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BIKE TECH

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IN THIS ISSUE

SPECIAL HPV SECTION

Streamlined Human-Powered Vehicle Anatomy

Crispin Mount Miller

Ever since Francis Faure used a streamlined recumbent during the 1930s to break every cycling record in sight, it's been clear that a standard bicycle isn't the fastest human powered vehicle. But most of the cycling community wasn't interested at the time, and the Union Cycliste Internationale (UCI), seeking to keep races a contest of riders and not mechanical inventions, amended its General Rules to provide that

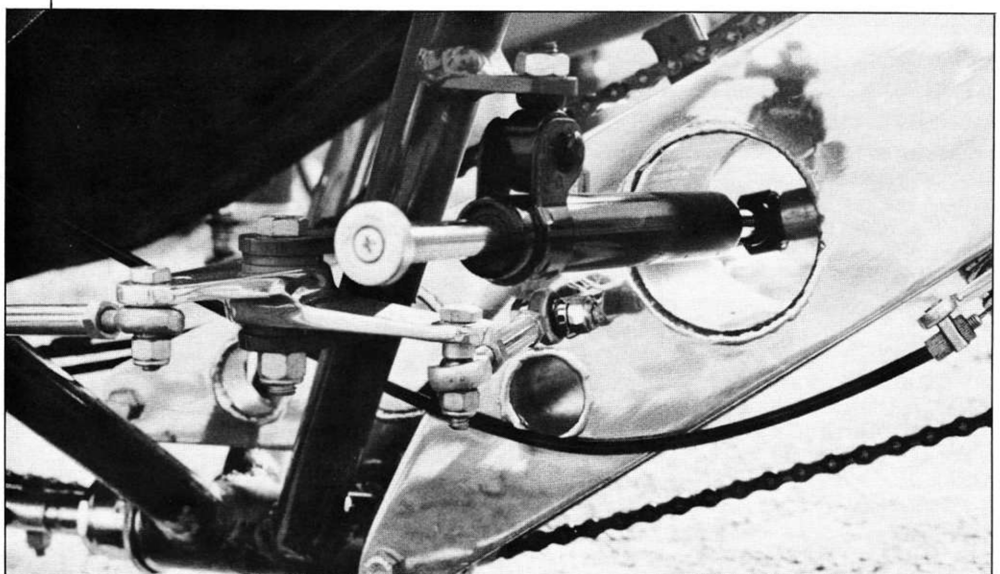
> Article 51: Machines of all types shall be permitted . . . except . . . that they have no device intended to reduce air resistance. . . . Moreover, the machines shall have the following features:

and went on to specify four dimensions that effectively outlaw any prone or recumbent vehicle; for instance,

> (b) the distance between the verticals passing through the metallic end of the point of the saddle and the chainset spindle shall be equal to or less than 12 cm.

While there's something to be said for standardizing the conditions of a race, one wonders what might have happened if the UCI had been in power when Dunlop invented pneumatic tires.

For the next 40 years there was no organization that sanctioned contests of non-standard bicycles, and only an occasional independent experimenter bothered to build any odd-shaped or streamlined bicycle. (See



Crispin Miller

Horizontal rear "headset" of the San Luis Plating *Special.* Tie rods and bellcrank transmit motion from steering handles to tilt rear fork (polished girder) on headset bearings (bottom); horizontal shaft (extending to left from bearings) operates front wheels' steering. Black cylinder (upper right) is steering damper.

Chester Kyle, "Where it all Began," *Bicycling,* May 1982.)

But now that's changed: in 1974 Chester Kyle and Jack Lambie, interested in developing streamlined bicycles, stepped into the gap and founded the International Human Powered Vehicle Association (IHPVA) specifically to encourage the development of unorthodox machines more efficient than standard bicycles.

They've succeeded dramatically. Record speeds for a flying-start 200 meters have gone from 44.69 mph in 1975 to a current record of 58.89 mph. (Since power depends on the cube of speed, if other conditions are assumed not to change much this increase represents an efficiency improvement of about 130 percent.) At the IHPVA's eighth annual International Human Powered Speed Championships in October 1982, more than 40 machines came to bear out the promise of Faure's rides.

These racing machines are impressive in their own right, but also for the possibilities they raise of a new class of practical vehicles: since efficiency is the essence of their achievement, the ideas and hardware they use may be useful off the race course as well.

I went to the 1982 Speed Championships to find out what ideas and hardware they *do* use. I found an impressive amount of clever design; for any given functional requirement, the machines show a wide variety of approaches. They borrow much of their hardware from bicycles, of course, but because they have many different shapes and several experimental operating principles, they also contain much that's new. Between races I looked closely at all the high-placing machines, and all the other ones I could catch up with. I've described what caught my eye in the articles that follow.

The descriptions may leave you with one major question: "So what's the best one of these shapes (or drivetrains, or whatever)?" I'll answer with a chart, because there's no concise answer that's fair. To begin with, "best" means different things for road-racers and drag-racers (and different again for commuters or tourists, if they should apply any of these ideas). And even if one chooses a single area of performance, there are too many variables to allow comparisons of single details — one enormous variable in a contest, for instance, is the rider.

In the absence of controlled comparisons, then, I've compiled the accompanying chart as an admittedly partial answer: it's how the machines I've mentioned have done since 1980 in the IHPVA's main standardized event, the flying-start 200-meter time trial. Sort out what you can.

Performance of machines mentioned, for flying-start 200 meters in recent IHPVA Speed Championships (speeds in mph)

	1982	1981	1980
Vector tandem	57.90	58.47	62.92
White Lightning	52.08	57.25	61.04
Bluebell	51.92	–	–
Vector single	51.85	55.63	56.66
Abbott bicycle	50.44	51.87	–
Easy Racer	49.52	–	–
MIT New Wave	48.93	–	–
Dragonfly II	48.72	53.97	54.69
Texas A&M	46.35	–	–
Gentes tricycle	44.34	50.98	–
Manuped (single)	–	–	42.33
Roc-It	39.90	42.21	38.01
Rightmyer tricycle	38.69	–	–
Red Shift II	34.87	–	–
Land Scull	33.95	–	–
San Luis Special	33.06	–	–
Payne tricycle (no fairing)	21.71	–	–
Tensor (malfunction)	11.11	–	–

Help Wanted

The IHPVA welcomes new members and encourages members to form local chapters and to organize regional competitions. Dues (which include a subscription to the Association's newsletter *Human Power)* are $15.00 per year for addresses in the U.S.; $17.00 for Canada or Mexico; and $20.00 for all other countries. To join or seek information write to IHPVA, P.O. Box 2068, Seal Beach, CA 90740.

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SPECIAL HPV SECTION

Form and Structure

Most of the Funny Shapes Have Reasons

Crispin Mount Miller

Human powered vehicles come in an impressively diverse array of shapes. This diversity probably reflects some variation in designers' priorities, and in how methodically they apply these priorities in their design procedures, but I suspect much of it is due simply to differing theories about what works best.

A case in point is the choice between two wheels and three wheels. Of the several requirements a designer must address (aerodynamic drag, handling and safety, vision, rider comfort, mechanical efficiency, etc.) this choice affects two of the most important—handling and aerodynamic character—but with tradeoffs rather than a clear-cut verdict.

Three-wheelers have simpler handling on straight roads and gentle turns, because they don't have to balance all the time. The rider only has to pedal and steer, and keep balance in mind during hard turns.

But when a turn is really tight, the two-wheeler can lean into it for all its tires are worth, and stay completely balanced and in line with its load. Meanwhile the three-wheeler's rider is threatened with turning over—he can only hope that his body English keeps his center of mass far enough inside his outer wheel, and that his wheels can stand the sideways loading.

Aerodynamically the merits are split also. The two-wheeler can be very narrow where it approaches the ground, and incur minimal air drag from ground effect (more about this later).

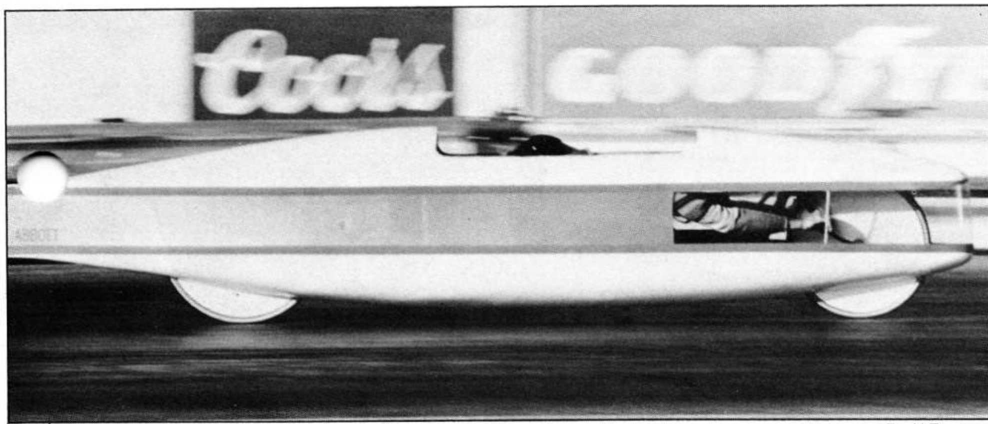
The three-wheeler usually has a wide underside near the ground, and has to deal with a potentially very large ground effect, but on the other hand, its three-point support and low profile (compared to most two-wheelers) make it far more steady in crosswinds.

Given these choices, how have people arranged their wheels?

Off the Shelf

Many of the early machines at IHPVA races were simply standard upright bicycles wearing fairings shaped like airplane rudders.

Most two-wheelers now are lower, with the rider in a somewhat more horizontal po-



Allan Abbott's prone bicycle (without hatch cover). David Epperson

sition. The rider usually reclines, but may lie prone instead. Of the three fastest two-wheelers in the 1982 time trials, two were standard off-the-shelf recumbent bikes—an Avatar 2000® christened *Bluebell* and an *Easy Racer*®—with fairings and minor mechanical adaptations for high speed; and the remaining one was a much longer and lower custom-built prone bicycle (with probably the smallest frontal area of any machine at the races) built and ridden by Allan Abbott.

All three of these machines' fairings are rounded on the underside (with the wheels slicing through to the pavement), but all have different tops: Abbott's is long and level, symmetrical with its underside; *Bluebell's* slopes in one smooth line from a low nose to a crest just over the rider's head, and down slightly to a tall trailing edge; and the *Easy Racer's* is similar to *Bluebell's* but lower, cresting at the rider's shoulders, with a projecting streamlined turret for the rider's head.

Ground Effect

The third wheel adds two more design decisions to the prone/reclining choice: do you add the third wheel in front or in back? and what do you do about the ground effect of a wide bottom?

The nearness of the ground presents a special streamlining design problem because it constrains the air flow under the vehicle. Whereas the air on the top and sides of the machine has unlimited freedom to dodge out of the way, the air forced between the machine and the ground is almost trapped. It cannot dodge downward; it can escape only by moving sideways (or rearward, but sideways is closer), and moving away much faster than the air elsewhere around the machine.

If the vehicle's nose deflects a large amount of air toward the pavement (i.e., an amount comparable to that deflected in other directions), the work of "squirting" this air sideways out from under the vehicle may cause considerable drag. (Unlike the air gently deflected up and sideways, this air deflected at high speed will not return to converge at the tail of the vehicle and give back the energy imparted to it. See "How a Fairing Works" in this issue.)

Designers of fairing shapes seem to take three approaches to ground effect: ignore it; recognize it and modify the fairing to minimize it; or attempt to abolish it by sealing the vehicle to the ground.

