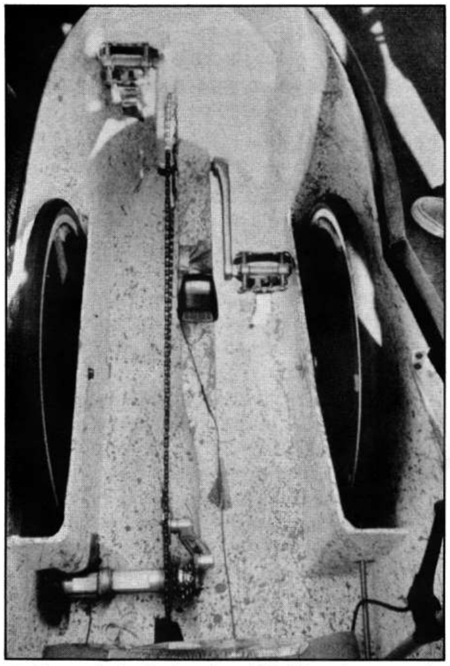
The other competing Moulton had a full aerodynamic shell and went over 50 mph in the 200-meter sprint. Under the skin it, too, was stock except for a larger chainwheel. It drove a 10-tooth small rear cog to produce 50 mph at a 120-rpm cadence.

• TORSO (46.0 mph). In the early IHPVA races, there many unusual drivetrains using arm or back power or linear-motion pedals. Few went very fast, because these designs increased frontal area and weight more than power output. Torso was a local Vancouver-built HPV that combined a rowing action with pedaling. Torso had a monocoque shell so it didn't need an internal chassis. The combined arm and leg drive train added little to the frontal area.

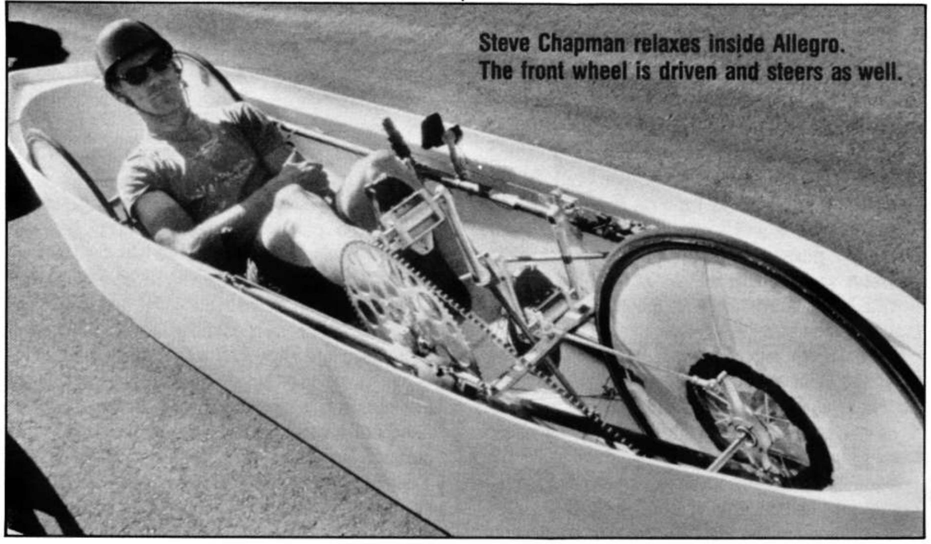
• TRIVIA (36.5 mph). This absolutely elegant Swiss two-person side-by-side HPV won *Bicycling* Magazine's $1000 prize for the most practical HPV. With so much frontal area, it was not much of a sprint racer. Trivia looks like it could be the first HPV to make a successful trip to the drive-in movies!

If you are interested in human-powered vehicles, the IHPVA costs $15.00 a year to join. Membership includes a subscription to Human Power, the IHPVA newsletter. Their address is:

IHPVA
P.O. Box 51255
Indianapolis, IN 46251-0255



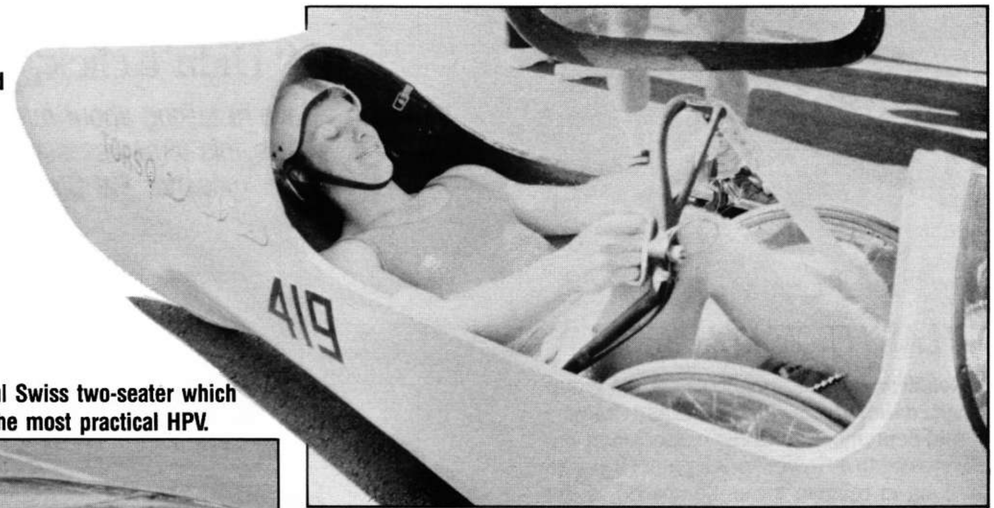
▲ **Powertrain in Laminar-86. Running gear is fixed directly to the load-bearing shell. Note that one wheel is jackshaft driven, while the other steers.**



