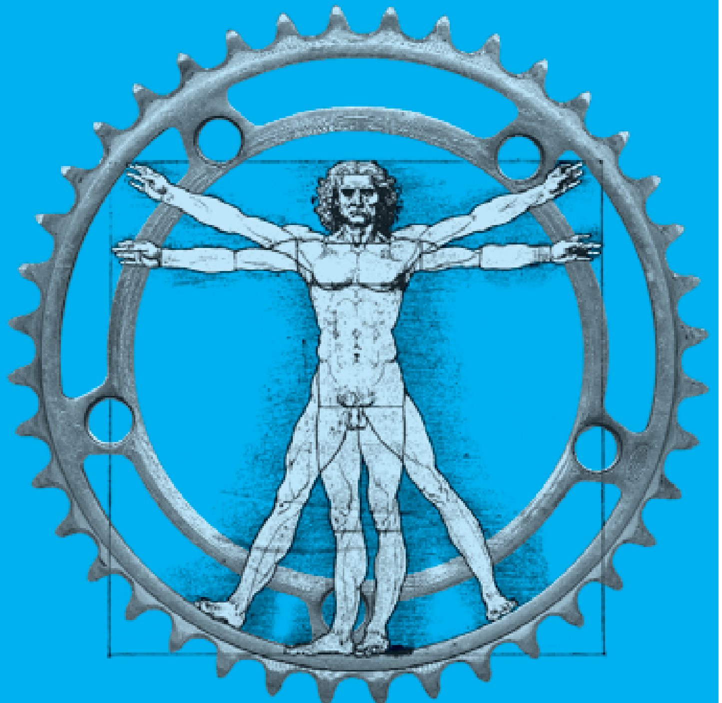

HUMAN POWER

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Table 5. Computation of forces for the direct-drive hub.

Computation of forces for the *direct drive hub*

Assumed force on pedal	2000	N	corresp. 200 kg
Crank length	170	mm	standard
Diameter planet gear carrier	**57.4**	**mm**	optimized
Number of planets	4		optimized
Force on planet shaft	2 962	N	
Diameter small planet gear	14.7	mm	optimized
Diameter large planet gear	24.5	mm	optimized
If only one tooth per planet gear interlocks at once, the load each tooth carries is:			The worst case is the combination of smallest planet with largest sun gear or vice versa, all other combinations result in lower forces per tooth.
large planet gear:	1 111	N	
small planet gear	1 851	N	

Comparison to conventional hub

Assumed force on pedal	2 000	N	as above
Length of crank	170	mm	
Ratio chainring/cog	2.47	-	corresponds to a cog of 17, chainring with 42 teeth
Diameter of annular gear	38	mm	measurement of a 3-speed hub by renownd mfg.
Number of planets	3	-	standard for multispeed hubs
If only one tooth per planet gear interlocks at once, the load each tooth carries is	2 414	N	Worst case: annular gear-driven

Calculation

F_P: force on each planet gear shaft
L : length of pedals
F_T: force on pedal
D_P: diameter of planet gear carrier up to center of planet gear shaft
n: number of planet gear shafts

F_K: force on small planet gear
F_D: force on large planet gear
D_K: diameter of small planet gear
D_G: diameter of large planet gear

Figure 11. Unicycle with transmission surely won't need all those gears, but after a slight modification of the hub, the unicyclist enjoys higher speed.

load on a tooth of the direct-drive hub is 23% lower!

ONE DIRECT-DRIVE HUB: MANY BICYCLES.

A whole new spectrum of bicycles emerges with the coming of the direct-drive hub. Use of the hub is thus not limited to chainless recumbents. The following pictures show possible variations with further specific advantages.