Stilts

The first response is usually a non-approach, but one example deserves mention: the Northeastern University *Tensor*, whose very tall wheel struts support the body so far off the ground that ground effect is probably legitimately negligible (the clearance under the body is 30 inches, twice the maximum radius of the body). The gamble, of course, is that the drag avoided by escaping ground effect will pay for the drag incurred by the struts.

The second approach is to build a vehicle that still sits clear of the ground and has some air flowing under it (I'll call this an "underflow body"), and try to minimize the underflow by lowering the nose, so that no more air goes under the nose than can fit under the midsection. Of the underflow-body vehicles that placed high in the 1982 races, most—*Bluebell, Easy Racer,* and all the *Vectors*—have very low noses.

Half-Body

The third approach, which I'll call the "half-body" method, is based on a principle of symmetry for flow around objects. If an object with a symmetrical top and bottom moves horizontally through *free* air (i.e., not near the ground), it will deflect air vertically at its upper and lower surfaces, but the flow around its horizontal midplane will be entirely horizontal.

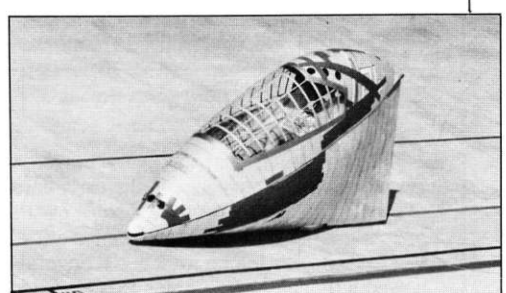
The surface of the ground restricts air flow to this same condition: at the ground, the only way air can move is horizontally. If the body described is cut at its horizontal midplane, then, and the top half is set flat on the ground and slid forward, the air flow around it will be almost the same as before. (It would be exactly the same, except that friction of the air on the ground will slightly alter the air's deflection around the body—though not its motion past the body, since the body is moving past ground and air at the same speed.)

In practice this technique has an additional problem, which is that the underside has to have some clearance from the ground to avoid scraping on bumps. But this creates a space for air flow that is not part of the original "whole-body's" flow pattern, and may cause some disruption in the ideal "half-body" flow.

Two Steered Wheels

The preeminent three-wheeled design since 1980 has been Al Voigt's *Vector.* This design (and several frank attempts to beat it at its own game) places two steered wheels in front and drives the rear wheel. The rider reclines, almost lying down, and pedals a large chainwheel in the nose of the fairing; the front wheels are beside the rider's knees. The fairing is of the "underflow" type, clear of the ground, but with a very low, fairly sharp nose to minimize underflow.

Almost all three-wheelers that attempt road races use this wheel arrangement, if not this fairing shape. (Under a combined braking and cornering load, frequent in road races, the two-in-front arrangement offers much better support than does the one-in-front configuration; and it also does not suffer from the oversteer tendency that has been found to make the one-in-front arrange-



Nosey Ferret Racing Team's *Bluebell.*

Gardner Martin's streamlined *Easy Racer.*

Richard Takagaki

Versatron Research Corporation *Vector* (single-rider model).

ment unstable in hard cornering.) (See Paul Van Valkenburgh, "Getting the Numbers Right," Part 3, *Bike Tech,* October 1982.)

One notable exception to the two-in-front pattern is Roc Fleishman's *Roc-It,* which has a single front drive wheel and steers with the paired rear wheels, through a linkage that tilts the whole machine into the turn. Whether the stability concerns mentioned before apply to this unusual articulation, I don't know; when I peered briefly at the steering linkage, I saw so many springs and pulleys that I reserved the question for further study.

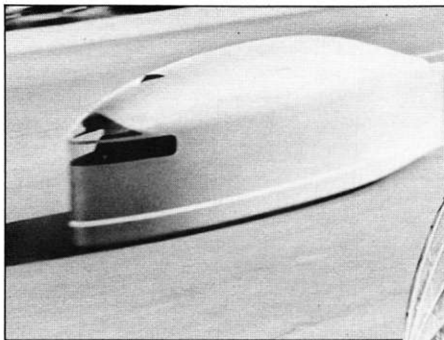
Two high-placing straight-line sprint machines also use the one-in-front wheel arrangement, in conjunction with the half-body fairing shape: Steve Ball's *Dragonfly II* (for one rider) and Northrop University's *White Lightning* (for two riders). The *Dragonfly's* rider lies prone, while the *White Lightning* crew sits supine.

These machines rarely have to steer hard, so they trade off the stability of the two-in-front arrangement for the compact fit inside the fairing offered by the one-in-front arrangement. (The stability required for straight sprints isn't negligible, though—I saw at least one three-wheeler turn over while it tried to go straight down a dragstrip. Paul Van Valkenburgh describes similar problems in the article already mentioned.)

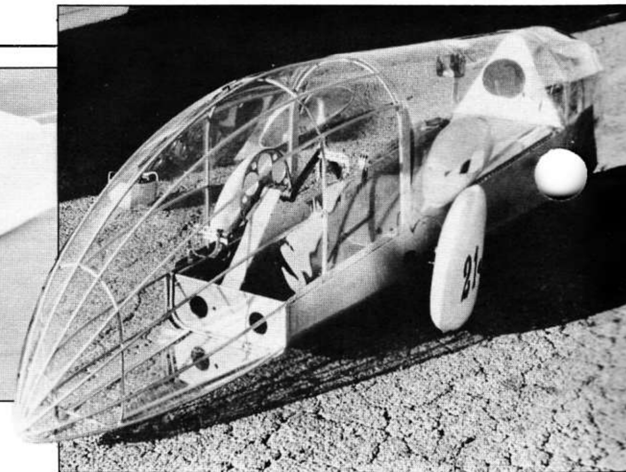
Stringers

Fairings can be built in several ways. A very widespread technique in the early days of the IHPVA was to stretch a flexible plastic membrane over a supporting framework of small sticks or tubing called "stringers" bowed into lengthwise curves that enclosed the vehicle. Some vehicles still use this technique; one handsome example is Tom Rightmyer's three-wheeler. The method also lends itself to quicker and cheaper jobs—Fred Tatch's entry-form description of his *Manuped's* fairing this year was "bamboo, vinyl, and whatever it takes."

But while the stringer-and-membrane style is still around, several of the more conspicuous machines now wear rigid-skinned fairings that support themselves without stringers and form smoothly convex surfaces instead of the taut ridge-to-ridge contour of a stretched membrane.



Richard Takagaki



Crispin Miller

Steve Ball's *Dragonfly II.* (Right) Tom Rightmyer's aluminum three-wheeler.

The most common form of rigid shell is resin-doped fiberglass, like a fiberglass kayak. In addition to offering a very smooth shape, this type of shell—used by the *Vectors,* and the *Easy Racer,* for instance—offers the large attraction of being almost crash-proof—I saw both *Vector* and *Easy Racer* "wipe out" and go sliding across the pavement, and then be set right side up and finish the race.

Some builders apparently less concerned with crashes seek a greater rigidity-to-weight ratio with a variation of the fiberglass shell style: between the layers of fiberglass fabric they sandwich a layer of bulky, rigid, but very light filler material such as polystyrene foam or plastic honeycomb, so that the strong surface layers are spread apart and can better resist bending of the surface. (If forced to bend, though, this sandwich will be damaged.)

This construction appears in the *Dragonfly II* and *White Lightning* (with 1/4-inch honeycomb) and also was used in the latest fairing of the Nosey Ferret *Bluebell* (with 1/16-inch styrene foam, covered with extremely fine 1/8-ounce fiberglass). Very light but very fragile, the *Bluebell's* fairing narrowly survived a velodrome crash at the IHPVA championships and was demolished—"exploded," said an observer—in another a week later.

The machine inside the fairing usually has a frame of welded or brazed steel tubing (*Vectors,* in fact, are made of plain mild steel—Al Voigt says that so far the design team has considered other design aspects to be more important than weight-shaving.). Most of them are custom-designed, of course, but the style of construction is about the same as in any custom-vehicle frame. White Lightning is one exception to this pattern—its frame is made of aluminum tubing epoxied into homemade lugs.

But a more radical exception—considered by some to be the ultimate evolutionary form of HPV bodies—is a style called "monocoque," in which there isn't any "machine inside" the fairing, because the machine *is* the fairing. In these machines the shell is the load-bearing foundation and the wheels, drivetrain, and controls are mounted on struts or brackets attached to the inside.

I noticed three examples of this construction at the 1982 championships. One used aluminum: Tom Rightmyer's tricycle, with the stringers-and-membrane nose and top, has a load-bearing aluminum "box" as its underside and tail. The others use the honeycomb sandwich arrangement described, beefed up with thicker honeycomb (1/2-inch). Kevlar® fabric instead of fiberglass, and reinforcements of graphite fiber tape at heavily loaded points.

One of these machines was Tom Milkie's *Red Shift II,* a compact single-rider tricycle; the other was the longest and tallest machine of all, the four-rider, five-foot-high, 40-foot-long Northeastern University *Tensor.*

Northeastern University *Tensor.*

Crispin Miller

How a Fairing Works

For a streamlined object moving through still air, the theoretical ideal performance is to get the displaced air to converge behind the tail and come to rest, as still as it was before it opened around the nose. If the object leaves moving air behind it, it has lost energy by setting that air in motion, and it "feels" this loss through a retarding force called drag.

(The object must also spend energy to accelerate the air it spreads open around its nose, but in the ideal flow pattern the air *gives this energy back* through the pressure forces it exerts as it flows around the object and closes behind it. Streamlining that approaches this ideal, then, is quite an elegant trick. In practice, of course, an object always leaves some amount of moving air; but far less if the air closes neatly than if it doesn't.)

In order to close at the tail of an object, the air must follow the object's surface all the way to the end without "separating," i.e., flowing out away from the surface.

While it might seem that air would naturally tend to follow the surface, in fact for most objects it separates. Separation occurs because the "boundary layer" of air immediately against the surface experiences friction and loses speed (viewing the air for a moment as moving air flowing past a still object). This friction in itself may be minor, but it can control the whole flow pattern. If air in the boundary layer stops completely, and accumulates on the side of the object, then it blocks the path of the air that comes next, and deflects that air away from the surface.

A separated flow usually creates a large "wake" of disturbed air at the back of the object, which trails along behind the object instead of leaving it cleanly and coming to rest (relative to the surrounding air). Pressure in the wake is lower than in an unseparated boundary layer where it closes at the tail, so the energy "invested" at the nose of the object is not returned. This wake is the major source of drag for unstreamlined objects.

One important effect that keeps the boundary layer "moving," if it does keep moving, is friction with the "faster-moving" air outside it. The principal task of streamlining is to expose the boundary layer to a sufficient amount of this friction. Stagnation and separation are most likely to occur around such surface shapes as projections and sharp curvatures, where the boundary layer is "sheltered" from the outer stream of air; and the need to keep the boundary layer "out in the wind" is what determines the characteristic smooth curvatures and gentle tapers of streamlined shapes.

SPECIAL HPV SECTION

Controls

Twist-Grip Steering and Orange-Crate Stopping

Crispin Mount Miller

The major part of a human powered vehicle's control system is generally its steering linkage. Like drivetrains, these mechanisms range from the mundane to the bewildering. For any wheel location, there's some design that steers with it.

Usually, though, the front wheels do the steering. HPVs that steer with a single front wheel—bicycles (recumbent and otherwise) and some of the one-front-wheel tricycles—mostly follow the obvious bicycle tradition and steer by mounting the wheel in a fork.