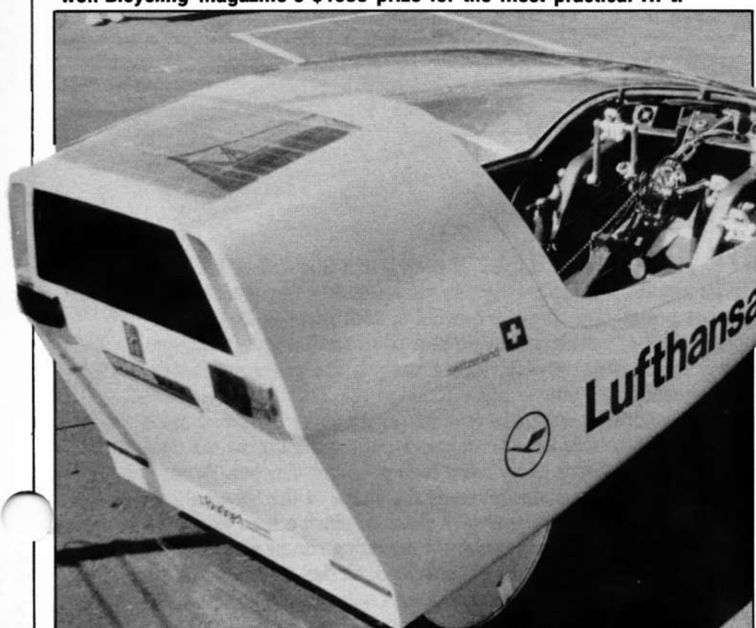
**Steve Chapman relaxes inside Allegro. The front wheel is driven and steers as well.**

PAUL SCHAFFER

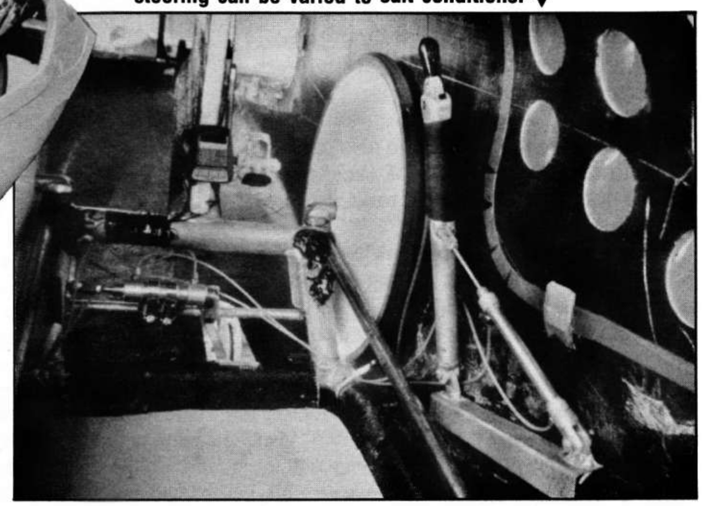
▶ The Torso tricycle combines pedaling and rowing power. Steering is accomplished with the right hand, braking and shifting with the left.




▼ Where's the runway? Trivia, the beautiful Swiss two-seater which won *Bicycling* Magazine's $1000 prize for the most practical HPV.




Drivetrain on Presto. The mechanical advantage of the hydraulic steering can be varied to suit conditions. ▼



▼ A study in contrast: fully recumbent Allegro and partially recumbent Laminar-86. The Allegro crew member is blowing fresh air into the body shell while designer/builder Don Witte tapes the top in place for a run.

# NEWSLINE...

## "Didn't click, didn't sell."

*If we're talking about mid- and upper-end bike sales, this terse assessment by Denver Spoke manager Pat Clark sums up 1986.*

### A FLASH FROM COLOGNE:

Needless to say, Shimano's new 105 group received a lot of attention at IFMA in Cologne in mid-September. With the extension of the SIS system to a "lower" price point (if you're thinking in relative terms compared to the going rate for 600 SIS componentry), plus the inclusion of a less expensive, stamped aluminum Biopace chainring set, and the real crowd pleaser of the year, the 105's SLR brakeset, it looks like 105 SIS may have an even more successful first year than its ubiquitous big brother, 600 SIS.

