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HUMAN POWER

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IS SOLAR HUMAN POWER?

by Peter Ernst

If we were to interview the builders of thousands of HPVs conceived over the past ten years worldwide, we would discover the following priorities which the inventors tried to incorporate into their brain-children.

- safer handling characteristics
- higher energy efficiency
- better ride comfort
- fossil-fuel independence
- weather protection and others.

Over the same decade hundreds of traffic studies worldwide affirmed that individual urban transport (ab)using one-ton-per-passenger automobiles is a slap in our own ecological face. Yet decision-makers know that one kW of tractive effort is enough for one person to zip along in city conditions.

Between June 25th and 29th of last year, the Swiss had a chance to witness on unrestricted public roads such evolution, finding the one-kW formula not only practicable, but even extendable over longer distances. This exploit was launched by The Swiss Solar Energy Society.

The world's first solar-vehicle rally, the **Tour de Sol**, gathered 58 entrants to brave the 368 km (230 mi) distance separating Lake Constance from Lake Geneva.

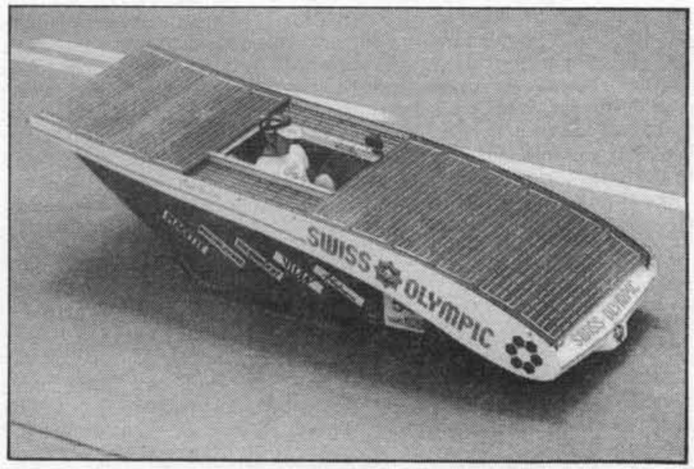
What are the deeper implications of this publicity stunt, which was thronged by spectators and watched by millions of TV fans? Firstly, it demonstrated the inherent possibilities of a yet-untapped, clean form of energy. Technical feasibility in transport was evidenced. Solar awareness was won for a larger public.

RALLY CATEGORY I: SOLAR-ONLY

In keeping with the organizer's aim, the main class of entries consisted of purely solar-powered vehicles, all limited to a maximum solar-panel surface corresponding to an output of 480 W (peak). Within given limits battery storage of energy was mandatory, in view of our unstable climate. Thanks to this "tiger in the tank", most vehicles sported oversized DC motors of 0.5 to 1.5 kW-rated output. (On the Swiss mountain gradients, some of these overzealous truckers would burn out their motor windings on account of impatience and wrong gearing ratios.) Most systems ran on 24 V, with some using 12 V, and, in a few rare cases, 48 V or over. Since in some designs large panels up to 6 sq m (60 sq ft) were used, the elite-class jobs tended to look like zeppelins, or dinosaurs by our HPV standards.

A handful of designs featured novel concepts, or professional body styling. Unfortunately, the scales often recorded weights of over 200 kg (440 lb). The heaviest vehicle was a stripped and solarized FIAT 126, which weighed 460 kg (1012 lb) and just did not make it, as it ran out of juice from sheer lack of available panel surface!

Photo courtesy of Swiss HPV Group, FUTURE-BIKE



Der Elegante II seems well-named. The pilot, Daniel Wunderlin, seems lost in that pool of photovoltaics - the output of the solar generation surface on this vehicle is listed at 480 Wp.

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Notes of Interest

DISCLOSURE DOCUMENT PROGRAM: A SERVICE FOR INVENTORS

This is a note about an alternative to the immediate application for a patent, which can be very costly. The leaflet of the above name, which can be obtained from the US Patent and Trademark Offices and which was sent to me by Des Messenger of Ontario (Joyrider designer and builder) states, in brief, the following.

"A paper disclosing an invention and signed by the inventor(s) may be forwarded to the Patent and Trademark Office by the inventor, by the owner of the invention, or by the attorney or agent. It will be retained for two years and then destroyed unless it is referred to in a separate letter in a related patent application filed within two years.... The Disclosure Document is not a patent application.... This program does not diminish the value of the conventional witnessed and notarized records as evidence of conception of an invention, but it should provide a more credible form of evidence than that provided by the popular practice of mailing a disclosure to oneself or another person by registered mail.... A fee of $10 must accompany the Disclosure Document: mail to the Commissioner of Patents and Trademarks, Washington, DC 20231."

Des Messenger took the trouble to send also some details of similar programs in Canada and Britain. In Canada one files a Caveat, with a fee of $25, to the Commissioner of Patents, Ottawa. In Britain one can apply for a Provisional Specification, using Patents Form 1 (stamped with one pound) accompanied by two Patents Forms 2 (unstamped); and may leave the complete specification (Form 3, stamped four pounds) at any later date within twelve months, or with application for extension of time on Patents Form 6 (stamped two pounds) within thirteen months.

Presumably, other countries have similar systems. They give one time to try to get commercial sponsorship without the huge expense of full patent coverage.

SCIENTIFIC SYMPOSIUM ON BICYCLE RESEARCH

This interesting symposium was held at the university of Oldenburg, West Germany, in September 1985, and was organized by Falk Riess, who is professor of physics and is head of the Bicycle Research Group. (He is also undertaking the translation into German of BICYCLING SCIENCE). The ADFC, the All-Germany Bicycle Club, has put out an "Extra" issue of its "Pro Velo, Das Fahrrad-Magazin", containing the proceedings of the symposium, edited by Dr. Herbert F. Bode, and obtainable for six marks from:

ProVelo Buch- und Zeitschriften-Verlag
Am Broicher Weg 2
4053 Juchen, West Germany

There are reports by many friends (and members) of the IHPVA, including Paul Schondorf, Gunther Fieblinger, Van der Plas, Hans-Erhard Lessing and Wolfgang Gronen, as well as by Falk Riess. Almost all of these names would be preceeded by "Prof. Dr." if we were more punctilious; that, and the fact that senior officials of the university gave the opening welcome to the symposium, shows that human power is taken more seriously in Germany than it is in many US institutes of higher technology. We will endeavor to give a summary, atleast, of all the papers presented, in the next issue of HP.

BROOKFIELD BOATBUILDING INSTITUTE

For those who want to build HPBs of any of several traditional types, the courses offered by the Brookfield Craft Center, Box 122, Brookfield, CT 06804, (203) 775-4526, should be worth looking into. The brochure includes sea kayaks, ultralight canoes and skiffs, recreational shells, and cedar and canvas canoes in different courses during the summer.

COMPARATIVE SPEEDS OF TRADITIONAL HPBs

Phil Thiel has sent a list of the finishers of the eighth annual "Round-Shaw Row", August 10, 1985, 12.1 nautical miles (14 miles, 22.6 km) to give comparative data on the speeds of various designs of traditional boats. Multiply knots by 0.52 to obtain speed in m/s. There was a "stiff chop and wind off Hankin Point at the east end of the island", so that the shells and sculls are of the sea-going type.

1	Blakemore/Watson	Double Scull	2:10:40	5.63
2	Jim Raney	Single Kayak	2:15:15	5.43
3	Dave Drummond	"	2:15:20	5.43
4	Matt Broze	"	2:16:43	5.37
5	Shane Baker	"	2:16:53	5.37
6	John Mann	"	2:18:50	5.29
7	Cam Broze	"	2:18:56	5.29
8	Tony Canavarro/Mike Ree	Wherry	2:19:50	5.26
9	Dennis Malone	Single Shell	2:20:26	5.23
10	Kent Miller	"	2:29:20	4.92
11	"Glide"	21' Gig	2:30:45	4.88
12	Greg Thompson/John Willis	Double Rowboat	2:33:12	4.80
13	Anne Voegtlen	Single Shell	2:35:00	4.74
14	Phil Andress	"	2:35:22	4.73
15	Bob Davis	"	2:35:30	4.73
16	Phil Nishman/Donna Manders	Double Rowboat	2:36:00	4.71
17	Vibran/Adams	Double Kayak	2:37:45	4.66
18	Lary & Todd Schlemer	"	2:38:30	4.64
19	Jim & Chris Llewlllyn	Double Rowboat	2:38:58	4.62
20	Christensen/Christensen	"	2:40:44	4.57
21	Jane Gascock	Single Kayak	2:45:00	4.45
22	Ulrick/LeCuyer	Double Kayak	2:48:33	4.36
23	Tom Williams	Single Scull	2:49:33	4.33
24	Browning/Kretz	Double Rowboat	2:53:32	4.24
25	Bold/Hoffman	"	2:56:58	4.15

A recumbent kayak, propeller-driven, is being developed by Whitman H. Dunham, 530-B Sutton Road, Friday Harbor, Washington 98250. It will have a completely-enclosed cockpit with vents, and be operable in Beaufort-Force-Ten winds. Bill McGown is also involved, designing a three-seater pedalled kayak. His address is 1103 E Republican, No. 1, Seattle, WA 98102.

GRANT FOR THE DISSEMINATION OF THE PAPERS OF FRANK ROWLAND WHITT

Frank Rowland Whitt, a man who loved bicycles and who became the foremost authority on the past and present technology of bicycles and human power, died in 1984, soon after the publication of the second edition of his **Bicycling Science** (MIT Press). He left his papers jointly to his co-author David Gordon Wilson and to Fred DeLong, whom he admired greatly and who is also a prominent author on bicycling matters.

The papers are voluminous and would be invaluable to historians and to others working in the topic of human power. The Cutler Delong West Scientific and Educational Fund for the Present Private Interest has given a grant of one-thousand dollars to cover the recording of about one-third of the papers on microfiches and for copies to be sent gratis to the principle world research centers working on human power. Individual copies of microfiches will be sold to interested individuals at cost.

Dr Cutler West, a former senior scientist working with Dr. Edwin Land at Polaroid, is a strong believer in the contribution that the use of bicycles can bring to the modern world.

The papers will be first catalogued, and introductory editorial notes will be added by David Wilson and Jim Papadopoulos, an MIT doctoral student. The first material to be recorded on microfiches will be some priceless historical documents, including two volumes by C. Bourlet which are a century old and are quite rare.

Other funds will be approached to support completion of the work.

