8

The Development of Modern Recumbent Bicycles

David Gordon Wilson

A *recumbent* pedaling position is one having the pedaling axis substantially in front of the rider. Further recumbents of the type where the rider is in a sitting position may be designated as *semirecumbent* and those where the rider is lying down, as *fully recumbent*. For this chapter, the boundary between semirecumbent and fully recumbent is set as a seat-back angle of 45° with the horizontal. Abbott defines four possible fully recumbent positions: the supine position with face upward; the prone position with face down; and on the right or left side, the right or left decubitus positions (Abbott, 1988). In general, full recumbents are used only for speed-record attempts, because of the position's inherent problems for both seeing and being seen. Technically speaking, the first pedaled bicycles were "recumbents," but this chapter briefly traces the development just of *geared* recumbent bicycles, from the first known examples that appeared in 1895 to the Cheetah of 1992. Case studies of the Avatar 2000 and of the Tour Easy and Easy Racer bicycles are covered in greater depth. Variations such as front-wheel drive and front-steering recumbents are introduced.

Recumbent bicycles have had many revivals. A recumbent called the Velocar disturbed the conventional bicycling world in the 1933 to 1935 period because it was used to topple most existing bicycle records, and it was ruled "not a bicycle." The latest revival of interest in recumbents has come about because of the formation of the IHPVA. Faired recumbent bicycles currently hold most of the world HPV records. Moreover, often the same recumbent bicycles that have won the Speed Championships have also been awarded practical-vehicle prizes. The recumbent bicycle, therefore, could have very wide application.

The Evolution of Safety Bicycles and the Upright Riding Position

Karl von Drais designed the first known bicycle (circa 1817) simply as a running aid, so it is difficult to define it as having a recumbent or upright

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sitting position. However, the designers of the first pedaled bicycles, Kirkpatrick Macmillan in about 1839 and Pierre Lallement in about 1865, used the recumbent position, probably because riders of what were then unusual machines wanted to start with their feet on the ground. However, the direct coupling of the pedals to the wheels meant that the effective gear ratio was, in modern terms, superlow. Gears and chains were not developed to the point where they could be used to improve the gear ratio (the impedance match). Accordingly, the pedaled front wheels of the Lallement bicycles were steadily increased in diameter until they were as large as could be comfortably ridden: the machine became the high-wheeler. The only way in which the high-wheeler could be both pedaled and steered was for the rider to be almost vertically over the front wheel. Riders were exhorted to "get over the work," that is, the pedals. When the development of improved chains and sprockets (circa 1884) allowed the development of the geared safety bicycle—so called because the high, precariously balanced riding position of the high-wheeler was extremely unsafe—the upright pedaling position, regarded as normal, was retained. Accordingly, when the recumbent bicycle reappeared in geared form, it was regarded as an aberration.

The Geared Recumbent's First 30 Years, 1895 to 1925

The modern safety bicycle had evolved almost to its present configuration by soon after 1890. The geared recumbent made by Challand in Ghent, Belgium, around 1896 (Salvisburg, 1897) was very close in design to one form of modern recumbent, such as the one shown in Figure 8.1. In Challand's recumbent the rider sat high, directly over the rear wheel, so that starting off from rest may have been difficult. A recumbent patented by Wales in the U.S. in 1896, incorporating hand-and-foot drive, positioned the back of the seat forward of the rear-wheel center, but still over the wheel. Another American recumbent was that produced by Brown (Dolnar, 1902), in which the rider's seat was entirely forward of the rear wheel and the front wheel was forward of the cranks (Figure 8.1), an arrangement now characterized as long wheelbase or LWB. It was received rather scathingly by the British bicycling press, although its virtues were grudgingly acknowledged.

Peugot produced a recumbent bicycle in France at an unfortunate time: 1914, the start of World War I. Perhaps this machine had the greatest possibility of success of all unorthodox bicycles, because Peugot, a significant company, had a great chance of influencing the French-dominated Union Cicliste International (UCI). However, the war ended this effort. After the war Swiss engineer Paul Jaray, whose fame came from his work on the Zeppelins, made the J-Rad recumbents (see Figure 8.2) in Stuttgart in 1921, with limited success. They used a swinging-lever constant-velocity transmission having three ratios given by using pedals at different radii along the levers.

FIGURE 8.1 Brown's recumbent.

The Velocar

Later in the 1920s a class of cycle car racing became very popular in Germany, with the American-German sailboat researcher Manfred Curry taking a prominent part. In France a self-taught engineer, Charles Mochet, was making small motorized cycle cars (Schmitz, 1990). He also made a one-seat, four-wheeled pedal car for his son, Georges, who would "amuse himself by pedaling fast and passing ordinary bicycles with ease." Charles switched his production entirely to a two-seat, four-wheeled HPV that he called a Velocar. According to Schmitz it had free wheels, a differential, and a three-speed gear and was fast enough to pace bicycle racers on the track. Its instability on turns gave Mochet the

FIGURE 8.2 J-Rad, 1921 (from a photograph owned by the Veteran-Cycle Club, U.K.).

idea of "cutting the Velocar in half, figuratively" by building a recumbent bicycle for racing. The front wheel was steered "through a bevel gear connected to flat handlebars by a long horizontal tube." After it was finished in 1932 the champion professional, Henri Lemoine, rode it and found it comfortable and easy to pedal, but he did not want to switch to it.

One who did take to the Velocar was Francis Faure, a second-rank racing cyclist, who defeated the champion, Lemoine, in a 4-km pursuit race (see Figure 7.9). He also broke track records. A professional road racer, Paul Morand, won the Paris-Limoges race "going away" on the Velocar in 1933 (Schmitz, 1990). Mochet had written to the UCI in October 1932 to verify that the Velocar accorded with the UCI's racing rules. The then-existing UCI rules required that the crank axis be between 240 and 300 mm from the ground; that the vertical through the crank axis be no more than 120 mm from the nose of the saddle, between 580 and 750 mm from the vertical through the front-wheel axis, and no more than 550 mm from the vertical through the rear-wheel axis; that no power be obtained from hand motion; and that no means of reducing air resistance be used. The UCI met in some disarray and in 1934, after much controversy, passed rules that disallowed recumbent bicycles for officially sanctioned racing and, therefore, the records that Faure and other had set (Abbott, 1988; Barrett, 1972).

