PROCEEDINGS OF THE THIRD EUROPEAN SEMINAR ON

VELOMOBILE DESIGN

ROSKILDE TECHNICAL SCHOOL
AUGUST 5TH 1998

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The First European Seminar on Velomobile Design
took place in Lyngby, Denmark, July 1993.
Proceedings were published by the Danish Cyclist Federation.

The Second European Seminar on Velomobiles/HPV
took place in Laupen, Switzerland, August 1994.
Proceedings were published by Future Bike CH.

The Third European Seminar on Velomobile Design
took place in Roskilde, Denmark, August 1998.
Proceedings are published by Velomobile Forum.

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I S B N 87-987188-0-0

Third European Seminar on Velomobile Design

The future of "green transport" is of great concern to rational planners and politicians, who want to find better solutions to the many environmental problems caused by the extreme popularity of the automobile.

The velomobile is one alternative. It has, as concept, attracted increasing attention through the last 10 - 15 years. It is important to encourage and support further development of practical velomobiles and other human powered vehicles.

Therefore, the Third European Seminar is sponsored by *The Green Fond*, Danish Ministry for the Environment.

It is a true international event, where visions and practical design solutions from three continents meet.

Let it be an inspiration for designers and users of human powered vehicles and a challenge to those who think, that it is impossible to live without a motor car.

July 1998, Carl Georg Rasmussen

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Who is who in this volume?

The author Anders BRAGE was born in 1946, and holds a masters degree in material science and engineering and is a IHPVA member. A daily work with composite material research, for The National Defence Research Establishment in Stockholm Sweden, inspired to his HPV implementation of knowledge earned, from light weight structures and problem solving in general. The IHPVA periodicals and the e-mail "trikes-list" meeting has been a great inspiration. e-mail: abrage@sto.foa.se

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Vytautas Dovydėnas, Doctor of Technical Sciences, biotransport constructor from 1976. Published the first book on Velomobiles in Lithuanian 1979.
The book VELOMOBILES was published in St. Petersburg in 1986 and in Berlin 1990. Published also about 200 articles in Lithuanian, Russian and English.

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is Chemist and working on material science. He constructed the "Aeolos" velomobile and has passed more than 30000 km in everyday riding conditions. To compare different HPV's, he made up a practical vehicle test. His latest project is a fully faired tricycle that can be converted into a two-wheeler.

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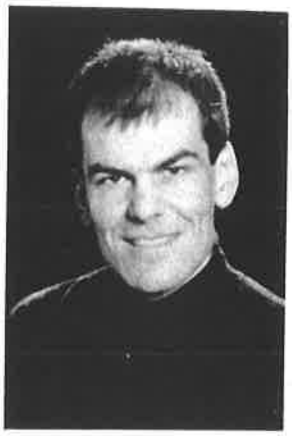

Andreas Fuchs, Brienz, Switzerland 1963. Ph. D. in climate physics. Reviewer of Future Bike CH. R & D in the field of velomobiles and all-seasons all-weather human power electro hybride vehicles.
Most important result: The first working electrical human power transmission (electrical design by Jürg Blatter).

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Harald John has executed the described experiments in his diploma thesis with Stefans instructions. He is now working at his Ph.D following the question how to design products for easy recycling.

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After spending a few years in designing aids and appliances for disabled people in New Zealand, Dr Nayak joined the Faculty of Medicine at the University of Birmingham as a Lecturer in Bioengineering.

During his stay with the Department of Geriatric Medicine he designed and developed a measurement laboratory to assess disturbances of gait and balance in the elderly.

Further research work among the elderly has led to the establishment of the Centre for Applied Gerontology at the University of Birmingham. Dr Nayak was one of the founder members of the Centre and as Director he is responsible for all research and academic activities of the Centre.

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Roger Newport's background is in product design practice and overseas development in design, before teaching design theory, history and practice. Roger heads a Faculty research group in Design for Manufacture and has also advised on new product development in India, Taiwan and Jamaica.