Letters to Human Power

MOULTON CONVERSION

I would like to encourage you to be an aggressive and critical editor... Perhaps a concise delineation of specific controversies would encourage letters on that subject... I have a recumbent built largely from Easy Racer plans, and have put a lot of miles on it (3000?) and find it ok except when very icy. I need a windshield on it. When it is very cold and icy, the idea of the Windcheetah or Leitra becomes more and more attractive... I have an old Moulton model that I am willing to sacrifice to make a short-wheelbase recumbent. Do you know of anyone who has made that conversion?

Lorkel J. Shields
5214 E. 24th Ave
Anchorage, Alaska 99508

FORMAL AND INFORMAL SECTIONS OF HP?

To simplify the editing, divide the journal into two sections, a formal and an informal section, the latter being "Letters to the Editor" and "Design Ideas Swap Section"...

Edwin G. Sward
215 Cambridge Street
Worcester, MA 01603

HPBs ISSUES

The Spring '85 HP is fantastic - and opens up much that is state-of-the-art... I've been in touch with Jon Knapp (Saber Proa), Dick Ott (Water Strider), Yvon Le Caer (who has some major undertakings planned) and others. Le Caer among other projects would like to organize a two-leg 120-mile crossing from a Caribbean island to the Bahamas and Florida. . .

Fred DeLong
2405 Huntingdon Road
Hatboro, PA 19040

SOURCE DIRECTORY APPRECIATED

I thought the Fall '85 issue of HP with the HPV source directory was worth the whole year's membership fee! Keep up the good work.

Tom Briggs
P O Box 35
E. Waterford, ME 04233

A PLEA FOR INTERNATIONALISM

Please avoid the "two-by-four lingo" - ie, the many colloquialisms that abound in our daily language wherever we are. Many of our members here cannot understand the IHPVA publications, since what would "grab a 2x4" mean to anyone who has never lived in the USA? Editors of IHPVA publications should apply strict rules to the texts that go to 25 different countries, many of which have only a rudimentary command of school-book English:

all dimensions should be clearly given and stated at least in ISO units; and

the text should be devoid of slang expressions that cannot be found in the dictionaries of overseas members.

Keep up the good work, and thanks again.

Peter Ernst, president
FUTURE-BIKE Club
Alex. Moser Str. 15
2503 Biel-Bienne
Switzerland

HP VIDEOS

I really appreciate what you people are doing. It is a great information service for those of us who live in the boonies... We are rather appropriate-technology-minded out here. Really delighted with Ray Wijewardene's piece (HP, Spring '85). Are you folks going to market any of the material listed in "references"? ... If you know of anyone interested in producing HP video, pass my name along. Thanks again.

J. W. Roberts
Box 408
Chimayo, NM 87522
(505) 351-4835

SITUATION IN SOUTH AFRICA

I feel that I must comment on the deplorable and tragic situation that South Africa is in right now. There seems to me to be mischief on both (or all?) sides trying to get the most out of it, while the majority of us (people of all shades) want little more than to see the end of apartheid and the recognition of human dignity. We hear that the world is shown a continuous, and instantaneous, series of pictures of rioting and condemnation, but that there is little appreciation of the goodwill which has always existed amongst our various population groups, of the meaningful changes which are taking place, of the complexity of the matter.... Since the media thrives on bad news you may need to come to look for the good news yourselves. The biggest bicycle event of the year is our Argus Cycle Tour, scheduled for March 8, 1986. [The exchange rate for dollar and] rand is so low that there could hardly be a less-expensive time to make the trip.

John Stegmann
1 Heath Street
Newlands, Cape 7700
South Africa

LIGHTNING CAMPS ACROSS EUROPE

Fully-loaded for touring, we pause at Stonehenge.

I had a wonderful time in Europe (as you can see from the photos). I travelled and camped for two months (3000 mi) on my customized **Lightning**. I am planning an article for **HPV NEWS** on my experiences.

Because of Expo '86, the organizers of the Hull Festival have decided not to have HPVs in the program this year, though the Festival will be held in early August 1986. I'm rebuilding my bike for a cross-country ride after the Expo '86 events. See you in Vancouver!

Dennis Taves
110 Frank St #1
Ottawa
Ontario K2P 0X2
Canada

IS SOLAR HUMAN POWER?

Panel efficiency is 10% at best. Thus, the maximum permitted **solar** output of 480 W amounted to

- approx. 4.8 sq m (48 sq ft) of active panel surface
- approx. panel cost of US$ 4800. or US$ 10. per W!

Such energy plants invariably resulted in bulky, heavy, and costly vehicles of mostly four-wheel configuration. They indeed surpass the average do-it-yourself budget. Some even represent a major financial hurdle in industrial R&D programs. Luckily, a few wise panel-makers and distributors **loaned** their products to builders, benefitting from this "automotive" experience and gaining wide publicity. To circumvent such grave finance- and weight-handicaps, the entrant with the lightest, smallest vehicle in this class resorted to the device of solar concentration: he placed horizontal strips of highly reflective material in between rows of embedded solar cells. These cheap troughs allowed a substantial reduction of the costly photovoltaic panel surface. No dust-collecting problems were noted, since respectable Swiss auto owners polish their vehicles nightly before retiring anyway!

The cost for power-control systems and battery-storage components cannot be assessed accurately yet, as many "home-grown" items were applied. Readymade hardware is non-existent, improvisations are rife. Standard-stock solar-mobiles are not yet here. When one realizes that each of the top runners represented a six-digit US-dollar value, then one realizes that solar-transportation acceptance at retail level is miles away.

The incentive to forge ahead is there, and lavish prize money of 40,000 Sw.Frs destined for the winners of this "king" category provides no small motivation for future developments of solar-only vehicles.

RALLY CATEGORY II: SOLAR-PLUS-PEDALS

Due to **the modest** solar-energy input density of a maximum **one-kW per** exposed sq.m. of surface, the organizer **allowed** and tried a second vehicle class. Open to solar-plus-pedal-powered vehicles, this category took the fancy of most active members of the Swiss HPV scene; only one decided to enter the solar-only class.

Upon closer examination, a good dozen of category-II construction were actually normal HPVs, supplemented to receive 1 to 2 sq m of solar cells. The ready-made solar panels were in 67% of cases of US-origin, such as **ArcoSolar** and **Solarex** brands. These components, plus batteries, controls, motor, etc, very often doubled the original weight. Some 97% of entries used the traditional mono-crystalline silicone cells, and very little experimentation with newer solar-power generation techniques was evident.

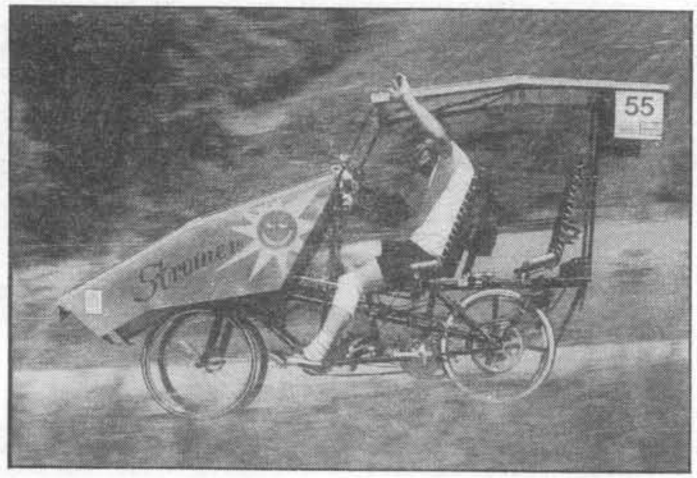
While **some** 59% of the category-I, purely-solar powered **vehicles** did not finish, the Category-II entries **evidenced** a better stamina, as only 40% abandoned. The failure-rate dropped even lower, to 20%, when the results of members of the Swiss FUTURE-BIKE club are singled out.

No small portion of category-II reliability is due to the IHPVA's long-standing missionary drive and technical dissemination work. A great many entrants were in fact HPV-sympathizers, whose machines are truly practical HPVs, with years of thorough de-bugging behind them.

The solar conversions and controls were a more immature affair. Most participants of the "sun/push" class could not afford to develop software and hardware for microprocessor-heavy control systems. The old calf-waxing diehards relied instead on ampere- and voltmeters, sensing the state of the battery, and knowing out of experience when to reverse the motor instead of applying the brake. When I asked one of the finishers how his new **Weinmann HP 2000** worm-drive brakes had fared, he said, "Don't know, never used them!" At any rate, during the initial 250 km (160 mi) of cloudy weather, a great many hefty muscle-shoves made up for the lack of large cell surfaces "that even work under cloud cover" (quoted from advertisement).

Micro-electronics do enhance energy management. Use

Rolf Disch and Helmut Enssle pedal **Der Vierplatzer.** The third seat appears to have its own set of pedals as well. Could this be the future family vehicle?



of pulse-width-modified speed controls will spread, and recuperative braking will become standard. Thanks to microprocessors, riders will be able to fully concentrate on traffic ahead. For this, we have the example of the three home-modified **Sinclair C-5** three-wheelers that were entered.

Battery-wise, builders instinctively played it safe, the majority relying on commercially available brands. Exotic storage systems were rare. No flywheel- or rubber-band-energy accumulators were seen. Since commercial batteries are still (too) heavy, most competitors chose their storage capacity for the rockbottom permissible limit, at around 1 kWh, no more, in order not to stress the already taxed frames of existing HPVs. This was OK on flat stretches in the midlands, but felt like a "pain in the butt" uphill, according to the actors.

Even with the storage batteries, weights of the usually-slim cycles could be kept in the 40-150 kg (88-330 lb) range. The **Instant Solar Bike** had an excellent power-to-weight ratio, but it was devoid of weather protection. Its recipe: take a 10-speed, or better still, a regular tandem, pull a trailer filled with batteries and panels behind, and go! The DC motor either drives one of the trailer wheels, or it is fitted up-front. You may pull a string to adjust the angle of inclination of the solar panels. Jules Verne did not foresee this!

Regarding the weather protection, 71% of the designs in the popular category II combined the energy-captive elements with the shielding structure in order to save weight. **Many** styles of "pagoda-roofs", or tank-like decks could be seen. A certain "Coupe de Ville" idea inspired most trike builders to adopt the 1x2 tricycle configuration, since the wide rear track provided sufficiently large sun decks. Smart engineers had their solar panels hinged along a horizontal axis, so that during parking stages the panels could be propped to face the precious sunrays orthogonally.