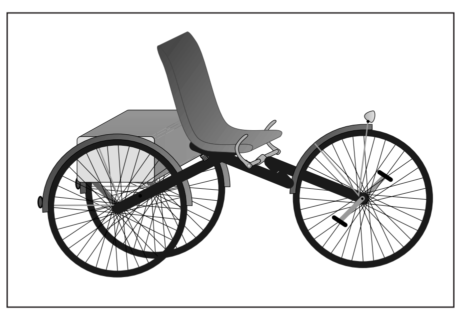

Figure 6. Recumbent tricycle: with direct drive this trike neither requires a differential nor is it driven on just one side.

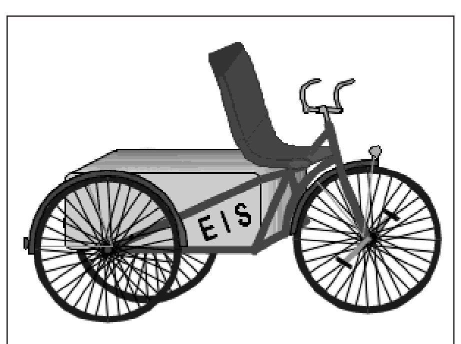

Figure 7. Cargo Bike: Don't be working on a chain gang!

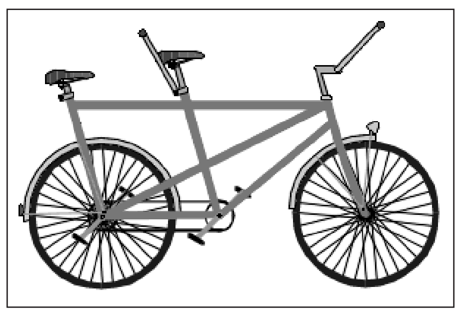

Figure 8. Tandem: Not much longer than a 'normal' bike

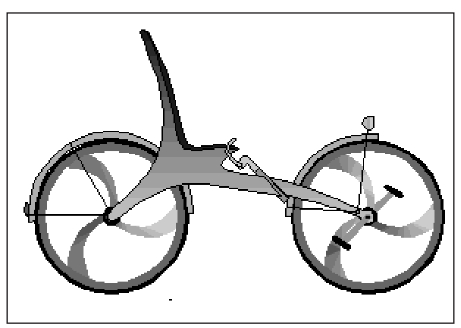

Figure 9. Recumbent, carbon: This form won't be "laid in chains"!

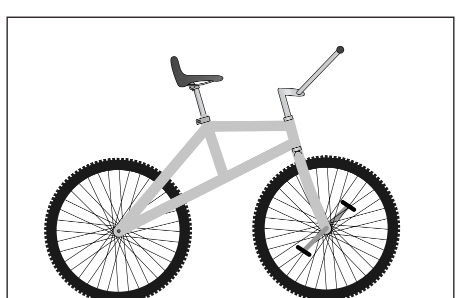

Figure 10. Funbike—with a drive immune to sand, water and mud

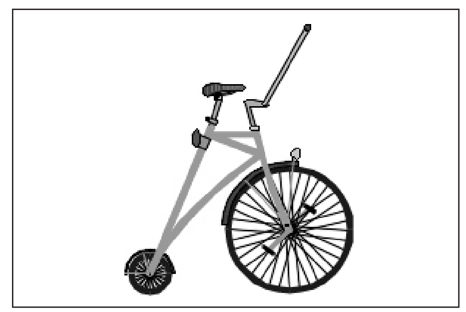

Figure 12. Smilebike: The bike for special occasions.

PRESENT STATUS

The multispeed direct-drive hub is not yet a reality, but a prototype should be finished in 2000. The test bike used until now has only one gear, with a ratio of 1:2.5 and without a freewheel. When the prototype is finished, the author hopes to find a manufacturer who would be interested in producing a hub for general sale. There are no restrictions on production and sale of the hub anywhere the world except Germany: the patents are German.

Thomas Kretschmer is an engineer working in a small German company. Until now, bicycle construction was only a hobby for him.