Floating Axle

The *White Lightning* steers with one front wheel, but uses a radically different arrangement. The steering assembly is mounted in a triangulated framework near axle level, roughly like the rear triangle of a standard bicycle.

To each "dropout" is mounted a triangular aluminum plate parallel to the wheel and four or five inches high, with its bottom corner attached to the "dropout" by a ball-and-socket swivel joint. These plates form a "floating mount" for the axle, which is attached to each of them by a similar ball joint two or three inches above and aft of the first.

The two plates are stabilized and controlled by a pair of tie rods, one attached to the top corner of each plate (again with ball joints). These tie rods extend up and rearward to a further linkage operated by the handlebars.

When the front rider turns the handlebars, say left, the right tie rod pushes and the left one pulls, so that the right plate rocks forward, carrying its end of the axle, and the left plate rocks backward with its end. As a result, the wheel steers left.

The wheel moves almost as if it were mounted in a fork with a 75-degree head angle, except that the range of motion is limited to about 10 degrees each way. Meanwhile, though, the wheel is braced almost as firmly as a rear wheel. Its action is reportedly very smooth and stable.

Kingpins

HPVs that steer with two front wheels all (so far as I could see) use the standard kingpin-and-tie-rod linkage used on pre-ball-joint automobiles. A short crankarm on the steering column operates the tie rods, which push and pull the arms of the steering knuckles to rotate them about the kingpins and steer the wheels. Sometimes the kingpins are angled and offset to create "rake" and "trail," and in at least one machine—the San Luis Plating *Special*—the wheels themselves are strongly angled or "de-cambered" to place the contact point (with the ground) wider apart than the hubs, so that in a hard turn the outside wheel, which bears most of the cornering load, is more nearly aligned with the load.

The *Special* is unique among machines of its configuration in having a rear wheel that also participates in steering motions. The rear wheel always points straight ahead, or very nearly so, but it tilts from side to side, "banking" to line up with cornering forces. It's mounted in a fork whose "headset" is approximately horizontal in front of the wheel and a few inches off the ground.

Rear-wheel steering (in which the wheel actually changes headings, unlike the *Special)* is generally unstable, even for three-wheelers (and legendarily challenging for two-wheelers) but I saw two three-wheelers that use it. Both have single front wheels used as drive wheels; this arrangement offers a greatly simplified drivetrain in a recumbent vehicle, so it may have been one reason for the rear steering.

One machine, the Texas A&M entry, is purely a straight-line sprint machine, and is probably designed to steer only at such small angles that oversteering force is small and not a problem.

The other, Roc Fleishman's *Roc-It,* is very different; while it steers with the two rear wheels, the steering linkage also tilts the whole vehicle, front wheel and all, into the turn (I wasn't able to see exactly how). This machine enters road races and handles very well, even in hard corners.

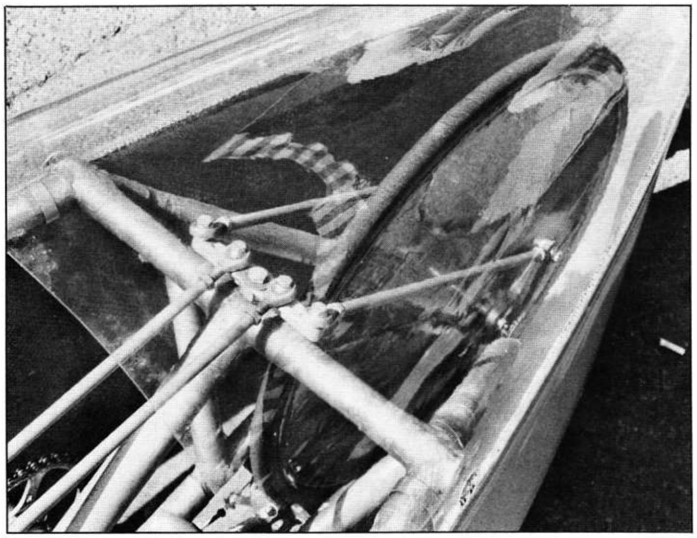
Independent Motions

So far I've discussed the linkage at the "business end" of each machine. At the other end—the rider's hands—most machines can use some simple steering column or bell-crank-and-tie-rod arrangement that doesn't merit any special description.

But for one class of machines that generalization isn't true—the machines whose rider's hands operate part of the drivetrain. How can they do that and still steer the vehicle?

I examined three machines that faced this problem: Fred Tatch's *Manuped,* Yoo Hoo Racing's *Land Scull,* and Steve Ball's *Dragonfly II.* Their approaches differed.

The *Manuped* uses the rider's hands to turn cranks that operate a chainwheel at the top of the steering column, roughly in place of the handlebars, while the feet operate a second chainwheel at the bottom of the fork. The whole drivetrain is mounted on the



Crispin Miller

White Lightning: **(Left) front end. (Right) Detail of front wheel (with shiny spoke cover) and floating axle-suspension plate.**

steering assembly and moves with it. The rider steers, therefore, in more or less a normal bicycling manner, except that he has to keep the strong propulsion forces on the pedals and hand cranks from disrupting the steering (and balancing, for *Manupeds* with two wheels). The design enables a practiced rider to manage this requirement by phasing the hands' and feet's cranks so that their steering torques cancel out. (To help the hands oppose the feet, the hand cranks are set twice as far apart as the pedals.)

While the *Manuped* uses gross limb motions for both power and steering, the *Land Scull* and *Dragonfly* steer more subtly: with wrist motion. In each of these vehicles the rider's handgrips can tilt, independently of their large-scale forward-and-back motion (rowing in the *Land Scull;* "ladder-climbing" in the *Dragonfly),* and an output linkage can transmit the control motion from the handgrips, again independent of the large-scale motion.

The *Land Scull's* output linkage is a cable loop which runs down the "oar" and leaves it at its pivot axis, so that the cable's path length stays constant regardless of the "oar's" position. The *Dragonfly,* whose handgrips move along slideways, has each slideway mounted on lengthwise hinges so that the handgrip can tilt it without changing its forward-and-back orientation; and the slideway has a small swingarm and tie rod attached, with which it operates the steering.

Shallow Slant

Provisions for the driver's vision aren't exactly a control feature, but this seems the best place to mention them.

Most HPVs just have windshields—the portion of the fairing in front of the rider's head is made of transparent material. There is one significant problem with this approach: the part of the fairing in question is often so shallowly slanted that the windshield takes the form of a long, vaulted "canopy" like a sailplane's, and the rider has to look through it rather obliquely. With a plastic windshield that's often a "homemade" heat-forming job, the optics of this arrangement may leave something to be desired.

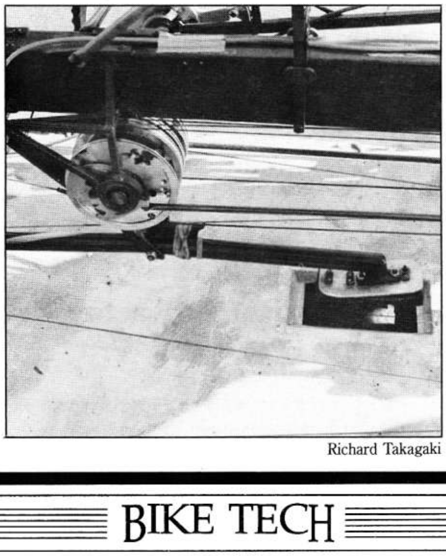
The large clear canopy may cause another problem on sunny days—it can demonstrate solar heating all too well. A common courtesy extended by race officials at the starting line is to shade the riders with their starters' flags until the "ready" call comes; and several machines appear at long road races with large pieces of aluminum foil taped to the inside of their canopies, leaving as little clear area as the driver thinks wise.

But despite these inconveniences, most designers seem to consider direct vision a fairly fundamental requirement, and make do with the problems. I saw only two exceptions:

Steve Ball's *Dragonfly II,* whose rider lies prone, has a compact periscope that allows the rider to see straight ahead—through a hole in the nose of the fairing—while looking obliquely downward rather than straining his neck.

And (who else?) MIT ups the ante of high tech and abstraction another quantum jump. The five-rider Group Velocity *New Wave* has a completely opaque nose, except for a tiny fixture in the very middle. The fixture is the front lens of a fiber optic cable, and the rear lens of the cable is worn as a monocle by the pilot.

Brake of *Dragonfly II.*



Richard Takagaki

Orange Crate

Finally, how does an HPV stop?

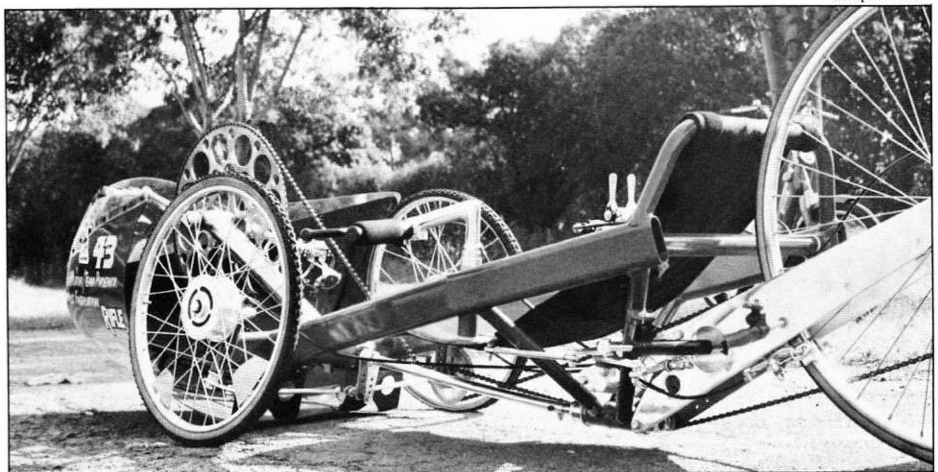
Generally, the simplest way available. Wheels mounted in frames or forks (i.e., mounted like bicycle wheels) usually have caliper brakes; for instance, the rear wheels of *Vectors* and their relatives, and of course both wheels of the bicycles.