Class-II vehicles with their "popular-mechanix" approach hardly collect enough solar energy to become autonomous: out of pecuniary modesty the solar trickle rarely exceeded the 120-250 W range (a few were 300-400 W). With such panels it is possible on a bright day to harvest 0.6-1.3 kWh (some produce 1.5-2.0 kWh). This alone will not exactly break your spine under full acceleration! Such candlelight energy, unassisted, barely permits a modest cruising gait. Should payloads, hills, or winds hamper progress, extra power is needed. HPV-enthusiasts knew how to get it and how to feed it into the system efficiently:

- temporary human power output	500 W max.
- DC motor load (overload)	500 W max.

Again, the one-kW formula may not fill speedways, but it can get people from point A to point B in perfect health, especially if paired with light and ergonomically-sound space-frames. Category II was a treasure chest for prototypes of future mixed-commuting vehicles. The traditional **Avatar**-frame inspired 1x2 tricycle adaptations with the load over the rear axle. But even normal recumbent bicycles could be seen with flanged-on side-cars, carrying the "powerplant". While in category I, little convergence on practicality was detected, here are a precious few HPVs which stood the solar test, and which are now being hand-crafted in small series.

SOME GENERAL THOUGHTS AND CONCLUSIONS

Both categories of vehicles stimulated daring thought and action. Progressive goals called for novel detail solutions with better component performance. No major stumbling blocks are expected on this road to improved vehicle structures. Already, composite materials are used in some cases to obtain light-weight monocoque bodies. Far more expectations of solar propulsion depend on the following pair of crucial elements.

- Solar cells **must** come down in price. Perhaps future thin-film techniques will reduce physical mass, and the energy needed in manufacture, so that with automation and mass-production, the cost and energetic pay-back point will come down. Thin films would also possibly permit bending and better panel shaping, to comply with vehicle's aerodynamic aspirations.
- Batteries are still a sore point. Energy-storage density and therefore battery weights leave much to be desired. They are hardly compatible with HP piano-string engineering. A few rare pioneering solutions were spotted: a new sodium-sulphur battery system was said to have a storage density of 100 Wh per kg (45.5 Wh/lb), where classical batteries hold 25 Wh per kg (11.4 Wh/lb). Unfortunately its development is still in the experimental stage. The overall winner (a German/Swiss joint effort) successfully defended his chances with a silver battery system. Deep-cycling efficiency of batteries in today's "stop-and-go" traffic will also have to receive better attention.

On the motor end, better torque and overload (overheating) characteristics are welcome improvements. The hillier the topography gets, the more hopes rest on microcomputer-based energy-recuperating controls. A single-handed governor should relegate the friction brake to parking and emergency functions. Once we can store energy efficiently, even modest capacities of 0.51-1 kWh "on tap" would improve the commuting feasibility of solarized HPVs considerably, so that many more urban commuters might switch from mobile carbohydrate-oxidizing ovens to a more humane transportation mode. Weight is crucial.

Experiments with bicycle hub-gears or derailleurs did not guarantee safe motor currants at all times. Gearing was either not spread finely enough, or it was sluggish. Continuously or instantly changed ratios are desireable, as for pedal power. On the bike side, no narrowly-stepped variable chainwheel drives were spotted. (One wonders how far mass production of the **CamBio Gear** by Excel, or the automatic **Deal Drive** ever got?)

Eight "sunny" competitors tried a novel friction-drive variator, the **DELTAMAT**, developed by Deltavis Ltd, 4503 Solothurn, Switzerland, finishing in honorable ranks. Such variators use high revs and work on electric motors. Within a span of 1:4, gearing is automatically and steplessly adjusted (thus keeping motor near peak power, best efficiency). Very high amperage on hills soon spoils the battery's energy-storage capacity, unless excessive currents are limited by adequate gear reduction. Frequent overload bouts reduce battery yield to the point where the operating range of the vehicle becomes very small.

Here the DELTAMAT drive permits the optimal use of permanent-magnet motors (PMM), allowing recuperative braking. PMM are 15% more efficient than the usual series-wound motors, so that together with improved battery yields, vehicle ranges may increase up to 25%. For a given task, smaller motors can do the job, if supplemented with a DELTAMAT. Practical handling of the new drive was reported to easy: the electric power level may be pre-selected by a control lever, setting the desired pace. As soon as drag or gradients intervene, the variator automatically adjusts the speed downwards, etc.

This equipment circumvents the micro-electronics option. It is one of the many solutions imagined by inventive spirits, which found a common testing ground under the sun.

Myriads of other inventions have been put to work, albeit less obvious ones. The stage is set for men facing men's own challenge for the future, that of achieving benign transport, preserving the vital ecosphere.

Many individual pioneers as well as sponsors are willing to prepare for an even better 1986 event. I hope that next year the **Tour de Sol** program gazette will drop advertisements for so-called "clean cars with catalytic exhaust systems". Future shapes of practical solar vehicles will also possibly drift away from classic-automobile counterfeits, or aircraft imitations.

But will muscle power in future claim priority over solar? Are they rivals? Certainly not, since photovoltaic power is but the natural (faster) brother of our own, biomass-derived human power. Solar- and muscle-power being of the same family, they make an ideal team in which one form supplements the other in time and space. Such a symbiosis is worth developing into a truly benign transportation tool for the good of man and mother nature.

Peter Ernst
Moserstrasse 16
2503 Biel-Bienne
Switzerland

FOOTNOTE: The 1986 **Tour de Sol** starts at Freiberg, in the south of Germany, on June 23. Six separate rally stages will then lead competitors into the heartland of Switzerland. More vehicle categories are planned to encourage overseas participation. If solar-vehicle enthusiasts wish to skip the moderate (up to 1008 m, 3300 ft) hills in pre-alpine Switzerland, they can conserve their strength for the July 5-6 endurance race at Geneva.

The event organizers may be contacted at:
The Swiss Solar Energy Society (SSES)
Belpstrasse 69
CH-3007 Bern
Switzerland

The last **HPV NEWS** carried a report of the solar-vehicle kits being produced by Max Horlacher to encourage participation in this event. I would like to repeat the address here:
Horlacher Ltd
4313 Moehlin
Switzerland

Der Linksausleger shifts into "super-low" for a steep grade.

PHOTOS courtesy Swiss HPV Group, FUTURE-BIKE.

Mike Burrows Reports from Britain

This is the story of how an attempt to break records on empty runways led to me riding to work in safety and comfort. It started when a group of us, all local bicyclists, decided to go to Brighton for the Aspro Challenge in 1980 to see what it was all about.

We decided that it was all about fun. None of us was a dyed-in-the-wool cyclist, and the challenge seemed irresistible. We had a useful team. I had a machine shop. Ian Borwell worked in the local bike shop, and Dave Kilburn was an engineer in a local mental hospital. We know how useful that can be! In addition to all the usual facilities it had a spare boiler room, less boiler, where we could assemble our device. Although the Vector had won in a most impressive performance we decided to base our design on "Poppy Flier", but with a ground-effect shell. After many hours' work it finally took shape and was taken for testing to our local RAF station. It was a bit of a disappointment. We had expected 50 mph (22 m/s) and got about 43 (19 m/s). It did hold the British record for 14 hours in '81, and we came fifth at Brighton, but it was not the fastest.

As cyclists we decided that the engine needed tuning. The engine was Andy Pegg, a local time-trialist who was getting stale and who took to HPVs with even more enthusiasm -- and near-madness -- than the builders. In no time at all he was riding the bare chassis around the roads of Norfolk just for fun, and quite remarkably not getting killed.

In fact, it was quite the opposite. Motorists who would normally cut up a regular cyclist were driving past on the other side of the road. This convinced me that a road trainer was the answer to our "tuning" problems, and set about designing something that was safe, strong and reasonably compact, but with no real thought of performance as such. The Vector layout seemed the obvious choice, offering excellent stability, braking and maneuverability. As I was already working in large-diameter alloy tube this was the obvious choice rather than the more-usual bird-cage of steel tube. And so the Speedy was born (Windcheetah SL to you!) looking much the same as now but with large wheels (20-inch plus 27-inch) and with a conventional rear triangle and all-welded construction.

It was on the road by Christmas '81 and was used in the Christmas Day ten-mile (16-km) time trial. Although we did very little training we had a lot of fun, especially on the ice and snow, and lines of people soon formed whenever it appeared. Most were amazed by its ease of handling and cornering power, all of them with big smiles on their faces.

In February Ian Barwell moved to Holland to live, and he took the Speedy with him. I set about making two Mark-2 machines for Andy and myself. They still had the large wheels but used a cantilever rear end with the wheel running on a stub axle and the chain on the left. Also I used glued joints and castings for the first time. They were on the road in April, just in time for a local town criterium which had a class for tricycles. The local tricycle association had voted to accept any unfaired three-wheeler. We decided to show them how it was done, and we sure did. I showed them how to come fifth and Andy showed them how to be lapped. We learned quite a lot. I came in second in the next and we have won every one since.

Meanwhile, back in the flat lands of northern Holland Ian was finding that his Speedy was not just fun but the most useful form of transport that he had. The lack of hills, abundance of cold winds and icy roads made it ideal. Also by now Andy and I had done enough miles that the pain in our knees was downgraded from excruciating to unbearable, and we could cover useful distances. Some people asked about producing the Speedy commercially. I felt that it needed more testing. When some students from Imperial College asked if I could produce a machine for a charity ride around the coastline of Britain (3690 miles, 5940 km) it seemed an ideal opportunity.

I set about producing the first Mark-3, using the new 17-inch Moulton rims just becoming available to HPV builders by Alex Moulton. These allowed more steering angle for the same track width. The rear wheel was then reduced to 24 inches to maintain the balance and to make the machine even more compact. The glued casting system seemed to have proved itself and welding was abandoned except for the handbrake boss.

Two machines were built for the students; one they fitted with a shell of their own design, with the rider's head out in the open but the wheels inside. It gave good aerodynamics but was very wide to allow a good steering lock, and was named the "whale". The ride was a success for the college and for the Speedys, the only serious problem being a glued joint. I was using a two-part epoxy, but changed in favour of cyanoacrylates (Loctite) and all is now cured.

I also built two Mark-3 machines for Andy and myself, and before production started the last design changes were made on my machine. I used a "live" rear axle with the wheel on one side of the tube and the block on the other, putting the chainset on the right and allowing the use of standard front derailleurs (making your own is really a dead loss). Thus Mark-3a was born, and I made a batch of five for sale.