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CYCLE RICKSHAWS AS A SUSTAINABLE TRANSPORT SYSTEM FOR DEVELOPING COUNTRIES

by Anil K. Rajvanshi

ABSTRACT

Most cities in developing countries are highly polluted. The main reasons are the air and noise pollution caused by transport vehicles, especially petrol-powered two- and three-wheelers called autorickshaws. We have developed three types of improved rickshaws: (a) a pedalled rickshaw (IPCR); (b) a motor-assisted pedal rickshaw (MAPR); and (c) a completely battery-driven rickshaw called ELECSHA™. The details of these rickshaws are presented in this paper. It is shown that these rickshaws can provide an environmentally friendly, energy-efficient and cost-effective transport system and can replace the existing autorickshaws. An economic analysis of these rickshaws is presented and policy issues are identified. Besides reducing pollution, these rickshaws could provide large-scale employment in urban and rural areas of India.

INTRODUCTION

To illustrate the pollution problem mentioned above, in India there are close to 18 million petrol-engine-powered two-wheelers and about 1.5 million petrol- and diesel-powered three-wheelers. The population of these vehicles is growing at a rate of about 15% per annum. Besides being a major hazard to people's health, these machines consume petroleum products for which the country has to pay dearly in foreign-exchange outflow.

An electric cycle rickshaw can provide a nonpolluting and silent transport system for urban and rural areas of India. It is in addition a very energy-efficient and cost-effective vehicle. Work done at our institute has shown that improved cycle rickshaws powered by electric motors and batteries have a potential to provide an attractive alternative to petrol- and diesel-powered three wheelers. They can also provide large-scale employment and extra income to the rickshaw puller.

Figure 1. NARI improved pedal-cycle rickshaw (IPCR)

EXISTING CYCLE RICKSHAWS

There are approximate estimates that close to one million cycle rickshaws ply the Indian roads carrying about three to four billion passenger km/year. In some cities they are the major means of transport. They provide year-round employment to about 700,000 rickshaw pullers (plus work for migrant and seasonal workers), are very maneuverable, and are completely nonpolluting—hence they provide an environmentally friendly means of transport. It is very unfortunate that deliberate policies in most of the urban towns of developing countries have been made by the concerned authorities to phase out these rickshaws. These nonpolluting vehicles are being replaced by polluting (both air and noise pollution) petrol- and diesel-powered three-wheelers. Our data show that three-wheeler diesel "tempos" in Lucknow city (capital of Uttar Pradesh) produce a noise of close to 70–80 decibels at a distance of 1–2 m, besides emitting huge amounts of particulates into the air .

Nevertheless the existing standard rickshaw is poorly designed so that it takes a heavy toll on the health of a rickshaw puller. The existing cycle rickshaw has hardly changed since it was introduced in India in the 1930s and '40s. The gearing gives a very poor impedance match. Hence the rickshaw puller has to work very hard while climbing even a slight slope. A common sight is of a rickshaw puller dismounting so that he can, on foot, pull the rickshaw and passengers. The braking system is also poor in that only front brakes are fitted. Thus when going downhill at high speeds sudden braking produces a catapult effect. Similarly the seating arrangement is very uncomfortable and the aerodynamic drag of the system is very high. It is therefore humanly degrading to pull the existing inefficient cycle rickshaw. Yet because of poverty, laborers become rickshaw pullers and suffer adverse consequences to their health.

Rickshaw manufacturing presently is a footpath industry with no quality control and there are as many rickshaw designs as cities in which they ply. These rickshaws are so poorly made that often they have to be replaced completely every two years. Thus there is a need to improve the existing rickshaw and bring quality control into its manufacture.

NEWLY-DEVELOPED MODELS

Our institute has therefore designed and developed three types of rickshaws: (1) an improved pedal-cycle rickshaw; (2) a motor-assisted pedal-cycle rickshaw; and (3) a completely battery-driven rickshaw called ELECSHA™. The details of the work accomplished follow.

