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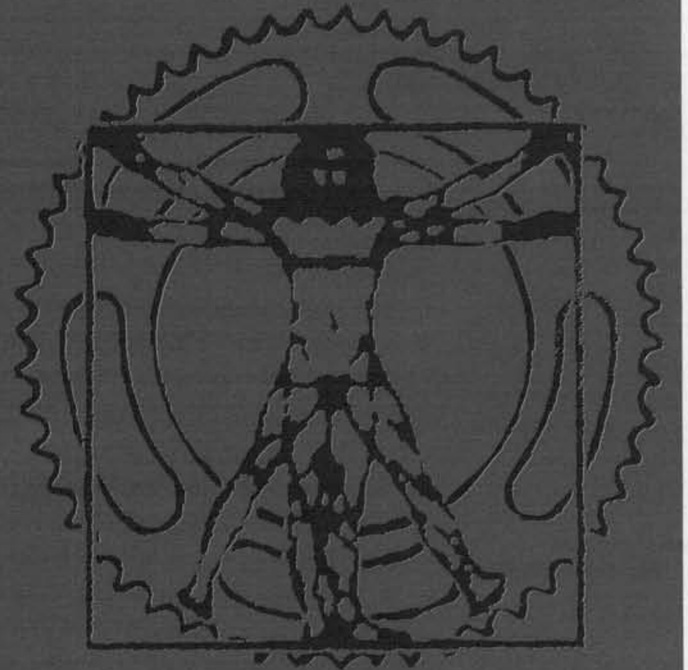

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Letters

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Reviews

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Stability and other factors in the design of displacement boats

Bob Stuart, a well-known Canadian builder of beautiful small boats and HPVs, and a previous contributor to *Human Power* and *HPV News*, reviews the rather extraordinary range of choices open to the designer of human-powered non- hydrofoil boats, giving the advantages and disadvantages of each approach.

Lower-extremity power output in recumbent cycling: a literature review

In the last issue of *HP* (13/2 p.19) your editor confessed that he had been remiss in not reviewing such highly relevant publications as the *Journal of Biomechanics*, and appealed for more-qualified reviewers. His plea was quickly and thoroughly answered. Raoul Reiser and Mick Peterson have condensed a major study of the whole biomechanics literature concerned with human power into a scholarly paper. This, with its large number of references, is longer than we normally carry. However, the topic is so central to the activities and enthusiasms of readers that we have waived the rules and have included it complete. Although Reiser and Peterson show that there is still some disagreement among research findings, there are ranges of recumbent positions that appear to give improved endurance and short-term output that can be used for the design of at-least near-optimum recumbent HPVs.

Looking ahead—human power in space

John Allen, normally the most down-to-earth of authors, muses about the advantages of using human power for transportation in future space colonies.

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Misplaced machismo? by Dave Wilson

CONTRIBUTIONS TO *HUMAN POWER*

The editor and associate editors (you may choose with whom to correspond) welcome contributions to *Human Power*. They should be of long-term technical interest (notices and reports of meetings, results of races and record attempts, and articles in the style of "The building of my HPV" should be sent to *HPV News*). Contributions should also be understandable by any English-speaker in any part of the world: units should be in S.I. (with local units optional), and the use of local expressions such as "two-by-fours" should be either avoided or explained. Ask the editor for the contributor's guide. Many contributions are sent out for review by specialists. Alas! We are poor and cannot pay for contributions. They are, however, extremely valuable for the growth of the human-power movement. Contributions include papers, articles, reviews and letters. We welcome all types of contributions, from IHPVA-affiliate members and nonmembers.

Stability and other factors in the design of displacement boats

By Bob Stuart

A boat is generally used to improve upon swimming for crossing a body of water. Thus, the best boat should provide a fast, dry ride. Of course, much boating is done for amusement, as is swimming, so we have no hard mandates. However, a boat without sufficient stability becomes, at best, a poor raft, generally spoiling the moment. Providing stability, on the other hand, will usually slow the boat down, detracting from our other main goal.

Maneuverability is also a major factor in making a boat safe and pleasant, and is often affected by decisions about speed and stability. There have evolved many arrangements to change the balance of these trade-offs and/or provide entertainment for the boaters. Amusement for the spectators, while sometimes achieved, is not usually the designer's intent.

In choosing an appropriate level of stability, we have to consider the conditions we expect to encounter. Ocean crossings often involve terrific storms and require great stability, at least during those periods. Inflatable supplementary floats are being developed for damaged yachts, and may prove useful for preventing damage too. Boats used for recreation on small inland waterways are little challenged by waves or winds, though conditions can change rapidly with almost no warning. This is a serious safety issue. In cold water, even a rather short swim may be impossible. In general, inland boats trade speed for maneuverability, the split between ocean and whitewater kayaks being very distinct. The loading of a boat can also affect its stability tremendously, for better or worse. Heavy loads high up are hazardous, and certain passengers bear watching.

The preferences, abilities and expectations of the operator must be catered to. Some people assume it is a boat's business to stay upright. Others stay aware of the possibility of capsize. Some sportsmen even enjoy taking frequent corrective action, as does a bicyclist or pedestrian. For them, providing the brains for the human-hull system is as satisfying as the traveling. With any craft, an experienced captain will compensate for worsening conditions by changing the windage, loading, course, speed and anything else available for the purpose.

One view of Bob Stuart's Lambordinghy. Photo: Bob Stuart

SINGLE VS MULTIHULLS

Most boats have only one hull, supporting weight by displacing water. Catamarans have two, and trimarans have three. Those with one hull are usually called monohulls, though the spokesman for Farrier Trimarans refers to the three types as "Cats, Half-Cats, and Cat-and-a-Halfs." The undoubted excellence of sailing multihulls has given their pioneers a certain élan, not unlike that of recumbent cyclists.

With two or three hulls, stability is virtually assured, and one can use very slender, slippery shapes. This comforting situation will change suddenly if a hull should get completely above or below the surface. This is as startling as the transition when a trike lifts a wheel. Besides providing a more gentle and controllable capsize mode, the big advantage of a single hull is that it will always have more room inside in proportion to the surface area, which is always expensive to build and maintain.

A monohull with the width and loading of a typical catamaran would be about as stable, but its extra wetted area would make it slow, as is indeed an empty barge. With increasing length-to-width ratio comes greater speed, but as we approach the 30:1 proportion of a rowing shell, the load gets squeezed out and up, and the craft becomes very tippy indeed. Racing shells, especially in the smaller sizes, require almost constant correction by oar work to remain upright. Similarly, narrow kayaks need active balancing, whereas wide ones are usually safe for paddlers without special skills.

TRIMARANS

Since HPBs need much less extra stability than sailboats, our trimarans are often more like augmented monohulls. The extra floats, or "amas", are small enough that a capsized boat can be easily righted by the swimming captain and then re-boarded. Gordie Nash pedals a long, narrow hull with very slim amas, and is quite successful racing against sculls on open water.

Sailing trimarans often have their secondary hulls set high enough that at least one of them is normally out of the water. A. Gast adapted this convention of "flying amas" for kayak hulls converted to pedal power. These are usually kept upright by slight motions of the upper body, but the small outrigged floats are always available for backup.

Charlton Bullock refined this idea,

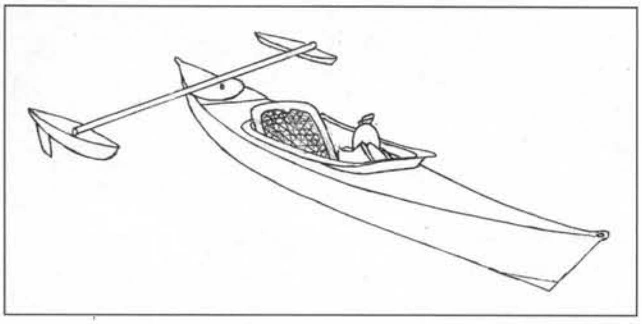

Figure 1. Lambordinghy, with swiveling outriggers

adding small, angled hydrofoils to tiny, raised floats, which help to maintain balance. For him, these have additional merit, because he also adds a sail, and the foils' effect is increased in proportion to need, along with wind speed and boat speed. His paddle and sail boat is in production as the Triak. One or two foils mounted to the side could also be actively controlled by a surface follower, like the front hydrofoil on the Flying Fish HPB, or the side foils on some sailing hydrofoils. One would normally be sufficient, but two would be safer for choppy water. Richard Ehrlich has been experimenting successfully with a pedal kayak using amas that get lift from planing as well as displacement. These are attached to his spare paddle, which is then clipped to the after deck.

The author has built a pedal-kayak, Lambordinghy, equipped with a special paddle. This normally rests in a pair of yokes connected to the rudder lines, and so is used for steering. However, the foil-shaped blades are held at a positive angle, and begin work instantly when needed. They plane initially at speed, but may also be used for all the usual kayak paddle tricks. It was hoped that the foil-shaped blades would provide useful buoyancy at rest, but they give so little that thin, smooth blades would probably serve as well.

Designing for speed usually involves a long, slender hull, which is hard to turn quickly. Adding more hulls or fins, especially toward the ends, makes the boat even less maneuverable. This effect can be much reduced with little loss of speed by adding "rocker"; that is bringing the keel line up gradually to near the water surface at stem and stern (fig. 5). Another experiment on Lambordinghy had flying amas mounted on a swivel near the stern so that they could replace the rudder, and help rather than hinder the turning. This worked quite well after the addition of small skegs (fins) to the floats (fig. 1). This scheme has the additional merit of allowing docking without interference from the outriggers.

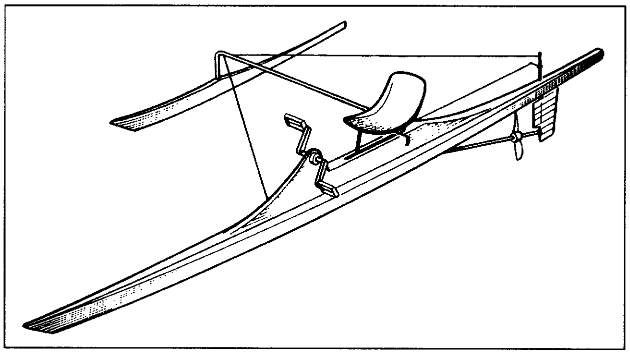
Figure 2. Saber Proa (illustration used with permission of Scientific American)

CATAMARANS

Catamaran arrangements are often used for human-powered boats (HPBs), and have enough excess stability to carry riders easily much higher up than do most monohulls. Tourists often rent paddle-wheel cats, and several manufacturers offer much faster propeller-driven versions. Buckminster "Bucky" Fuller was especially delighted with an inspiration he called "Rowing Needles."

Cats almost always have enough extra stability to carry sail, though I have heard of this being exploited only once, with a pedal-prop supplement to a Hobie Cat. Another way to pick up energy to rival what a pedaler provides is to exploit wave action. An experimental craft called the Gausfin achieved 4 to 5 knots in a moderate chop.

One drawback with two full-length hulls is that this shape has the greatest resistance to turning. Sometimes, two riders (notably at European HPB contests) each pedal one of two widely separated props, which provides superb maneuverability. In other boats, two people would generally use one prop with the pedals out of phase, since a prop is much more efficient with a constant torque.

A special case of two hulls is the proa, with one hull much larger than the other. The small hull works as a float or counterbalance as needed, and this combination has less surface area for the displacement than two equal hulls. The Saber Proa is an outstanding pioneer HPB of this type (fig. 2). The large hull could also contain the load low down, as does a monohull, thus reducing the need for supplementary stability. A sailing proa usually wants to keep the wind on the same side, so instead of tacking normally, it changes direction, sailing "forwards and backwards." Sailors call a proa that does not change direction a "tacking proa". The borrowed name may need some explanation applied to an HPB.

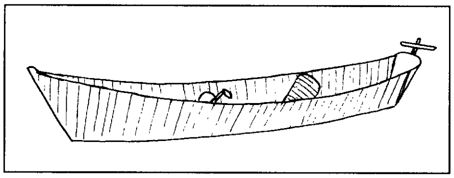
Figure 3. Phil Thiel's Dorycycle

CONVENTIONAL MONOHULLS

The obvious way to improve stability with a single hull is to make it wider (fig. 3), but there are a couple of tricks that can give good results with less added drag. Sailboats, which need a lot of stability to counteract the wind loads, and also have little speed to spare, often use ballast at the bottom of the keel, the bottom of the hull, or moveable ballast on the windward side. Extra weight is carefully trimmed from other areas, as it is otherwise a liability in fast vehicles. Another problem with ballast is that it is usually very dense, and can cause abrupt sinking if water gets in. Some HPBs also use ballast, notably Garry Hoyt's Mallard, now renamed Escapade and being produced in Michigan (fig. 4).

Traditional dories have relatively narrow, efficient bottoms, but widely flaring sides. The total effect is a bit like a trimaran; it starts to tip easily, but is soon caught by the buoyancy of the sides. One thorny problem with adding pedals to a dinghy is the change in trim between having one and two persons aboard, as the pedaler's position is hard to change.