The Velocar inspired several commercially produced recumbents, especially those built in Great Britain by Grubb. These had handlebars beneath the seat, an excellent design introduced in the last century for high-wheelers and known as Whatton bars, after their inventor. Neither the Whatton bars nor the Velocar-inspired recumbents became established. Nor did an interesting variation known as the Ravat Horizontal, sold in Great Britain as the Cycloratio, in which the pedals and cranks were over the front wheel. The present author would later unwittingly borrow this design idea. As the seat was partly over the rear wheel, this style could be called the high, short wheelbase. Another variation of this style was the 1939 Velocino in Italy and the Donkey Bike, built by Emil Friedman in Frankfurt, West Germany, in 1965. The front wheel had a diameter of only about 310 mm. A high, long-wheelbase recumbent using a steering wheel but otherwise being constructed of conventional bicycle components was the Moller Triumph (see Figure 8.3).

Oscar Egg, the renowned Swiss bicyclist who competed with Marcel Berthet for the 1-hour record from 1907 to 1914, when he set a record which was to last until 1933, built a streamlined recumbent bicycle, propelled via levers, with the intention of

FIGURE 8.3 Moller Triumph (from a photograph owned by the Veteran-Cycle Club, U.K.).

becoming the first bicyclist to exceed 50 km in 1 hour. Berthet had reached 49.992 km in November 1933 in a streamlined, regular (pacer) bicycle. But it was Faure and a streamlined Velocar who reached 50.537 km in 1 hour, in March 1939 (Schmitz, 1990).

The Postwar Doldrums

After World War II, the principal users of recumbents who received any notice were some in Great Britain still riding Grubbs and Dan Henry in the U.S., who designed and built a long-wheelbase (LWB) machine for his own use. The LWB design positions the rider entirely between the wheels. Henry used standard 27-in. wheels and designed very effective springing on both. Most previous recumbents were built with small front wheels, because in the long-wheelbase machines little of the total weight is carried by the front wheel, so that the small increase in rolling resistance (which is inversely proportional to wheel diameter and proportional to the normal load) is probably outweighed by a reduction in air drag at normal speeds. At the same time the bicycle mass and length are decreased and the steering is likely to be more precise. In the short-wheelbase recumbent, the front wheel is made small because it is located under the legs or feet, which must be able to reach the ground.

The Evolution of the Avatar 2000

The Avatar 2000 was developed largely in ignorance of the foregoing history. To some extent we (David Gordon Wilson and Richard Forrestall) repeated what had been done before. However, had we known of the existence of previous recumbents, we might well have taken the same course, because little had been reported of either their deficiencies or their advantages.

The design evolved from many initial sketches and careful layouts on the drawing board. There was even some simple analysis. But progress mostly came from old-fashioned trial and error. This was not through laziness or lack of rigor. Any device that interacts closely with human beings—a nuclear-power-station control room, for instance—should be designed with great attention to detail and overall logic, but even so some major deficiencies become apparent only after a device is in use. A review of the stages we went through and the conceptual errors we uncovered may help others to avoid similar mistakes.

The first two recumbent bicycles in the series were made by H. Frederick Willkie II, who had been inspired by a design contest I organized and had requested a sketch of what he thought would be an advanced bicycle that he could build. Willkie called the first (1972) of the two bicycles Green Planet Special I (GPS I) and, unknown at the time to the designer and builder, it bore a strong resemblance to the Ravat. Willkie used the GPS I around Berkeley, California, reportedly achieving high speeds, but he found the rather crude seat jarring to his spine. It also seemed hazardous to have the handlebars and stem almost directly in front of his face, because of the risk of injury in an accident. Willkie asked the author to sketch a revised design.

The result was the 1973 Green Planet Special II (GPS II), in which the cranks were lowered as far as possible and the steering-head tube was brought back so that the front-wheel rim would clear the heels. This also permitted the handlebars, while fastened directly to the fork-steerer tube, to be under the thighs. Although Willkie used a hard, molded-plastic seat, he found that this machine was far more comfortable than GPS I, partly because it had a far more open angle between the torso and the line connecting the hips to the crank axis, allowing better breathing, and partly because he was now sitting more on his buttocks and less on his coccyx.

The 16 × 1-in. tubular front tire was, however, heavily loaded, with a typical life of less than 160 km (100 miles). The author bought GPS II from Willkie and brought the rear wheel about 300 mm (12 in.) forward to reduce the load carried by the front wheel, fitted a robust 16 × 1-3/8-in. wheel and wired-on tire, and experimented with many seat types and angles until he arrived at the approximate configuration shown on Figure 8.4 and a construction using 19-mm (3/4-in.) O.D. aluminum-alloy tube and a stretchable-canvas slung seat.

A large fiberglass trunk was also fitted. On this much-modified version of GPS II, renamed the Wilson-Willkie (WW), many thousands of miles were covered in great comfort and enjoyment, in summer heat and winter cold.