Improved pedal-cycle rickshaw (IPCR)

The new design of pedal rickshaw has a five-speed gear, a reduction in the length of the long chain drives used in existing rickshaws, back-wheel braking, better suspension and a lower aerodynamic drag than the existing rickshaws, as shown in figure 1, the improved NARI rickshaw. Tests done at our institute have also shown that it enables a rickshaw puller to take two passengers on a 6–10% slope quite easily and without getting down from his seat. This rickshaw is made of mild-steel angles, is light in weight and is sturdy. The weight of the rickshaw is 90 kg; its life estimated to be 7–10 years.

Our data from urban towns of India have shown also that many rickshaw pullers are migrant laborers from villages whose sole possessions are their rickshaws. Hence at night they often sleep on the cramped seat of the rickshaw for fear of its being stolen. Our new design allows the seats to be arranged in such a way that a long bed results which allows a rickshaw puller to sleep properly without the fear of his rickshaw being stolen at night.

The cost of this rickshaw is estimated to be Rs 7000 in mass production and compares very well with Rs 4000–5000 which is the cost of existing regular rickshaws.
[In October 1999, $1.00 = Rupees (Rs) 43.44; 1 Euro = Rs 46.84.
—Ed.]

Motor-assisted pedal rickshaw (MAPR)

Our data (from discussions with rickshaw pullers) also revealed that with a small battery-driven motor [permanent-magnet DC (PMDC) type] attached to the improved rickshaw (with a five-speed gear) it may be possible for the rickshaw puller to go uphill with ease. Similarly he can also carry loads at speeds of 10–15 km/h. Consequently calculations showed that a 0.375 kW PMDC motor with a 24-V, 40-A-h lead-acid battery could easily take two passengers on a 10% slope at a speed of 10 km/h without the rickshaw puller getting down from his seat. This would be a major improvement for him. A simple strategy has been employed in this rickshaw. A manual contact switch allows the rickshaw puller to switch the motor on or off depending upon his convenience and load. Thus the gearing is arranged such that pedal and motor work in tandem to ease the load on the rickshaw puller. A current-overload switch cuts off the circuit when motor draws more than 20 amps. However the rickshaw puller has to pedal continuously: thus it is a motor-assisted pedal rickshaw (MAPR). The weight of this rickshaw (including batteries) is 129 kg (figure 2).

The cost of this rickshaw is envisaged to be Rs 17,000 in mass production. The price includes rickshaw, PMDC motor and battery. Patents have been applied for for both the IPCR and the MAPR.

Figure 2. Motor-assisted pedal rickshaw (MAPR)

ELECSHA

In major cities of India there are petrol- and diesel-powered three-wheelers called autorickshaws. They are some of the most polluting vehicles on Indian roads. They use two-stroke engines, inherently more polluting than the regular four-stroke engines. In addition, data we have collected show that in the traffic conditions prevalent in most inner-city areas these autorickshaws run at only 15–20 km/h. They therefore produce even more pollution because they are designed to run efficiently at 40–45 km/h. The pollution is further compounded because they are continually starting and stopping. Our data also show that on an average these autorickshaws travel about 50–60 km per day. Based upon these data it was felt that an electric rickshaw designed to run 60–80 km/charge and with speeds of 25–30 km/h would be an excellent substitute for these autorickshaws. In a fair-weather country like India, a silent and nonpolluting electric rickshaw with the above attributes could be a boon.

Consequently an electric cycle rickshaw has been designed and built. It has been patented and registered as ELECSHA™ (figure 3). At the time of writing it has logged more than 3500 km in test runs. It runs on a 36-V 100-A-h lead-acid battery that powers a 1.3-kW PMDC motor. An electronic card "soft starts" ELECSHA and provides dynamic braking. It is estimated to cost about Rs 70,000 in mass production, which would compare very favorably with the cost of petrol- and diesel-powered three-wheelers which are priced in some cities between Rs 75,000–1,00,000. Table 1 shows the specifications of the ELECSHA. Efforts are being made to reduce its weight and to make it easy to drive. This could also help it to become a low-cost personal vehicle for middle-class families.