BOATS LIKE BICYCLES

Recently, David Witt and George Tatum have independently hit on the idea of using a deep central fin, pivoted like a rudder and under constant manual control to generate a righting moment for an upright rider on a very narrow hull. David uses his fin to double as a forward rudder, while George finds

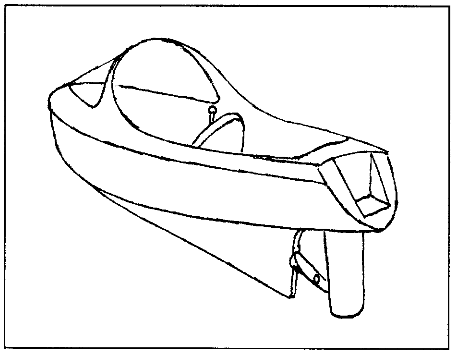
Figure 4 Escapade, a ballasted monohull

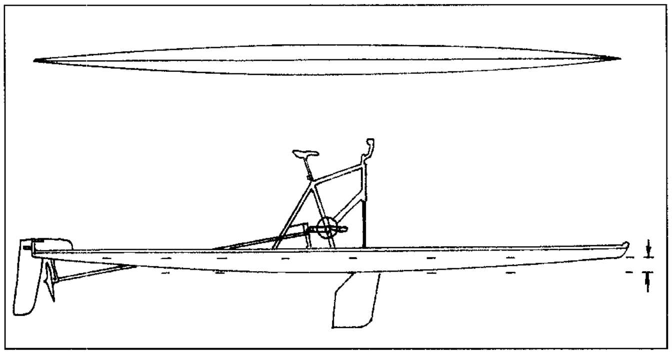

Figure 5. Wave Bike, also illustrating "Rocker" (between arrows, above)

less drag using a separate rudder at the stern (fig. 5). He was very successful at this year's Hydrobowl event, achieving 9.57 knots in the 100 m contest, and about 7 knots for 2 km. This boat is also headed for production as the WaveBike. Bill Volk has suggested that George's fin could be automatically controlled by a pendulum. So far, all boats of this type have used retractable outriggers for stability at low speed. A rigid rigger holding the float(s) high might be used instead.

SUBMERGED-BUOYANCY BOATS

Another type of monohull has much potential, but needs major help for stability. This is the submerged-buoyancy craft, which has most of its hull well below the surface on a strut (fig. 6). Since it does not make the usual big waves there, it can be shorter and wider than usual, with less surface area for the weight supported. Theo Schmidt built one of these using four angled hydrofoils to provide stability with limited success. It could also be stabilized by at least two small floats, or by three or more thick struts between surface and main hull. Once underway, active foils could take over the job of providing stability. The designer must take into account the radical trim changes during boarding, and the need for fine trim changes for different loads.

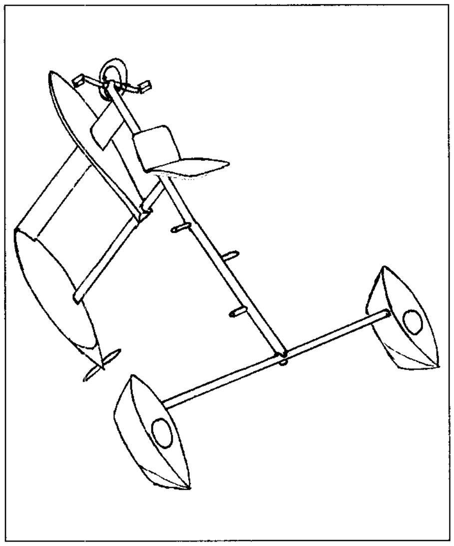

Figure 6. Submerged buoyancy craft, unladen, with two amas

HINGED AND FLEXIBLE HULLS

One production cat, the Water Bike (fig. 7), provides a hinge about two thirds of the way back along the hulls, so the whole aft ends worked as rudders. The turbulence at the hinges may not cause much more drag than a rudder, and in a tight turn, the overall resistance is much reduced.

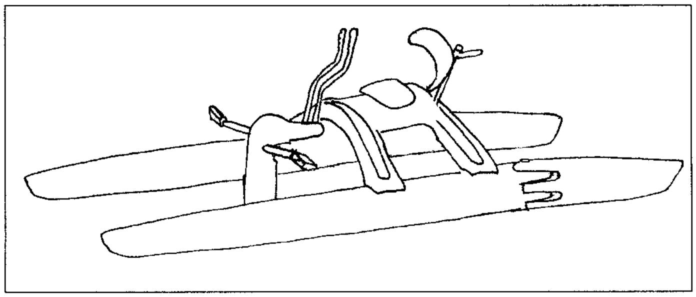

Figure 7. Water Bike, with and and foot power, aft hull parts steered by seatback

A fully flexible hull, like a water snake, may be theoretically ideal, but is difficult to build. Machines which walk or flap wings also have much trouble imitating nature with machinery. The snake has the right proportions for use on the surface. The "S" shape, while always undulating for propulsion, would also provide the width for stability. For submarine use, MIT has experimented with the "Robotuna", but now is moving on to imitating a penguin, with a rigid body and moving feet. With surface craft, the traditional sweep oar at the stern imitates a fish's tail. Calvin Gongwer and Harry Bryan have both improved the efficiency of this action with spring-mounted foil shapes.

Some boatmen, notably in the Caribbean, have mastered a tricky motion standing in the stern with a single stern oar held almost vertically. The blade moves from side to side as a foil, and then is levered back to keep up a constant thrust at the ends of the strokes. This keeps the oar engaged in a simple notch in the stern without extra hardware. Caucasian mariners are also usually unfamiliar with two other ways of using extra muscle groups for power with ancient craft. Chinese postmen row with their feet, facing forward. Native Americans paddle canoes with a motion that employs the whole upper body rocking back and forth.

RECOMMENDATIONS FOR HP BOATS FOR DIFFERENT PURPOSES

The catamaran is deservedly popular as a configuration suitable for operators of any level of ability operating in fair weather. Stable monohulls will carry the most load per dollar, and are handier to load and use than undecked cats. Any multihull can carry a "trampoline" or a solid deck between the hulls, providing great lounging area and versatility. The long, slender monohulls with one or two supplementary floats have a slight edge in speed, and are better suited to provide shelter for riders and their gear than the cats. The tall, fin-stabilized monohulls may be faster yet, and provide the fun of balancing over the ever-changing waves. The submerged-buoyancy craft is the least developed, and may be best for racing over distances out of range for pure hydrofoils. A kayaking friend of mine, when told the range of my speedy boats, protests "but—once I'm on the water, I'm ***there***!" So, you will probably have fun whatever you build if it works at all.

Bob Stuart lives on Salt Spring Island, between Victoria and Vancouver, British Columbia, Canada. Before working on propeller-drive units and complete HP boats he designed and built the Car-Cycle X-4, a prototype for a streamlined, suspended trike.
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Lower-extremity power output in recumbent cycling: a literature review

by Raoul F. Reiser II and M. L. Peterson

INTRODUCTION

The recumbent cycling position has become popular for high-performance human-powered land vehicles. The popularity is due mainly to its reduced frontal area, and thus reduced aerodynamic drag, as compared to the familiar upright position (Gross *et al.*, 1983). In addition to the reduced frontal area, the recumbent position has several other features that make it attractive as a cycling position when compared to other riding positions. The center of mass of the vehicle may be positioned relatively low to the ground making the vehicle more stable and safer since there is less distance to fall if a crash were to occur. In a crash situation the head is protected in the recumbent position as compared to the upright position where the head leads the body if thrown forward over the handlebars (Wilson *et al., 1984*). Visibility is improved in the recumbent position with the head naturally facing forward which improves the safety of the vehicle by keeping the oncoming road in the field of vision (Martin, 1984; Wilson *et al.*, 1984). The natural forward-facing position of the head may also reduce neck strain (Ice & Waite, in preparation). For many riders the seat position is more comfortable in a recumbent position, reducing the likelihood of crotch pain and injury (Kita, 1997; Wilson *et al.*, 1984), and gives the rider firm support to push against while pedaling (Wilson *et al.*, 1984). This position also reduces the strain on the lower back and wrists as compared to the familiar upright position (Ice & Waite, in preparation; Wilson *et al.*, 1984).

While the recumbent riding position has these many advantages when compared to the standard cycling position, it may have two key disadvantages. The recumbent position may not allow for peak-power production and sustained aerobic performances from the rider that are as high as those obtained in the upright cycling position. Several studies have found that the standard position is favorable to other positions (Diaz *et al.*, 1978; Kyle & Caiozzo, 1986; Metz *et al.*, 1986), while others have found just the opposite (Nadel & Bussolari, 1988; Wescott, 1991).

However, the recumbent riding position has been very successful which seems to indicate that the advantages outweigh any disadvantages, at least for a high-speed sprint vehicle. Three noteworthy recumbent-position human-powered vehicles have been ridden over 96.5 km/h [60 mile/h] on flat terrain unaided by a tailwind. In contrast, the top speeds in the standard riding position are under 80.49 km/h [50 mile/h] (Gross *et al.*, 1983). The Vector tandem was a tricycle that reached 101 km/h [63 mile/h]. The Gold Rush, a bicycle, attained a top speed of 105.9 km/h [65.84 mile/h] and the Cheetah, another bicycle, currently holds the human-powered vehicle speed record at 110.6 km/h [68.73 mile/h]. While all three utilized the recumbent riding position, all three had slightly different positional variations relative to the other designs. The Vector Single utilized a hip position approximately level with the pedal crank, while the Gold Rush had the hips slightly above the cranks. The Cheetah had the rider positioned with the hips slightly below the cranks. However, the exact riding positions are not known for these designs, as are a number of the other biomechanical parameters and design factors.

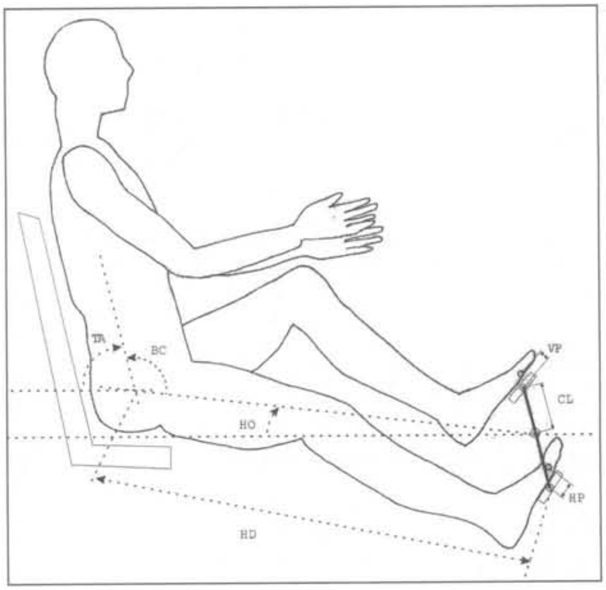

Figure 1.Geometrical variables which must be defined to completely describe the cycling position of the rider: hip orientation (HO), torso angle (TA), hip distance (HD), crank-arm length (CL), and horizontal (HP) and vertical (VP) foot position, as well as the foot-to-pedal interface (not shown). Body configuration (BC), which may be deduced from TA and HO is also included to help describe the cycling position.

At the present time, it is unclear what the impact of slightly different riding positions is on the performance of the vehicle, and it is possible that higher speeds could have been achieved by utilizing a different riding position. However, a small body of research has emerged which addresses some of the questions surrounding the biomechanics of recumbent cycling. In particular, the optimal position for power production is of interest for these type of vehicles.

DEFINITION OF TERMS

Due to the wide variety of cycling positions and variations among each position, several geometrical terms must be defined so that any cycling position may be clearly and completely described. First, **hip orientation** will refer to the angle, HO, that is produced by the intersection of a line connecting the hip joint and the center of the crank spindle with a horizontal line through the center of the crank spindle (0° with the hips horizontal and behind the crank). For clarity, all terms are represented graphically in figure 1. Second, **hip distance**, HD,will refer to the straight-line distance from the hip joint to the pedal spindle when the leg is in its most extended position of the cycling motion (similar to saddle height in upright-cycling nomenclature). Third, **torso angle**, TA, will refer to the angle that is produced by the intersection of a line connecting the shoulder joint and the hip joint with a horizontal line through the hip joint (0° with the shoulders horizontal with and behind the hips). Fourth and fifth, the **horizontal** and **vertical foot positions**, HP and VP, will refer to distance between the pedal spindle and the ball of the foot in the directions parallel and perpendicular to the bottom of the foot, respectively (positive distances with the ball of the foot in front of and above the pedal spindle). Additionally, the term **body configuration**, BC, (a combination of the hip orientation and torso angle) will refer to the angle produced by the intersection of the line connecting the shoulder joint and the hip joint with the line connecting the hip joint and the center of the crank set.

REVIEW OF LITERATURE

When a geometrical parameter (hip orientation, hip distance, foot position on pedal, foot-to-pedal interface, torso angle, and crank-arm length) or operational parameter (pedaling cadence and load) is altered in the cycling motion the tendency is to produce also a change in the kinematics of the lower extremity (Brown *et al.*, 1996; Too, 1994; Too, 1991b). When the kinematics are altered, the body's ability to produce a force on the pedal is also affected (Kroemer, 1972). The pedal force can be separated into a muscular component that is due directly to the net joint moments and a non-muscular component due to gravitational and inertial effects. Both of these pedal-force components contribute to propulsive and non-propulsive forces on the crank-arm and may be altered by a change in one or more of the geometrical or operational parameters (Kautz and Hull, 1993).

Musculoskeletal biomechanics

The net joint moments are predominantly a sum of the individual joint moments produced by each muscle that crosses a joint. In addition to the muscular contribution, passive structures such as ligaments and joint friction produce moments about the joint. In healthy joints that are not operating near the extremes of motion, friction and passive structure contributions to the net joint moment may be ignored (Winter, 1990; Zajac & Gordon, 1989).

The moment produced by the muscle is a product of the tensile force in the musculotendon and the moment arm created by the joint geometry. Both the ability of a muscle to produce force and the moment arm vary as the joint angle varies (Hoy *et al.*, 1990; Kulig *et al.*, 1984; Winters & Stark, 1988). Some muscles cross more than one joint (biarticular) and therefore have a dependence on two joints for their ability to produce a moment at a single joint (Kulig *et al.*, 1984).

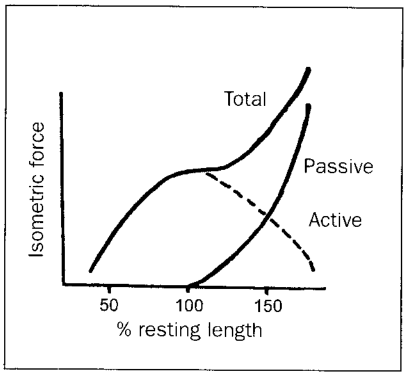

Figure 2. The force-length relation of a muscle/muscle fiber.