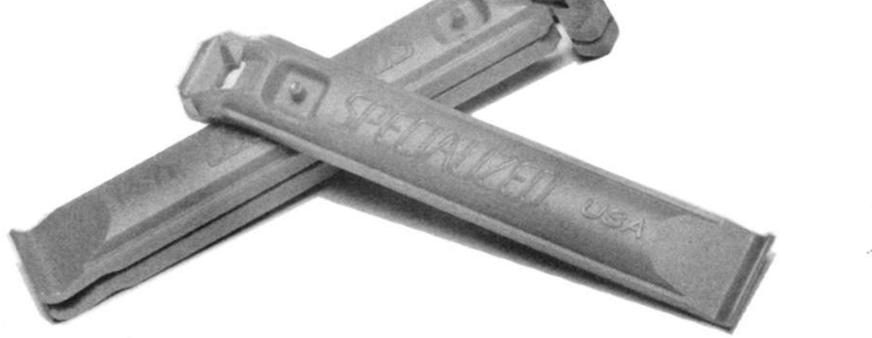
On the future note, Shimano also showed a nonfunctional prototype of their pedal/binding system, probably just to let us know they're serious about 1988.

Campagnolo introduced their Syncro indexing derailleur system, ending months of industry speculation and steadfast, vehement company denials. It's intended to mate with the Victory gruppo, but is compatible, according to Campagnolo, with the rest of the Campy derailleur line and any freewheel/chain combination. Unofficially, it's also claimed that Campy's new shift lever will index almost any other rear derailleur as well.

Ofmega and Huret also introduced indexing derailleur systems in Cologne. Look for details on the new systems in a future issue.

**THEY DIDN'T CALL HIM *SPEEDY* FOR NOTHING** You've gulped down your pre-race cup of extra-thick coffee for the caffeine blast and followed it with a generous allowance of baking soda to buffer your blood against lactic accumulation. Now your arteries are throbbing inside your head and your stomach is threatening a major revolt. You're probably thinking, "What can I take now to feel better and get even *more* speed benefits?" Well, superstar, how about some sodium phosphate, most easily found in Alka-Seltzer?

Dr. Robert Cade, the developer of Gatorade™, claims his research shows ingesting sodium phosphate can increase $VO_2$ max (your maximum oxygen capacity) by as much as 20%, making you more competitive. Unfortunately, some recent studies do not support this claim. Ethical considerations aside, we think you'll do better with Alka-Seltzer because it soothes your caffeine-induced headache and settles your queasy stomach.



DONNA M. HORNBERGER

**MORE COMPOSITE ACCESSORIES:** It seems that Specialized Bicycle Components isn't going to let any dust settle on their newly acquired composite technology. It started with their new water bottle cage, 2-piece molded in both graphite and glass short-fiber-reinforced nylon. *Bicycling*'s review showed that compared to steel and aluminum cages, the Specialized models offer cleaner styling, lighter weight, and greater strength, while Specialized also claims many times longer fatigue life.

Now Specialized is introducing another composite product: short-fiber-reinforced nylon tire "irons." The slippery surface qualities of nylon are an important contributor to the ease with which these levers slip under the tight beads of a typical high-pressure clincher. According to Jim Merz of Specialized, extra attention was also given to the shape of the "spoon" end of the levers to make them easier to work with, as well as less likely to pinch a tube during remounting. The levers are very light, and don't require a mounting clip or pouch—they clip together tightly, one against the other. According to Specialized, all development and production of both the bottle cage and the tire levers has been done, and continues, in the United States. Suggested retail is $3.00 for three.

With the current trend in exchange rates, could composite products be the starting point for a new American components industry?

## NOW YOU CAN, NOW YOU CAN'T. NOW YOU CAN, AGAIN!

Were you as confused as the *Bicycling* technical staff was when we tested several new bikes with welded aluminum frames made of "7000" series alloy? "Not possible!" I stated emphatically to the rest of our editors, who said as much to the manufacturers, who in turn retorted that the alloy in question has, indeed, a 7000 series designation. Developed in Japan, it's a high zinc-content alloy that's obviously weldable and furthermore, according to the manufacturers, is stronger than 6000 series aluminum. Okay, so we don't know everything.

Later (after publishing, of course), we discovered that the mystery alloy is *not* a U.S.-equivalent 7000 alloy—and that there is no correspondence between a Japanese 7000 series designation and the 7000 category in the USA. We'll try to get the alloy's exact designation and mechanical properties for the next issue of *Bike Tech.*

So now everything is fine, you can't do the 1/4 mile in less than 8.63 seconds, the dollar is strong, and you can't commercially weld 7075 or 7178 aluminum. Right? Not even close!

Just by chance, on a recent visit I happened to see Easton Aluminum's new aluminum tube mill, set up to continuously weld (you guessed it!) 7000 series strip into tubing. At one point, Easton used to own most of the downhill ski pole market back when poles were fabricated from seamless drawn tubing. That is, until some hot-shot French company named Pechiney (sound familiar, Peugeot lovers?) scooped up the market with their less expensive *welded* 7000 alloy poles. Count on Easton to get back in the fight.

So now you *can* weld 7000 series alloy, but, of course, you *may* not—neither Easton nor Pechiney is volunteering to tell you how to do it. It's probably almost impossible to do on a hand-held basis, anyway.