ECONOMIC ISSUES

We plan to introduce these rickshaws in Lucknow and Pune, cities having the maximum number of cycle rickshaws and autorickshaws respectively. The comparison of electric rickshaws and autorickshaws can take place only when ELECSHA is used in actual conditions. However, a simple economic analysis based upon existing data has been accomplished, as follows.

IPCR

Discussions with rickshaw pullers in various cities reveal that they propel their rickshaws to a maximum of 25–30 km/day. During the hot season (which is the majority of the year) their range is reduced to 15–20 km/day. On an average they charge Rs 3–5/km. Hence they can make between Rs 75–125/day. After giving Rs 15/day as rickshaw hiring charges they can earn about Rs 60–110/day. Data on our rickshaw have shown that with gears

the rickshaw puller can easily go 30–40 km/day. The addition of a five-speed gear could therefore increase his earnings substantially.

MAPR

In this case our data have shown that a rickshaw puller can easily pedal 50 km/day and in some tests he has increased this distance to 70 km/day in two shifts. Thus with the cost of MAPR at Rs 17,000 he can earn at least Rs 150/day (by charging Rs 3/km). If the rickshaw owner charges Rs 40/day as hiring charges (the puller will get at least Rs 110/day as net income) then the owner will be able to repay the rickshaw loan in five years. He will also at the same time earn a profit of about Rs 4,600/year for ten years on each rickshaw. This includes battery replacement cost every third year and 18% interest on the loan.

ELECSHA

The ELECSHA owner can make a net profit of Rs 25,400 every year for ten years. This requires that the fare will be Rs 3.50/km and that the rickshaw will travel 70 km/day. Other assumptions are:

- Driver will be paid Rs 75/day;
- ELECSHA will run for 300 days/year;
- Battery replacement cost is Rs 15,000 and it will be replaced every other year;
- Interest is 15% per annum and loan has to be paid back in five years; and
- The electricity cost is Rs 5/kWh.

Presently the petrol autorickshaws charge Rs 4.50/km and hence, even with the reduced fare for ELECSHA, the owner can make a good profit. This is because of the low running cost of ELECSHA. Thus it seems that for both rickshaw puller and owner it is economically viable to ply these rickshaws.

OTHER ISSUES

The battery and its charging

One of the major issues facing the large-scale introduction of electric vehicles is the issue of batteries. With the present level of technology development the batteries used virtually have to be lead-acid. Deep-discharge lead-acid batteries are presently imported into India and are very heavy. The issue of battery charging can be tackled in two ways.

1. An onboard charger that can be plugged into any electrical outlet can be fitted. This concept has been used in most of the electric vehicles. This concept can be attractive for private owners of ELECSHA. However the disadvantage of this method is that it increases the cost of ELECSHA since the charger will be a part of it.

2. A network of battery-charging stations could be developed. In this concept it is envisaged that the battery-charging station would take out the discharged batteries from ELECSHA and put in a set of charged ones.

The advantages of this concept are that one does not need to worry about charging and the battery could be of lower capacity and hence lighter weight, which in turn will improve the performance of the vehicle. Also, regular automotive batteries could be used which can be discharged to only 50% depth. At the same time no extra cost of a charger is incurred. This concept will be very useful for rickshaws being used as taxis. Nevertheless, the issues of old vs. new batteries and the economic viability of charging stations will have to be sorted out.

Figure 3. Electric cycle rickshaw (ELECSHA™)

The electricity to power these batteries could come from any renewable power plants like biomass, solar thermal, solar photovoltaic, wind, etc. In these cases these rickshaws could truly be called a renewable-energy transport system. To convert all existing one-million rickshaws in India into electric rickshaws would require only one 600-MW power plant to run them. [If battery-charging is carried out off-peak, including during the night, no additional generating plant would be required. —Ed.] It is also instructive to look at the energy efficiency of electric rickshaw vis-à-vis petrol-engine-powered autorickshaws. From power-plant to traction-energy point of view ELECSHA consumes 110 Wh/passenger-km as compared to 175 Wh/passenger-km consumed by petrol autorickshaws. In this calculation we used the following assumptions.