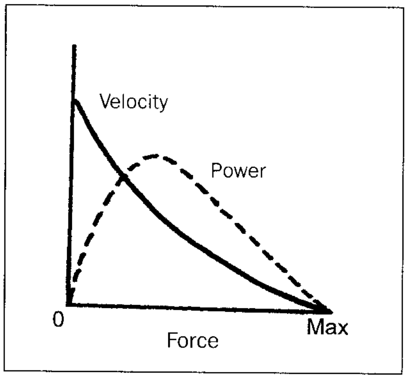

Figure 3. The force-velocity of shortening (solid line) and force-power (dotted line) relations of muscle.

Geometrically, the ability of a musculotendinous unit to produce force is dependent on the muscle length, tendon length, arrangement of muscle fibers, and the rate of muscle shortening/lengthening (Hoy *et al.*, 1990; Winters & Stark, 1988; Zajac, 1989). Skeletal muscle is connected to bone at each end by tendon. Tendon is a passive structure which stretches under load. Since the tendon is in series with the muscle, both transmit the same load and any change in length of the tendon causes a change of length in the muscle in order to maintain tension on the bone or prevent damage to the tendon, muscle, or bone.

Muscle is comprised of individual muscle fibers. Each muscle fiber has a force-length-velocity profile which is a combination of the active and passive force-producing elements in the fiber (fig. 2) (Winter, 1990). The passive force-producing elements are similar to tendon in that they produce a force when stretched beyond their no-load resting length. The active force-producing elements (sarcomeres) generate force by attempting to shorten. There is an optimal length for producing peak force. Any shortening or lengthening of the fiber from this optimal length (resting length) reduces the fiber's ability to produce force. In addition, the velocity of shortening/ lengthening has an influence on the fiber's ability to produce force (Gregor & Rugg, 1986; fig. 3). The faster the fiber shortens, the less force it is able to produce. Peak power from the muscle fiber occurs at approximately one-third the maximum force-production level (fig. 3). Peak power is the product of the peak force and the velocity of shortening.

The individual muscle fibers can vary in resting length and orientation relative to the line of action of the entire muscle (Alexander & Ker, 1990). These variations give each muscle its own unique force-length-velocity profiles which are further altered by the type of muscle fibers, number of muscle fibers, and fatigue level of the fibers (Kulig *et al.*, 1984). The active force produced by a muscle is then altered through nervous-system control by varying the number of muscle fibers active at any one time. The net joint torque that a person can generate is further influenced by age, sex, body type, motivation, and exercise conditions (Kulig *et al.*, 1984). It is beyond the scope of this review to discuss these factors in more detail. However, it is important to understand that they do contribute to the force a muscle can produce as well as increase the complexity of finding the optimal position for high-performance recumbent cycling.

The moment arm of a muscle is altered as the joint angle changes due to changes in the line of action of the muscle. Most muscles act directly along a line connecting the origin and insertion of the muscle. However, some muscles do not follow a straight-line path due to a bony obstruction. The obstruction may be present for all or just part of the range of motion of the joint that the muscle crosses (Hoy *et al.*, 1990; Seirig & Arvikar; 1989).

Cycling is a highly planar activity that involves the hip extensors (gluteus maximus, gluteus medius, gluteus minimus, biceps femoris (long head), semimembranosus, and semitendinosus) and flexors (iliospoas and rectus femoris), knee extensors (vastus lateralis, vastus intermedius, vastus medialis, and rectus femoris) and flexors (biceps femoris, semimembranosus, semitendinosus, and gastrocnemius), and ankle plantar flexors (gastrocnemius and soleus) and dorsi flexors (tibialis anterior) (fig. 4) (Gregor *et al.*, 1991; Hull and Hawkins, 1990; Hull and Jorge, 1985; Too 1993a; Too 1991a). Additional muscles are also involved during

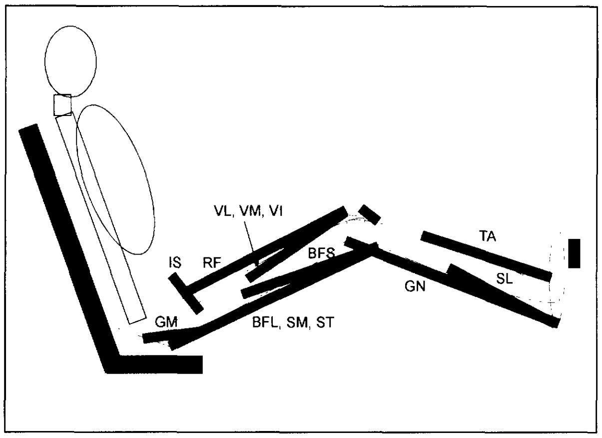

Figure 4. Schematic representation of the muscles of the lower extremity identified as prime movers in cycling: biceps femoris long head (BFL), biceps femoris short head (BFS), gastrocnemius (GN), gluteus maximus (GM), gluteus medius (GM), gluteus minimus (GM), iliospoas (IS), rectus femoris (RF), soleus (SL), semimembranosus (SM), semitendinosus (ST), tibialis anterior (TA), vastus lateralis (VL), and vastus medialis (VM).

all movements to a smaller degree as joint stabilizers that may act synergistically or antagonistically (Zajac & Gordon, 1989). Investigations have found that the moment arms of many of these muscles change dramatically with joint angle (Hoy *et al.*, 1990; Nemeth & Ohlsen, 1985; Spoor & van Leeuwen, 1992; Spoor *et al.*, 1990). For example, Nemeth & Ohlsen (1985) found that the moment arm of the gluteus maximus decreased 48 mm, the moment arm of the hamstrings decreased 20 mm, and the moment arm of the adductor magnus increased 46 mm when the hip was flexed in the sagittal plane from the anatomical position to 90°. This change could have a significant impact on the power production of this important muscle.

As mentioned, the non-muscular components are also affected by alterations in the geometrical and operational parameters. The gravitational contribution to the pedal force is altered with variations in hip orientation. As the hip orientation is changed, the horizontal distance between the pedal and seat also changes. The gravitational force contributed by each segment that is shared between the pedal and seat is therefore altered. In addition, the torque contribution of gravity on each segment will be altered with a change in hip orientation. Finally, the inertial contribution is dependent on pedal cadence. The faster the pedaling cadence, the greater the inertial forces (Kautz & Hull, 1993).

Since both the muscular and non-muscular contributions to the pedal force are dependent on the geometric and operational parameters, it is hard to predict the best rider position to produce optimal joint moments from the hips, knees, and ankles. A number of investigations have been performed to examine the effects upon recumbent cycling performance by varying one or more of the biomechanical factors. A summary of the key results as they relate to the hip orientation and torso angle follows. While the other geometrical and operational parameters are important, they do not contribute large changes in the design of the vehicle in terms of the size and shape of the vehicle nor does space allow for adequate discussion of these parameters. However, references are provided for the reader on these parameters in the appendix.

Experimental investigations into recumbent cycling

Too (1991b) systematically altered the hip orientation from -10° to 65° in 25° increments while maintaining a 90° torso angle (fig. 5). Fourteen male recreational cyclists (ages 21–32 yrs) with very little to no recumbent cycling experience performed the Wingate anaerobic cycling test with a resistance of 0.83 N/kg of the subject's body mass [BM] (5.0 joules/pedal rev/kg BM) in each of these positions. Subjects were strapped to the seat and back rest by means of a lap belt and shoulder harness while pedaling with toe clips. Additionally, hip distance (100% of trochanteric leg length (distance from floor to greater trochanter when standing erect)) and crank-arm length (not specified) were controlled for each subject.

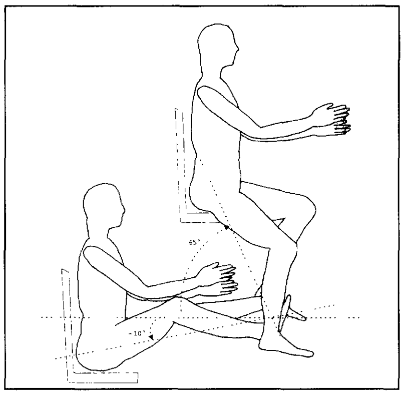

Figure 5. Test position range utilized by Too (1991b): hip orientation from -10° to 65° in 25° increments with constant 90° torso angle.

Kinematic analysis found that the mean ankle and knee angles stayed relatively constant, ranging from 90.1 to 92.8 and 98.2 to 103.6°, respectively, while the mean hip angle increased from 58.9 to 114.0° from the hip orientation of -10 to 65°. Relative peak power output (highest average power during any successive five second interval divided by body mass) varied from 10.55+/-1.38 to 11.73+/-1.03 watts/kg BM with the 15° hip orientation yielding the greatest values. The 15° hip orientation was significantly greater than the -10 and 65° hip orientations, but not significantly different from the 40° hip orientation (table 1). Additionally, relative average power (over the entire thirty-second test) and fatigue index (percentage of peak power subtracting the lowest power from the peak power and dividing by the peak power) were calculated. Relative average power values followed a similar trend to the relative peak power scores while the fatigue index was similar across all hip orientations studied.

From this experimental design it could not be determined if the changes in power output were attributable to changes in mean hip angle (body configuration), gravity effects on the lower extremity, or a combination of both. Too (1994) refined the experimental design to try to isolate the effects of gravity on peak power output. A similar setup and test protocol was utilized while varying the torso angle along with the hip orientation in order to maintain a constant body configuration of 105°. The 105° body configuration was selected because it was the most powerful in the previous study. Sixteen male recreational cyclists (age 20-36 yrs) performed the Wingate anaerobic test against a resistance of 0.83 N/kg body mass with a hip orientation of -15, 15, and 45° (torso angle of 60, 90, and 120°, respectively) (Figure 6). Kinematic analysis confirmed that mean hip (80°), knee (100°), and ankle (83°) angles did not vary significantly between these three positions. The relative peak power was found to be greatest in the 15° hip-orientation position, but not significantly greater than the -15° hip-orientation position (the total range of relative peak

Table 1

Hip orientation degrees)	-10	15	40	65
Torso angle (degrees)	90	90	90	90
Body configuration (degrees)	80	105	130	155
Peak power (W/kg BM)	10.91	11.73	11.43	10.55
Average power (W/kg BM)	7.84	8.29	8.14	7.53
Fatigue index (%)	47.9	49.6	49.8	49.4

power was between 11.68+/-1.25 and 12.29+/-1.19 watts/kg BM) (table 2). Similar trends occurred for the relative average power calculations. The fatigue index was similar for all three test positions.

Too (1989 & 1990) performed experiments in similar hip orientations and torso angles as in the previous two studies, but measured cycling duration and total work output to exhaustion using a pre-selected sequence of power outputs (varying both pedal cadence and work load). He found that the 15° hip orientation (90° torso angle) produced significantly greater cycling duration and total work output to exhaustion than any of the other positions studied from -10 to 90° (all with 90° torso angle). When torso angle was varied along with hip orientation (similar to Too (1994)) to maintain the same body configuration no significant differences were found in cycling duration and total work output to exhaustion between the three positions.

In order to get a sense of why peak anaerobic power output and aerobic performance might change with different hip orientations, Too (1991a & 1993a) repeated the recumbent positions tested earlier and examined electromyography (EMG) levels while cycling with a resistance of 0.64 N/kg of body mass and pedaling cadence of 60 rpm. EMG gives an indication of muscle activity levels by measuring its electrical activity. EMG of the gluteus maximus, rectus femoris, biceps femoris (long head), vastus medialis, gastrocnemius (lateral head), and tibialis anterior of the lower right limb were monitored. Based on his analysis there was a forward shift in pedal position location that the muscles were active and inactive from the -10 to 90° hip orientation (torso angle at 90°). However, there were no significant differences in muscle activity sequence/timing or duration of activity with changes in hip orientation. A similar shift in the pedal position location where the muscles were active was found when both the torso angle and hip orientation were altered simultaneously. No differences in cycling performance could be attributed to the differences in EMG patterns examined from these studies.

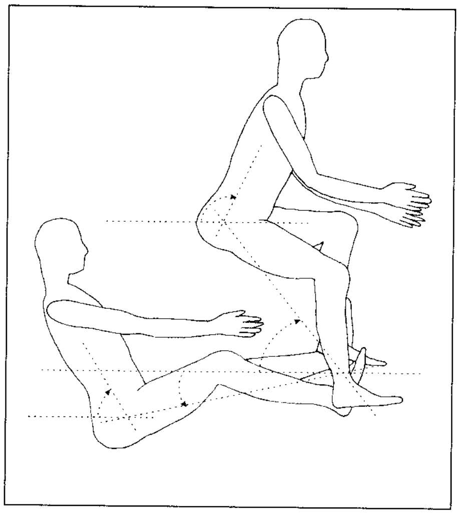

Figure 6. Range of test positions utilized by Too (1994): hip orientation of -15° to 45° in 30° increments. The torson angle was adjusted with hip orientation from 60 to 120° in order to maintain a 105° body configuration.

Brown *et al.* (1996) also simultaneously manipulated the hip orientation and torso angle while subjects (seven males and four females, healthy recreational cyclists, average age 27.5 yrs) pedaled at a constant power level (workload of 80 W and cadence of 60 rpm). In addition to collecting EMG from the tibialis anterior, gastrocnemius (medial head), rectus femoris, and biceps femoris, the lower-extremity kinematics and pedal forces were also measured. The kinematics and pedaling kinetics were combined to calculate the ankle-, knee-, and hip-joint moments using inverse dynamics. In this experimental protocol the hip orientation and torso angle were identical, with data collected at angles of zero through 80° in 10° increments (fig. 7).