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Military Pilot

Fixed wing single and multi engine, including single seat supersonic a/c, helicopter single and multi engine, single rotor and tandem rotor consultant to the following:

Edward Flight Test Center, computer modeling for a/c systems
Hughes Helicopters, flight test procedures and rotor dynamics
NASA Ames, avionics development for low alt helo flight

Advised the 8 year effort that resulted in the successful hover of the human powered helicopter, da Vinci III

Teach a university level bike design course ME 441. Based upon handling qualities rather than hands free stability.

Currently writing the *"Being the Chronicles of the Lords of the Chainring"* Technical advise for bike and motorcycle designers.

Dian and Bill Patterson on their 2 wheel drive tandem WYMS.
photo courtesy of Gunner Fehlau

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John Snyder is an artist, writer and cyclist. He is currently holds colleague status in the National Sculpture Society and is a member of the International Human Powered Vehicle Association.

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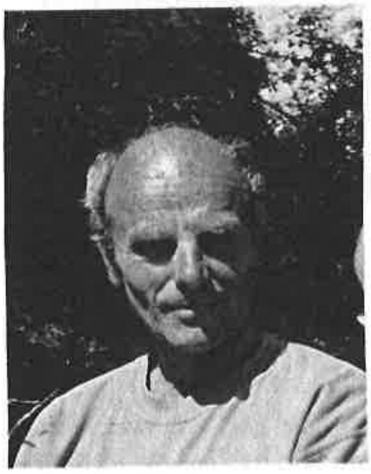

Werner Stiffel is a popular recumbent designer. He is publishing his constructions as plans and is author of some small booklets about recumbent building and design. Werner Stiffel was one of the first constructors who built fully suspended recumbents with a long suspension range

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has been teaching engineering and turbomachinery design at MIT and has been supervising research in design and in power and propulsion projects. In 1967 he offered a prize for developments in human powered transportation. Resulting was "Bicycling Science", co-authored by Frank Whitt, and a series of recumbent bicycles. He is former president of the IHPVA and editor of "Human Power".
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BIOTRANSPORT AND "GREEN TOWNS" OF EUROPE

by V. Dovydėnas

A man travelling by car uses the same quantity of energy as an elephant or even a whale. No wonder that towns degrade using such irrational transport.

Biotransport and its system of paths the main of which are the streets of secondary traffic, solve a lot of urban traffic problems.

European Union could be a new effective initiator of biotransport.

The greatest problem of urban transport is traffic jams.In European towns it will be soon necessary to build highways like in Japan, Bangkok or New York. It will finally destroy the charm of old European towns and cost a lot of money. The environment of towns will entirely degrade.

Paris, London, Athens, Rome which pretend to certain centres of world civilization did not make any progress in the field of urban transport, rather on the contrary. But reliable ideas come from Copenhagen, Amsterdam,biotransport constructors of Germany and other countries.

And what's the news in Eastern Europe got free of the ruined empire? (Really these countries are in Central Europe, because the geographical centre of Europe is 20 kilometres from Vilnius and time in Lithuania is the same as in Paris). A stream of old, but from the local point of view very good cars flew here because they are rather cheap: 2-3 thousand of dollars for "Mercedes" or "AUDI" and they are almost tax free. The price of petrol is twice lower than that in Western Europe. Our streets now are overcrowded by cars and there are lots of traffic jams.

Some years ago we prepared the draft law of biotransport to the order of Lithuanian Ministry of Transport. But now in the ocean of cars it is forgotten and lies in the drawers of this ministry, But nobody can deny the advantages of biotransport comparing it with old-fashioned automobile transport. During the last fifty years the use of automobile fuel did not practically decrease, but the average speed in towns decreased several times. Thus the travel by car in a town leads to nowhere.

During the last twenty years a lot of articles in the world press and several books about biotransport have been published. It is interesting to note that they were met with enthusiasm and without opposition. It was only doubtful as to the lazy nature of a man and the inertia of thinking. These doubts are real. But the parliaments, governments and institutes of local administration must take great blame upon themselves. Without infrastructure a cyclist is a pariah. The efforts of a country and a town are needed. The advertising of cars fascinates everybody. Like tobacco advertisement it perhaps should be limited. Governments should popularize biotransport instead.

What is a town with biotransport?