ELECSHA

- The efficiency of electric power plants including transmission and distribution losses = 0.255;
- Charging/discharging efficiency of batteries = 0.64; and
- The Elecsha takes two passengers and travels 80 km per charge.

Petrol autorickshaw

- Average mileage = 25 km/l of petrol
- Calorific value of petrol 8.74 kWh/l

Thus if the ELECSHA uses batteries charged from fossil-fuel power stations, it would use 60% less petroleum energy than a petrol autorickshaw. Besides being environmentally-friendly ELECSHA is also very energy-efficient. We also feel that small systems like rickshaws are most suited for electric-vehicle development. This is because the present level of battery technology precludes large power outputs from lightweight batteries. Hence, the electric rickshaw can be easily designed with existing motor and battery technology.

Policy issues

There is need for a policy decision by governments of developing countries to permit only improved cycle rickshaws and electric rickshaws in congested areas of inner cities. This

TABLE 1. Specifications of the NARI ELECSHA™

Payload	180 kg
Gross vehicle weight	230 kg
Range	60–80 km (for 60%–80% depth of discharge)
Top speed	30 km/h
Battery type	Exide Automotive Battery
Battery weight	96 kg for 3 batteries
Battery capacity	100 Ah
Battery specific power	7.95 W/kg
Battery energy density	39.7 Wh/kg
Battery pack voltage	36 V (Nominal)
Cycle life and self discharge	150–200-cycle for battery at 60% discharge depth
Charger	36-V 10-A standard Indian make, running from wall plug
Charge time	10–12 h
Motor	1.2-kW PMDC, Indian make
Transmission	belt pulley/sprocket with 6:1 ratio
Controller	Indian make, high-frequency, micro-processor-based MOSFET controller
Frame/body type	Rolled-steel-angle construction
Frame/body material	Mild steel
Length/width/height	2390/1050/1330 mm
Ground clearance/turning radius	200 mm/2.3 m
Maximum gradeability	6–10%
Tires	Regular two-wheeler tyres
Wheel	Regular two-wheeler wheels
Brakes	Hub braking (both front and back wheels)

will help reduce pollution, provide a clean sustainable transport system and provide employment. Already courts have banned three-wheeled diesel "tempos" from certain parts of Lucknow. Electric and improved rickshaws could provide an attractive alternative to help the "clean air" movement. There is also a need for the government to enact legislation such that banks could provide lower-interest loans to the rickshaw owners. Since this is a renewable energy system, it should get all the benefits presently available to such systems in other areas. Besides creating a non-polluting transport system in India, electric rickshaws would also provide dignity to rickshaw pullers. Presently rickshaw pullers are treated as belonging to the lowest rung of society. Many rickshaw pullers told us that a motorized rickshaw would give them dignity. It is felt that the police and the people in general treat the drivers of motorized transport with slightly more respect. Besides giving dignity, electric rickshaws could also provide extra income to the rickshaw puller since he can ply his rickshaw to greater distances in one day.

CONCLUSIONS

In developing countries most of the cities are very congested with narrow roads that for historical and political reasons cannot be broadened. For such roads non-polluting vehicles like those described could provide a very attractive transport system. With enlightened government policies allowing only such vehicles in these areas, the cities of developing countries could become pollution-free and livable.

ACKNOWLEDGEMENT

Grants from E&Co, New Jersey and Ministry of Non-conventional Energy Sources, New Delhi are gratefully acknowledged.