Results showed that the changes in body position systematically altered all net joint moments. Mean hip torque showed increased flexor values as the cycling position became more vertical, while at the knee there was increased extensor values, and mean ankle torque showed increased dorsiflexor values. The EMG results supported the alterations in joint moments by adjusting muscular activity. Integrated EMG showed heightened levels of tibialis anterior, rectus femoris, and biceps femoris, and depressed levels of gastrocnemius activity as the body was tilted into a more vertical position. Slight changes in pedaling kinematics were also noted as the body orientation was altered. The authors concluded that these changes were necessitated by both alterations in the mechanical aspects of gravitational forces and sensory consequences from the changes in cycling position.

Table 2

Hip orientation (degrees)	-15	15	45
Torso angle (degrees)	60	90	120
Body configuration (degrees)	105	105	105
Peak power (W/kg BM)	12.14	12.29	11.68
Average power (W/kg BM)	9.00	9.27	8.73
Fatigue index (%)	46.0	44.3	46.1

Kyle & Caiozzo (1986) performed power-output studies with subjects in standard cycling, supine, and prone positions. Little information was given about the exact positions studied, training state of subjects, or details of the power-output tests. It was found that the greatest power outputs were achieved in the standard cycling position, followed closely by the supine position, and finally the prone position. This trend occurred for power-output tests lasting less than one minute and tests lasting one minute and longer.

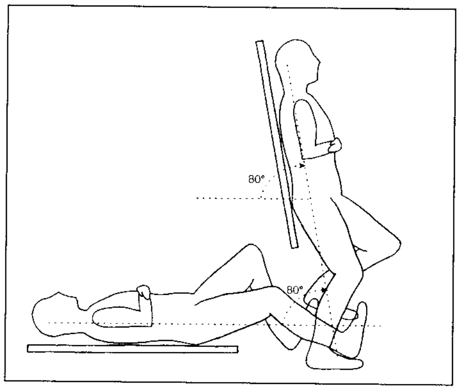

Figure 7. Range of test positions utilized by Brown et al. (1996): hip orientation and torso angle were varied together from zero to 80° in order to maintain a 180° body configuration in 10° increments. Note: while not diagrammed, a seat was used to maintain a constant hip-to-pedal distance when pedaling as well as to remove the effects of the upper-body mass on the cycling kinematics and kinetics.

In addition to the two sets of experiments performed by Too (1989 & 1990) that examined time and total work output to exhaustion, others have investigated the effects of body position on long-duration cycling performance (Bevegard *et al.*, 1966; Diaz *et al.*, 1978; Metz *et al.*, 1986; Nadel & Bussolari, 1988; Stenberg *et al.*, 1967; Wescott, 1991). The body's ability to perform sustained work was found to vary with body position due to alterations in its ability to circulate the blood and exchange gases in the lungs (Bevegard *et al.*, 1966; Stenberg *et al.*, 1967). The blood both provides nutrients to the working muscles and removes waste products of energy production. While tasks that are primarily aerobic in nature must consider these physiological adaptations that occur with changes in body position, a primarily anaerobic task, such as a performance for setting the human-powered speed record which takes approximately two minutes to complete, does not rely on optimal blood circulation and ventilation in the lungs during the task (Foster *et al.*, 1995; Too, 1994). However, since a large amount of time might be spent training in the vehicle or in the run-up leading to the sprint, blood circulation should be considered no matter what the intended goal of the vehicle.

Analytical investigations into recumbent cycling

The only analytical approach directed to investigate the recumbent position was by Lei *et al.* (1993). This model took into account both the geometry of the rider as well as the effects of the riding position on the aerodynamic cross-section of the vehicle. The model did not include any muscles and therefore the effects of different muscle lengths in different rider positions. Hip orientation, torso angle, hip distance, and crank-arm length were all varied within constrained limits which included a minimum torso angle in order to maintain adequate forward visibility. Both anaerobic and aerobic performances were evaluated by means of two different cost functions. For anaerobic performance the cost function was designed to minimize the moment variations on the hip and knee joints while for aerobic performance the cost function was to minimize both the average and maximum variation of the hip- and knee-joint moments. The model was designed for a target speed of 40.0 km/h with a vehicle weight of 50.0 kg, air drag coefficient of 0.15, rolling friction of 0.01, and pedaling cadence of 60 rpm with a 50th percentile male rider.

The optimal aerobic (endurance) performance was computed to occur with a hip orientation of -5.70° and torso angle of 26.72°. The optimal anaerobic (speed) performance was calculated with a hip orientation of -25.4° and torso angle of 48.1°. Both simulations found the optimal hip distance to be 0.751 m and crank-arm length to be 0.15 m. The model was also run without taking aerodynamic drag into account in order to compare with the results of Too (1991b). This simulation found the optimal anaerobic position to be with a hip orientation of 22.9° and hip distance of 0.662 m as compared to 15° and 0.666 m, respectively, experimentally established by Too (1991b). Since the length of muscles crossing the hips are not considered by the model and aerodynamics no longer a concern, allowable torso angles include any angle that would maintain visibility. Crank-arm length of this modified model was not reported.

Other analytical investigations have been performed to investigate the effects of hip orientation on steady-state cycling performance, as reviewed by Gregor *et al.* (1991). However, these studies generally constrained the hip orientation to stay greater than 70° in order to stay within the bounds prescribed for the standard bicycling position. The most comprehensive multivariable analysis was conducted by Hull & Gonzalez (1990). They found that changes in hip orientation significantly altered the results of the joint-moment-based cost function. It was also found that the optimal hip orientation was altered by rider size. In addition to being constrained to maintain a standard cycling position, muscles were not included in the model. Without muscles, the effects on performance by changing their lengths and moment arms with the changes in position could not be assessed.

Additional experimental investigations have looked into various hip orientations and torso angles while maintaining the upright riding position, such as Umberger et al. (1998). However, the majority of these studies have concentrated on the aerodynamic implications of the various positions with the assumption that time training in the most aerodynamic position will make it a viable riding position. These studies are reviewed in Gregor *et al.*, (1991).

From the reviewed literature it is clear that varying one or more of the biomechanical parameters may alter the power-production capabilities of the cyclist. However, the optimal recumbent riding position is still not clear. Nor is it clear whether the standard cycling position is better biomechanically and physiologically than recumbent cycling, since none of the reviewed articles tested the subjects in the standard cycling position as well as the recumbent positions.

Effect of gravity on performance

Brown *et al.* (1996) showed through inverse kinematics and EMG analysis that muscle-group contributions do change as the effects of gravity are altered on the lower extremity. Too (1991a) also noted alterations in muscle activity when only the effects of gravity on the extremities were altered. However, due to the low power output of the cyclists measured relative to their peak power in these two studies it cannot be concluded that peak power output would be altered by the effects of gravity on the lower extremities. Too (1990) showed that altering the effects of gravity on the lower extremity and blood circulation did not alter the work output and time to exhaustion in the three positions studied. In addition, two out of the three positions studied were not significantly different in peak power output (Too, 1994). While this limited number of studies is not conclusive, it appears that the effects of gravity on performance may be small, at least in the range of positions studied.

Effect of body configuration on performance

No studies to date have altered the body configuration while maintaining a constant hip orientation in order to remove the effects of gravity on the cycling performance. However, assuming that gravity is a secondary effect based on the previous discussion, body configuration has a major effect on power production while cycling. Based on the work of Too (1989 & 1991b) the 105° body configuration may be optimal for both peak power production and sustained aerobic performance. However, the differences in the peak power at the 130° body configuration were not statistically significant. Also, with 25° increments between the body configurations tested, the optimal configuration may be a position not tested. Gravity also may play a large enough role to alter the optimal body configuration at some hip orientations. More research is needed into the effects of body configuration as well as the effects of gravity to make any solid conclusions about the optimal riding position.

It is interesting to note that the 105° body configuration falls in the range used in the standard cycling position. Cavanagh & Sanderson (1986) reported that elite pursuit cyclists rode with an average torso angle of 145°. Considering that the standard cycling position general uses a hip orientation (seat tube angle) from 70 to 90° (Burke & Pruitt, 1996), the cycling position for these elite pursuit riders has a body configuration from 105 to 125°. The 125° body configuration is within 5° of the position that Too (1991b) found to be not statistically different from the 105° body configuration. This knowledge lends further support to the assumption that the musculoskeletal biomechanics at the hip may be of more concern than the effects of gravity on the lower extremity for power output. These conclusions may be a bit premature, however, since Too (1989 & 1991b) did not test his subjects in the standard cycling position and they would not be considered 'elite pursuit riders' who may have trained into their riding position. The human body is highly trainable and may be able to adapt to a seemingly non-optimal position and make it optimal, as long as the cycling position is not too drastically different from a good power-producing position.

Additionally, care must be taken when implementing the results from Too and Brown. These studies are based on results from recreational cyclists with little to no recumbent cycling experience. Also, these results are based on studies where the subjects used toe-clips rather than clipless pedals which are more common for high performances. Clipless pedals may make a large difference in recumbent cycling since gravity is acting differently on the legs than in the standard cycling position.

While analytical models can provide great insight into what position may be optimal and why, the results from those reviewed in this article were not used here to justify one position over another. These models did not incorporate the effects of changing the muscle lengths and moment arms across the hips that appear to be a major determinant of performance based on the experimental results. Without the inclusion of these musculoskeletal effects the analytical results are difficult to use, even if they appear to be consistent with the experimental results.

CONCLUSIONS

Along with the power-production capabilities of the rider and the aerodynamics of the vehicle, additional performance factors and practical constraints must be considered when designing a successful human-powered vehicle. Performance factors include the power-train efficiency, vehicle dynamics, and road friction for a land vehicle. The fairing must also be designed to allow adequate air flow in order to keep the rider cooled. Practical constraints include the visibility, controllability, structural stability, safety, and comfort of the vehicle. Many of these factors are not independent. For example, the rider position, in addition to affecting the rider's ability to produce power and the aerodynamic design of the vehicle, may also affect the drive-train construction and thus its ability to transfer the energy from the pedals to the wheels efficiently. For these reasons, the overall design may not include the optimal riding position for peak-power production/sustained performance or the design with the lowest aerodynamic cost. However, a global optimal for all design constraints should be selected.

More research is needed into the effects of body configuration and gravity acting on the lower extremity, as well as the effects of training on cycling position. None-the-less, an aerodynamic position with a low hip-orientation angle (either positive or negative) combined with a body configuration from 105 to 130° appears based on current literature to be justifiable for a high-performance human-powered vehicle.

APPENDIX

The following are references that discuss geometric and operational parameters beyond hip orientation and torso angle. References followed by an 'R' have information directly related to recumbent cycling.

Hip distance: Gregor *et al.* (1991), Too (1993b) R, Too (1990b) R

Crank-arm length: Gregor *et al.* (1991), Inbar *et al.* (1983), Too (1990b) R, Too (1996) R, Too (1998) R

Foot position on pedal : Burke & Pruitt (1996), Hull and Gonzalez (1990)

Foot-to-pedal interface: Broker & Gregor (1996), Gregor *et al.* (1991), Moran (1990), Moran & McGlinn (1995), Wheeler *et al.* (1995)

Pedaling cadence and power output: Coast (1996), Gregor *et al.* (1991), Too (1990b) R, Urlocker & Prassas (1996), Whitt & Wilson (1982)

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LOOKING AHEAD: HUMAN POWER IN SPACE

John S. Allen

The IHPVA has competitions for surface, air, and waterborne vehicles. It is only a matter of time until there are also competitions in extraterrestrial environments. This article will look into some of the challenges and possibilities of human-powered travel on other moons and planets and in space stations. The insights to be gained may be useful in planning space missions; but also can lead to some useful Earthbound applications.

This article is not the first discussion of human power in extraterrestrial environments. In his early story "Pokanyne of Mars," science fiction author Robert Heinlein described human-powered aircraft that flew in a sealed cavern used for a moon colony's air storage. Conditions in the cavern were much more favorable for human-powered flight than on earth, due to the moon's low gravity and to an atmospheric pressure 3–4 times that on earth. Heinlein's were birdlike wing-flapping craft, not propeller-driven ones like those that have now actually been built and flown. In his juvenile story "The Rolling Stones," Heinlein described bicycling on the surface of Mars (1).

Human Power editor David Gordon Wilson suggested a human-powered lunar vehicle to the National Aeronautics and Space Administration (NASA) some 15 years before the Apollo lunar missions. NASA rejected Wilson's idea and sent an electrically-powered cart, the Lunar Rover, with the astronauts on the Apollo mission. The astronauts brought back movies of the Lunar Rover throwing rooster tails of dust, skidding and bouncing like a dune buggy. This was possible because of the moon's low gravity, and despite the Rover's low power. Wilson described the human-powered lunar surface vehicle in an article which appeared in Galileo magazine in 1979 (2).

In his article, Wilson argued that a human-powered off-road lunar surface vehicle would effect impressive savings in launch weight for an Apollo mission, and could go about 18 mph (30 km/h) with a rider's power input of 75 watts (1/10 horsepower) —even faster than the electrically-powered vehicle that actually went to the moon. In a surprising turn, Wilson showed that human power would actually be too high for safe personal transportation on paved surfaces on the moon. The low gravity would both increase speed and decrease the ability to corner and brake. As an alternative, Wilson pointed out that the power-to-speed relationship for a human-powered aircraft in a lunar colony would be ideal, and determined that flying such aircraft would be great fun — not the hard work it is with the higher gravity on Earth. Wilson also advocated low-speed human-powered transport vehicles for use in lunar colonies.

Let's look into some of the science that underlies Wilson's observations about surface travel, and see where that leads us.

Gravitation has many important effects on human-powered travel. Yet, if we do not venture beyond Earth, Earth's gravity is easy to take for granted. When we look into environments beyond earth, we can begin to understand just how drastically the amount of gravitational force affects the operation of human-powered vehicles.