The sight of an obviously relaxed and cheerful rider on this unusual machine attracted media attention, and the bike was the subject of many newspaper articles and photographs, TV interviews,

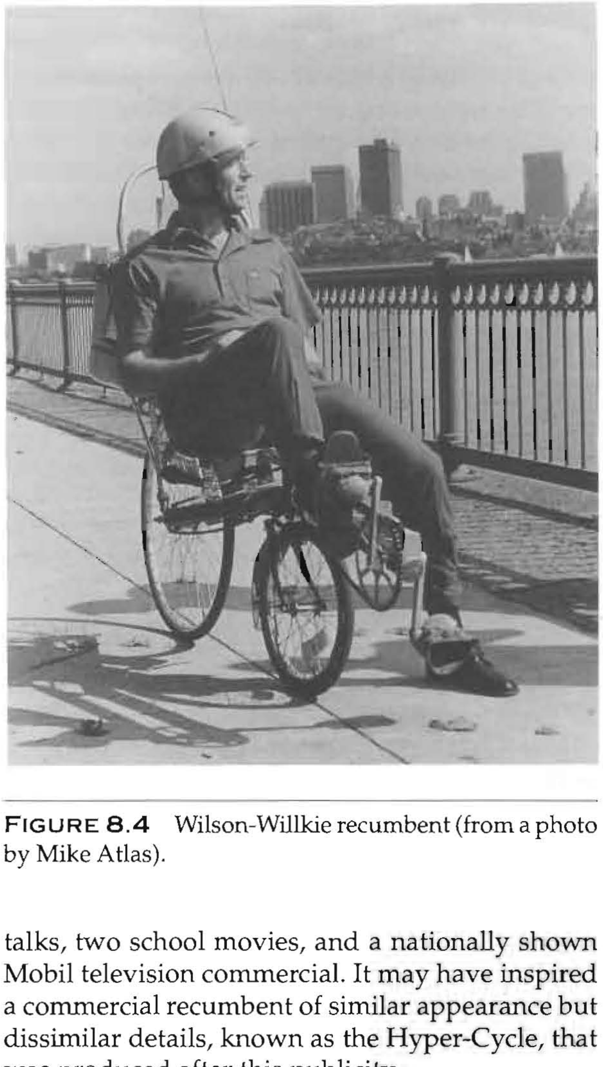

FIGURE 8.4 Wilson-Willkie recumbent (from a photo by Mike Atlas).

talks, two school movies, and a nationally shown Mobil television commercial. It may have inspired a commercial recumbent of similar appearance but dissimilar details, known as the Hyper-Cycle, that was produced after this publicity.

The WW did have flaws, despite its delightful features. It was still heavy on the front wheel, causing even the wired-on heavy-duty tires to last only 1,000 to 2,000 miles (1,600 to 3,200 km). Spokes in the front wheel regularly broke. Snow at a depth of more than 3 in. caused front-wheel sliding. Heavy braking on the front wheel could cause the rear wheel to lift, and after an emergency stop the rider could end up standing in front of the now-vertical bicycle. On two occasions there were more dramatic stops when, in one case, the front-brake retaining nut shook itself off, and the brake fell out onto the tire, rotated around the rim, and became entangled in the spokes. The front wheel locked, the forks bent back, and the rider, travelling at about 12 m/s (27 mph), tumbled forward, feet over hands. Nothing more than abrasions and bruises resulted. This and the other spills confirmed the outstanding safety features of the recumbent design with below-seat handlebars.

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FIGURE 8.4 Wilson-Willkie recumbent (from a photo by Mike Atlas).

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Serendipity

One of the many pleasures of design and development is encountering serendipitous advantages. My initial interest in designing recumbents had been purely for safety: I had been saddened to read of many deaths and serious injuries to riders of regular bicycles who had been thrown over the handlebars by encounters with dogs, potholes, and anything that could jam the front wheel. I had expected that the result would be a compromised machine, with safety advantages, but with many other disadvantages. Yet, unexpected advantages kept appearing. It had not been expected, for instance, that it would be possible to pedal around corners without any danger of the pedals hitting the ground. The great sense of relief coming from a relaxed upper body and the ability to breathe deeply using the diaphragm was another pleasant surprise. When the brakes failed during a downpour on a high-speed descent down a hill with a sharp bend and a dangerous intersection at the bottom, it was an even greater relief to learn that one tennis shoe put flat on the road provided rapid and safe deceleration under full control.

Another unexpected finding was that the canvas seat acting over the full area of the back gave stiffness against pedaling thrusts, and relieved the hands and upper torso of any need to exert a reaction force, but the weight acting against the small area of the pelvic bones and buttocks was resiliently and comfortably sprung. The safety flag, easily installed on a recumbent bicycle, together with the brightly painted surfaces of the large trunk, made the vehicle far more visible to other road users than is a conventional bike not so equipped. The relaxed seating position at a level with that of the drivers of most private automobiles seemed to promote instant communication, and there resulted a higher degree of courtesy from other Massachusetts road users than had been thought possible. There was a remarkable absence of neck and eye strain, of nerve damage in the hands and crotch, and of back pain, compared with what is generally accepted in the conventional bicycle racing position.

Front Wheel Loading and Rolling Resistance

Through the interest of a potential manufacturer in an improved version of the Wilson-Willkie, the author met Richard Forrestall in his search for builders willing to work on what may have seemed the somewhat strange designs he was drawing. Forrestall and his partner, Harald Maciejewski, first built the Avatar 1000 (A1K) (see Figure 8.5), an improved version of the WW, in 1978. In this design the front wheel was moved forward about 250 mm (10 in.) from that in the WW to further reduce the