By the time this issue of Human Power is mailed, this paper will have been published in the proceedings of "International Symposium on Automotive Electronics and Alternative Energy Vehicles" to be held in I.I.T. Kanpur from 19-21 November 1999. Anil K. Rajvanshi is a mechanical engineer. He earned his B.Tech. and M.Tech. from I.I.T.Kanpur in India and his Ph.D. from University of Florida, Gainesville, USA. He is the director of Nimbkar Agricultural Research Institute (NARI), a non-profit organization. NARI does R&D in renewable energy and agriculture.

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Is the .deciMach Prize attainable?

by Michael Eliasohn

In 1986, Fred Markham pedaled the Easy Racer Gold Rush to 65.5 mph (105.4 kph) to win the DuPont Prize of more than $18,000 for the first human-powered vehicle to exceed 65 mph. In 1992, Chris Huber pedaled the Cheetah 68.7 mph (110.6 kph) to break Markham's mark. There was no monetary prize, but being on the cover of *Popular Science* may have been compensation.

The new barrier for straight-line speed is 75 mph (120.7 kph). It's the barrier established by the .deciMach Prize for Human Powered Speed, the prize being $21,000 plus interest to the first rider/team to exceed that speed, which is approximately one-tenth of the speed of sound. There's no deadline for winning the prize. (Contributors to the prize are Garrie L. Hill, 10 shares; the HPVA, five shares, and one share each from the Indiana chapter of the HPVA, Easy Racers, Inc., and Rob Hitchcock.)

The speed has to be attained over a distance of 200 meters on a course "flat to within 2/3 of 1 percent," to quote from the rules. Making the task more difficult are some of the requirements: Attempts (scheduled annually) must be made at a course specified by the prize committee and the altitude cannot be more than 700 meters (2,297 feet) above sea level.

.deciMach Prize organizer Garrie Hill, a long-time HPV builder/racer and HPV race organizer from Granville, Ohio, points out one change has been

see next page

made from the original rules, which specified "all vehicles must demonstrate the ability to self-start and stop without assistance." So-called unlimited vehicles, which need outside assistance for starting and stopping, are now permitted. However, if the winning .deciMach prize vehicle has self-starting/stopping abilities, there is a premium (amount to be determined) that will be added to the $21,000 prize. Hill said the maximum 700 meters altitude was selected because that's the average elevation above sea level worldwide. He said "people bitched" about the high altitude allowable for earlier speed-record attempts. Both Markham and Huber made their record runs at altitudes of at least 7,700 feet (2,347 meters) to take advantage of the thinner air at that altitude.

Does Garrie Hill think it's possible for an HPV to go 75 mph? "A lot of people feel it's possible, but not probably with anything that exists today," he said during the North American HPV Speed Championships in Sparta, Wisconsin, in August 1999. Hill said before establishing the prize, he talked to some aerodynamicists and physiologists who thought 75 mph is attainable.

"I think what will happen is someone will build something from scratch, maybe with a breakthrough in air-flow control," he said in talking about what it will take to win the .deciMach prize. The only two vehicles in Sparta with a history of high speed were the Varnas raced by Sam Whittingham and Paul Buttemer. The front-wheel-drive mostly carbon-fiber Varnas were built by George Georgiev of Gabriola Island, British Columbia. He has built four so far, each slightly different.

At the International Human Powered Speed Championships in 1996 near Las Vegas, California, on a course with too steep a slope to be legal, Whittingham pedaled through the 200 meters to a speed of 73.3 mph (118.0 kph), with Buttemer second at 71.0 mph (114.3 kph). The fastest legal speed done by Whittingham was 63.8 mph (102.6 kph) to win the Colorado Speed Challenge in 1993. But that was done at high altitude. In July 1998, he set the IHPVA 200-meter low-altitude record (below 700 meters) at 62.2 mph (100.1 kph).