This starts with the human body itself. Humans, like other life forms on Earth, have evolved in response to Earth's gravity. It is well-known that larger creatures must work harder against gravity than smaller ones; the heavy bones and strong muscles of large dinosaurs, bears and elephants are necessary to maintain the ratio of bone and muscle cross-section to body volume.

Since aviators frequently experience high-gravity conditions, the effect of higher-than normal gravitation in the short term is well-known. Several times Earth's gravity can be tolerated in a seated or recumbent position, but mobility is seriously impaired.

Since it is unlikely that anyone will subject experimental subjects to life in a centrifuge for weeks at a time, the effect of higher-than normal gravitation in the long term can only be imagined, and this will be the case for a long time, since all planets in our Solar System that have higher gravity than Earth are gaseous: they have no surface to stand on. Even a hypothetical nuclear-powered space station for interstellar travel would accelerate very nicely at a comfortable 1 g.

The effects of zero gravity on the human body are well-known, thanks to long tours of duty on the Russian Mir space station. In the long term, muscles and bones degenerate in zero-gravity or low-gravity space environments where they are not subject to the loading for which they are designed. A program of exercise is necessary to minimize these effects. In the future, space stations may be placed into rotation to simulate gravity and avoid these issues.

As Wilson has pointed out, human-powered vehicles can provide some of the exercise necessary to counteract the ill effects of low gravity. But the vehicles, too, would have to adapt. Let's examine how travel in wheeled HPVs would be different on the Moon, with 1/6 the gravity of Earth.

The coefficient of friction (μ) between tire and road surface does not vary greatly with loading. Therefore, a bicycle's maximum lean angle on an unbanked turn would be the same on the moon, since both weight and cornering force are proportional to gravity. However, with less gravitational force, any given curve radius (r) would require a lower speed (v). You would lean way over in a turn, without being able to turn very sharply.

With one-sixth Earth's gravity, the achievable cornering radius would be $\frac{r_m}{r_e} = \left(\frac{v_m}{v_e}\right)^2 \left(\frac{g_e}{g_m}\right) \left(\frac{\mu_e}{\mu_m}\right)$ so that if $\left\{\frac{g_e}{g_m}\right\} = 6$ and if $\left\{\frac{\mu_e}{\mu_m}\right\} = 1$, the cornering radius on the moon, r_m, would be six times that on earth for the same speed, v. For the same cornering radius, $r_m = r_c$, the speed would have to be reduced by $\sqrt{6} = 2.45$

The "instant turn" emergency maneuver, pulling the handlebars in the direction opposite the turn, would still be the fastest way to begin a turn, but it would take seconds, not a half-second.

If the front wheel were to skid from steering too quickly or leaning too far, the resulting fall will be so slow that it would be possible to recover control. The technique would be to yank the bike upright to increase traction momentarily, at the same time steering into the turn. Skilled BMX riders recover from low-speed front-wheel skids on earth, but anyone could do it on any bike on the moon.

Falls will be in slow motion, 1/6 earth speed, so there will be little risk from falling off the bike onto the pavement. Most serious accidents will be collisions, with impact due to forward motion. And it will be hard to stop that forward motion. In lunar gravity, braking would suffer as much as cornering, since the achievable braking force is directly proportional to weight. On a conventional bicycle, excessive front-wheel braking causes unweighting of the rear wheel, and in the extreme case, the rider is pitched forward off the bicycle. On the Moon, pitchover would occur at 1/6 the braking force on earth. It would take only a very weak front-brake application on a diamond-framed bike to pitch a rider forward, arcing slowly upwards two to three metres (ten or fifteen feet) while moving forward at full speed.

Speed on upgrades and downgrades will vary much less from that on the level; six times the slope would be needed to achieve the same acceleration or deceleration as on earth. Hills and bumps also would pose a serious hazard. A bicyclist could ride very quickly up steep hills, and would easily leave the surface at a hillcrest or at any large bump in the road.

Acceleration would be limited by front-wheel lift, up to quite high speeds. It would also be very easy to skid when accelerating ("burn rubber") with a bicycle; special care will be necessary to avoid it when starting. Careful control of motions of the center of body mass would be necessary to keep from lifting the tires off the pavement, and if they lifted, they would bounce—again...and... again—as in a slow-motion movie, before they finally settled down. At low speeds, it would easily be possible to yank the front wheel up into a "wheelie" and even to flip over backwards.

These conditions would also tend toward high speeds. Yet it would be much easier to learn to balance and steer a bicycle on the Moon than on Earth. Since the bicycle would fall over much more slowly, slow steering corrections would keep it upright. On the moon, a conventional bicycle would be a fool's thrill machine the way a fast motorcycle or Jet-Ski is on earth.

Given all the problems, a recumbent would have a major safety advantage under conditions of low gravity. And, given the probable small size of lunar colonies, slow, three-or four-wheeled transport vehicles would be most practical for use inside the colonies. Such vehicles could transport loads many times the rider's mass. A vacuum or magnetic device to increase friction would be helpful for emergency braking, and be more practical the larger the vehicle.

The advantage of the slow rate of falling does point toward a device which might be useful on Earth: a bicycle simulator that would slow down the rate of falling to allow people to learn to balance and steer easily. (I understand that a virtual-reality company in Cambridge, MA has built a bicycle simulator, but I don't know whether this has been used to teach balancing and steering).

Traffic behavior

Due to the low traction, the traffic capacity of roads in moon colonies would be lower than on earth. This leads to another point in favor of human power: the higher speed of motorized vehicles would not be desirable. Greater following distances would be required, and it would be necessary to slow down more when approaching intersections—just as when riding or driving on packed snow on earth.

The limitation on acceleration, along with the low rolling resistance and air drag (assuming low pressure of the artificial atmosphere) would afford very little advantage for a motorized vehicle over a human-powered vehicle for personal transportation in a lunar colony.

It is conceivable the bicyclists might ride on steeply-banked tracks in a lunar colony, for exercise and for sport. A bicycle track with high bank angles could approximate the conditions of cycling on earth, and provide lunar cyclists with healthy exercise, while the artificial gravity due to the centrifuge effect of the track prevented bone degeneration.

Since air supplies in a lunar colony have to be renewed artificially, combustion engines would be out of the question. Vehicles would have to use either human power, or electrical power with batteries charged from a solar or nuclear power plant. Distances in lunar colonies would be small, typically like those in a large warehouse or factory complex on earth. Weather would be controlled, and lighting would be available at any time—it would have to be, since the moon's night lasts fourteen earth days.

The environmental conditions, like the operating conditions, point to the usefulness of human power for goods transport—and perhaps also as a stationary power source, rather than primarily for personal transportation.

One possibility for higher-speed travel would be a pressurized tunnel in which cyclists would travel in a helical path. This would allow travel between colonies.

Pedaling technique

The moon's gravity would have a very dramatic effect on pedaling technique. Toe clips would be essential, and cleats or clip-in pedals highly recommended, because gravity would be little help in keeping feet on the pedals and an excessive pedal thrust could loft a rider right off the bicycle. Saddles and bicycling shorts might have mating Velcro patches to keep the rider in place.

The most effective pedaling technique by far will be a light spin. Standing up on the pedals as we know it will not be effective, since the rider's weight will be so small. A standing rider would have to push with one leg and pull with the other. Pulling hard isn't good for the knees, so lunar cyclists will probably experience a new knee ailment: "moon knee." As a stress injury, this would be unusual on the Moon.

On the moon, the recumbent position will have a much smaller effect on the way leg weight influences pedaling. The advantage of being to push against the seat back will be more important.

1) Thanks to cyclist and science-fiction fan Sheldon Brown for the Heinlein references.
2) Wilson, David Gordon (1979). "Human-powered space transportation." *Galileo* magazine nos. 11 & 12 (double issue) Boston, MA 1979. A brief article about the pedal-powered lunar rover also appeared in *Time* magazine of January 8, 1979.

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LETTERS

TIRE DIFFERENCES ON VEHICLES

There are two points on which I disagree with Dietrich Fellenz, in "Tip over and skid limits of three- and four-wheeled vehicles" HP (13/2/p.8). He assumes that all tires in vehicles are identical. On many recumbents this is not the case. From my experiments, if all tires have the same tread and tire pressure, the product of tire width and diameter should be proportional to tire loading.

If the designer tries to equalize tire-contact areas by combining a small-diameter wide wheel with a large-diameter skinny wheel, as is often done on short-wheelbase bicycles, it does give the desired skid performance, but also gives strange and unpleasant characteristics to the ride and to the steering. On rough surfaces, one end feels as if it is dancing to a waltz, which the other end is doing a jig. Also, spreading the wheels further apart seems to slow down the transition into a skid, so that a person with normal reflexes has a chance of recovering. Bikes with two wheels close together can be 'out from under you' before you know it. Presumably, three- and four-wheelers with close-set wheels also break free quickly.

In his discussion, Fellenz does not go into detail on the importance of front-to-rear position of the center of gravity on skid performance. As Huston, Graves & Johnson make clear in "Three-wheeled-vehicle dynamics" (IHPVA Second Scientific Symposium), the CoG should be located forward of the midpoint of the wheels. (They also assume that all wheels are identical—what is it with these multi-track people?) If the front wheels do the steering, one wants the rear wheels to start skidding a little before the front. Thus the operator has a chance to correct the skid, given this remaining ability to control the vehicle. This condition is given with about 55% of the weight on the front wheels for two or four identical wheels.

Automakers use this forward weight bias, combined with softer suspension in the front than in the rear, not only to give good handling properties at the limit, but also to improve the ride (the "flat" or "boulevard" ride, first used in 1934 in the Chrysler Airflow). On unsuspended bicycles, however, the ride qualities improve with a more rearward weight distribution (within reasonable limits). I set up my unsuspended bicycles with identical wheels to have about 45% of the weight on the front wheel for the ride improvement. I lean forward when riding and encountering a patch of gravel, for instance. This setup can be modified for vehicles with non-identical wheels as described above.

On a related but unconnected matter, one would think that the ride qualities of unsuspended bicycles could be pretty well predicted by the wheelbase, the CoG height, the wheel diameters, the vertical flexibility of the frame, the tire shock absorption, and the weight distribution. I rated (subjectively) all of the thirty-odd bicycles I've built over the years for ride quality, and matched my ratings agains my experience. The correlation was pretty good except for the five bicycles that had the most-similar tires on both ends seemed to ride about 20% better than expected. They had a general similarity to the Rotator 'Tiger': three had all-20" tires, and two had 16" front and 20" rear. The 20" models had the nicest steering of any of my bikes. Is there something special about this layout?

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Dietrich Fellenz responds

I read Charles Brown's letter with interest and have the following comments.

I am delighted to see such outpouring of empirical and anecdotal information derived from actual riding experience. I believe any disagreement is with what I didn't write, rather than with what I wrote.

My paper was restricted to first principles, and obviously one can think of a lot of fine tuning for specific applications.

I agree with the observation that the mixing of unequal wheel types and sizes may introduce strange dynamic ride effects. I also agree that a short wheel base would contribute to a hair-trigger skid behavior. As far as the lateral holding ability in a turn is concerned, Charles Brown seems to say:

when you exchange a large-diameter/skinny wheel with a small-diameter/wide wheel that the product of tire width and diameter should be held constant, all other parameters being the same. That is nearly the same as requiring that the contact area should remain constant, which I would agree with.

I am not sure to which extent wheel load and contact area contribute to the lateral holding ability in a turn. I only know that both are involved, so that I feel justified in stating that a lightly loaded wheel with the same tire would have more lateral holding ability than would be expected if it was determined only by its proportionality to the wheel load. From this would follow: if you want a safe rear-first skid setup (because only so can you steer your way out of a skid) you should unload the front wheels slightly.

I don't think the 1934 Chrysler is a good example of a safely skidding vehicle. Front-loaded vehicles have a way of skidding in front first if you attempt to make a fast turn, meaning that at that point there is no more steering authority available.

A slightly rear-loaded vehicle would perhaps skid at the rear, but you can steer your way out of the skid if you do it soon enough. A small amount of rear loading would be desirable. over any front loading.

I am still hoping that someone will step forward with a realistic tire-friction model, where the effects of tire dimensions, contact area and wheel load, and perhaps others like rubber characteristics are properly accounted for. That would go a long way towards putting this issue to rest.

Charles Brown states that he can predict the ride qualities of unsuspended bicycles from design parameters. I would be interested to see how this process is quantified.

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MORE ON CLIMBING WITH LOW BOTTOM BRACKETS

Zach Kaplan

I normally cruise at a cadence of about 90 RPM. I go up to 120 RPM only in sprints or if the particular HPV I am riding doesn't have a high enough top gear to maintain a lower cadence on a particular downhill. However I don't do much sprinting and I usually coast on descents unless I want to get a running start for a climb that immediately follows the descent. On long rides (over 12 hours) my cruising cadence often drops to 80 RPM. I have found that with the better circulation I get with the low-bottom-bracket position I am able to pedal at slightly lower RPM in general. I find a cadence of 90 RPM+ more essential on a high-bottom-bracket bike to reduce fatigue in the muscles of the legs though my knees will protest if I "lug the engine" at too low a cadence regardless of bottom-bracket height.

In the course of extensive riding of both high- and low-bottom-bracket recumbents I have found in general the steeper the climb the greater an advantage the low-bottom-bracket position has over a high-bottom-bracket position. This is because the steeper the climb the closer to pedalling upside down is the rider of a bike with a high bottom bracket. As far as I know the muscles in the legs of the human body were designed to work most efficiently with the best blood circulation when low in relation to the level of the heart such as when walking or running. In this respect the typical upright diamond-frame bicycle has a more ergonomic position than any of the currently produced recumbents. This is perhaps why many people find they climb faster and easier on a diamond-frame bike than on a recumbent. The pedalling dynamics of a low-bottom-bracket recumbent are closer to that of a diamond-frame bike. Perhaps pedalling in the low-bottom-bracket position also feels more natural because one does not have to support the weight of one's leg as much during the power stroke on a low-bottom-bracket bike. Gravity can be used more to get the crankset past the dead spot at the bottom of the power stroke. By lifting the leg on the return stroke energy can be stored and used to help push the leg back down during the power stroke. This may help spread the total energy expenditure of the leg muscles out over a greater duration of each revolution of the bottom bracket thus decreasing peak stresses and fatigue. In any case I believe the low-bottom-bracket position enables better climbing both because of the way the muscles operate in relation to the effects of gravity and through improved blood circulation for similar reasons. I admit this is all speculation on my part and more research needs to be done in this area, perhaps some tests using heart-rate monitors and watt meters that can measure power applied to the pedals during the various portions of each revolution of the cranks.