This was the time to turn to the shell. I was going to follow the lines of the students' shell, but my man in Holland told me that the law forbade anything over 750-mm wide from using the cyclepaths. Thus "wheels in wells", the automobile solution, was mandated. At the time it seemed a dreadful thing to do to an HPV but in practice it has proved to be very effective. We had learned in our battles with the trikes that the ability to move your CG sideways is very important if you want to corner fast, and so the fabric top was devised. It also lends itself to be an easy non-rattling door system. We use a clip-on hood on the head for racing, but for road use this is oppressive and dangerous.

I finally made two more batches of ten machines before getting stale. Twelve were fitted with shells. Only a minority of people bought them to race: most want them just for fun. One of the racers recently took two third places at the Zapple Festival, one at the expense of yours truly!

I have now built a Mark-4 for myself, with a Moulton-style rear suspension that is an improvement, but it is not yet at the Rolls-Royce level. But after producing 33 Windcheetahs I stopped, partly because it was not economic, but also because it seems that turning a hobby into a job is not always good. I do have a works replica, a lightweight with an all-moulded shell and weighs 36 lb (16 kg), mainly due to the chassis being made from magnesium castings and holes (mostly holes). It is interesting looking back now five years to the original speed machine, designed just to race without compromise, which won nothing. The Speedy was designed to be a trainer with strength and stability as first priorities, and has so far notched up about a dozen wins and many places, and has won something like five-thousand pounds in prizes. Not bad for a supermarket trolley.

Just as a footnote, the wheel seems to have turned full-circle, as I am now building a "straight-liner" for an attempt on the Du Pont prize. After all, I can't let the $15,000 go without some sort of a struggle.

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TRAVEL TO EXPO 86

The IHPVA "Specialized Period" at EXPO 86 is August 24-31. Mike Wilson of the New England chapter reminds US citizens intending to take a vehicle there that US Customs could give problems on the return crossing, unless a "Certificate of Registration" is completed before leaving the US. You should obtain Customs form 4455 (020984) and complete it preferably before arriving at the border, and get it signed by the customs officer on leaving and again on return.

THE SECOND HPV-BUILDERS' WORKSHOP

On a record-cold weekend in January 1985 the first HPV-Builders' workshop was held at the IIT in Chicago (reported in HP v3n4, summer, 1985). It was so enthusiastically received that organizer Blake Davis recruited Bill Darby and Wayne Kirk, president and VP of the New England HPVA, and their committee of helpers, to provide the venue for a second workshop. The place was MIT; the dates were Friday, Saturday and Sunday, January 24-26, 1986, and the lecturers and instructors were stellar.

Your reporter was given the enjoyable duty of making an opening review of HPVs and of introducing all the following lecturers. We had a four-ring circus, only one ring of which held the formal lectures. Simultaneously Terry Hreno, designer and builder of the Indy-winning Mobies, was giving a forum titled "A DESIGN APPROACH TO BUILDING AN HPV", followed by individual advice in an open-house format; Gary Helfrich, who builds for Fat City Cycles, demonstrated welding techniques including TIG and oxy-acetylene in the welding shop; and a team from RPI led by Prof. Diefendorf, Dr. Ashok Bhatnager, and Volker Paedelt, and including two doctoral students, Steve Winckler and Don Radford, demonstrated composite-fabrication techniques with vacuum-bagging on and in flat surfaces and male and female molds. Course participants expressed enthusiasm and gratitude for these instructors and the techniques they demonstrated so superbly.

The keynote lecturer, however, did not have to compete with these other attractions. Dr. Bruce Holmes of NASA Langley spoke at the Friday-night opening session on natural laminar flow for HPVs. His message may be summed up by figure WS1: shape your fairing to produce as great a proportion of natural laminar flow as possible by putting the maximum-area cross-section well aft, and, if you want to capture some speed records, use suction through slots or porous bands to force laminar flow on much of the rest of the surface. The power required for suction will, unless done extremely crudely, be a small proportion of the power saved in overcoming drag, if the speed is of the order of 29 m/s, 65 mph (where did that number come from?) He reviewed methods of flow visualization, recommending the use of liquid-crystal coatings to show, reversibly, the relative drag and the presence of turbulent and laminar boundary layers on a fairing. These liquid-crystal coatings were a new and dramatic development for most of us, and could well be the key to the Du Pont prize.

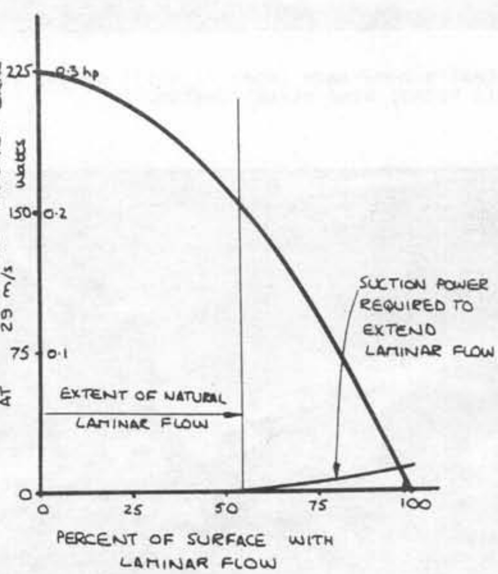
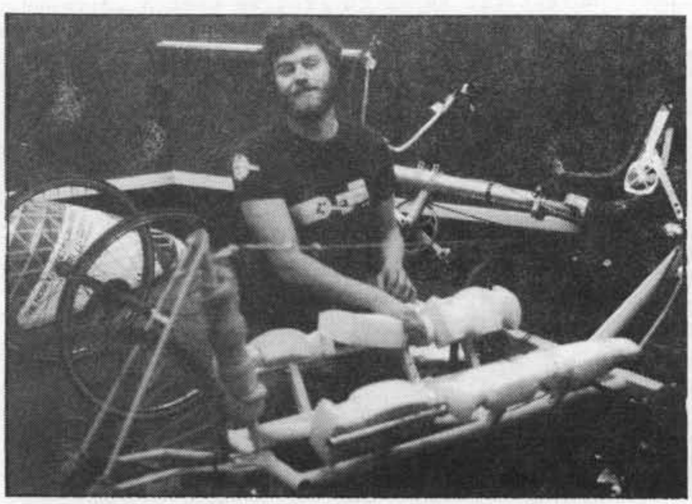


FIGURE WS-1 AERODYNAMIC-DRAG POWER OF TYPICAL HPV AT 60 MPH, 29 m/s VS PROPORTION OF LAMINAR FLOW (DIAGRAMMATIC ONLY – AFTER HOLMES)

On Saturday morning, Prof. R. J. Diefendorf presented the complex subject of designing with composites with clarity and impact. He pointed out that 0.5-percent elastic strain is too much for most structures, which is why glass-fiber-plastic bicycle frames have been found to be too flexible. A high specific modulus, or stiffness/density, is therefore highly desirable, and graphite has the highest specific modulus of any known substance. Graphite also has one of the highest specific strengths available. But with fiber-composite construction, the highest stiffness and strength is obtained when the fibers are laid up to be parallel ("unidirectional)". To produce two-dimensional stiffness and strength, successive layers of fibers should be laid at at least 45 degrees to each other, and the resulting properties decrease in any one direction from the values for unidirectional layups. If one wants to withstand loads in all three axes, Prof. Diefendorf's advice was to stick to metals. He gave a great deal more valuable information, but I'll close with three warnings: composites are not good at resisting compressive loads; they can be weakened greatly if the fibers are made to go around sharp corners; and their fatigue life is often uncertain.

A short introduction to one particular fiber, Spectra 900, a highly oriented polyethylene, was given by Dr. Hew Won Chang of Allied Fibers Technical Center, Petersburg VA. This fiber is lighter than water, and is apparently capable of considerably exceeding the specific modulus and specific strength of structures using Du Pont's Kevlar or graphite. However, it is good up to only about 120C. Motorcycle and other helmets 30-percent lighter than existing (generally polycarbonate) helmets were examples of prototype uses of Spectra fibers.

Gary Hoyt, the designer behind Freedom Yachts, a pilot, surfer, former world-champion sailor in the Sunfish class, next talked about designing the human-powered Waterbug (HP v3n4, Summer 1985) and showed a videotape of it in action. He explained that to produce a safe, versatile boat for pedalling in virtually all weathers (Mrs. Hoyt told me that Gary had been out in Newport harbor the previous week when the air temperature was between 10 and 15 degrees F (-9 to -12C) and had to partially strip to keep cool) it had to have maneuverability. Therefore it had to be short. That immediately limited its speed: "hull" speed, at which bow and stern waves combine to confine the boat to a trough, is about 5 mph, just over 2 m/s, and Bernard Hinault couldn't get a short boat to go any faster. To give stability there is 140 kg (310 lb) of lead. The videotape showed the advantages of this added mass - the boat was being pedalled smoothly through crashing waves without hesitation. Then one rider tried to overturn the Waterbug by standing on the side and heaving at the edge of the cockpit.



Matt Thompson adjusts the foam on his suspension-support tricycle.

Eventually he managed only to fill the cockpit with water, at which time he got in again and pedalled it to shore. (A baling pump is included with which he could have given himself a more-or-less dry trip home). Gary Hoyt incorporated a traditional propeller. He tried one designed by Gene Larrabee ("Mr. Propeller", whose designs are being used by almost all recent HPAs and HPBs), but although it was more efficient at full speed, its stalled performance during starting produced very slow getaways and sluggish astern operation.

The Waterbug is an extremely impressive design. Its economics are currently similar to those for other HPVs: the tooling cost was $70,000, and the selling price of about $1900 for the open-cockpit and $2600 for the enclosed version means that Harken-Vanguard, with sales of only about a hundred so far, are losing money. Nevertheless, Gary Hoyt with, presumably, Harken-Vanguard is bringing out two more HPBs, one being the Skua which will be unballasted and cartoppable. He hopes also to design an HPV tricycle. Expect some formidable designs.

Bob Baals, like Bruce Holmes from NASA Langley, spoke about wind-tunnel testing of HPVs. He made his low-speed wind tunnel at home, mostly of wood, like his beautiful faired tricycles that have done well at Indy. He showed that, although small models at low speed do not have full flow similarity with full-scale machines, and do not have the moving ground plane of a road machine, he could still learn a great deal about the drag of a vehicle from a small model in his 180x250 mm (7x10 inch) wind tunnel. His setup includes a simple force-measuring balance, but Bob learns more from visualizing the airflow with smoke or tufts.