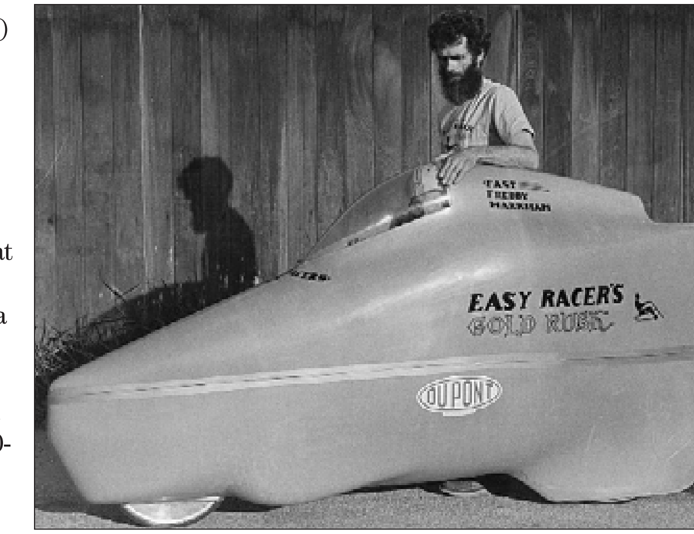

Figure 1. Gardner Martin and "Fast Freddy" Markham with the Gold Rush that won the DuPont Prize. —Courtesy G. Martin

Buttemer's response to the question of whether 75 mph is atttainable was that he feels it's possible, but only with a top athlete riding the best vehicles available today, on an ideal course (10-kilometer run-up and 2/3 percent downgrade) with ideal weather conditions (hot, dry and low barometric pressure). Huber had a run-up of about 2.5 miles to set the present record, according to Whittingham. Markham needed 1.8 miles to get up to 65 mph.

Buttemer said the idea of the super-long run-up (6.2 miles) is to get up to cruising speed without working at full power, then to sprint up to the maximum speed. The Varna riders said that a big oval track would do; the long run-up doesn't have to be in a straight line.

Gardner Martin, builder of the first HPV to go 65 mph, also stressed the importance of having the proper course and conditions. For starters, find a course as close to the 700-meter maximum elevation as possible. Next find the maximum downward slope of 2/3rds of one percent. He suggested one of the big oval test tracks used by the auto companies in Arizona might do and somewhere along its length would be 200 meters with the allowable downward slope. Next, have the runs on a suitably hot day, since air gets thinner when it's hotter. "As any aviator knows, it's harder to take off on a hot day," Martin said. For instance, a temperature of 95 degrees F may mean a 2,000-foot elevation (about 700 m) would be the equivalent of racing at 4,000–5,000 feet. But, he cautioned, it can't be "so hot it cooks the rider."

As for the long run-up that Whittingham and Buttemer feel is necessary, Martin said as much as three miles may be necessary, but stressed some riders might need more, some less. "Different athletes like to work differently." Buttemer said the run-up issue doesn't depend on just the rider: it also depends on the position that the rider is in. The Gold Rush position (seat higher than the bottom bracket) is much better for acceleration than the Varna position (seat lower than the bottom bracket), meaning that someone riding Gold Rush would require less of a run-up than the same person riding a Varna.

Martin said he feels the key to going 75 mph may be in the .deciMach rule that says, "Vehicles may be of either single- or multiple-rider design." He suggested that it may be possible for an HPV to go that fast without a design breakthrough simply by using more than one rider.

Martin used the 1993 Colorado Speed Challenge to make his point. Whittingham had the top speed of the meet, 63.8 mph (102.7 kph; over 200 meters), with Markham in the Gold Rush second at 63.5 mph. But those riders teamed to propel the Double Gold Rush to 65.0 mph (104.6 kph). "It's quite obvious the Double Gold Rush is faster than the single Gold Rush," Martin said. It's not fast enough to go 75 mph, however, even under the right conditions. "I don't have a vehicle currently that can do 75 mph," Martin said.

However, at the fourth International HPV Symposium in August 1992, he suggested a design for such a vehicle. The front rider, flat on his back, pow-

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