It remains clear to me that I climb faster with less apparent effort on a low-bottom-bracket recumbent vs. a high-bottom-bracket recumbent. Contrary to Tim Brummer's speculations, in my case the steeper the climb the greater the advantage the low bottom bracket has. I would think most "normal humans" with "normal" circulation and muscle development would have similar results if they were accustomed to riding in both positions and climbed a steep hill with high- and low-bottom-bracket recumbents of similar weight.

In Northern California we have an annual 320-km (200-mile) ride called The Terrible Two. It is known as one of the most difficult double centuries in the US as it has 4880 m (16,000 feet) of climbing sometimes in the 15–20% range. Only a small number of recumbents have completed this ride within the 16.5h time limit. I have completed The Terrible Two three times. All three times I was in very similar physical condition and the weather conditions were similar. In 1995 on a Lightning R-84 with stretch-fabric F-86 full fairing my time was 14:47. In 1996 on a Lightning R-84 with a more aerodynamic sailcloth F-86 full fairing my time was 14:46. In 1998 on an Easy Racers Gold Rush with stretch fabric body stocking my time was 14:38. The ride does have some level portions and on level ground the Gold Rush with body stocking is about 20% slower than the F-86. The Gold Rush also weighed slightly more than the F-86 as it has wide tires running at 4.5 bar (60–70 psi) rather than narrow tires running at 8 bar (110–120 psi). I attribute the 8-minute time savings riding the less aerodynamic Gold Rush entirely to the climbing superiority of its low-bottom-bracket position.

I am tall for my weight, so that this makes me more sensitive to cross winds when riding a fully faired Lightning. However even if I gained a lot of weight I would still be relatively sensitive to side winds when riding a two-wheeled vehicle with an aerofoil shape and lots of side area. I know of 90-kg (200+ lb.) riders who have been blown off the road riding Lightning F-40s. One of my scariest cycling moments was when I was riding a Lightning F-40 with a full touring load down the shoulder of US 101. A strong gust of wind from the right side blew me into the traffic lane. Luckily the vehicle in that lane had just passed me.

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Paul Buttemer

Starting in 1990, I have had the pleasure of riding and competing in HPVs built by George Georgiev (the Torso and Varna streamliners). In conjunction, we have built several unfaired recumbents for the purposes of training. These unfaired recumbents were designed to put the rider in the same position as is required to ride the fully faired vehicles. The bottom bracket is between 250–280 mm (10 and 11 inches) above the seat, and the rider is reclined such that the shoulders are slightly below the highest point attained by the knees during the pedal stroke.

Since starting to ride recumbents, my riding has been split roughly 50/50 between the recumbent and the road bike. My local club has weekly time trials, and I regularly ride these TTs on either type of bike. Initially, it was obvious to me that climbing on the recumbent was noticeably slower. My hope was that this was due to lack of training in the recumbent position, so I purposely did lots of hill training on the recumbent.

In order to properly evaluate the two positions in relation to climbing, it is important to equalize both the weight and the aerodynamic properties of the bicycles. The increased attack speed and the preservation of momentum, both due to streamlining, make it possible to "roll over" some quite substantial hills on a recumbent, especially a faired one. I will cite two, although admittedly extreme, examples. The road race at the 1991 IHPVA Championships, in Milwaukee, took place on a ring road around a park.

When Matt Weaver was checking out the course, he noticed a hill and was worried that he didn't have the right gearing in his Cutting Edge to climb the hill. After the race, he didn't remember the hill at all, and never had to shift out of his top gear. We had a similar experience when first testing Georgiev's Varna at speed. We found a good road to ride on, except that it had one worrisome hill. This road is actually part of my local club's 20- and 40-km time-trial courses, so I knew this hill well. On a road bike, I have to shift to the small chainring and climb out of the saddle to get over this hill. On my first run with Varna, I gave my best sprint just before the hill. To my great surprise, I crested the hill at over 79 km/h, 22 m/s, 49 mile/h, and actually had to put on the brakes for fear of going airborne off the lip!

When testing hill-climbing potential, I have attempted to equalize my road bike and my recumbent with respect to the properties noted above. My road bike weighs in at 10 kg (22 lb.) and my recumbent at just over 12 kg (27 lb.). When testing the road bike, I always rode carrying a bag of tools and a full water bottle (bringing its weight to approximately 10 kg. without drawing the attention of my fellow cyclists), with a set of Specialized composite wheels, and with time-trial bars set for my best aero position. The aero bars were not used when the speed dropped below about 7 m/s, 25 km/h. The road bike gearing is 42-52 front and 12-21 rear, with 175-mm cranks. When testing the recumbent it was always equipped with spoked wheels front and back, a mirror and a small pannier bag. The recumbent gearing is 34-44-54 front and 12–21 rear, with 175-mm cranks. Coast-down tests, where the speeds were in the vicinity of 9 m/s, 32 km/h, gave a very slight advantage of 0.1 m/s to the recumbent. This difference increases to 0.8 m/s in the vicinity of 14-m/s, 50 km/h, coast-down speeds.

My recumbent could be made faster by reclining the rider further, and with the removal of the mirror and pannier bag. (The pannier bag fits only partially within the profile of the rider, and adds about 40 square inches or 0.026 square meters to the frontal area. The mirror adds 9 square inches or 0.006 square meters.)

The data below were collected in 1992, after three seasons of recumbent riding, and at a point that represents my best level of fitness between 1990 and the date of writing (1998). I have roughly verified these data in 1998, with performances on both types of bicycles at levels slightly below the 1992 results. The data represent climbing at a time-trial level of exertion with mid-season fitness. I have experimented with cadences from 50–90 when climbing, but I get my best results on both bikes when pedaling at a cadence in the range of 60–75, the steeper the grade, the lower the cadence. However, the ideal cadence was not possible to maintain in some of the situations described below, especially on the recumbent.

1. Our 16-km course rises at an average of about a 2.5% grade for the first 6 km. To date, I have ridden this time trial 26 times on the recumbent and 25 times on the road bike. I have various checkpoints along this course, but a major one is the end of this rising grade. Here, on my road bike, I generally show an average speed of about 9.7 m/s, with my best being 10.0 m/s (36 km/h). On the recumbent, I generally average 9.2 m/s, with my best being 9.4 m/s (34 km/h). Just for interest's sake, the return trip on this stretch generally goes as follows: 12.2 m/s average on the road bike and 13.2 m/s average on the recumbent. I am usually faster over the complete 16-km course on the recumbent, even though I get behind by about 40 seconds by the end of the 2.5% grade.

2. Close by, we have a hill which is two-km long and rises mostly at a steady 6% grade, with the last 200 meters at 8% grade. Some of the local club members like to train on this hill, but we have never held a race on it because there is too much traffic for an organized event. I have probably climbed this hill over a hundred times on each type of bike, and almost always go hard. On the road bike I can climb this hill at an average speed of 7.8 m/s (28 km/h), but on the recumbent my very best is 6.7 m/s.

3. The last kilometer before the turn-around of our 20-km TT course rises at about an 8% grade with the final 100 meters a nasty 12% grade. When riding the recumbent, I am always pushing as hard as I can in my 34 x 21, but it is all I can do to maintain 3.1 m/s (11 km/h) on the 12% grade. While on the road bike, my speed never drops below 5.3 m/s (19 km/h).

4. One of our hill-climb TTs starts at the 20-km TT course turn-around. This is a road up to a ski resort, and goes skyward at a 14–16% grade for the first 2.5 kilometers. I have tried to ride up this hill on my recumbent many times, but this is a sprint effort for me, and I can ride only about 200 meters before falling over. Perhaps a lower gear than 34 x 21 would help, but I can ride it on my road bike in a 42 x 21 gear, albeit out of the saddle at a snail-like 3.3 m/s by the end, legs searing.

Despite my best training efforts, and my wishes otherwise, I have to concede that I cannot climb as well on a high-bottom-bracket recumbent as I can on a road bike. It seems that the steeper the grade, the more this is so. I have read that this could be due to increased lactic-acid buildup, but I don't believe this, because I can make my legs burn much more when climbing on the road bike. To climb well, you have to be able to push hard on the pedals, and I feel as if I can push harder while on the road bike. I can also accelerate faster from a standstill on the road bike (even without rising from the saddle), and before any lactic acid could have built up. Perhaps the upright position allows the legs some mechanical advantage over the recumbent position when pushing hard. On level or downhill road, where cadences are higher and pressure on the pedals is lower, I don't perceive a pedaling difference between the two bikes, and the recumbent realizes a speed gain consistent with its measured aerodynamic advantage.

Of course, one rider's experience does not allow us to draw any definitive conclusions, and, relatively speaking, I am not a good climber. Any mountain goats out there that ride both road bikes and high-bottom-bracket recumbents?

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A PROPOSED STANDARD FOR MEASURED DRAG REDUCTIONS

Mike Saari

Performance of any human-powered vehicle is determined by a variety of factors including weight, inherent drag (especially aero drag and rolling resistance) overall rider strength and other ergonomic factors. While most bike manufacturers publish "vehicle weight", they generally do not publish hard data regarding the inherent drag or "overall speed" of their vehicle. The reason is simple: there is no established standard method for doing so.

(Bicycle "performance" can consist of several parameters including hill-climbing ability, starting acceleration, level-ground sustainable cruising speed, plus various other more subjective individualistic aspects such as rider comfort, etc. Here I am focussing solely on the measurable issue of level-ground cruising speed.)

"Drag coefficients" (Cd or CdA) come close to solving this need but are not quite sufficient. For one thing, the total drag depends on the individual rider. For another, CdA measurements do not include rolling-resistance drag elements. As a consumer trying to choose between an upright and various recumbents with or without aerodynamic fairings or other enhancements, at present all that we really have to go on are various anecdotal reports, e.g., "Such-and-such recumbent is really fast." This is not enough to convince a consumer to change her/his riding position. We need to do better.

One might object that the goal is impossible, given that "every rider is different". But I believe we can define a single useful, measurable criterion that any rider can use. Here is a straw-man proposal. Most likely it can be improved upon or replaced with a much better version, but this could help to get the ball rolling.

"Inherent Speed Factor" (ISF)

We would start by specifying a "baseline upright bicycle" which is defined to have an "inherent speed factor" of 1x. (This baseline configuration would need to be specified precisely for reference, e.g., "Model XXX with 5-bar (75-psi) tires, no add-on components, rider in upright position.") It should not be necessary to specify the rider height and weight, since we are looking to define a ***relative*** criterion not an absolute one.

Now if a given recumbent bike and rider exhibits a level-ground cruising speed of 22 km/h versus only 20 km/h for the baseline upright, then that recumbent bike could claim "Inherent Speed Factor (ISF) of 22/20 or 1.1x".

Thus a given manufacturer might publish something like the following. "Measured ISF as follows: 1.1x for baseline model; 1.2x with front fairing; 1.33x with front fairing and body stocking; 1.35x with front fairing, body stocking and front/rear wheel covers." (*Please note:* I have no idea if these values are realistic.)

How would a consumer use these values? The consumer simply begins with her/his existing flat-ground speed on an upright bike, then multiplies by the ISF to determine the approximate improved speed assuming a similar level of effort. For example, consider an average rider who can sustain 20 km/h on an upright bike. A semi-streamlined recumbent with a published Inherent Speed Factor of 1.3x would result in a predicted sustainable speed increase of 6 km/h (or 26 km/h total).

Manufacturers could measure their ISF by a variety of means. We would do well to publish some precise methods, but the simplest would have a rider simply cruise on the upright and then on the test recumbent, striving to maintain a similar level of effort, then compare the speed difference. (Other methods might be more precise.)

A slightly different alternative system could measure "Inherent Drag Reduction" (IDR). For example, a bike with half the total drag at a given speed (compared to the upright) would have an IDR of 2x. A simple cube-root function converts an IDR to an ISF. (A bike with an Inherent Drag Reduction of 2x would have an expected Inherent Speed Factor of 1.26x.

IDR (Inherent Drag Reduction) values are a bit more precise and meaningful (and also larger so they look better), but require the consumer to perform a cube-root operation to calculate a speed increase—messy. But in either case, with such a system recumbent-bike makers would have something tangible to crow about and consumers would have a realistic basis for comparison.

I propose that IHPVA define and specify an industry standard for specifying the inherent drag reduction (IDR) or inherent speed increase (ISF) for various human-powered vehicles. I am willing to organize such a committee if asked (I know some techniques whereby any committee can reach good, fast decisions—without requiring a strong autocratic chairperson and without falling into the morass of "consensus" nor the mayhem of "majority rule").

We all know that a streamlined recumbent bike is "significantly faster" than an upright on flat terrain. With a well-defined standard we can better quantify such gains (if any), better serve the bicycle consumer, and possibly do a better job in teaching one of the tangible benefits of recumbents.

—Mike Saari <Saari@aol.com>

TECHNICAL PAPER REVIEW

"Trim of aerodynamically faired single-track vehicles in crosswinds", Andreas Fuchs. Presented at the 3rd European Seminar on Velomobiles, 5 August 1998, Roskilde, Denmark.