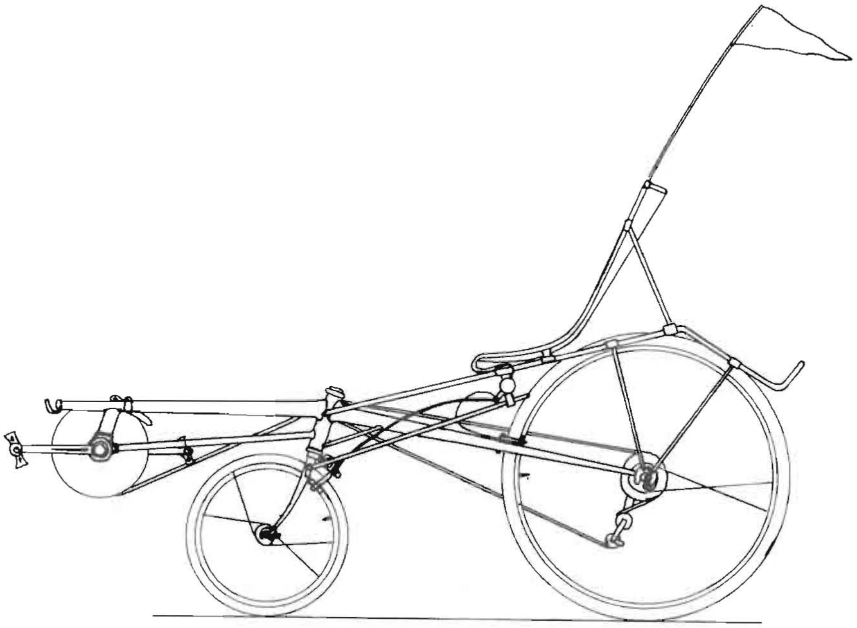

FIGURE 8.5 Avatar 1000.

load on the front wheel. This was done despite the potential interference between the heels and the front-wheel rim, because this could occur only at speeds below about 2.5 m/s (6 mph); at higher speeds, the maximum amplitude of front-wheel steering movements was too small for interference to take place. To retain the previously convenient and comfortable placement of the handlebars below the seat, a ball-jointed steering rod was used to connect the handlebars to the fork crown.

The A1K was a considerable improvement on the WW, and gave longer front-tire and front-wheel life. The learning period needed to become used to keeping the heels out of the way of the front tire at very low speeds was short. Only in extremely heavy braking did the rear wheel show any tendency to lift. Comfort, already impressive on the WW, was further enhanced with the reduction in front-wheel loading.

The rolling resistance is formally given as the force resisting forward motion divided by the vertical force, or load, on the wheel; it is termed the coefficient of rolling resistance (C_r). The C_r for bicycle tires on normal roads is between 0.0025 and 0.015. It is a function of the wheel diameter, being lower for larger diameters. It is also affected by tire suppleness, tubular tires being formerly more supple than clinchers. However, improved reinforcing materials, synthetic rubbers, and construction have brought lightweight clinchers in the 1990s almost to the C_r range of tubulars. Rolling resistance is also greatly affected by tire pressure. Approximate values taken from tests by Whitt (1982) for 27 × 1-1/4-in. pre-1980 tires for pressures of 2, 4, and 6 bar (30, 60, and 90 psig) are 0.008, 0.005, and 0.004, respectively. At 4 bar the C_r for a tire of 16 × 1-3/8-in. (and similar vintage) was approximately twice the value for the larger tire on a similar (in this case, "medium-rough") surface.

Thus, although rolling resistance is usually small compared with aerodynamic drag, it is far from negligible. Suppose, for instance, that the weight of a sprint-record machine, like the Cheetah or Gold Rush, plus the rider were 1,000 N (224.7 lbf) and that it were traveling at 30 m/s (67.1 mph). If the tires have a C_r of 0.005, the power lost to rolling resistance would be $1{,}000 \times 30 \times 0.005 = 150$ W, more than 0.2 hp. Reducing this C_r to 0.0025 through better tires and a smoother road surface could make a major difference when the rider's output at that point in a record run is probably well below 1 hp (746 W). Having most of the weight of the rider and vehicle over a large-diameter rear wheel also reduces rolling resistance. The small-diameter lightly loaded front wheel, although having a higher coefficient of rolling resistance, probably allows a much greater reduction of aerodynamic drag than the increase of a rolling drag.

However, with the load on the front wheel, C_r was still higher than on a conventional bicycle. Table 8.1 shows approximate percentages of front-wheel and rear-wheel loading for conventional and some recumbent bicycles.

Table 8.1 FRONT-REAR LOADING DISTRIBUTIONS

	Front	Rear
Three-speed (Roadster)	36%	64%
Ten-speed (Sports)	40%	60%
GPS II (estimated)	70%	30%
Wilson-Willkie (WW)	65%	35%
AVATAR 1000 (A1K)	62%	38%
AVATAR 2000 (A2K)	31%	69%

The higher loading on the smaller front wheel of the A1K, compared with the conventional bicycles (three speed or ten speed), inevitably leads to higher rolling resistance. There was no reluctance to load up the rear wheel, and interstate trips were confidently and comfortably undertaken loaded with camping and hiking gear. However, the performance on soft ground, in snow, and with a soft or flat front tire was poor: having so great a proportion of the weight over the front wheel meant that its tracking needed to be precise to give the rider good control. This weight distribution gave good slow-speed balancing on hard surfaces with a fully inflated front tire, but this was not enough compensation for the alarming loss of control when the front tire deflated or when snow or mud was encountered. (Other experimenters have reported improved performance using large-diameter mountain-bike tires.)

We felt that to improve on the A1K we should further decrease the loading on the front wheel. The weight distribution of conventional bicycles, with 35% to 40% of the weight on the front wheel, combined with the lower center of gravity given by the recumbent position, seemed desirable, giving good traction, excellent and safe braking, and easy balancing. For this the ideal front-wheel location would seem to be for the wheel to have a common vertical tangent with the front of the pedaling circle. To avoid the high pedaling position of the Ravat and the GPS I, a "squashed" pedaling path, for instance an elongated elliptical or a linear motion, would have to be used. We built and tested several lever transmissions that seemed in prospect to have many advantages over rotary cranking, but when tried out they had unforeseen disadvantages (see Figure 8.6).