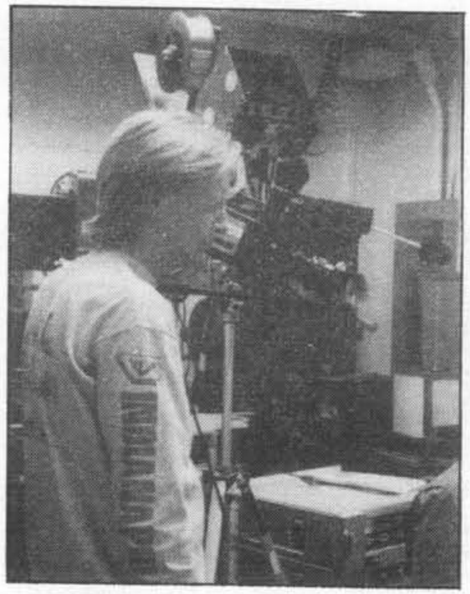
Last on the Saturday schedule was Barry Willey, president of National Cycle, the largest manufacturer of motorcycle fairings in the country. He discussed mold requirements, material selection and heat sources for thermoforming plastics. Alas! Your reporter had to be elsewhere preparing for another event, and missed this interesting presentation.

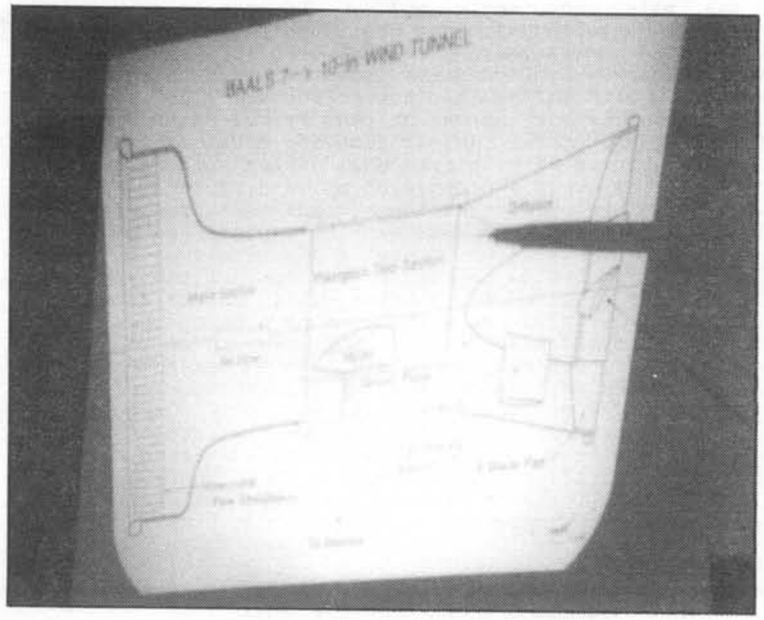
The Sunday lectures were started by NEHPVA president Bill Darby, service manager of the Bicycle Exchange in Cambridge, and former race-car builder and driver, talking about steering layouts for HPVs, especially tricycles. His slides illustrating good and bad points of many vehicles were full of practical advice, and started a good discussion (questions of steering seem to do this). I will ask Bill, and the other lecturers to whom I have not done justice, to write something for a future HUMAN POWER.

The last three talks of the workshop were also of design experiences, full of fascinating details of techniques and of overcoming problems, and again difficult to do justice to in a short report. Volker Paedelt and Steve Winckler described and showed slides of the design, construction and flight of an all-composite sailplane, RP-2, built by students at Rensselaer Polytechnic Institute under the NASA Air-Force-Officer Scientific Research Program over a five-year period. RP-2 has a 45-ft, 14-m, wingspan, limited by

Wayne Kirk and Tisha Clark were the Boston coordinators.

Proceedings from the workshop were videotaped, and will be available after editing.



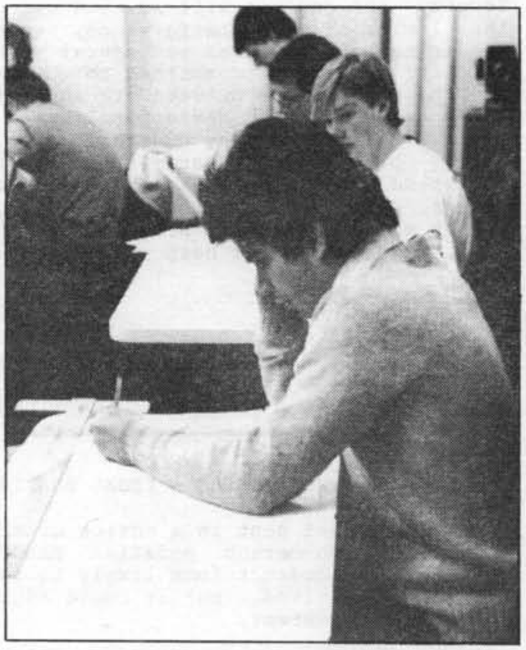


Robert Baal's home-made (does it still count, even if his "home" is NASA?) wind-tunnel design.

Terry Hreno explains the finer points of design.

ker Paedelt and Don Radford prepare the vacuum-bagging monstration.

TOS BY MARTI DAILY



Back to the drawing board....

E PHOTOS ON PAGE 15

One room was filled with all shapes and sizes of alternative designs. Trying them out in the halls of MIT was a highlight of the weekend.

the size of the "home"-built autoclave (a high-pressure oven). The fibers used were Celcon 3000 carbon, S-181 weave Kevlar cloth and glass cloth of the same weave. The resins were Ciba-Geigy 509, 224 and 225, and Shell Epon 828. The high-temperature-cure resin was Fiberite 934. The wing surfaces were sandwich construction, using Kevlar cloth, single-sided, and 0.055-g/cc Klegecell foam, with a three-day-cure resin (Ciba-Geigy). They would make a flat panel, and on the second day, when it was viscous and tacky, would drape it over the wing framework. This interesting and successful procedure was used because the cost of making a female mold set up for vacuum-bagging would have been too high, and because the autoclave could not take the wing. Incidentally they used an aluminum parking-lot light pole as a mandrel for the main tail boom.

Ted Van Dusen, president of Composite Engineering, is an MIT-UMass naval-engineering PhD who started making composite shells while still at school. His boats have been used by all US Olympic teams since 1976, and last year all his boats placed, with a gold, a silver and a fourth place. They have had a clean sweep in all the US Mens' Nationals. At one point he had to add weights to his boats because they were considerably lighter than the (World) Olympic Committee considered possible. The type of composite construction he showed in his slides was usually Nomex (Du Pont) honeycomb, 3/32-inch (2.4-mm) high with Kevlar or carbon-fiber tape or cloth. He often uses very-slow-setting resins to avoid high heat production during cure.

Juan Cruz was a member of the MIT Monarch HPA team (HP v3n1, Spring 1984) and is now part of the same team working on the Daedalus project (see separate news brief). He described the design considerations that went into this aircraft and its predecessor Chrysalis, and compared them with their rivals Bionic Bat (from Paul MacCready's team, also described in HP v3n1) and Musculair-2, the amazingly fast German plane (about which we hope to have an article in the next issue of HP). All these have now won Kremer prizes. We could also compare the construction with that used for the RP-2 sailplane.

This was my first experience of an HPV-builders' workshop, and I was greatly impressed with the high quality of the speakers and instructors, most of whom had travelled considerable distances and given a great deal of time to make superlative presentations. I hope that more workshops may be given in other parts of the country and internationally, by local and world experts. I would like to be able to pay tribute to all of those who put so much of their time into planning and implementing this event, but it would take too much space. I would like, however, to thank Marti Daily, Indy-chapter president, who came to help and whose photos will, I hope, enliven this report. We should also thank MIT for allowing this workshop to be included as part of the diverse offerings of its Independent Activies Period. The fees for the workshop, which just about covered the major out-of-pocket expenses, were $25 for MIT students and $65 for the rest of us. It was a bargain.

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The Daedalus Project

History records many more poetic, romantic, and mythical references to flight than descriptions of vehicles capable of achieving it. Perhaps none is more famous than the Greek myth about Daedalus, a master craftsman who flew to freedom from imprisonment on the island of Crete using wings he had fashioned himself. Until recently, such a voyage remained purely in the realm of the imagination: from Crete to a major land mass is a distance of more than one hundred kilometers. The greatest achievement in human-powered flight to date is about thirty-five kilometers. Recent advances in aircraft structures, aerodynamics, and propulsion may now make it possible, however, for Daedalus' flight to become a reality. The Massachusetts Institute of Technology and the Smithsonian Institution have become partners in an effort to evaluate the feasibility of such a flight and the benefits it might bring in terms of scientific knowledge and cultural awareness.

This ambitious undertaking was proposed by the MIT group of Aero/Astro students who won the first of the recent Kremer prizes with their Monarch HPA, headed by John Langford and Mark Drela, doctoral students. Their department and university have backed them enthusiastically, and the National Air and Space Museum of the Smithsonian Institution has become a partner in the enterprise.

The myth of the original flight of Daedalus is well-known: imprisoned in the labyrinth of Crete (he is credited with its construction) for the crimes of aiding Theseus to slay the Minotaur, and of building too-lifelike a mechanical bull, Daedalus builds wings of wood, feathers, and honey (or wax) and flies to freedom. After his escape, the inventor-engineer built an intricate system of hot water baths for King Cocalos of Sicily, in which his daughters supposedly scald to death the vindictive King Minos, who had pursued him to from Crete.

Daedalus is one of the few creatures of Greek mythology who represents techne -- craft, cleverness, and production. (The only other major figure is the Greek god Hephaistos, known to the Romans as Vulcan.) Significantly, Daedalus is also one of the few mortals credited with flight.

The final destination of Daedalus' flight is variously cited as Sicily (700 kilometers west of Crete) and the island of Ikaria (250 km northwest). The MIT project draws on the navigational strategies Daedalus might have used had he possessed the appropriate technology. The primary transportation method of the time was nautical, suggesting that Daedalus might have taken his voyage one step at a time, hopping between small islands or along the coast. Thus, his most difficult hurdle would have been a distance of over one hundred kilometers -- the distance across the straits between Crete and the Greek mainland at one point, or the island of Thira at another.

The record for human flight is a distance of 35.9 km (22.3 mi) in 2 hours and 49 minutes. But since the flight of Bryan Allen in the Gossamer Albatross on June 12, 1979, there has been steady, evolutionary progress in ultra-lightweight aircraft technology. Concepts under consideration by the Daedalus project feature wingspans of around 100 feet and weights near 70 pounds. Advances in technology should allow an aircraft almost 50% faster than the Gossamer Albatross for the same size and power. In addition, the Daedalus group believes that careful planning, study, and selection will allow significant improvement in pilot performance and the prediction of meteorological conditions.