One of the fundamental problems limiting the acceptance of fully faired bicycles is their sensitivity to crosswinds. While the effect varies with vehicle design and the strength of the wind, this problem is not going to go away. One of my favorite sayings on crosswind handling is, "Small-boat warnings apply!"

Andreas Fuchs has studied the literature on this topic and then made a major advance—he has taken a moderately complex math model of bicycle handling and added in the forces and moments due to crosswinds. With this tool, he then analyzes a number of typical HPV configurations.

The title points out that this is a "trim" analysis, which implies that the solutions are static, not fully dynamic. Static analysis and test (i.e., most wind-tunnel testing) is still used extensively in aircraft design. Properly interpreted, statics can be a very powerful tool for understanding the nature of stability and control problems.

The paper opens with a through outline of the literature (both bicycle and motorcycle) and then presents a good summary (with figures) of the bicycle model developed at the Cornell University Bicycle Research Project. Next is a complete derivation of the addition of the aero forces and moments to the model. To quote directly from the paper, "The resulting equation allows the designer to trim a single-track vehicle so that it keeps its course in a steady field of crosswind."

The next sections describe various ways to develop the aerodynamic data required by the model. This has not been measured to any great extent—most bicycle wind-tunnel tests report the drag (in one form or another) but not the side force and yawing/rolling moments required to locate the center of pressure. In recent personal correspondence, your reviewer was able to supply a sample of this type of data, taken from tests sponsored by Moulton and published (in part) in the IHPVA's Second Scientific Symposium volume.

Final sections look at the consequences of different design decisions, as expressed by the various terms of the trim equation. All the primary variables are included and different trade-offs between fairing and chassis design are discussed. This is perhaps the most interesting section for vehicle designers. One notable conclusion (which agrees with practice) is that in most cases the center of pressure should be in front of the center of gravity. The paper ends with suggestions for further research (graduate students take note!) and an excellent reference list.

I would like to personally thank Andreas for taking the time to research and write this excellent paper. It should be "required reading" for all designers of faired bicycles.

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Doug Milliken has been an IHPVA member since the early 1980s, serving as the director of the DuPont Watercraft Speed Prizes and VP-water for five years. Starting with his wind-tunnel test work for Alex Moulton in 1980, he has been interested in the effects of crosswinds on faired bicycles. He wrote "Stability? or Control?" for Human Power in 1989 (referenced in Andreas' paper) and has been waiting since then for a detailed analysis of the effect of crosswind—which Andreas has now done.

REVIEWS

Major Taylor: the extraordinary career of a champion bicycle racer

by Andrew Ritchie

ISBN 0-8018-5303-6 $15.95

Reviewed by Wade Nelson
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Imagine cycling in 1898. Bicycles greatly outnumber cars. Paved roads are few and far apart. Bicycles, or "wheels" as they are called, had undergone a remarkable transformation: The high-wheelers of yesterday have been replaced by all new, chain-driven safety bikes. Saturday-night bike races held on high-banked wooden tracks thrill large crowds long before sports like baseball or football captured America's attention. From among the riders of the day emerges an unlikely hero, Major Taylor, a young black man. At a time when many white members of society are still arguing whether blacks are "fully" human, Taylor stuns everyone by becoming the world's fastest bicycle rider. More amazing still is the number of people today who have never heard of Taylor, or his rise to the pinnacle of bicycle racing. Fortunately, a recent book by Andrew Ritchie describes this man's courage in the face of obstacles probably greater than those faced by any athlete at any time in history. If you love cycling or just want to read an account of a true, untarnished American hero, this book is for you.

As a child, Taylor became acquainted with a young white boy, Dan Southard. The two were inseparable, and when Dan and his mates began riding "wheels," Southard's wealthy father ensured that one was available for Taylor to ride. At the time, the exorbitant cost of a bicycle, nearly $100, was something few blacks could afford. Unable to participate in many other sports dominated by whites Taylor got on his bike and rode, rode, and rode. At 13, Taylor took his bike to the Indianapolis firm of Hay & Willits for repair. Afterwards, he performed a piece of trick riding which led to an offer of employment as a greeter for the shop. Hay soon pressed Taylor, nicknamed "Major" for the snappy military uniform he wore each day, into participating in a ten-mile road race. Taylor broke down in tears and begged Hay not to make him ride. To everyone's surprise, he won. Taylor's win and association with the shop led to his meeting "Birdie" Munger, a bicycle racing hero of days gone by who was ultimately to become his coach and mentor.

Ritchie's book covers Taylor's meteoric rise into the world of bicycle racing, the incredible discrimination he fought, and the "world" of bicycle racing during that era. Every issue one sees in cycling today seems to be present in 1895, whether battles between sanctioning organizations (LAW vs. ACRA), issues over technology (chains vs. shaft-drive bicycles), personality battles between rival superstars, even arguments over the best possible diet for cycling. Discrimination against blacks, even in many northern towns, was the order of the day. Bicycle racing was "big business" rather than the obscure, niche sport of today. Owners of bicycle tracks were mixed in their decisions to allow Taylor to race, knowing that he could be extremely good for the purse, while at the same time under intense pressure to exclude blacks. Taylor's wins and losses led to tremendous excitement in the crowd.

Writing this book, Ritchie turned to Taylor's daughter who maintained a complete scrapbook of newspaper articles about his career. Cycling was, in that era, the leading spectator sport and reporting of cycling events was far more comprehensive than it is today. The Worcester, Massachusetts Telegram provided nearly race-by-race coverage of Taylor's career. Interestingly enough, an e-mail bicycling newsletter by a writer for this same paper is how I first learned of Major Taylor and Ritchie's book.

Taylor wrote his own biography, entitled "The fastest bicycle rider in the world" which Ritchie also used as a resource. As Taylor's racing career took him first to Europe, and later to Australia, foreign papers coverage of "The Black Whirlwind" was extensive. Ritchie's book takes advantage of that excellent coverage and truly gives the reader a taste of the flavor of the era.

Cash prizes meant that a good rider could earn a fair income from racing, and indeed, Taylor did. Yet there was one thing he would not do; race on Sundays. After his mother's death Taylor made a commitment to Christianity he never relinquished. Time after time race promoters offered Taylor huge sums of money to race on Sundays. He declined these offers till the very end of his career. It is Taylor's sticking to his beliefs, and his turning the other cheek to numerous fist-fights and other racetrack battles desired by his white opponents that lead the reader to respect him so immensely. On only one occasion is Taylor described as physically defending himself, when he swings a piece of lumber at a group of white riders coming to his locker room ostensibly to kill him. Perhaps by the grace of God, he misses, and escapes unharmed. Were there more such circumstances? We don't know, but from Ritchie's book we get the flavor of a man whose beliefs shaped his life and his cycling success into something all might seek to emulate, regardless of the color of our skin.

The end of Taylor's life is a sad story. The depression and a series of bad investments robbed him of his considerable wealth, eventually leaving him penniless. He died alone in a charity hospital, and was buried in a pauper's grave. In 1948 we see members of a bicycle club approaching Frank Schwinn, of the then mighty Schwinn Bicycle Company, and obtaining the funds to re-inter Taylor in a more suitable grave in the Mount Glenwood Cemetery, south of Chicago, a place this reviewer hopes some day to visit. A small bronze plaque was purchased which perhaps says it all:

> Dedicated to the Memory of Marshall "Major" Taylor 1878-1932 World's champion bicycle racer who came up the hard way without hatred in his heart, an honest, courageous, and God-fearing, clean-living gentlemanly athlete. A credit to his race who always gave out his best. Gone but not forgotten.

If you love bicycling, or just want in this day of school-yard massacres, philandering presidents and other bad news to read the story of a man who lived life in a way we would all do well to emulate, Ritchie's book is for you.

THIRD EUROPEAN SEMINAR ON VELOMOBILE DESIGN

Roskilde, Denmark, August 5, 1998

Reviewed by Dave Wilson

"Velomobile" is European for "HPV". I was asked to be the North American representative on the committee. I did not do a great deal of the grunt work. That fell mainly to Carl Georg Rasmussen, who produces the famous three-wheeled "Leitra" nearby, and to Andreas Fuchs, a powerhouse from the Bern, Switzerland, Engineering School (university). The seminar was similar to HPV symposia in the US in that there were, at first, no papers offered and little apparent interest. However, the snowball started rolling and in the last few months several authors had to be turned away. The seminar was different from US HPV symposia in three respects:

(1) there was a considerable charge for attendance; (2) would-be members of the audience had to be turned away by the previous week; and (3) audience members each received a bound copy of the papers upon entry to the seminar room.

I would like to add a fourth: English was spoken! But that would be unkind. We English-speakers were very favored in that all papers with one exception were given in English.

Doug Milliken has reviewed one paper (by Andreas Fuchs) elsewhere in this issue. I hope that we will have more in-depth reviews of other papers. My purpose here is to give brief comments on the papers and on any trends that might be of general interest. One observation may be made at the start: human power is a respectable academic pursuit in Europe, because a large proportion of the speakers had university careers or backgrounds. That included the moderator, Carl Georg Rasmussen, a physicist who was secretary of the technical university until he decided to devote full time to velomobiles. There is also great enthusiasm for human power and the movement is very much alive and well. This symposium had particularly strong representation from Germany.

The first speaker was Vytautas Dovydenas, a pioneer in "biotransport", who published his "Velomobiles" (and thus is the originator of the word) in Lithuania in 1979 (subsequently translated and published in St. Petersburg (1986) and Berlin (1990)). He is a passionate advocate for human power, pointing out that a common feature of almost all cities, rich and poor, developed and developing, across the world is traffic jams and fumes, noise and anger.

Carl Etnier, "kinetic Yankee in King Harald's port", gave a light-hearted but valuable paper co-authored by John Snyder on issues in pedicab design. Carl operates a pedicab in Oslo, John one in North America, each as a combination of a hobby and a second job. They gave the advantages and disadvantages of most different forms of pedicab (did you know that when a pedicab driver in tuxedo and shorts is riding "traditionally" in front of his fares, young women tend to reach out to pat his thighs, something impossible to do when he is semi recumbent?) They now use Quadracycles in preference to the several alternatives tried for their particular routes and clients.

Jurgen Eick, a professor of engineering from Wiesbaden and a daily Leitra user, was discouraged by the advances made in automobile fuel efficiency, stating that the last hurdle to the use of automobiles in China may have gone if a car with an extremely miserly fuel appetite is developed. He surveyed about 150 Leitra purchasers and gave some answers to questions such as "Why isn't this type of vehicle more widely used?"

Joachim Fuchs, committee member from Germany (no relation to Swiss Andreas Fuchs) defined a velomobile as a fully faired recumbent bicycle for everyday use, and arrived on one. The front fairing slid forwards as if he were in a jet fighter. He prepared a spreadsheet program to show that, if the time involved in earning money to buy and maintain a velomobile, a car and a bicycle are accounted for in finding the average speed, the velomobile is fastest, the bicycle is a close second, and the car is a more-distant third.

Three authors from my once-home city of Birmingham, England (Philip Hwang, Laxman Nayak and Roger Newport) wrote a paper on human-powered vehicles for third-agers as a mode of local transport. The third age is defined as active independent life beyond work and parenting: the early years of retirement. A questionnaire was sent to

300 members of a panel, and 255 responses were received, a high proportion considering that each respondent had 110 decisions to make. The authors' conclusions were that the use of HPVs by third-agers is beneficial, and that more thought should be given to designing and producing vehicles for this group, and to designing the infrastructure needed for them.

Per Lindhardt, a ship-engine designer, wrote, but did not present, a paper on a simple trike with a roof for elderly people in Denmark. He felt that he had arrived at a happy compromise having the best features of a full velomobile and a bicycle. However, he found that his target group was not ready for such a machine. He concluded that perhaps we must wait for public attitudes to change (or try to change them ourselves).

Your reviewer presented the next paper, prepared at Carl Georg's request, on the effects of US liability litigation on HPV design. My conclusions were that, while some shocking stories of ridiculous litigation reach the headlines, some liability litigation is needed to put some restraints on the power of manufacturers to sell us truly dangerous products (in cases where regulation is difficult or expensive); that the number of liability cases has fallen dramatically in the US in the last ten years; that defendants win these cases more often than lose them; that there are almost certainly too few liability lawyers in Europe; and that since we in the US seem to have a surplus of such lawyers, we would be happy to export a proportion as a neighborly gesture.

Johannes Lund reviewed the organization of the Danish bicycle-design competition of 1966. It had two categories, with several sub-categories: improvements in traditional bicycles, and improvements in HPVs (velomobiles). It was sponsored by the Danish Cycle Federation, the Association of Danish Designers, and the Danish Ministry of Traffic; 132 entries were received, and five prizes were awarded. He felt that the "form-over-function" designers got the upper hand in the specifications and the judging, with the result that the creative-appearing designs chosen were not as practicable as the Danish Cycle Federation, of which Johannes is the national chair, would have wished. There was considerable audience participation in the discussion!

Timothy A. Taylor presented a paper co-authored with Kevin Blake (both from the University of Missouri, Columbia) on a study of the design of a practical velomobile for the next century. They calculated the energy requirements of various alternatives, and discussed factors such as manufacturing, marketing and style among many that need greater emphasis if a practical velomobile is to become widely used in the next few years.

Anselm Kiersch gave a method for "tuning velomobiles for everyday use", employing a systems approach with 40 evaluation criteria and emphasizing goal-seeking and a "wholeness approach". He showed interesting examples of the evaluation of alternative configurations of velomobiles with different equipment.

William B. (Bill) Patterson of Cal Poly, San Luis Obispo, gave "single-track-vehicle dynamics", illustrated with examples of experimental bicycles made by students in his classes (who certainly seemed to be having fun). Bill applies his airplane and helicopter experience in seeking to guide designers to achieve appropriate control sensitivity. He brought demonstration versions of his new publication "Lords of the chain ring" and a computer program that can aid people in using his methods.