The lever drives included a simple piston-crank mechanism, with the pedals taking the place of pistons. The line of action of the pedals did not pass through the crank axis, giving a quick-return motion that seemed to have advantages. But the mechanism, designed as it must be to withstand high pedaling forces, weighed far more and had far more friction than the pedals it replaced. Reluctantly, we put the search for a lightweight, efficient mechanism to produce a linear or an elongated elliptical motion (possibly having ergonomic advantages) on a lower priority basis, and in 1979 we solved the

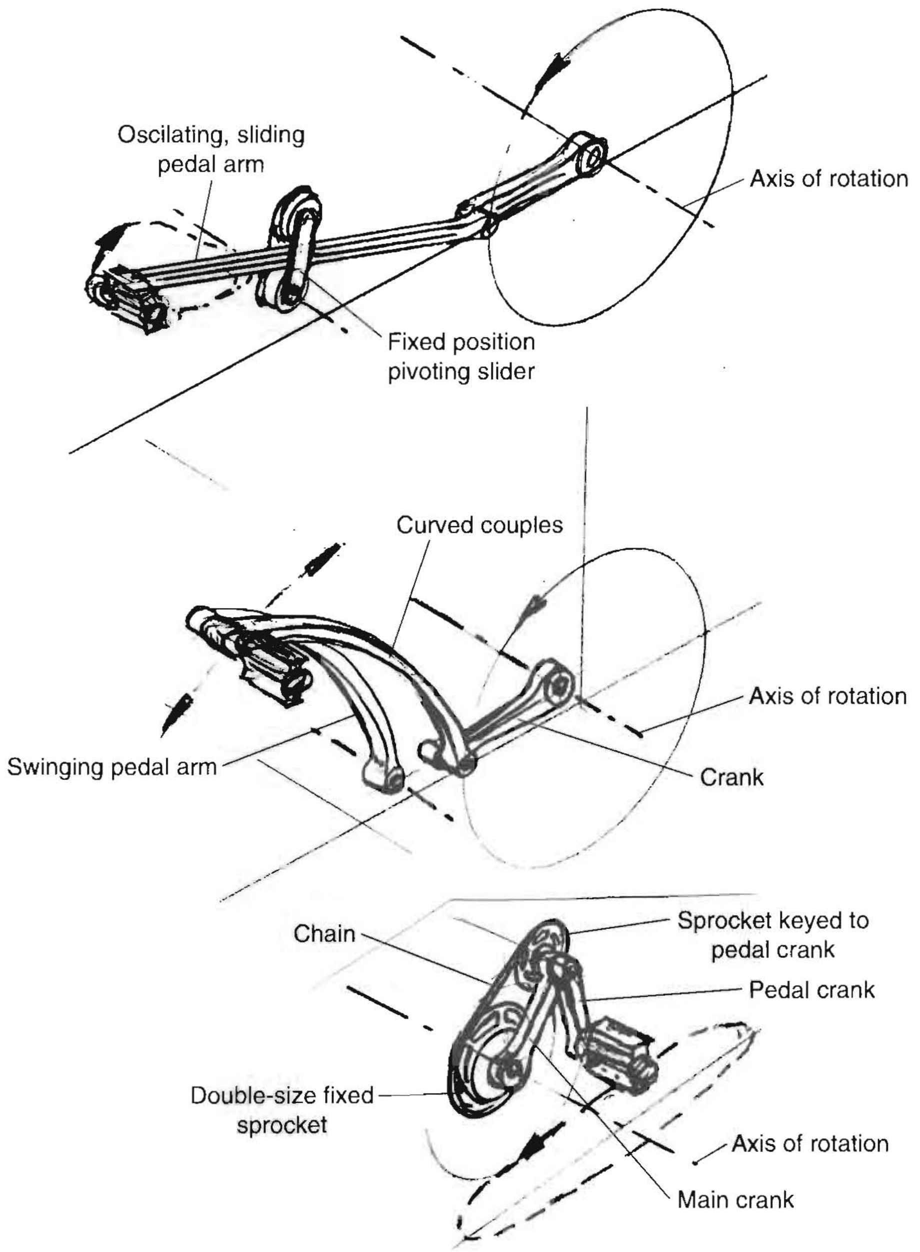

FIGURE 8.6 Lever transmissions giving elongated pedaling motion.

nose heaviness of the short-wheelbase recumbents by going to a long-wheelbase design. We called this the Avatar 2000.

Avatar 2000

Again, serendipity rewarded us. The sole "cost" to moving the front wheel forward appeared to be that the Avatar 2000 (A2K) (see Figure 8.7) became longer than the A1K, which was almost identical in length to a conventional bicycle. There was not necessarily an increase in mass, because although two frame tubes, the steering rod, and the brake cable become longer than in the A1K, the frame is much simplified, stresses are greatly reduced, and two idler cogs needed to route the chain over the front wheel in the A1K are no longer needed. In addition, the following advantages over the short-wheelbase A1K were found, some of them unexpectedly, to be added to the already listed advantages of the recumbent bicycle over conventional bicycles:

1. Tracking accuracy became very precise. Although all bicycles should go where the riders steer them, the outstanding ability of the A2K in this respect extended to ice and snow conditions, in which the light loading on the front wheel allowed it to climb over ice and snow ridges that would cause the short-wheelbase versions to skid. (It is not claimed, however, that recumbent tracking ability in ice and snow is better than that of the conventional bicycle, which is very good in this respect.)
2. Full braking on both wheels could be used at all times except on slippery surfaces. In normal circumstances a front-wheel skid cannot be induced. An early abnormal circumstance was when an improperly mounted tire pump broke loose from the top tube, fell onto the rider's right foot, and went through the spokes of the front wheel during a turn onto a busy street. The front wheel locked and skidded, but the feet could be immediately put on the ground and the rider remained seated on the bicycle. This type of accident on a conventional bicycle can result in very severe injury, often including skull or spinal fracture. In the case mentioned here, the pump was ruined, one front-wheel spoke was slightly bent, and the front-fork paint was chipped, but no other damage occurred, and the 35-mile run continued.

FIGURE 8.7 Avatar 2000.