As currently envisioned, the Daedalus project will consist of three phases. The first is a feasibility study. This portion is fully funded and scheduled for completion in early 1986. If the results and tests are positive, a second phase featuring the design and construction of a prototype aircraft, and its testing in the US, will begin. With design performance verified in flight, a third phase would cover the construction of the actual Daedalus aircraft and flight operations from Crete. Under the current plan, flights from Crete will take place in the spring of 1987.

The preliminary design goals concentrate on the development of an aircraft capable of crossing the shortest open-water strait between Crete and the mainland, thus establishing the design range at 11 km (60 nmi). In order to minimize sensitivity to winds and turbulence, the aircraft's speed will be as high as possible. The design goal of 7.8 meters per second (15 knots, 25 feet per second) will require aerodynamic characteristics comparable to the world's best sailplanes, at considerably lower speeds. In addition, the group will study the possibility of allowing the aircraft to operate at night, or in conditions of light fog, where no horizon reference is available to the pilot. (This would require instruments or an automatic flight control system.)

They give three reasons for the venture. "First, the project will advance aeronautical technology. The challenge of creating a vehicle of such efficiency that it can fly more than one-hundred km on human muscle power alone will provide a stimulus for significant improvements in aircraft structures, aerodynamics, and vehicle design; these advances in turn will prove applicable to a range of more common vehicles. Second, the project will advance our understanding of the limits of human performance, especially in tasks requiring both physical and mental workloads. Finally, the project is committed to increasing awareness of the connections between art and science, and between technology and Western culture". The group has received help from many quarters: for instance, Bryan Allen, pilot of the Gossamer Albatross, came recently to spend a working weekend with several of the task groups. For the project to continue, and for the flight to be on for its projected spring, 1987, schedule, major financial help is now required.

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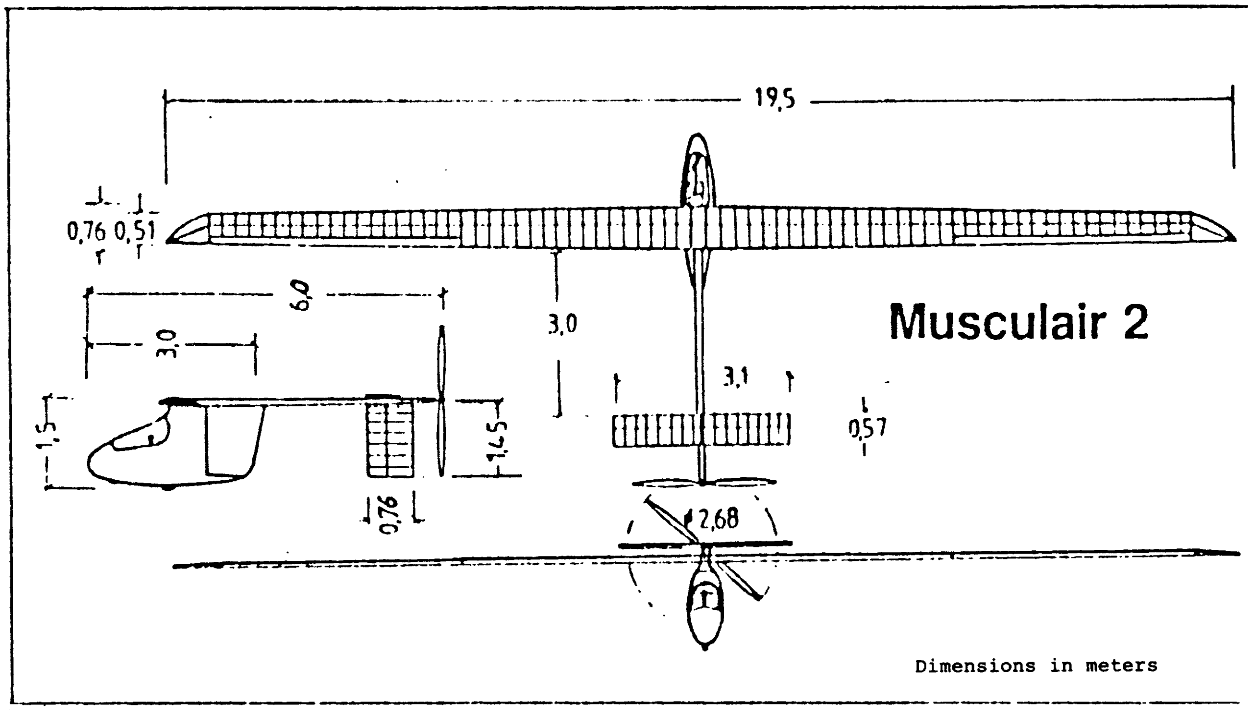
NEW AT SEARS - PEDAL BOATING!

Phil Thiel sent in a notice of the Sears new Sea Runner, a two-person pedalled paddle boat, price $499.99. It doesn't look likely to get anyone in the IHPVA over-excited, but it could educate the market place to some extent.

From the Sears catalog: "Pedal boating's a pleasure in the Sea Runner! Designed for handling and pedalling ease, it's so portable you can carry it on the car top or in back of the van. High-density polyethelene construction combines light weight with durability and weather resistance. ...Shipping weight 90 lbs, price $499.99."

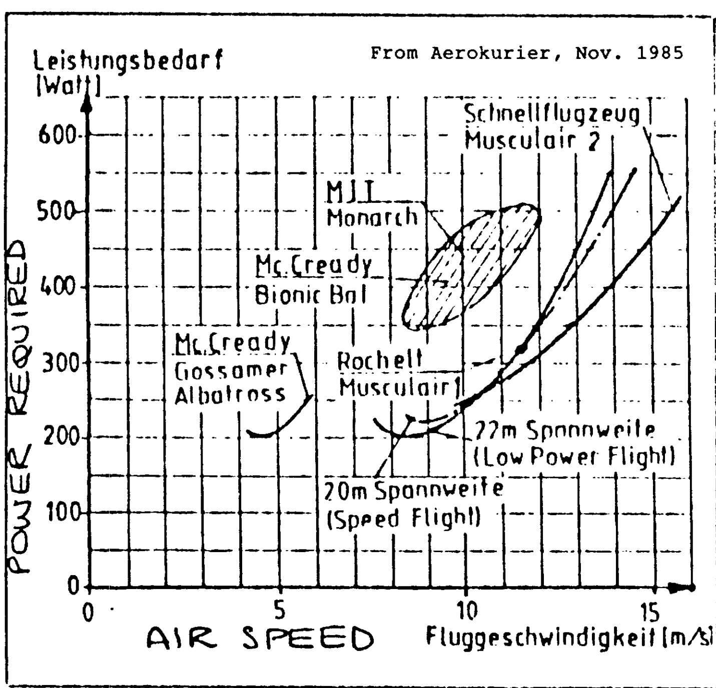


The Rochelt Musculaire II

As forecast elsewhere, we hope to have a full report on the amazing HPA Musculair-2 in the next issue of HP. Meanwhile, here is a little about it to whet your appetites. Ernst Schoberl, who performed most of the aerodynamic analysis and design, including that of the propeller, sent me a clipping from AEROKURIER, November 1985, with a graph and plan that I hope we can reproduce (figure RM-1). The Royal Aero. Soc. MPAG newsletter tells us that the plane completed the Kremer 1500-m course in 122 seconds, at 27.5 mph (12.3 m/s) on October 2, 1985, using no stored energy (a little is allowed under the rules), and is consistently exceeding 30 mph (13.4 m/s) given the three turns required. Mark Drela and Debbie Douglas, of the MIT Daedalus group (see below), brought back from a "state-of-the-art" meeting at the R.Ae.Soc. in London, December 11, 1985, the accompanying table from a presentation by Admiral Nicholas Goodhart (table RM-2). Gunter Rochelt also reported that one week before the record flight, his pilot (and son) Helger Rochelt was flying Musculair-2 at a county fair at the extraordinary height of 20m (70 ft) and encountered "wing flexion" and crashed.

There is another Kremer prize for human-powered flight being planned, but details are not yet settled. Meanwhile, some people are designing and building human-powered helicopters, stimulated by a prize of $15,000 offered five years ago by the American Helicopter Society. I hope to report further on some of these efforts in the next issue.

Dave Wilson



Kremer Speed Prize-Winning Aircraft

Aircraft		Monarch	Bionic Bat	Musculaire I	Bionic Bat	Musculaire II
Date		11/5/84	18/7/84	21/08/84	2/12/84	2/10/85
Time (sec)		175.7	163.3	151.4	143.1	122.0
Pilot		Frank Scarabino	Parker MacCready	Holger Rochelt	Bryan Allen	Holger Rochelt
Span	ft	61.5	55.5	72.2	55.5	64.0
	m	18.7	19.9	22.0	16.9	19.5
Wing Area	ft^2	178.0	149.5	172.2	149.5	128.1
	m^2	16.5	13.9	16.0	13.9	19.5
Empty Weight	lbm	72.0	72.3	61.6	72.3	52.8
	kg	32.7	32.9	28.0	32.9	24.0
Wing Ldng	lb/ft^2	230.0	212.0	182.6	212.0	173.8
	kg/m^2	104.5	96.4	83.0	96.4	79.0
Flying Weight	lbm	1.29	1.42	1.06	1.42	1.36
	kg	6.30	6.90	5.19	6.90	6.64
Pilot Weight	lbm	158.0	140.0	121.0	140.0	121.0
	kg	72.0	64.0	55.0	63.0	55.0

ROLLING DRAG: THREE IS LESS THAN TWO?

by Chuck McConica

Three wheelers have less rolling drag than two **wheelers.** It is possible to reach this conclusion by **first noting** that the coefficient of rolling resistance ,**Cr**, is a **function** of the square root of the inflation pressure **P** in the denominator. The curves A, B, D, and E in Figure 5.6, **Bicycling Science**, Whitt and Wilson (Ref. 1) show this for pressures less than 100 psi. This can be verified by fitting an equation of the form,

(1) $$Cr = \frac{c}{P^{n}}$$

to the curves, where **c** is a constant, and the values of the exponent **n** are 0.51, 0.44, 0.50, and 0.45 respectively. Thus taking **n** to be 0.5 is reasonable. The coefficient of rolling resistance is dimensionless; therefore, by dimensional analysis, there must be a dimension of the square root of force in the numerator. That force must be the load **L** on the wheel. In equation form, this is

(2 $$Cr = K\sqrt{\frac{L}{P}}$$

where **K** is a constant with the dimension, one over length. If the pressure is increased, the coefficient goes down, and if load is increased, the coefficient goes up. For equally-loaded wheels on an **N**-wheeled vehicle of weight **W**,

(3 $$L = \frac{W}{N}$$

substituting for the load in equation (2:

(4 $$Cr = K\sqrt{\frac{W}{PN}}$$

The rolling drag for each wheel, **dr**, is equal to the load **L** times the coefficient of rolling resistance **Cr**;

(5 $$dr = \frac{KW}{N}\sqrt{\frac{W}{PN}}$$

Thus the rolling drag, **Dr**, of an **N**-wheeled vehicle is

(6 $$Dr = N\ (dr) = KW\sqrt{\frac{W}{PN}}$$

That is, the rolling drag Dr is reduced by increasing the number of wheels.