Ian Sims came over from Australia to discuss the "stability of faired recumbent tricycles" in a breezy and entertaining manner: it was partly the development history of his Greenspeed tricycles. He described how he chose a fairly high caster angle, 11 degrees, to give good steering "feel", and how it also gave excellent stability in cross winds until he mounted wheel disks. The negative effects of these were nullified by fitting a tail-fin of similar area, which he described, along with some results of tests on faired vehicles.

This reviewer will pass over Andreas Fuchs' paper, expertly reviewed by Doug Milliken elsewhere in this issue, and related to the topic of Ian Sims' paper.

Frank Lienhard's paper on minimizing aerodynamic drag of a fully faired racing recumbent was a short commentary on wind-tunnel testing of a scale model. The three aspects I took from the paper were that the ground effect was smaller than expected; that a major reduction in drag coefficient (from 0.05 to 0.03) was achieved by adding a long fin; and that measurements of the drag coefficient of penguins show that their drag coefficient is about 0.02.

Stefan Gloger and Harald John wrote an important paper, one of the several for which there was no time available for an oral presentation to be made, on an investigation of the passive safety of ultra-light vehicles, a continuation of work on what they called "The May-bug principle" reported in the first two velomobile seminars. One-fifth scale-model motor vehicles and HPVs had masses scaled 125:1 (11 kg vs 800 g) and collisions of various types were recorded on video and on accelerometers located near the rider's head position. The photos shown are graphic and realistic. The conclusions were that injury to the rider could be greatly reduced if:

1. velomobiles had safety belts or something similar; 2. the structural shape of the vehicle front end were round or elliptical; 3. a stiff safety panel or roll bar were fitted around the rider; 4. the outer surface of the fairing were of low friction; and 5. the front of the vehicle were deformable while the sides were stiff.

Werner Stiffel, one of the world's most prolific recumbent designers (he gave us an advanced design in HP vol. 8 no. 2 (1990)), had a tantalizingly short paper on "smallish recumbents" using small (400-mm O.D. or "16-inch") wheels. He mused on the pros and cons of striving for compactness and showed just two photos of small bicycles that he has produced.

Another prolific idea-person, Anders Brage, a materials scientist from the Swedish defense industry, gave an entertaining paper on a "linear-driven HPV design family". He also mused on alternative designs, ranging in his case from scooters to foldable bikes to trikes and including filament-wound wheels: all good reading.

Clemens Bucher, who is credited with having designed some interesting practical scooters, showed us his impressive designs of a "recumbent with encapsulated drive chain". It was more than that: it had an enclosed drive train, including the derailleur(s) and hub gear on a countershaft. He showed us parts and photos of five models. They work! As I've always wanted something like this I confidently predict that the industry will move in his direction. (If any of you listen to the McLaughlin Group discussing politics you will know how much weight to put on the reviewer's predictions).

Thomas Senkel extolled the virtues of building lightweight vehicles in aluminum alloys (my rough translation of "Aluminium im Bau von Leichtfahrzeugen". He took us through comparisons of the properties of different alloys and the various ways of forming and treating the materials, and then showed us, as an example, "Senkel's Easy", his design of a "people's recumbent". A principal feature was a specially produced hollow-I-beam extrusion that was bent to a graceful curve for the monotube design. His idea of using a vee-belt drive was questioned, however. (Reviewer's confession of bias: Thomas has recently made a special version of his "Viento" 20-20 USS double-suspension CLWB for me, and I like it).

"Measurement and simulation of the vibrational stress on cyclists" was a paper by Matthias Wachter, Norbert Zacharias, and Falk Riess, of the Bicycle Research Group in the physics department of Carl von Ossietzky University in Olderburg, Germany, another long-term body that continually produces valuable information and confirms that studies of human-powered machines is academically respectable in Germany. Vibrational stress was quantified by reference to international (ISO) and German (VDI) standards where the spinal column and the hand-arm system, for examples, are allocated different weighting factors over a wide frequency range. Seven bicycles, including two recumbents, were ridden over twelve mostly horrible surfaces (cobblestones being merely one of them) and the vibrational stress was categorized into G1 (health impairment after one minute) through L60 (reactions impaired after 60 minutes) to W60 (comfort impaired after 60 minutes).

It was typical of the organizer and moderator, Carl Georg Rasmussen, that he put his paper "Fiber composites as shock absorbers" last and that he sacrificed his presentation of it when the program ran a little late. The printed paper, and the examples of his Leitra tricycles in the grounds outside the lecture hall, showed beautiful examples of the use of composite flexures being used as structural suspension components in his vehicles, in some cases for the last fifteen years. He gave sample calculations, and reported that no fatigue has developed so long as the design stress is not exceeded, even through operation in snow and salt. He used 75% carbon fiber surrounded by 25% glass fiber.

The printed proceedings have six "poster presentations" at the end of the volume:

"The Pelican turns in an instant with 250-kg on the carrier in front"—Bino and Lars Leikier;

The Nihola Bike, also a two-in-front with a carrier between the wheels - Niels Holme Larsen;

"Fortbewegung mit muskelkraftbetriebenen Fahrzeugen" showing a two-in-front single-rider tricycle - Prof. Dr.-Ing. Hans-Peter Barey;

Lissy II, a two-person two-in-back tricycle that can carry large loads in place of one person - Peter Lis;

Recumbents for children, showing a wide range of creative designs - Hans Jorgen Pedersen; and

a list of pedicab manufacturers by Carl Etnier and John Snyder.

The proceedings of the Third European Velomobile Seminar are available from the three following locations: Danish Cyclist Federation, Att. Butikken, Rømersgade 7, DK-1362 Copenhagen, Denmark; HPVA Orders, PO Box 1307, San Luis Obispo, CA 93406 USA; Future Bike CH, Attn. Andreas Fuchs, c/o Jürg Hölzle, Spitzackerstrasse 9, 4410 Liestal, Switzerland. Prices to be determined.

PROCEEDINGS OF THE EIGHTH INTERNATIONAL CYCLE-HISTORY CONFERENCE.

Reviewed by Dave Wilson

The international cycle-history conferences were started in Glasgow, Scotland, in 1990, as pointed out when the seventh-conference proceedings were reviewed in HP vol. 13, no. 1 (fall 1997). The eighth conference returned to Glasgow at the end of August 1997, and the proceedings were published in April 1998 by Van der Plas Publications, San Francisco. The distribution is through Motorbooks International of Osceola, WI; ISBN 1-58068-003-3. I paid $45.00 plus $4.00 for shipping. That amount might seem high, but it is very good value for a beautifully produced book with a limited market. The purpose in reviewing a book of this sort is to give you the highlights, so that you don't have to buy the book; and also to show you how much more there is than the small amount I can mention, and thus encourage at least some of you to buy it. We owe a debt to publishers of books like this, and if we don't repay their loyalty with some of our own, we will be in danger of losing a vital resource.

There are nineteen papers and other contributions in 160 large-format pages. I will mention all in the order in the table of contents, and review those that are particularly relevant to HPVs; those with a high technical content; and those that happen to appeal to me. As always, I welcome other reviewers with their own "angles".

1. "The velocipede craze in Maine" by David Herlihy, an internationally recognized historian of the early days of pedalled machines, records that there was indeed a craze for them in a state that I would have thought least likely to indulge in such a movement.

2. "The quest for safety: what took so long?" by Nick Clayton, the originator of the cycle-history conferences, and the author of a paper in the first conference on the Meyer-Guilmet safety bicycle of 1871–2. I presume that this Meyer is the same Eugene Meyer whom Clayton credited with inventing the lightweight metal tension wheel in 1870. This wheel led rapidly to the high-wheeler or "ordinary" in order to give ungeared machines a reasonable impedance match for racing. The high-wheeler in turn led to the need for safety, so serious were the effects of "headers" and "croppers". In beautifully researched detail, Clayton shows that there were many bicycles that would fit the description of "safety", which in general would mean that there was a much-reduced possibility of being thrown over the handlebars, well before the 1885–6 series of Rover safeties. These, and Starley, the principal designer, have been credited with the whole responsibility for the total switch to the safety bicycle in the following five-to-seven years. Why didn't the earlier designers and entrepreneurs bring about this change, and get credit for doing so? Nick Clayton points out the high degree of luck involved in being the right person at the right time; the somewhat difficult personality of Harry Lawson, who had been proclaiming the need for safeties for many years, and had built several machines; the establishment of a "Rover race", that led to world-record times being created; and, in an interesting parallel to part of the home-computer story, the fact that Starley and Sutton did not patent the Rover design. "From 1886, dozens of similar models, diamond- and cross-framed, began relentlessly to squeeze out ordinaries and tricycles from the catalogues. . ." J. K. Starley was also a good

businessman - "an entrepreneur in charge of his own firm. Two years after launching the Rover he took sole direction, changing the name to J. K. Starley & Co. . . . Despite the early derision heaped on the safety, he was confident of the basic soundness of his idea. Perhaps he was lucky launching the Rover in a boom year, but it was his courage in putting serious money first into publicity, and then behind the road-record attempt, that ensured its success." He was also a good speaker and writer.

There has been no controversy, so far as this reviewer is aware, on the role of J. K. Starley in originating the safety bicycle that has been the standard machine from 1886 to this day.

The theme of who was responsible for past developments is one that tied together several papers in the proceedings.

2. Within living memory: tomorrow's history, by Alastair Dodds, who discusses the reliability of the memories even of people who experienced events first-hand and recalled them later. This paper formed an introduction to the next, which was about this very subject.

3. Who invented the mountain bike? by Frank J. Berto, an engineer who has long been pre-eminent in commenting on and testing bicycle transmissions, particularly derailleurs, and who lived in the region where the modern mountain bike emerged. "This paper will describe the development of the mountain bike as told to me first-hand by the five major participants: Gary Fisher, Charlie Kelly, Joe Breeze, Tom Ritchey, and Mike Sinyard.... Gary Fisher has long claimed to be the inventor of the mountain bike. After reading this paper, Gary agrees that he did not invent the mountain bike." This is an arresting beginning.

After introducing these five principals and several others, Berto makes several definitions. A mountain bike is one with fat tires, upright riding position, flat handlebars, derailleur gearing, good brakes, off-road use, and Marin-County origins. An inventor must pass three tests: s/he must have the original idea and not copy someone else's prior idea; s/he must make the first prototype, which can not be a copy of someone else's prototype; and s/he must actively participate in the subsequent developments that lead to the utilization of the invention.

Knowing that these characteristics of an inventor might be controversial, and that there were many developments of off-road bikes throughout this century, Berto cites the case of John Boyd Dunlop, who invented the pneumatic tire in 1888. Yet another Scot, R. W. Thompson, patented the pneumatic tire in 1845, "and Dunlop's patent should have been invalid because of what is called prior art." However, all the developments of today's pneumatic tires stem from Dunlop's invention, development and involvement, and not at all from Thompson's. Therefore Dunlop is rightfully the inventor.

What follows is a fascinating account of who did what and when. One of the significant factors was the statement by Gary Fisher that he came up with a certain development six months before he actually did, thus avoiding giving credit to one of the others, who had demonstrated the development to Fisher and others during that six months. Berto knew everyone involved, and went from one to another, and frequently back again, with a tape recorder and a full understanding of all the implications. At the end, he was praised by all, and Gary Fisher wrote a gracious letter acknowledging that he was not, in fact, the inventor of the mountain bike. Berto's conclusion is that no one person invented the mountain bike: it was a group effort in which "the early pioneers piled enough developmental logs on to the mountain-bike bonfire...critical mass was achieved and the mountain bike mushroomed."

All the while I was reading this gripping story I was thinking about the current controversy about who invented the pedal bicycle (it seems fairly certain, according to David Herlihy, that members of the Michaux family "backdated" certain crucial events by as much as ten years in order to claim credit for the invention) and about who invented HPVs, recumbents and so on. Berto anticipates these musings: he has a powerful section on "Lessons for cycling historians" that is highly relevant.

(To be concluded in the next issue)

EDITORIAL

Misplaced machismo?

'"Snap" went a collarbone; "crack" went a wrist; "pop" went a hip': this was the essence of a macho title under a photo in a bike magazine of two men hitting the road as their tandem skidded out from under them at high speed. They were competing in a race involving a long downhill, and their front tire went down suddenly after they had negotiated a sharp bend. My guess is that the captain had braked hard, his front-wheel rim had become too hot for the tube, the tire suddenly deflated, and the flat tire made the machine uncontrollable. A recent thread of discussion on the HPV mail list concerned the tabs that some manufacturers are putting on bicycle forks to prevent the front wheel from dropping out while riding. The tabs also make it more difficult to remove a wheel. Several writers called them "lawyer tabs", implying that they were irritations that resulted purely from "ambulance-chasing" by greedy lawyers. There were macho sentiments expressed by writers who preferred the risk of a wheel dropping out to the hassle of manipulating the tabs for a couple of seconds. As readers of the Roskilde seminar review might have noticed, I have been reconsidering the role of product-liability lawyers. I have come to believe that they serve an important function in society. True, there are probably far too many in the US, and some are greedy. Others produce beneficial societal changes at probably much lower cost than would government regulation. I don't believe, therefore, that a macho attitude is helpful.

When our ancestors lived in caves, they knew that one unlucky step could lead to death, slow or sudden. Nowadays I believe that we all expect that we should not be killed or injured by a single false step. To get injured in a car now requires several failures or acts of stupidity to occur simultaneously. Some claim that modern cars actually encourage bravado, so difficult it is to take actions that could result in injury to the car occupants. (There seems little concern about the horrible injuries inflicted on others.) The contrast with the lack of concern for safety on the part of most manufacturers and users in the HPV community is dramatic and shocking. For example, I have no idea how to buy a combination of tire, tube and rim that will allow me to ride my recumbent safely down to a stop in the event of a front-tire flat. Machismo is not the right response. We should be campaigning to tell manufacturers to collaborate to solve this and many other serious problems.

—*Dave Wilson*

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