THE TOUR EASY AND EASY RACER

As I've said before, any device that interacts closely with human beings should be designed with great attention to detail and to overall logic. The Easy Racer team offers the following pair of anecdotes to support its claim that its recumbent is a truly practical, primary mode of transportation. Elisse Ghitelman commutes year-round to her Massachusetts high-school teaching duties. She rides a 1983 Tour Easy, repainted bright red following the November 1990 birth of Jacob Allen, with whom she "cocycled" 2,129 miles during their first three trimesters together. Elisse's total distance traveled on the Tour Easy now exceeds 30,000 miles.

Don Gray started riding bicycles in 1988. In 1991, at age 50, he was the first-ever recumbent rider to complete the Markleeville Tour of the California Alps, covering 206.8 km (128.5 miles) and climbing 4,627 m (15,180 vertical ft) in just under 14 hours. There is a general belief that recumbents are no good on hills, which seems to be a generalization from the poor hill-climbing performance of one or two particularly poorly designed and poorly geared recumbents. But obviously, a stock Easy Racer without fairings can climb hills! Challenged by the loss of an arm as the result of a motorcycle accident, Gray chose recumbent cycling for his fitness program. Gardner Martin stresses the personal satisfaction he derives from the human dimension of Easy Racer riding: an ergonomically kind vehicle that fits the practical needs of a wide range of riders with fewer barriers of age, sex, or physical limitation.

In a recent road-test article in *The Recumbent Cyclist* newsletter, the editor, Bob Bryant, had this to say about the Tour Easy:

> "Born to be wild!" This is the tune I hear in my head every time I climb on board the Tour Easy. The upright handlebar steering is a confidence builder for first-time riders. It is also among the easiest of all recumbents to learn to ride. By "learn" we are only talking about a matter of a few minutes and almost anyone can be cruising in comfort. The lower bottom-bracket height is also easier to handle in traffic or for starts and stops. The low-slung trademark Tour Easy design is also among the fastest. I'm sure there are SWB riders who may beg to differ, but when riding the Tour Easy equipped with a Super Zzipper fairing, I found it significantly faster than any other stock recumbent. As a general rule recumbents with upright handlebar steering are faster due to less air drag from your arms, shoulders and handlebars sticking out the sides, as on an underseat-steering recumbent. The acceleration is excellent, as is the high-speed stability. My test bike and I went up to 52-mph down a local hill together. (Please, for you at home, do not try this.) The LWB design does not offer the perfect weight distribution: the front wheel can be lightly loaded. In my many miles on LWBs, especially the Tour Easy, this has never been a problem. The Tour Easy has perfect road manners. The LWB makes up for its lightly loaded front wheel with great stability in all situations.

Many people ask about steering with those long forks and handlebars. It is a bit tiller-like but nowhere near what you'd expect. After a few rides on the bike, you don't even notice. A real plus for the steering is that it is direct, with no rods, cables or linkages; this keeps the bike simple. This long-wheelbase bike glides along almost effortlessly. It also takes much less attention to the road than its SWB counterparts. Some like this and others do not. In all my Tour Easy miles the only real drawback is not in the bike itself, but in how to transport a LWB recumbent. . . . To sum it all up, a fellow rider described the Tour Easy to me as "the recumbent from which all others are judged." Now it is up to you to decide.

3. The high proportion of the weight distribution on the rear wheel gives outstanding rear traction in snow and ice and outstanding rear-wheel braking in all conditions.
4. Although the seat frame undergoes almost the same vertical accelerations as the rear wheel, the resilience of a fabric seat (in the case of the A2K it is nylon mesh with leather border and straps) in the vertical direction gives the effect of springing.
5. At speeds above 2 or 3 m/s the combination of rolling and air drag for the wheels alone is lower than for two large wheels, because of the low forces on the small front wheel. The rear wheel runs partly in the lee of the rider's body, reducing its air drag. The semirecumbent position gives a lower frontal area, of course, than does a conventional bicycle, because having the legs out in front more than compensates for the somewhat more exposed attitude of the torso and head.
6. A small but appreciated advantage of the long-wheelbase recumbent is that it can be carried around almost like a briefcase by holding the top tube just in front of the seat.
7. Another unexpected advantage was the ease in dealing with aggressive dogs, which are responsible for many deaths and injuries among bicyclists each year. When such a dog attacks, it has to do so running alongside in easy reach of the rider, who can easily discourage it by hitting it on or near the nose. Trying to do this from a conventional bicycle often leads to a loss of control and a dangerous fall.

The Racing Avatar and Modern Machines

The Avatar 2000 gained some publicity in Europe when the author took it to Velo-City, an HPV congress in Bremen in 1980, and it appeared on television. Richard Ballantine, a prominent author and publisher of bicycling books and magazines, later purchased an Avatar 2000, tested it, and gave it outstanding reviews. Derek Henden, a British amateur constructor employed by Xerox, borrowed it to find how its performance would be improved by a fairing. He used a narrower seat to reduce the frontal area and increased the gear ratio with a crossover drive (the chainwheel on the pedaled shaft is on the left and drives a smaller sprocket on the left side of a parallel shaft; the regular chainwheel(s) is (are) on the right side and drives the rear wheel) in the normally unused bottom-bracket tube beneath the seat. HPV racing in Britain had started, with Ballantine's encouragement, and the new vehicle, named Bluebell from the color of its fairing and running for the Nosey Ferret Racing Team, named for its sharp-nosed appearance, began winning (Wilson, Forrestall, & Henden, 1984). Henden borrowed ticket money from Ballantine to compete in the IHPVA International Human-Powered Speed Championships in Irvine, California, in October 1982.

For 2 years, 1980 and 1981, the Vector tricycles won all the major HPV races, setting records for the 200-m flying start as well as over many other distances. On its first appearance in 1982 at the International Human-Powered Speed Championships (IHPSC), the Bluebell beat not only the

Vector but also the Easy Racer recumbent bicycle in the 200-m top-speed event. The speed was not a record, but the course and conditions were different from those at which the previous records were set. The rider, Tim Gartside, was an Australian lawyer touring in Britain who had never raced previously.