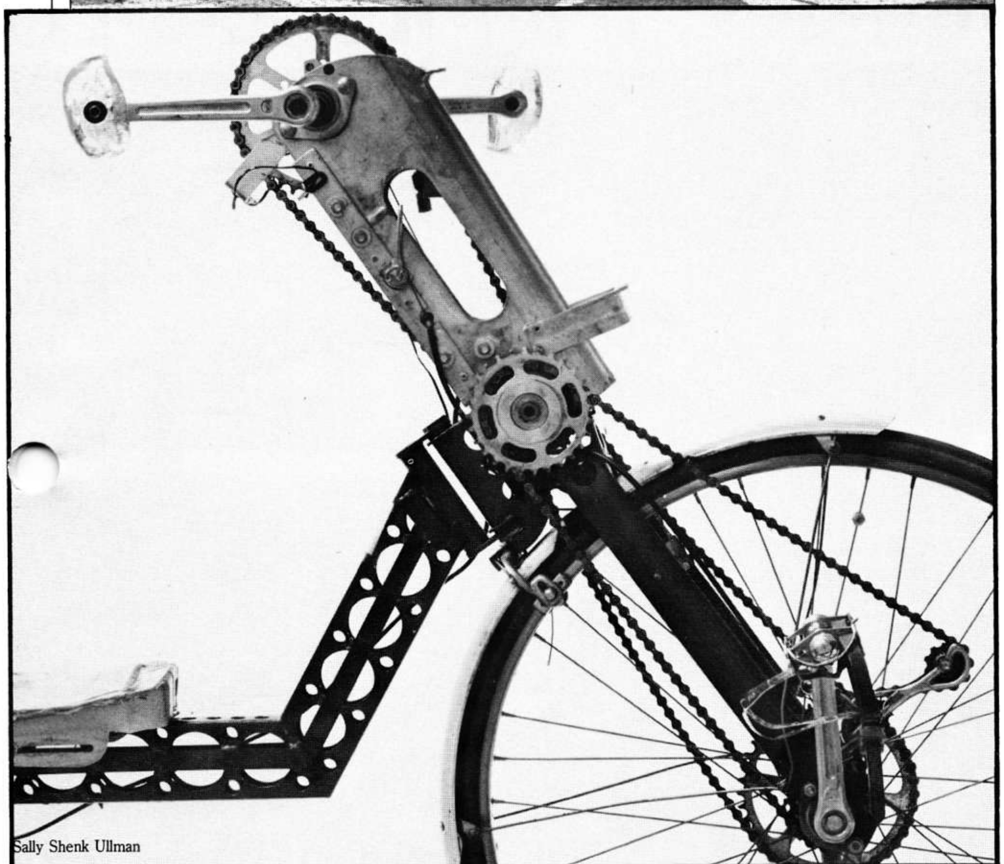
The front wheels of "two-in-front" three-wheelers usually have drum brakes, typically "moped" hubs. The braking torque is thus borne by the steering knuckles, which need to be designed with that in mind.

(One of these hubs saw interesting double duty in Jim Gentes's streamliner. The day before the time trials, the welded-on tie-rod arm broke off of this machine's left steering knuckle. Not to be defeated, Gentes realized that the location of the left hub's brake-cable-adjusting barrel was closely analogous to the snapped-off tie-rod arm; so he got a longer tie rod and used the adjusting barrel to bolt it directly onto the hub. It worked.)

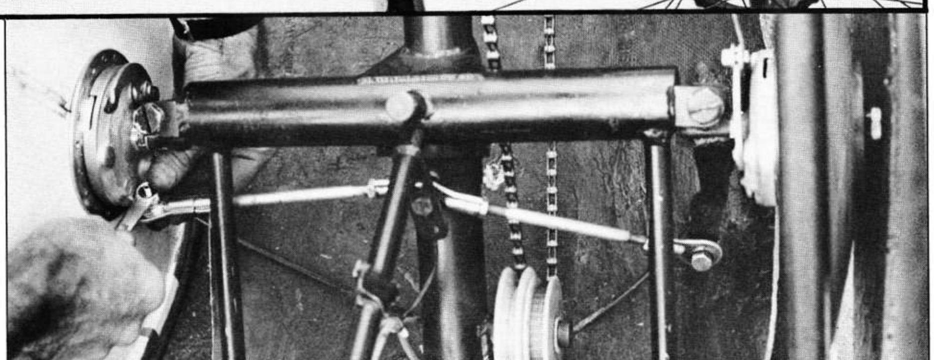
The most utterly simple and direct brake, though, is the one Steve Ball uses on his *Dragonfly II.* This machine, which has no bicycle parts in it except the chain-drive stage of the power train, has wheels that are hard to put brakes on: they're fiberglass-plastic discs with a thin layer of urethane cast onto the edges as "tires," and small bearing assemblies as "hubs." The machine never does any event but a straight sprint. So Ball chose the orange-crate-racer approach: at the end of a run, the rider reaches down and pulls a lever on the floor, and the other end of the lever presses a chunk of old car tire against the pavement.

Crispin Miller





Sally Shenk Ullman



Crispin Miller

(Top) San Luis Plating *Special.*
(Center) Front-wheel drivetrain of *Manuped.*
(Bottom) Jim Gentes installs tie rod on brake adjusting barrel.

SHOP TALK

Understanding Bicycle Tire Sizes

There's Order in the Chaos

John S. Allen

Bicycle tires come in what seems a confusing array of sizes; but there is in fact a relatively simple system to tire sizes. Once you know the system, you can memorize sizes more easily, and also make educated guesses about sizes you have never seen before.

The system became apparent to me during my work revising the tire chart for *Sutherland's Handbook for Bicycle Mechanics* (3rd edition). The key to tire sizes is to divide them into national groups. Each of the three major national groups, British, French, and Dutch, follows a fairly consistent pattern.

The chart in *Sutherland's* was intended to be as useful as possible to bicycle mechanics, so it lists all known tire sizes together in descending order of bead seat diameter. Sutherland's arrangement makes comparisons easy between sizes that are close to one another, but hides the national tire size systems.

The simplified and reorganized chart with this article serves a different purpose: it is intended to show the national systems as clearly as possible. The British, French, and Dutch sizes are shown in separate columns.

It is easiest to recognize the pattern of sizes in terms of the original system of measurement. The new universal European Tire and Rim Testing Organization tire markings (such as 37-622) show the width and bead seat diameter directly in millimeters, allowing direct comparison of all tires. However, of the three original tire size systems, only the French is metric. The British and Dutch systems are based on inch measurements.

For this reason, I give the bead seat diameter in inches as well as millimeters for inch-based sizes, indicating the original system of measurement in boldface. The original marking for each tire size is also in boldface, under its nationality.

Constant Outer Diameters

The "secret" of the system is that a tire's outside diameter was once its fundamental specification. These days we often think in terms of standard rim sizes, installing various widths of tires on them and not caring exactly what outside diameter we get, as

BICYCLE TIRE SIZES ORGANIZED BY NATIONALITY

	DUTCH Marking	DUTCH Bead seat diameter (if $\neq$ British) inches	DUTCH Bead seat diameter (if $\neq$ British) mm	BRITISH Marking	BRITISH Bead seat diameter inches	BRITISH Bead seat diameter mm	FRENCH Marking	FRENCH Bead seat diameter (if $\neq$ British) mm	Notes
28X				*1 1/4*	**25 1/2**	647	*700*		Still in Japanese industry manual.
	1 3/8			***1 3/8***	**25 1/4**	642	*700A*		Still in Japanese industry manual.
	— × 1 1/2(n)			**1 1/2**	**25**	635	700B(n)		The "Raleigh Tourist" tire: good worldwide availability.
	— × 1 3/4 or 1 5/8(n)			**1 3/4(T,n)**	**24 1/2**	622	700C(n)		Available wide and narrow in Europe; only narrow in US. Also 28 × 1.75 with hook edge in Germany. The most popular tubular size. EASILY CONFUSED WITH 27 × 1 1/4. LABELED 28 × 1 1/2 IN CANADA.
27X	1 1/4			**1 1/4(#,n)**	**24 13/16**	630			Bead seat is anomalously 24 13/16, not 24 1/2, probably for cyclometer accuracy. Width actually about 1 3/16.
				1 1/2	**24**	609			A British size used in Germany, also called 32 × 650. Unlike 27 × 1 1/4, size falls neatly into pattern.
26X	1 1/4			**1 1/4**	**23 1/2**	597	*650*		SCHWINN 26 × 1 3/8 IS THE SAME AS BRITISH 26 × 1 1/4.
	(1 1/2 ×) 1 3/8			**1 3/8**	**23 1/4**	590	650A		The most universally available size worldwide.
	— × 1 1/2			**1 1/2(T,w,n)**	**23**	584	650B		Common in widths from 32 mm to 47 mm. Also 26 inch tubular (not based on 1 3/4 inch like other tubulars).
	1 3/4			**1 3/4**	**22 1/2**	571	650C		Common Schwinn *and* British size. LABELED 26 × 1 1/2 IN CANADA.
	2.00, 650 × 50			**2.125(n)**	**22**	559	650 × 50		Hook-edge. Also 1.75 inch width. Common. EASILY CONFUSED WITH 26 × 1 3/4.
24X				**1 1/4**	**21 1/2**	546			SCHWINN 24 × 1 3/8 ALSO HAS 546 MM BEAD SEAT.
	Br: 1 3/8 × 1 1/2, 600A F: 1 3/8 × 1 1/4			**1 3/8**	**21 1/4**	540	**600A(#)**	**541**	Here the French sizes separate from the British. French size is anomalous, one silly millimeter oversize.
	Br: 1 1/2, 600B			**1 1/2**	**21**	534	***600B***	**533?**	I've seen a tire marked 533 mm on a Czech bike.
				1 3/4(T)	**20 1/2**	521	***600C***	**520?**	24 × 1 3/4: common Schwinn *and* British size, also 24 inch tubular with o.d. much smaller than other 24's.
				2.125(n)	**20**	507	600 × 45		Hook-edge. Also 1.75 inch width. Common. EASILY CONFUSED WITH 24 × 1 3/4.
	1 1/4, 550			*1 1/4*	**20**	508			Dutch size is a disused British size.

FRENCH SERIES

2-inch jump*

1 1/2-inch jump*

22X (MAIN BRITISH/DUTCH)	1 3/8,	550A	19 1/4	489	1 3/8	19 3/4	501	550A(w)	490	50 mm steps of French sizes start here. French size available in widths to 40 mm.
	1 1/2,	550B			*1 1/2*	19	482	550B	484	French size still in German catalogs, called 22 × 1 1/2.
					1 3/4(T)	18 1/2	470	550C	470	French size accidentally matches British; still in Italian catalogs as 22 × 1 3/4. Also 22 inch tubular.
					2.125(n)	18	457			Hook-edge. Also 1.75 inch width. Common in Japan.
20X	1 3/8,	500A	17 1/4	438	1 3/8	17 3/4	451	500A(w)	440	French size available in widths to 40 mm. 20 × 1 3/8 is a Schwinn *and* British size.
	1 1/2,	500B	17	432						
					1 3/4(T)	16 1/2	419			This is a common Schwinn *and* British size. Also 20 inch tubular.
					2.125(n)	16	406	500 × 45,50		Hook-edge. Also 1.75 inch width. EASILY CONFUSED WITH 20 × 1 3/4.
18X	1 3/8,	450A	15 1/4	387	1 3/8(w)	15 3/4	400	450A(w)	390	French size to 40 mm; British to 2 inches; takes place of 18 × 1 3/4 whose odd fate is related below.
	1 1/2,	450B	15	381						
					1 3/4(T)	14 1/2	369			In use as 18 inch tubular. Also special Moulton "17 × 1 1/4" inch so rim diameter same as tubular.
					2.125(n)	14	355			Hook-edge. Also 1.75 inch width. Common in Japan. Also in German and Dutch catalogs.
16X	1 3/8(#)	400A	13 3/8	339	1 3/8(w)	13 3/4	349	400A(w)	340	French size in widths to 40 mm. Dutch size anomalous. "Correct" Dutch 13 1/4 inch is German 16 × 1 3/8A. 16 × 1 3/8 British *is also* Schwinn.
	1 1/2,	400B	13	330						
					1 3/4(T)	12 1/2	317			Common Schwinn *and* British size. Also 16 inch tubular.
					2.125(n)	12	305			Hook-edge. Also 1.75 inch width. Common. EASILY CONFUSED WITH 16 × 1 3/4.
14X	1 3/8,	350A	11 1/4	286	1 3/8	11 3/4	298	350A(#,w)	288	French size in widths to 40 mm. French size is anomalous.
	1 1/2,	350B	11	279						
					1 3/4(T)	10 1/2	267			In use only as 14 inch tubular.
					2.125(n)	10	253			Hook-edge. Also 1.75 inch width. Common in Japan.
12X	1 3/8,	300A	9 1/4	235	1 3/8	9 3/4	248	300A(#,w)	239	French size in widths to 40 mm. French size is anomalous.
	1 1/2,	300B	9	229						
	12 1/2 × 2 1/4				12 1/2 × 2 1/4 12 1/2 × 2.25	8	203	320 × 57		This size, common in many countries, appears to be related to decimal size tires.