To develop a more complete model, it is necessary to drop back and look at the wheel and the contact patch. Whitt (Ref. 1) experimentally related the coefficient of rolling resistance **Cr** to the ratio of contact-patch length **2a** to the tire outside diameter **2R** as

(7 $$Cr = 0.070\ \frac{2a}{2R}$$

It remains to find a relation between the contact-patch half-length **a**, and parameters of the problem: load **L**; pressure **P**; tire outside radius **R**; and tire cross-section radius **r**. The half-length **a** of the contact patch can be related to the outer radius **R** of the wheel and the sinkage, **S**, by the Pythagorean relation.

(8 $$R^2 = a^2 + (R-S)^2$$

(9 $$a = \sqrt{2RS - S^2}$$

(10 $$a = \sqrt{2RS}\sqrt{1 - \frac{S}{2R}}$$

Note that for bicycle tires the sinkage **S** is very small compared to the tire outside diameter **2R**, so the contact-patch half-length **a** is approximately

(11 $$a \sim \sqrt{2RS} \qquad \text{where} \quad \frac{S}{2R} << 1$$

Similarly the half-width, **b**, of the contact-patch can be related to the tire's cross-section radius **r** as

(12 $$b = \sqrt{2rS}\sqrt{1 - \frac{S}{2r}}$$

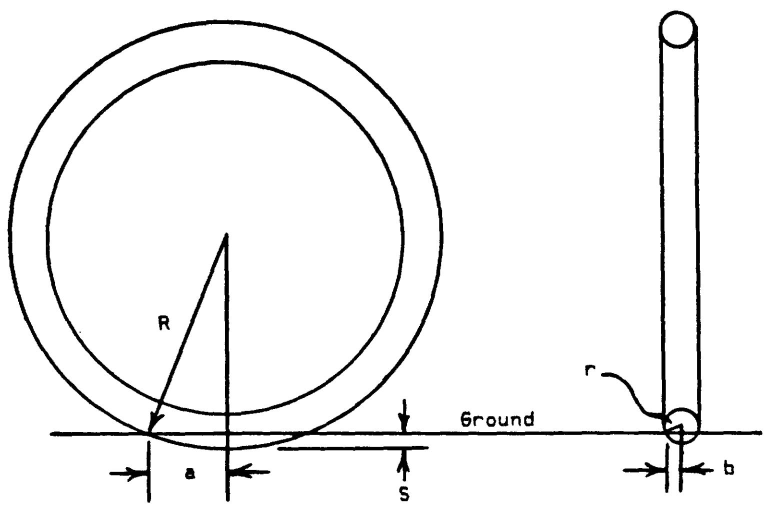
For high-pressure bicycle tires, the sinkage can also be small compared to the cross-section diameter **2r**; so that the the half-width can be approximated as

(13 $$b \sim \sqrt{2rS} \qquad \text{where} \quad \frac{S}{2r} << 1$$

This approximation will not be valid for all real-life situations. If it is assumed that the contact patch is eliptical, the contact-patch area **A** is

(14 $$A = (PI)\ ab \sim 2\ (PI)\ S\sqrt{Rr}$$

The bending stiffness of the tire changes the pressure that the tire applies to the road, but only in a narrow band around the edge of the contact patch. Assuming the effects of the bending stiffness of the tire are negligible, then the pressure in the contact patch is constant, and equal to the inflation pressure **P** of the tire. Summing the vertical forces (load, and



contact-patch area times pressure, **AP**) and setting them equal to zero yields

$$L = PA \tag{15}$$

$$L \sim 2\,(PI)\,PS\sqrt{Rr} \tag{16}$$

Solving this for sinkage yields

$$S \sim \frac{L}{2\,(PI)\,P\sqrt{Rr}} \tag{17}$$

Substituting this approximation for sinkage into the approximation for contact-patch half-length yields

$$a \sim \sqrt{\frac{L\sqrt{R}}{(PI)\,P\sqrt{r}}} \tag{18}$$

Substituting this approximation for **a** into Whitt's coefficient of rolling resistance relation gives

$$Cr \sim 0.040\sqrt{\frac{L}{PR\sqrt{Rr}}} \tag{19}$$

Thus the rolling drag **dr** for a single wheel is

$$dr \sim 0.040\,L\sqrt{\frac{L}{PR\sqrt{Rr}}} \tag{20}$$

and for an equally-loaded, **N**-wheeled vehicle, the rolling drag **Dr** is

$$Dr \sim 0.040\,W\sqrt{\frac{W}{PRN\sqrt{Rr}}} \tag{21}$$

If the vehicle parameters are the same for several vehicles with different numbers of wheels, then the rolling drag is given below as a percentage of the **Dr** of a unicycle and a bicycle.

Number of Wheels	% of Unicycle Dr	% of Bicycle Dr
1	100 %	141 %
2	71 %	100 %
3	58 %	82 %
4	50 %	71 %

Related thoughts: 1) The tire-construction parameters (like bending stiffness, hysteresis, and maybe mass per unit of surface area in the tread) are hidden in the 0.040 factor. 2) Three- and four-wheeled vehicles can have alignment (toe) problems between pairs of wheels that will increase the drag, using up their 20 to 30% advantage quickly. 3) The frontal area and aerodynamic drag coefficient will probably be increased by going from two to three or four wheels, and this may dominate over the rolling-drag effects.

These results have been derived two independent ways from two independent sets of experimental data. These results are tentative. The parametric behavior given in equation 19 has not been verified experimentally. Other researchers have found excellent fits to experimental data using an equation of the form

$$Cr = c1 + \frac{c2}{P} \tag{22}$$

(Ref. 3). The constant **c1** is the coefficient of rolling resistance at the limit of very high pressures. The constant **c2** is the modification to that limit using normal inflation pressures.

There are two limits that are of practical interest. One is low to moderate inflation pressure, where the effects of the tire's bending stiffness can be neglected compared to the pressure over the contact-patch area. The other limit is for very high pressures, where the effects of bending stiffness become the dominant load-carrying mechanism. There is a smooth transition in behavior between these two limits. Extending the current work to derive the parametric behavior at the upper limit and in the transition region would allow direct comparison with the curve fits of other researchers.

Ref. 1: **Bicycling Science**, Second Edition, F. R. Whitt and D. G. Wilson, MIT Press, Cambridge, MA, 1982, p.118, Figure 5.6.
Ref. 2: IBID, pp. 112 & 113, Figure 5.3, Equation 5.2.
Ref. 3: IBID, p. 127.

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Steering Geometry Note

If we accept Raymon Pipkin's simplified interpretation of the stability index (Bike Tech, Oct. 1983) as being a mathematically calculable dimension derived from trail and head angle, then it is also recognized that this figure represents a steering moment arm or a "tiller" length.

The moment generated by the weight of the rider times the out-of-vertical distance of the CG must be balanced by the weight on the front wheel times the steering moment arm.

It will thus be seen that as the height of the CG is lowered the angle of lean must be increased to generate a given turning radius, but this is limited by considerations of balance. The alternative is to increase the steering moment arm or "tiller" length.

The angle through which the front wheel is turned to describe a given turning radius increases as the wheelbase increases and therefore demands a greater angle of lean (limited as above) or a longer tiller arm the longer the wheelbase.

Therefore I believe that the three variables that dictate the steering moment arm, and by inference the trail necessary for good handling, are:

the position of the cg fore and aft, as this determines the proportion of total weight on the front wheel;

the vertical height of the cg as this determines the angle of lean to generate a given moment, or conversely the length of the steering moment arm; and

the wheelbase, because this determines the angle through which the front wheel must be turned to describe a given turning radius, and again the angle of lean necessary to generate the steering moment, or conversely the length of the moment arm.

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TESTING A VEHICLE DESIGN FOR SAFETY: THE LEITRA TRICYCLE

by Carl Georg Rasmussen

In previous articles published in **HPV NEWS** (March '84) and **BIKE TECH** (Feb. '83), I reported on personal experiences from the first 50,000 km in a **Leitra** fully-faired tricycle.

Since then we have completed a more extensive test program with about a hundred participants, who used a Leitra daily for periods of one month to more than one year. The cyclists were from 17 to 71 years old, women and men of many different professions. Several of them had never tried to ride a normal racing bike and were not used to operating a standard derailleur.

The test programs gave us valuable experience regarding safety and reliability, very important factors for a vehicle intended for commuting and touring. They are important for the general acceptance by cyclists as well as by other road-users.

Let me here summarize some of the design considerations behind the safety of the Leitra, and analyze the road-accident experiences during the last two years. The test program has so far covered about 150,000 km.

SEE AND BE SEEN

An HPV is usually much lower than a normal bike, mainly for reasons of stability and aerodynamics. Racing vehicles in particular are extremely low.

A vehicle for commuting and touring has to operate in ordinary mixed traffic with cars, buses, trucks, other bicycles, and pedestrians. A good view in all directions is, therefore, absolutely necessary under all weather conditions, by day and by night.

A Leitra-cyclist has the eyes at the same level as most car drivers. This makes it easier to get eye contact, and in general it is easier to be seen.