In road racing also the three-wheeled Vector and its clones lost their dominance at the 1982 IHPSC. The two-wheelers reasserted their superiority as the Easy Racer recumbent bicycle pulled away from the tricycles for a solid win. The Bluebell was competitive in this event, but crashed in a fast corner. (This was a notable demonstration of the high level of safety of the recumbent design. Gartside ran into the chain-link fence at a speed approaching 22 m/s [50 mph] after the wind load on the banked fairing lifted the front wheel. He was strapped into the seat solely to allow him to push harder on the pedals. The combination of the feet-forward position, the fairing, and the straps enabled him to walk away from this spectacular crash with no more than bruises from the shoulder straps.) The battle continued on the velodrome, where the Vector produced a final win in the 4,000-m pursuit race, beating the Easy Racer by a fraction of a second. This was the first time on a velodrome for both rider and vehicle. Two weeks later Gartside in the Bluebell won over Vector and Easy Racer when both crashed. After the 1982 racing season, the Vector retired from racing. Two-wheeled recumbents have gone on to win almost all events through 1994.

One shouldn't try to make too much of individual wins. However, in HPV racing as in rowing, fashions follow winners. In 1981 and 1982 most challengers were building low tricycles inspired by the Vectors. Afterwards, there was a switch to short- and long-wheelbase recumbent bicycles. As Australian writer and racer Doug Adamson wrote in the December 1983 issue of *Bicycle Magazine*: "An interesting aspect of the [1983] speed trials was that half of the vehicles in the top ten were bicycles. Most previous thinking had concluded that low frontal area and increased stability of three wheels was the way to go for speed." Presumably as a result of the Bluebell IHPSC and European-circuit wins and of exposure of the Avatar 2000, on European television, several small companies in Europe and the U.S. began making machines that seemed to be inspired by the Avatar 2000—indeed, a few were almost indistinguishable from the Avatar 2000, even to its builders.

The Dominance of Gardner Martin's Easy Racer Team

Gardner Martin is a former automobile and motorcycle racer who was inspired to design improved bicycles by a 1974 *Bicycle Magazine* article by Chester Kyle, "Are Streamlined Bicycles in Your Future?" Martin entered the 1975 IHPSC with a very-low-frontal-area, flat-on-the-belly (prone recumbent) bicycle that earned the distinction of being the first vehicle to crash at an HPV speed meet. But by 1979 Martin had combined a refined vehicle with Olympic-class "Fast Freddy" Markham as rider to drive the vehicle, Jaws, over the 22 m/s (50 mph) mark, a first ever for a single-rider HPV.

In 1976 Martin started work on the laid-back Easy Racer design, partly because his wife, Sandra, objected to the impracticality and the hazard of the head-first prone recumbent for everyday use. Martin started by modifying an old tandem bicycle, removing the front seat, the rear pedals, and extending the handlebars. Gradually refined, this prototype became the Easy Racer and began winning road races and criteriums. Sandra and Gardner Martin proceeded to develop the Easy Racer into a vehicle that proved to be the world's fastest HPV bicycle, and yet, with minor changes, could be used for shopping and commuting. The Martins began marketing their everyday version under the name Tour Easy. In addition, with an openness that has been emulated by few others, they sold plans with which amateur builders could make their own Tour Easies, using two diamond-frames and standard parts.

Surprisingly, for some, even the "everyday" Tour Easies began winning races after fairings were installed, for example, setting a new record in the 4,000-m race at the Major Taylor velodrome and winning many road-race events. In 1982 and 1983 the first practical-vehicle contests were won by stock Tour Easies with partial fairings added. Beginning in 1983, Easy Racer's dominance was continually challenged, at times successfully, by Tim Brummer's beautiful Lightnings. Brummer tells his story in chapter 9.

The Easy Racer-Lightning rivalry intensified in January 1984 when the Du Pont Company offered $15,000 (plus interest) to the first single-rider HPV team to exceed 65 mph (29 m/s) over a 200-m run with a flying start. At least three vehicles comfortably exceeded 60 mph on several occasions, but the Gold Rush, an Easy Racer, (see Figure 8.8) was the first vehicle to achieve that goal. On a late evening in May 1986 the Gold Rush reached 65.484 mph on a state highway near Yosemite National Park. Now housed in the Smithsonian Institution, the original Gold Rush never raced again, but a regular-production aluminum-frame Gold Rush Replica went on to dominate IHPSC racing from 1986 through 1991, winning all top speed events, three times breaking the world 1-hour record.

In a dramatic 5-day race in the 1989 Race Across America, the Easy Racer and Lightning teams continued their competition. The Easy Racer team led for most of the way across the country in a street-modified Gold Rush Replica, only to have the Lightning team forge ahead decisively in Pennsylvania, where confusion over the route lost the Easy Racer team a great deal of time and poise.

Gardner Martin's success owes a great deal to dogged persistence, a drive for excellence, and a remarkable rider: "Fast Freddy" Markham. Markham has raced and won titles on Easy Racer designs since 1978 and as late as summer 1994 was the only bicyclist to win two gold medals in the Los Angeles Olympic Sports Festival on standard frames. Markham is the exception among world-class bicycle racers: most racers are reluctant to lose some undocumented degree of muscle training by pedaling a recumbent. Freddy Markham's three world-record 1-hour runs on Gold Rush serve notice that when more of the world's top racing cyclists switch to recumbents, single-rider speeds will continue to push the envelope.

Two points of coincidence between the Martin and Brummer teams are worth noting. One is that both teams used forward rather than under-the-seat handlebars to reduce frontal area and to suit riders who feel more comfortable pulling on something in front of them rather than on something underneath. The second point of coincidence: both shaped their fairings by eye, at least at first. The 2-year supremacy of the Vector design was earlier attributed partly to extensive aerodynamic analysis by computer and wind-tunnel testing, at a time when the back-yard mechanic was considered out of date.