BRITISH 1 3/8 SER

Symbols:

A, B, C, as in 700C: indicate widths of standard tires in French marking system.

A = 37 mm (1 3/8 inch)
B = 40 mm (1 1/2 inch)
C = 47 mm (1 3/4 inch)

These marking may be used in a two-part symbol such as 700A, indicating that the nominal outside diameter is 700 mm and the nominal width is 37 mm. Actual width, whether equal to nominal width or not, may be inserted in the middle, as in 700 × 28 C. French tires are sometimes also labeled with three-part "English" numbers such as 28 × 15/8 × 13/8. See Sutherland's *for details.*

T: this is also a tubular size.
n: the tire is available in widths narrower than the nominal one.
w: the tire is available in widths greater than the nominal one.
#: an anomalous tire size (one that does not fit neatly into the pattern of sizes).
—: more than one number is possible here; the number states the actual width of the tire, as opposed to the nominal width which follows it. (Caution: in some countries the "actual-nominal" order is reversed; see Sutherland's *for details.)*
Br, F: British and French. The Dutch system does not specify 24-inch sizes in the usual way; instead it adopts the British and French sizes and labels them with the numbers indicated here.

boldface *as in* ***27 × 11/4:*** *this is the original national marking (British, French, Dutch) or the original measuring system (inch vs. metric).*
CAPITALS indicate the most common sources of confusion.
italics indicates an obsolete tire size.
**: at this interval the outside diameter jumps by the usual two inches, but the British rim size for 11/4-inch and 13/8-inch widths jumps by only 11/2 inches.*

Bicycle Tire Sizes

long as the tire clears the frame. But at the time traditional tire sizes were named, tire and rim makers kept tires' outside diameters constant, by varying the rim diameter for every different tire width. For most of the traditional British and Dutch sizes, in fact, the difference between the nominal outside diameter and the bead seat diameter is exactly two nominal tire widths. (The French system works similarly but isn't quite so simple.)

Originally, then, the tires of each national grouping and nominal diameter but of different widths and rim sizes (French 550A, 550B, and 550C, or British 26 × 1¼, 1⅜, and 1½, for example) had the same outside diameter. But tire widths soon began to wander away from the standard. It was easy to make tires of different widths to fit the same rim, and there was a ready market for them among riders who wanted new tire widths but not whole new wheels.

As an example, note that the rim sizes for all tubulars except 26-inch are equivalent to those for 1¾-inch-wide British tire sizes. Tubulars originally were about 1¾ inches wide, with rims to fit; but with improvements in roads and tire manufacture, they have become progressively narrower. This historical fact is of practical importance, too. If you are installing tubulars on a bike with 24-inch or smaller wheels, it is usually best to use the next larger size; otherwise, brake reach will be very long and the bottom bracket very low.

Tire width shrinkage has occurred in wired-on sizes too, most notably the 28 × 1¾ which we know as the narrow 700C. As roads improved, narrower tires led to narrower rims, which in turn allowed even narrower tires. Finally, the 28 × 1¼ and 1⅜ sizes were abandoned in favor of the narrowed 28 × 1¾. The original wide version of the 28 × 1¾ is, however, still used on utility bikes in Europe. We've seen a similar narrowing trend in the 27 × 1¼-inch size over the past ten years.

With the abandonment of some smaller sizes (below 24 inches), an opposite trend has developed: remaining sizes have tended to become available in wider versions; for example, the 18 × 1⅜, now available in widths up to two inches. To be sure, rims of different widths are needed when tire widths vary over such a wide range.

Odd Jump

All three nations use the same 26- and 28-inch tire sizes, which originated in Great Britain. Only the names and the available widths are different.

The British 27-inch sizes apparently originated later and were not adopted by the French.

British tires continue downward to the smaller sizes in two-inch steps except for an odd 1½-inch jump in rim diameter in the 1⅜-inch-wide series. (Meanwhile the nominal outside tire diameter jumps by the usual two inches, so that all 1⅜-inch-wide sizes below this jump have rims ½-inch "oversized.") This is shown in the chart.

Dutch sizes (mainly Vredestein-Paragon and perhaps also Carideng products) also continue downward in two-inch steps, but without the odd 1½-inch jump. Consequently, Dutch 1⅜-inch-wide tires 22 inches and smaller are different from the corresponding British tires. (Exception: Dutch tires labeled "BSR"—"British standard rim.")

French sizes separate from the British at 24 inches. French sizes of 24 inches (600 mm) are a bit irregular, but smaller French sizes go into an even progression by 50 mm steps. Since 50 mm is slightly less than two inches (by 0.8 mm), the French sizes gradually draw away from the British and Dutch.

Italian sizes aren't shown on the chart because they are the same as British and Dutch. Since the Italians use both British and Dutch 1⅜-inch sizes, they try to prevent mixups by using different markings for British sizes. For example, an Italian 20 × 1¼ or 500A is really a British 20 × 1⅜. Don't ask me to justify that, I'm only explaining it. For more details, see *Sutherland's*.

There are a few anomalous British, Dutch, and French sizes that don't fit neatly into their national groupings, even accounting for width changes. I indicate this on my chart. Five or six additional German and Swedish sizes don't fit in either. I've left them out, for clarity's sake. Most are very close to British or Dutch sizes. If you have an explanation for odd sizes or know of additional sizes, please don't hesitate to write me or Howard Sutherland.

If you post the tire size chart in this article on your wall, you will soon be able to remember most tire markings and dimensions. The systematic organization saves your having to memorize unrelated numbers for each size.

Thanks to Howard Sutherland for making possible the research that led to this article, to Fred DeLong for the tire chart in his *Guide to Bicycles and Bicycling,* the most nearly comprehensive chart I could find when working for Howard—and for supplying International Standards Organization documents; to the many manufacturers and distributors who sent catalogs; to the Japanese bicycle industry for its very helpful technical manual (in English, yet!); and to D. Brian Williams of Toronto, Canada, for information on the smaller tubular sizes and "Special Moulton" size.

SPECIAL HPV SECTION

Drivetrains

There's a Chain, But the Rest May Be Strange

Crispin Mount Miller

So far, all serious competitors at IHPVA races have been wheel-driven machines (although a bicycle driven by a propellor in back did appear one year). Since drive wheels — or propellors, for that matter — are rotary devices, the simplest power input for them is usually a rotary one, such as the traditional crank and chainwheel.

Cranks and chainwheels are exactly what most HPVs use, with a few modifications to adapt them to high-speed, low-slung machines.

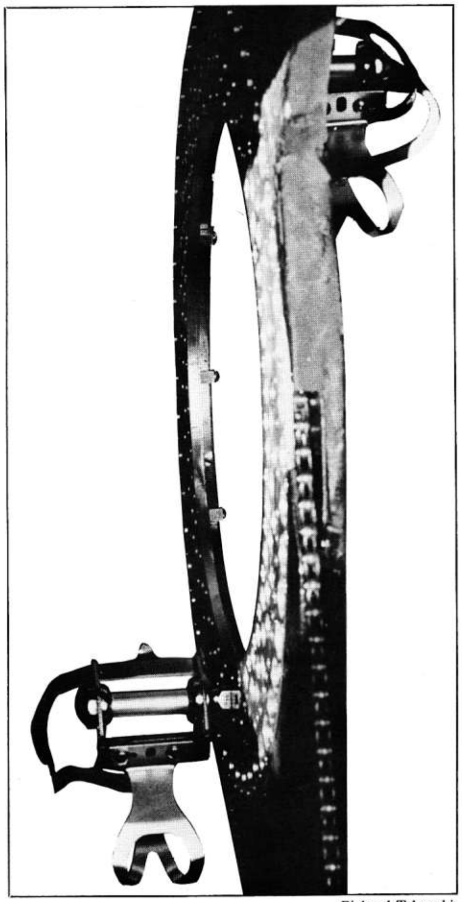
Competition HPVs use gears in the 150-inch range for road races, and in the 200-inch range for flat-out record attempts. Usually this means they use very big chainwheels, with tooth numbers ranging from 70 to over 100.

Most of these large chainwheels are mounted in the usual way to ordinary cranks, but the one in Tom Milkie's *Red Shift II* is an interesting exception: rather than having cranks and a bottom bracket, it has a flange bolted on beside its teeth that runs in bearings mounted around its periphery. The pedals are screwed directly into the chainwheel itself (which is of thicker material than most chainwheels). This arrangement cuts four inches from the width of the vehicle's nose by doing away with the crank spindle.

Occasionally, instead of a large chainwheel, a machine uses a two-stage chain drive, with a step-up of roughly 2:1 in the sprocket sizes on the intermediate shaft, and then a fairly "normal" chainwheel size. This was the setup used on the British *Bluebell,* whose framework was an almost-stock FOMAC Avatar 2000; this recumbent frame happens to have an unused bottom bracket shell at the base of the chainstays, just because that's the easiest way to attach chainstays; the bracket that holds the crank bearings is several feet farther forward. The *Bluebell's* crew simply installed a crossover drive in this rear shell (and switched sides with the front cranks) to make an "instant" two-stage drive.