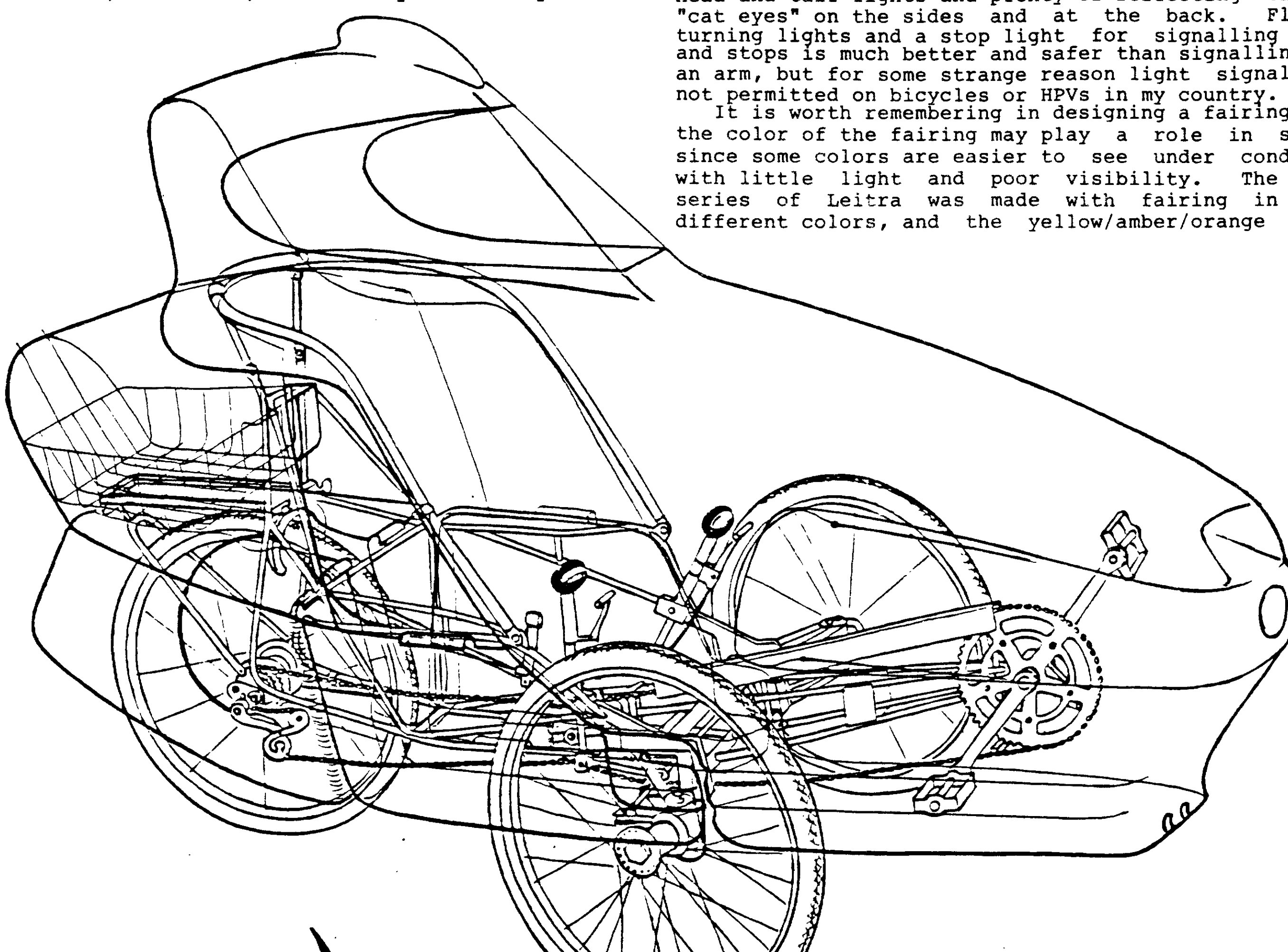
The windshield must be ventilated on the inside to prevent dew and ice, and a rear-view mirror is much more necessary on an HPV than on an ordinary bike, because you can't easily turn your body and head sufficiently to look back. The mirror on a Leitra HPV is mounted on top of the canopy as on the famous "Spitfire" from the Second World War. It is ventilated so that it always stays clear, and the mirror is protected by an aerodynamic fairing.

The test program demonstrated that the visibility by night through the windshield represented a serious problem. We used polycarbonate, which is an excellent material in many respects, but it has one serious drawback: it is too soft. In a short time it becomes covered with fine scratches. These don't disturb visibility much in daylight, but when you drive by night against the headlights of car traffic, the light rays are scattered by the scratches and you can see hardly anything.

The lower you sit, the greater is the problem. Since most of the driving takes place in dark and bad weather during the winter season, some solution must be found. The problem can be solved by using a piece of laminated glass, the same type as used in automobiles, for the front section of the windshield.

It goes without saying that you need very effective head and tail lights and plenty of reflecting tape or "cat eyes" on the sides and at the back. Flashing turning lights and a stop light for signalling turns and stops is much better and safer than signalling with an arm, but for some strange reason light signals are not permitted on bicycles or HPVs in my country.

It is worth remembering in designing a fairing that the color of the fairing may play a role in safety, since some colors are easier to see under conditions with little light and poor visibility. The first series of Leitra was made with fairing in many different colors, and the yellow/amber/orange colors



are clearly more visible at night than the blue/green/ red hues.

The conspicuous and very visible appearance of a Leitra HPV was not considered as an entire advantage by all the test riders. One of the young test pilots made the remark that he could not get away with his usual bad habits in traffic (such as ignoring traffic, driving by night with no lights, etc.). He felt he had to behave himself because there seemed to be alert witnesses at every corner.

We experienced a few collisions with other road-users during the two-year test period. All may be identified by the problem: see and be seen. In one case a bus driver did not see the HPV when he made a sharp right turn, and the rear wheel of the bus went over the front wheel of the Leitra. (The bus company paid for the repair.) In two other cases the collisions were with other bicyclists at night, in a crossing and on a two-way bicycle track.

DESIGN OF FRAME AND FAIRING

Steering and braking system, shock absorbers, and sensitivity to side wind are all important factors in relation to safety of an HPV as for other vehicles. A technical discussion of these subjects would take more space than can be made available for this article. Let us, therefore, confine ourselves to a few points concerning the design of frame and fairing.

Given a certain level of the eyes of the cyclist and the center of gravity of the vehicle/cyclist system, you have to choose a sufficiently large track width to obtain stability against overturning. The Leitra has a track of 900 mm (and a wheel base of 800 mm) which by normal use, even in a strong side wind, offers satisfactory stability.

The front wheels are suspended between two leaf springs of carbon/glass/epoxy. These shock absorbers make the steering less sensitive to shocks when a wheel hits a stone or hole, and the vehicle does not jump and roll as much as an HPV with a rigid frame.

In the case of a overturn, the frame and fairing will protect the cyclist against injuries. The Leitra frame is designed to form a cage around the cyclist, and this, together with the fairing (0.7 mm fiberglass/ epoxy), has proven many times to give effective protection in an overturn.

The recumbent position, with the legs forward, represents in itself a positive safety factor. We have seen a couple of frontal impacts with rigid concrete structures, where the vehicle suffered severe damage but the cyclist emerged unhurt.

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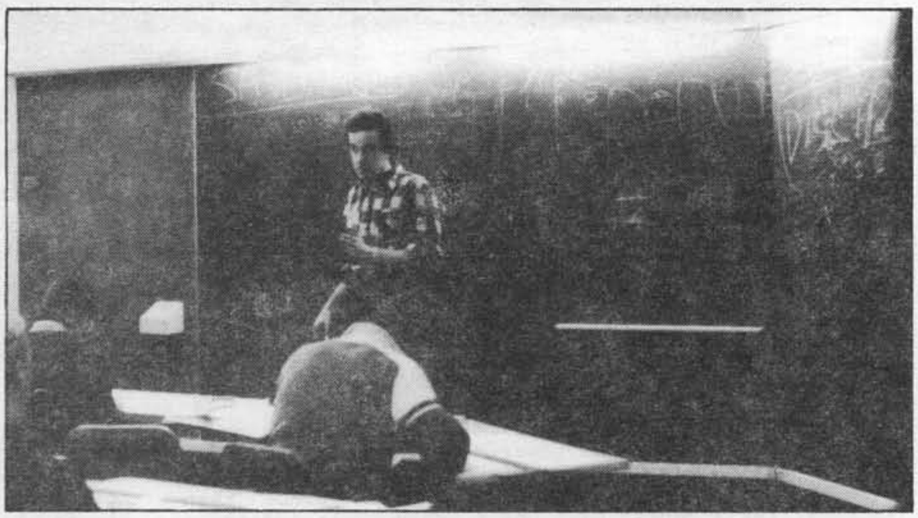
(Catalog is free, but return postage is required.)

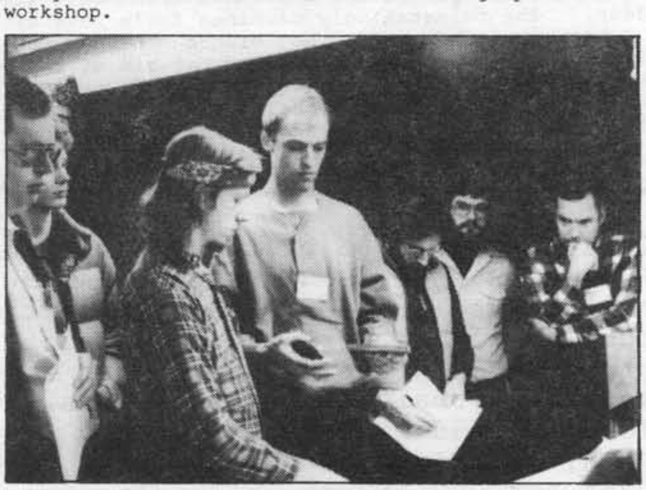
Second HPV-Builder's Workshop

PHOTOS BY MARTI DAILY

Gary Helfrich discussed and demonstrated a variety of welding techniques at the second HPV Builders' Workshop at MIT.



Terry Hreno waxes technical in the design portion of the workshop.



The workshop wasn't all serious study -- but you'd never know it from the concentration in these faces!

Foiled Again

David Owers (HP v3n3, Spring '85) has sent a photo (Fig. FA-1) of his human-powered hydrofoil racing boat **Foiled Again.** The boat was launched in June 1985 and made its first short "flight" in July. Since then various refinements have been made, including a carbon-fiber propshaft and a slimmer front-foil strut-rudder. The painstakingly machined foils have proved to be perfect. At the Milton Keynes event (1985.09.01), which was the principal aim of the project, high winds and weed in the lake gave both the hydrofoil boats, the other being the Flying Fish from California, a hard time, and no records were set. We did manage a short flight in front of the TV cameras, and a half-hour documentary should be produced.

I now have several ideas for improvements that I hope to incorporate into a new boat to take on the Flying Fish next year at Expo '86 in Vancouver. It will have the ability to retract the propeller for weed clearing, will be lighter and more stable than Foiled Again, and (of course) faster than any HPB yet constructed. So beware!

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