As the speed competitions heated up in the early 1980s, designers agreed on the overriding importance of aerodynamically optimized fairings. However, some unpredicted aerodynamic benefits of the free-form Avatar Bluebell fairing contributed to its defeat of the Vector. The Bluebell was in turn beaten by the Lightnings and Easy Racers. The Lightning used a free-form fairing, whereas the Easy Racer

FIGURE 8.8 Easy Racer's Gold Rush (photo courtesy of Gardner Martin).

combined underwater-torpedo laminar-flow analysis with free-form canopy, fins, and contours. Will the next big increase in speed be made by the team that rigorously optimizes the fairing, perhaps including boundary-layer suction to induce low-drag laminar flow?

Front-Wheel-Drive Front-Steered Recumbents

The types of recumbent bicycles that have been made and raced since the earliest versions have been predominantly rear-wheel drive and front-wheel steered. There has been a perception that the long chain that results from this configuration is heavy, attracts dirt and deposits some on the rider's legs, and adds too much weight. Whether or not reality accords with perception is a matter of debate.

A frequently tried alternative configuration is to use front-wheel drive with front-wheel steering. This involves either the cranks turning with the front wheel and the leg thrusts affecting steering, or the chain, or other transmission element, twisting from a fixed pedaling position to the steered wheel. This technology is at present in a state of interesting flux. Eliasohn (1991) assembled and edited a review of several different variations of front-wheel-drive recumbents in the summer 1991 issue of *Human Power*. Front-wheel drive could be part of machines with all-wheel drive, considered by some to be highly desirable for off-road vehicles. Recumbent bicycles are, however, completely unsuitable as all-terrain vehicles, which rely to a large extent on the agility conveyed by a highly independent rider.

Conclusion

Recumbent bicycles, in the form of the Cheetah (see Figure 8.9), the Lightning, and the UK's Bean hold, at the time of writing (1994), HPV records, respectively, for the flying-start 200-m event (over 29.4 m/s; 68.4 mph), the HPV Race Across America (5 days and 1 hour), and the 1-hour distance (over 72 km; over 45 miles).

Recumbent bicycles are therefore currently the leaders in the HPV racing world. Through the awards they have received as practical vehicles they are to some extent front-runners for commuting and touring. Their users almost universally are extremely enthusiastic about their favorable attributes. Recumbents have attracted, however, nothing like the astonishing explosion of enthusiasm that has

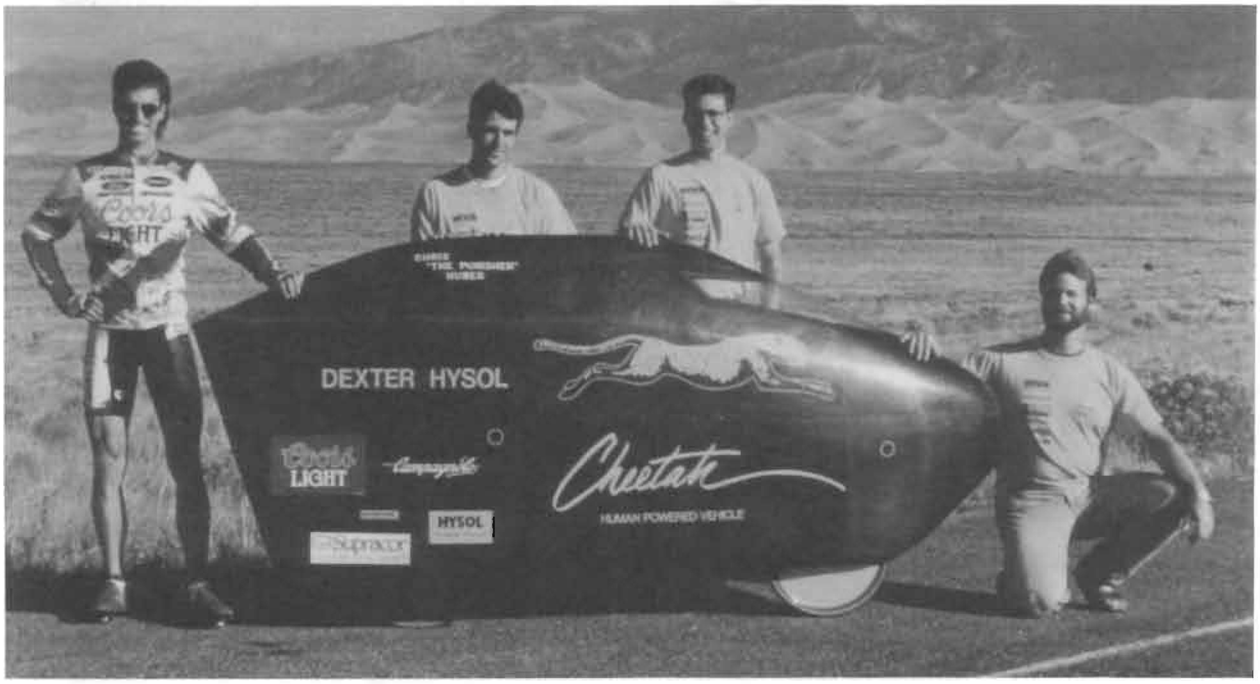

FIGURE 8.9 The Cheetah, holder of the 200-m speed record (29.4 m/s, 68.4 mph) in 1993.

greeted the mountain bike. The recumbent's time could come. The increasing frequency of total traffic standstills in many of the world's major cities, coupled with increasing environmental concern, could result in increased support for human-powered travel. A vehicle that is far more comfortable, easier to pedal, and faster than the alternatives will achieve considerable success, if mass-produced (and mass-advertised) so that the costs come down and options increase. The recumbent bicycle awaits its hour.

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