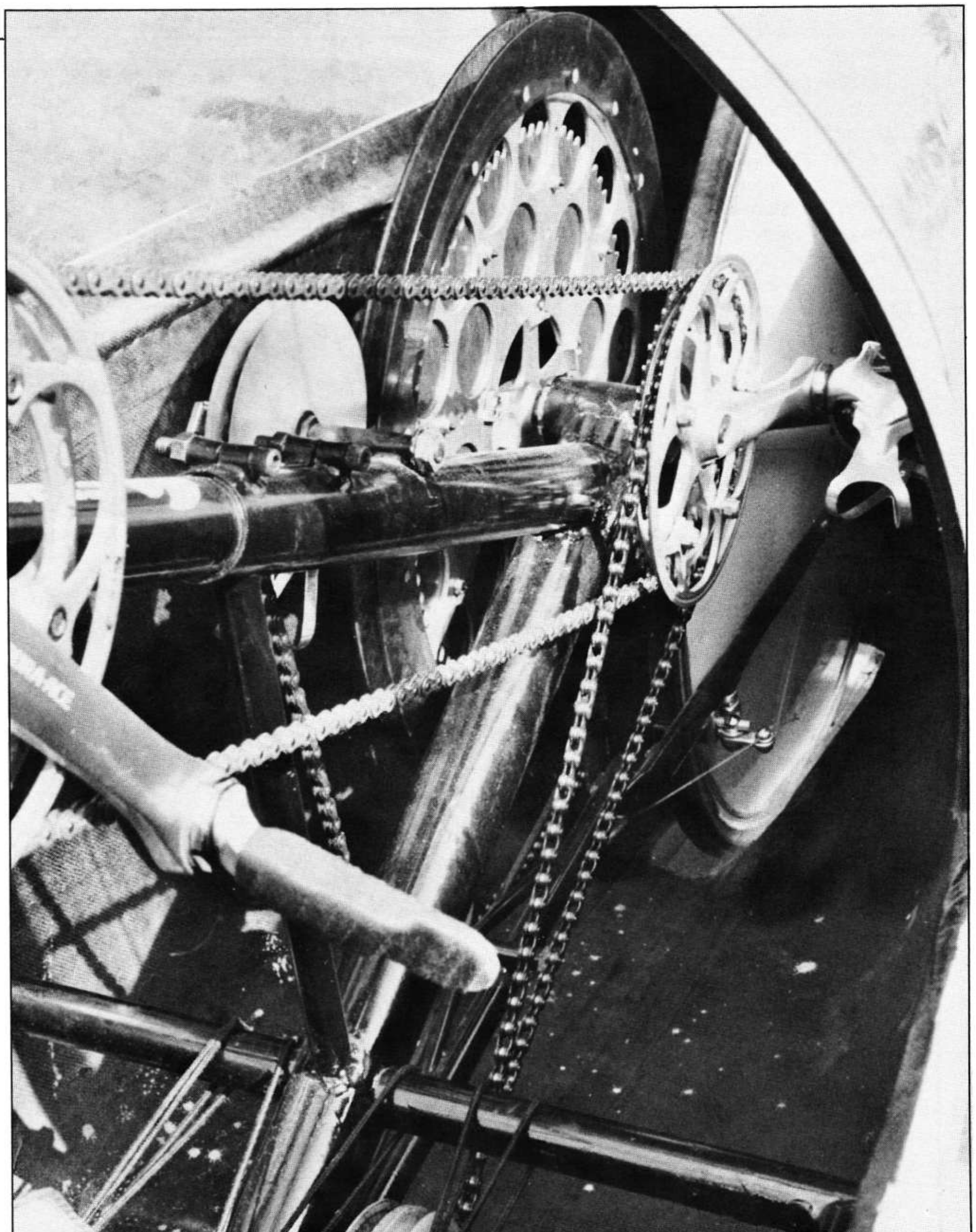
Beside Itself

The long path of the chain on a recumbent sometimes requires intermediate guide pul-



Richard Takagaki

Centerless chainring of *Red Shift II.*



Richard Takagaki

(Right)
Rear wheel and main chainwheel complex of tandem *Vector:* rear rider operates pedals and hand cranks, synchronized by upper chain loop. Lower chain loop delivers power from front rider. Return side of main drive chain is visible as vertical chain below white pulley at left.

leys or idler sprockets, especially on the very low-slung three-wheelers whose chain must duck under the seat, run along in the few inches between seat and pavement, and then slant back up to the rear hub. The length of the chain run does give the designer a bit of leeway, though: it allows the chain to dodge sideways enough that the pulleys for the two sides of the chain loop — forward-moving and rearward-moving — can sit side by side and share axles.

The tandem *Vector* exploits this arrangement handily for its special needs; its rear rider (who faces backward) wants to pedal in a rotary direction opposite that of the front rider, but they both need to drive the same main chainwheel. Since the chain can run beside itself, it can run in a figure eight as easily as in a simple loop, so the *Vector* builders did run the front rider's chain in a figure eight and used it to help drive the rear rider's crank.

Another application of this trick could have been used to return the rotation to the "proper" direction for the rear wheel, but apparently the rear chain run is too short to allow the sideways dodge; so the final chain is driven forward by the *underside* of the main chainwheel and then returns to the rear derailleur over pulleys that lead it back under the chainwheel, the same way it came.

Some designers choose to augment pedaling power input by hand cranking. Hand cranks are provided for the rear riders in both the *Vector* and *White Lightning* tandems, and for all but the front rider in the five-person MIT *New Wave.*

While some single-rider machines used other hand motions for power input, none in 1982 used hand cranks. In previous years, however, some single *Vectors* have used them (one of the two at the 1982 races had an empty crankbearing shell on the control stem). So has the *Manuped,* a front-wheel-drive recumbent which has appeared as a two-wheeled solo bike in previous years, but which was a tandem tricycle in 1982. The *Manuped's* front rider (or, in previous years, the only rider) has foot cranks whose spindle is concentric with the front wheel axle, and hand cranks instead of handlebars.

Spiral Drums

A few vehicles have experimented with input motions other than rotating cranks. The oldest and most successful one present in 1982 was Steve Ball's *Dragonfly II,* which uses strictly linear drive input by hands and feet: the rider lies prone and makes ladder-climbing motions, moving pedals and handgrips forward and back on roller carriages along tracks. The pedals and handgrips pull cables that are wound around small drums (one for each cable, mounted on a common shaft) amidships, and the drums take turns driving a chainwheel on their shaft through one-way clutches.

Linear drive is often (and usually correctly) considered inefficient, because the kinetic energy of the rider's limbs gets wasted at the end of each stroke; the limb must simply stop, instead of having its motion redirected, as with rotary cranks, to help begin the next stroke.

Ball's transmission avoids a large portion of this loss by a special feature of the cable drums. Where each drum holds the few inches of cable that are last to unwind, the radius of the drum decreases in a steep spiral (see illustration). (Adjacent turns of the cable are unaffected because each turn sits in its own groove on the surface of the drum.) As this final portion of cable unwinds, the drop in the effective radius arrests the cable and its carriage, and the change in kinetic energy of the rider's limb is fed into the vehicle's drivetrain.

Since the limb's speed is cut by more than half, and kinetic energy depends on the square of speed, more than three-quarters of the kinetic energy is reclaimed.

Another cable-and-drum scheme (in an entirely different-shaped vehicle) was used in 1982's tandem tricycle *Manuped* entry by Fred Tatch. This vehicle's front end has the standard *Manuped* hand-and-foot-cranked front wheel, from previous years' *Manuped* two-wheelers; new for 1982 was a rear seat, facing backward, flanked by wheels that the rear rider propelled by operating swingarms with his hands and feet. The swingarms pulled cables which turned drums which turned chainwheels.

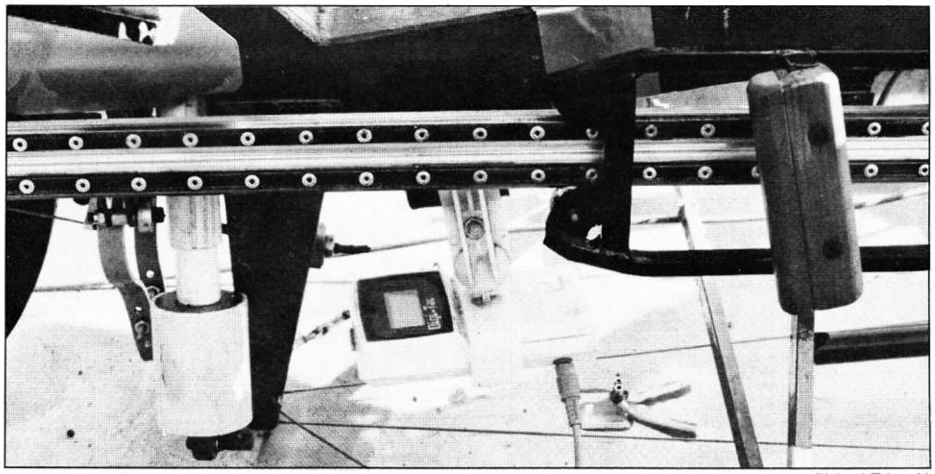
Rowing

Some studies have indicated that people can produce higher power outputs than those of pedaling by doing some kinds of rowing motions. Two vehicles in 1982 used "rowing" power input, but with different mechanisms and different resulting limb-velocity patterns.

The Yoo-Hoo Racing Team *Land Scull* uses handholds and footrests mounted on large levers, which are linked to chainwheel cranks by connecting rods (roughly analogous to piston rods). The resulting velocity cycles of the rider's limbs are approximately sine functions, like the motion of pistons on a crankshaft (timed slightly out-of-phase to avoid having a simultaneous dead center).

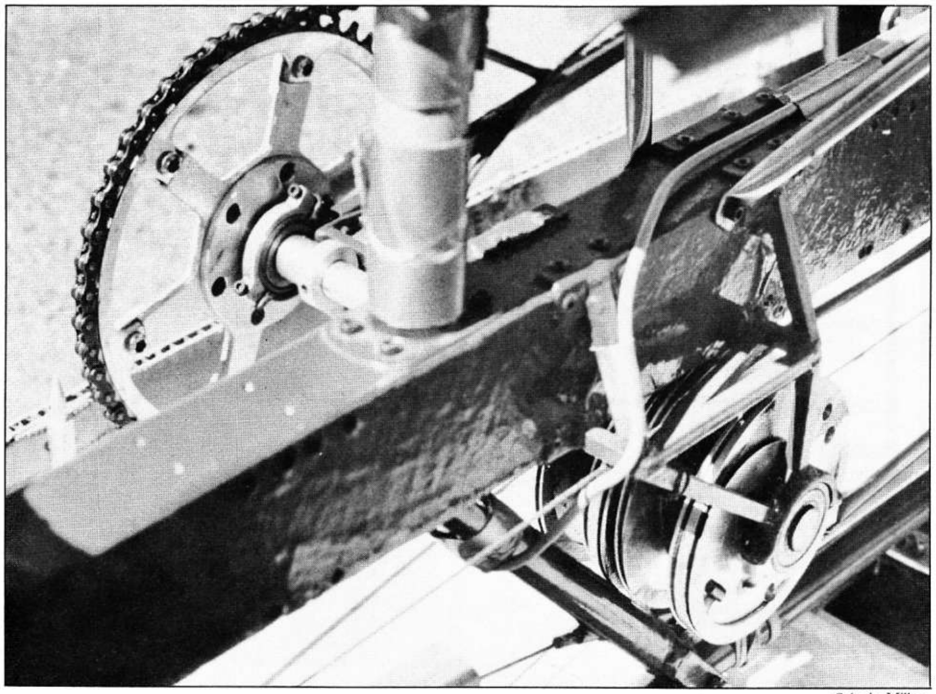
The other machine, built by Carl Payne, applies power to its primary power chain more directly, with linear ratchets whose pawls engage the chain links; the hands operate a lever that carries one ratchet and the feet operate a sliding carriage that moves the other.

This machine therefore gives a constant ratio of hand speed to primary chain speed, and (another) of foot speed to primary chain



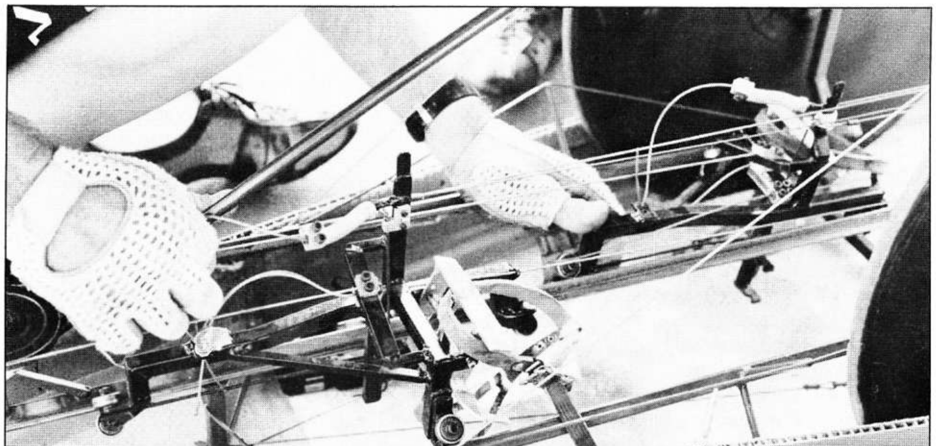
Richard Takagaki

***Dragonfly II:* handgrip and track. Front wheel, steering linkage, and steering damper (white cylinder) appear at left.**



Crispin Miller

***Dragonfly II:* cable drums and chainwheel. (Below) *Dragonfly II:* pedals and track.**



Richard Takagaki

speed. However, between the primary chain drive and the final chain drive there is an unusual feature, a large "windup" spring, whose input shaft can be twisted ahead of its output shaft by as much as one full turn to store energy and release it between strokes; so the overall drive ratio is variable, and not straightforward. (A one-way clutch prevents the spring from unwinding back against the rider.)

Both of these rowed vehicles use stationary seats (rather than the fixed footrests and rolling seats used in racing shells, where all the motion must be done by the hands, since they hold the oar). Stationary seats avoid the work required to oscillate the whole body mass, or, more precisely, to oscillate both rider and vehicle about their common center of mass, which would cause considerable inefficiency in a land vehicle. (In racing watercraft it's less of a problem because the boat weighs much less in proportion to the crew.)

Absent Ellipse

One type of drive that might be considered intermediate between standard pedaling and the more radical schemes was conspicuously absent at 1982's events (so far as I could tell): the elliptical chainwheel. I don't know why. It does appear in photographs of machines at earlier meets, and has some strong proponents among human-power experimenters. But clearly it hasn't been recognized as superior; its benefits, if they exist, may have been obscured by the sea of other variables, or may require more training with it than most HPV riders spend with the competition machines. (Many of the riders are high-ranking racers of standard bicycles, and are imported a few days before the HPV races.)

At the output end, where the power is fed to the driving wheel, all the drivetrains I saw in 1982 used conventional chain drives with derailleurs to shift gears. Clusters usually sat directly on the driving wheel and ranged from three to seven cogs, mostly the standard five or six. One machine, the Northeastern *Tensor,* mounted the gear cluster on a countershaft and drove the wheel with a simple chain drive, to remove the derailleur's bulk from the wheel pod, which projected down from the body of the machine.

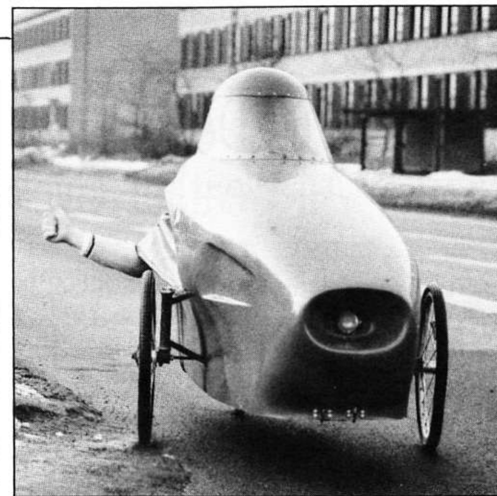
Chain ratchet on Carl Payne's vehicle (cover plate removed).

Crispin Miller

PROJECTS & PROTOTYPES

The Leitra M1 Recumbent: A Practical HPV

John Schubert



My first ride in a fully faired, streamlined recumbent tricycle was almost like being locked in a jail cell. It took one person to help me shinny into the cockpit and two to help me shinny out. After I had gotten in, my helpers sealed the windshield in place with duct tape. The windshield was a faraway slit that afforded only a minimal view of the road. The trike's owner warned me that I could overturn it quite easily. Being inside felt like shrink-skin packaging. So much for the "practical HPV."

My second ride in a faired recumbent was a different story. This trike, Carl Rasmussen's Leitra M1, is a wonderful mix of cargo-carrying ability, protection from the elements, ease of use and maintenance, and sophisticated streamlining—all designed by a man whose "other" current invention is a two-seat sailplane whose Volkswagen-powered auxiliary propeller neatly folds into the fuselage (like retractable landing gear) when the pilot wishes to soar.

It was sheer chance that I ever met Rasmussen. I was visiting friends in Copenhagen, Denmark, during my vacation, and one of them had seen a picture of Rasmussen's M1 in a Copenhagen newspaper. We arranged a visit to the Leitra workshop, where Rasmussen works on his bikes and sailplanes when he's not busy with his job as head of Technical University of Denmark's Research and Information Office. (Rasmussen, a mechanical engineer, holds a PhD degree from that university.)

In the accompanying article, Rasmussen describes the criteria he had in mind when he built the Leitra M1. What struck me about the bike was that it combined so many intelligent solutions to mechanical problems. The bike is the best "practical HPV" I've seen.

Part of the reason for this must be Rasmussen's distance from the IHPVA racing influence. It's obvious at first glance that the pilot/engineer from Copenhagen never thought his bike should look like a Vector. The Leitra M1's two front wheels are unfaired, the nose's clean lines are interrupted by a series of air scoops and a headlight socket, and the rear fairing consists of symmetrical, tapered molded fiberglass panniers with a fabric cover snapped over them.

If you ask Rasmussen how fast the bike will go, he dismisses the question. He's never tried to find out. (He has ridden it in a touring event of approximately double-century length, and placed very well.)

Aerodynamic perfection is compromised to make the bike practical. The exposed front wheels add drag, but they permit wide track with minimum overall width and they can't bring snow and water inside the driver's compartment. The fairing is open on the bottom, inviting ground-effect turbulence, but allowing the rider to stand on the ground when entering or exiting the vehicle. Because the wheels are outside the fairing, they can't splash water up through the opening. The fabric cover over the rear panniers maintains only approximately correct aerodynamic shape, but it snaps off in seconds (revealing a sizable quick-release grocery basket stashed above the panniers), and the driver can stick an arm between the fabric cover and the fiberglass main fairing to signal a turn.

Steering is via gearshift-style levers on either side of the driver; when you steer, your arms are in a relaxed position. It's a simple matter to hold one of the steering levers steady by bracing your arm against the built-in armrest as you turn around to look behind you.

When I test-rode the bike, Rasmussen "simulated" rain by throwing a bucket of water at the windshield. I stayed dry inside. The fairing includes an elaborate defroster system, described in Rasmussen's article, and two side vents that you can open and close to suit your needs.

The fairing is attached to a hinge point on the front of the frame, and held down by side hooks near the driver's hands. As easily as you open a car door, you can unsnap the hooks and rotate the fairing forward to step out. One quick-release later and the ten-pound fairing is detached. (Rasmussen says only a few boat companies in Denmark can make moldings that thin and still produce a good finish.) A single nut holds each pannier onto the frame, and the molded fiberglass seat snaps in and out of the frame without tools. Not bad for a bike that Rasmussen calls a pre-prototype stage research experiment!

The Design of an All-Weather Cycle

Carl Georg Rasmussen

Riding a bike is a pleasure on a calm, sunny day. The cyclist can wear normal clothes and carry parcels without caring about weather protection. Most people confine their cycling to such ideal weather conditions.

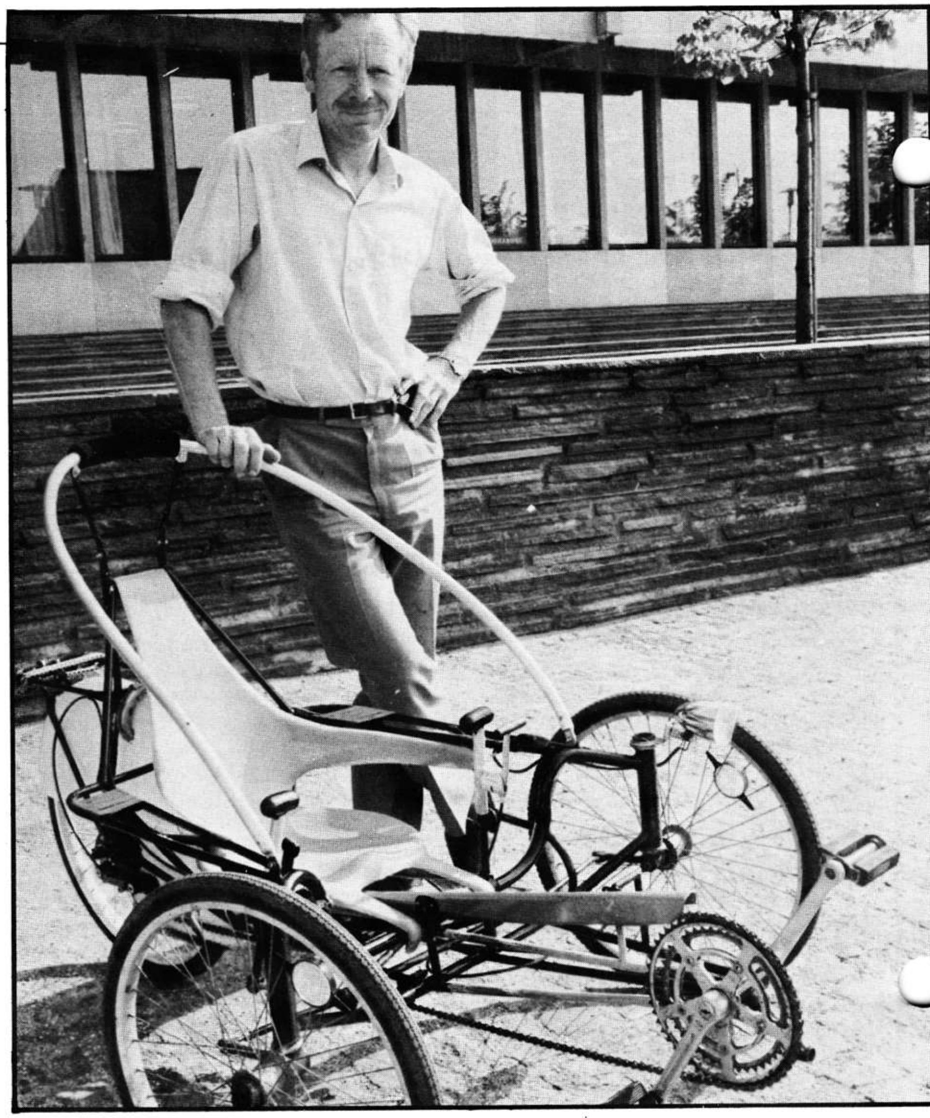
But where I live in Denmark, the number of cyclists goes down drastically as soon as the October rain starts. Only a few brave enthusiasts and people who have no choice go out to fight the head wind, with their rain capes blown up like braking parachutes.

For the winter cyclist, the wind, rain, and mud are just the prelude to more severe problems from November to April. Snow will fall and the road will be covered by ice and/or a mixture of salt, gravel, and slush.

With every year of winter cycling, I became more determined to find a reasonable solution to this problem. Why shouldn't it be possible to build a really safe human powered vehicle with complete weather protection? I tried it 30 years ago, when I was a teenager, but I didn't succeed. My 80-pound vehicle was far too heavy. For my current bike, I called on technical advances in design and materials, and on my background in light aircraft design and construction.

I sold my dear Volkswagen to get money for further development of the all-weather cycle. The few thousand dollars I got covered only a small part of the development expenses, but the psychological effect of being completely dependent on the new machine was much more important for the project. The all-weather cycle would have to satisfy my needs for commuting, shopping, visits, and recreational touring—so this motivated me to do careful work to obtain the best possible reliability, safety, and comfort.

As I write this, the Leitra M1 has covered more than 12,000 miles and endured three winters, with the fourth winter now in progress.



Carl Georg Rasmussen

Different Goals

The basic design goals for this vehicle are very different from those used when designing a super-aerodynamic recumbent, for instance, for the IHPVA competition. Speed has a much lower priority; the factors that get higher priority are good maneuverability, stability in curves and strong wind, good braking, and ergonomic design (including seat, cycling position, gearing, comfortable controls, easy entry and exit, and adjustable ventilation).

Other important features are luggage space, full weather protection, good view in all directions in all weather, strong headlight and taillight whether the vehicle is moving or not, reliability in poor weather, ease of disassembly and repair, low weight, and freedom to signal turns and stops with both arms (The use of turn signal lamps on bicycles is illegal in Denmark). And I haven't forgotten the importance of low aerodynamic drag.

Since it is not possible to discuss all these characteristics in a short article, I will confine this account to some of the problems encountered during winter cycling.

Ice

The Leitra M1 is a three-wheeled recumbent, with the wheels forming an equilateral triangle. The front wheels steer and the rear wheel propels. This configuration gives high overturn resistance—important in strong side gusts and rapid turns. At the same time, it gives very good maneuverability when combined with a suitable steering geometry (on which I have a patent pending).

Just how safe is a faired three-wheeler in winter conditions? The third wheel prevents falling on an icy road, eliminating a major cause of accidents. However, preventing falls does not eliminate all risk. The braking action is poor on ice, and the vehicle will immediately start to sideslip if the rear wheel is locked by the brake.

Last winter, I managed to perform five overturns because I went into uncontrolled skids and collided with some low obstruction, such as a curbstone. In none of these cases did I collide with any other road-user, and the fairing gave full protection. I never got even the smallest scratch or bump. Each time, I simply rolled over one of the front wheels and found myself bottom up. In less than 15 seconds, I could open the fairing's snaplock, get out, turn the vehicle back upright, and continue the ride.

In all five cases, I either drove too fast or otherwise took an unnecessary risk, such as driving down a steep hill covered with ice.

The three-wheeler's maneuverability is a real asset when you are riding on slippery or icy ground. In most cases, the cycle can be steered out of a beginning sideslip by a quick reaction.

Slalom

The M1 has a minimum turning radius of two meters (measured as the distance between the turning center and the track of the outer wheel). (Editor: We find that upright bikes do a bit worse than this—around eight feet. The Hyper Cycle short wheelbase recumbent is about as good as an upright bike; long-wheelbase two-wheeled recumbents are, of course, worse.) This high maneuverability allows me to ride "slalom style" among piles of snow in Copenhagen's streets and bikelanes. As a matter of fact, one of my overturns happened when I hit a frozen snow pile at full speed. The snow pile acted as a ramp for one of the front wheels and sent me into a nice ground roll.

The three-wheeler has never shown any tendency to roll over in strong side winds. Theoretically, this could happen at wind speeds between 50 and 60 mph, depending on the weight distribution in the luggage compartments. Strong and uneven gusts on the side of the fairing can affect the steering, e.g. when a truck passes by at full speed or when I drive through the wake of roadside trees and houses in a strong side wind, but at wind speeds up to 40 mph I have always retained full control with a firm hand on both control sticks.

Snow and Mud

One of the penalties for using three wheels is a higher rolling resistance. In practice, the effect is insignificant except on winter days with an inch or more of slush, mud, and snow, or on soft soil.

The first version of my cycle had mudguards for all three wheels, but this soon turned out to be a bad idea during wintertime. The spacing between the tire and the mudguard very often got packed with snow and ice. When the cycle was parked for a short time, this mixture froze to the tires and locked the wheels. They could only be loosened by melting the ice with hot water.

The current version has no mudguards on the front wheels, and the rear wheel has a special mudguard with close spacing at the rear to scrape off snow that would stick to the tire. The inside of the mudguard is very smooth, and it is mounted without screws or pins so snow and ice won't build up there. The rear mudguard also keeps the derailleur transmission dry.

The tires can cut right through drifts of light, soft snow up to about four to six inches. In high snows, the three-wheeler can be pulled over or through the snow drifts rather easily because of its moderate weight (approximately 55 pounds). To facilitate handling, the bike is fitted with several handles on its structural parts. I have tested this feature extensively on my winter commute; tall snow drifts often block the first kilometer of road from my isolated country house. I pull the bike through these drifts, then sit down comfortably inside and drive the remaining ten miles well protected against cold, wind, and precipitation.

Clothing and the Fairing

The cyclist's comfort is first of all governed by air temperature and humidity. In Scandinavia, I see air temperatures varying from 30°C (86°F) to -30°C (-22°F), with plenty of high humidity. Light wool clothing permits transpiration; with the Leitra's adjustable ventilation, it keeps the cyclist comfortable under a variety of outside temperatures.

The fairing acts as a rainproof cape, controlling the convective cooling of the body and keeping the feet dry and clean. A T-shirt is suitable for summer use. On chilly nights, I close the ventilation. In the winter, a light sweater over the T-shirt is usually sufficient.

Since the cyclist generates water vapor from breathing and perspiration, I have to prevent condensation and ice from forming on the windshield. I have a defroster molded into the fairing. Lightweight fiberglass ducts take in air through a nose inlet and the air is taken to a narrow defroster slit along the bottom of the windshield.

The slit emits a sheet of air that sweeps the whole windshield and keeps it dry and clear. The duct does not carry rain and snow into the cabin because the flow velocity is low in the inlet, and the duct is relatively long. This anti-dew system has operated well during summer and winter, and it has been tested down to -29°C.

Since the defroster system depends on the dynamic pressure at the air inlet, it does not work when the bike is still, or in a few rare cases with the wind from behind.

The Future

In the years to come, I believe we will see many innovations in bicycle design, including all-weather cycles. Several European manufacturers have managed to overcome their own conservatism during the last two or three years and they now have interesting things in the works.

This new development will probably require a revision of rules and regulations for human powered vehicles in many countries. I had to break through many barriers to get an official approval by the Danish authorities. I hope we'll see an international organization to help people like myself convince lawyers and politicians that the development of advanced bicycles is a serious matter, and not just a symptom of childish behavior of a few crazy designers.

Carl Georg Rasmussen invites correspondence at Post Box 64, DK-2750 Ballerup, Denmark.

LETTERS

Fatigue

I really liked "What Is Fatigue?" *(Bike Tech,* October 1982). Dr. Brown's writing was just technical enough to be quite meaningful, yet simple enough that it should be well-understood by nearly all the readers. I found it very informative; I feel that it gives me a pretty good grasp of what metal fatigue is and how it relates to the wear and tear on bicycles. As a bike store owner, I'll be better able to assist customers who ask probing questions in this area.

Best of luck to you and your staff in launching this new publication.

Mauris L. Emeka
Emeka Wheels
Port Orchard, Washington

Shape Up

What was "The View from Japan" *(Bike Tech,* October 1982) doing in a technical publication? Save that pablum for *Bicycling.* Why not use competent qualified writers such as Frank Berto in *Bike Tech?* I hope *Bike Tech* improves soon, as it has so far been a great disappointment and more than a slight ripoff compared to other trade or consumer publications. Shape it up or write it off.

Thomas C. Poland Jr.
Warwick, Rhode Island

On *Fahrradtechnik*

I wish to offer a postscript to John S. Allen's review of *Fahrradtechnik (Bike Tech,* June 1982). Allen has made a good point about engineers [the authors] apparently not riding bicycles; I can explain this and some other idiosyncrasies of the book.

In fact, *Fahrradtechnik* goes back to a true bicycle engineer, the late Ernst Hartz, who wrote the original version in 1962, in spite of the then-low esteem for the bicycle in Germany. The book went out of print and was a collector's item for several years, until the recent bike boom arrived. The publisher (who also publishes the old trade journal *Radmarkt,* mainly directed to the retailer) then felt pressed to do something to bring the knowledge of the retailers up to date. (One reason has been my *Fahrradbuch* of 1978, which gave the bicycle buyer more information than the average retailer had.)

Unfortunately, the publisher charged two retired motorcycle engineers, Rauch and Winkler, with the modernization of Hartz's book. While they were able to collect a tremendous number of technical drawings (including two from my book), they left some parts of the original book essentially unchanged (e.g., the dated paragraphs on frame stresses and on steering) — without even giving credit to Hartz!

The book was initially directed to the retailer, who also serves as a "Zweiradmechaniker-Meister" to instruct apprentices for their examinations. Only after the first modernized edition had been sold did the publisher decide to add a chapter on maintenance, in order to sell the second edition to the general public as well. The book will perpetuate the view held by many manufacturers that bicycle technology is nothing but manufacturing technology.

Prof. Dr. Hans E. Lessing
University of Ulm
Ulm, West Germany

Spin or Stand?

In *Bike Tech,* December 1982, Crispin Miller suggests that riders may stand on the pedals out of a choice to work harder when climbing. Certainly, this is a relevant consideration, because, as he notes, the rapid increase in air drag with speed means that lower total energy output over a trip is needed if a rider maintains a more nearly constant speed. I have a couple of additional hypotheses, however:

1) On steep hills, the changing direction of the force of gravity relative to the rider's position on the bike could have an effect on efficiency. Because the bicycle is tilted, the weight of a seated rider's upper body no longer counterbalances the force from pedaling. Additional muscular exertion may be needed to compensate, or the pedaling may be weakened. A standing rider, however, can tilt forward to whatever extent is needed to obtain maximum advantage.

2) When climbing at a low speed, the bicycle and rider accelerate and decelerate significantly with each pedal stroke. A sitting rider is more or less "glued" to the bike; the pedals slow down and must be reaccelerated just after the cranks have passed the vertical, when the muscles still are not in a position to provide much force. A standing rider can rock forward and backward to "throw" the bike and so vary the crank speed at different parts of the pedal stroke. I suspect that part of a standing rider's "dancing" motion serves to adapt the crank speed to increase pedaling efficiency at different parts of the stroke.

Hypothesis #1 could be tested by constructing a bike with a small front wheel and short front fork to put the rider in a normal, level-ground position when climbing a given slope. Elapsed time and pedaling style could then be examined for several riders riding a suitable climbing course, both sitting and standing, on this bike and a normal bike.

Hypothesis #2 could be tested by comparing performance of sitting tandem teams climbing over the same course, with the pedals in phase for some test runs and out of phase for others. With the pedals out of phase, the power flow is more even, nearly eliminating the acceleration and deceleration during each pedal stroke. Tandemists who prefer pedals out of phase do in fact claim this as an advantage.

Also, study of the motions of riders on solo bikes using high-speed cinemaphotography would reveal whether there is in fact an effort to adjust pedal speed at different parts of the stroke. Comparisons could be made between riders standing at low speed, when the acceleration and deceleration are significant, and at high speed, when it is not.

I note that riders who sit when climbing tend to use very low gears and to spin even faster than on level ground. In my own experience, this approach makes the weaker forces available at the top and bottom of the pedal stroke more nearly equal to the task of keeping the pedals turning. Perhaps the momentum of the mass of the lower legs also helps.

John S. Allen
Editor-at-Large
Allston, Massachusetts

TeeMOB Timetable

Part Four of Mario Emiliani's masterful series, "The Metallurgy of Brazing," has been bumped to the next issue (April 1983) of *Bike Tech* so that we could bring you this comprehensive IHPVA report. It's worth the wait! Mario describes the relation between heat and the internal structure of steel — and the resulting implications for the strength of bicycle frames.

Correction

The fourth paragraph of the internal hub article in the December 1982 *Bike Tech* said that the new cartridge-type Shimano coaster brake innards will fit into the old-type Shimano coaster brake shell without modification. The reference to single-speed coaster brake hubs was in error; the hubs and innards that interchange without modification are new and old Shimano non-coaster brake three-speed hubs.

Let Us Hear

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

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