It is - a town without traffic jams,

- a town in which it is not necessary to allot time for travel, because it is the time to avoid a hypodynamic disease,

- a town without noise and polluted air, degraded and dehumanized environment. It is easy to imagine that now towns are not living places for people, but for four-wheeled creatures,
- a town in which a traffic problem is solved by means of present highways and biotransport is hundred times cheaper than automobile transport and is the most economical known way of travel.

It is clear that there is no scientific alternative of such town in near future. Therefore, we never met any scientific opponents because to oppose such truths would be some kind of a scientic suicide.

Practically used versions of bicycle tracks of Denmark and Holland could be, in our opinion, modernized and put into practice in all Europe. It is strange that in countries with especially good climate for bicycles such as Portugal, Spain and France they are almost not used.

What modernization do we mean?

In order to avoid the neighbourhood of cars we suggest to make secondary streets as the main streets for biotransport (together with the paths of parks, riverside and sauares). Then a cyclist will be able to rest the most part of travel (recreational paths). Cars could pass here only at low speed and near distance. Such reorganization of a town would cost not much and there would be no need to build new overpasses. Town authorities should only look after the paths and clean snow from them.

What vehicles should be considered perspective? Of course for ten or even twenty years a bicycle remains the main means. It is like the violin of Stradivari having attained the gratest perfection. But a violin cannot be called an absolute musical instrument. It is possible to create other and better in their own way. A velomobile without any doubt is better for long travels. It is more comfortable, safer (especially on slippery roads) and good in any weather what is perhaps the most important.

In our opinion the simplest velomobiles are the most perspective ones. They are two-wheelers with a front screen which increases the average speed about 20%. They do not fear side wind and the screen can be used as a sail to speed up the movement. The front screen must be supplemented by an overcoat which protects from rain and snow. Pedaling is a classical movement. But its supplement with an academic rowing movement is very important (or both the movements can be in one vehicle). Movements like meals can be pleasant and various - "gourmet". In mountainous places a silent and clean engine is necessary for moving uphill (10-15 minutes per day). Besides such engine is useful in private life (for grass cutting etc.) therefore it can be very commercial. In richer countries more luxurious versions of velomobiles can be used.

What is the chance for the flourishing of biotransport in Europian towns? Small towns in Northern and middle Europe will accept this transport during 10-20 years. For example, inspite of cheap cars in such Lithuanian town as Panevėžys (one hundred thousand of people) we can see 100-200 bicycles in bicycle parking grounds. In our wonderful health-resort Palanga car traffic greatly decreased (though there are many cars) and the number of bicycles increased. And this happened spontaneously.

The situation is worse in large towns and mountaineous places. It requires long and systematic work.

We think that European Union can be a potential introducer of biotransport. In European towns distances are not large (about 4 kilometres for one travel), climate is good, in some places even ideal. Denmark, Holland and Northern countries could suggest general projects of biotransport for European Union.

Women are more rational and modest than men. They usually like small cars. Biotransport makes a person more attractive and better emphasises a woman's beauty. Besides it is very suitable for children. Threfore I think that women's organizations can help a lot improving such irrational urban transport created by men.

Inspite of rather long time during which we are spreading the ideas of biotransport we remain optimistic. We believe in rational nature of a man and his thinking. Laziness is only a certain form of energy economy created by nature. So **let us continue** this very useful work for the sake of a man improving biotransport, which means the improvement of such a masterpiece as bicycle, and even the improvement of nature, meaning the natural way of transportation.

ISSUES IN PEDICAB DESIGN

By Carl Etnier and John C. Snyder

ABSTRACT

Delta upright tricycles seem to be the predominant pedicab design in Asia, as well as the cycle most commonly marketed as a pedicab in northern countries. Other variations are possible and can offer advantages over the upright delta trike. The authors, both pedicab chauffeurs, explore the tradeoffs they and their colleagues have experienced in using delta upright trikes, tadpole upright trikes, recumbent quadracycles, two-wheel trailers and other types of pedicabs. Design requirements common to all types of pedicab are also proposed. Issues considered include the comfort and safety of both chauffeurs and passengers, speed, and convenience.

Introduction

"Meet the future," says Paul Newman, with a gallant wave towards a shiny new bicycle of the late 1800s. In the 1969 western film, *Butch Cassidy and the Sundance Kid*, the safety bicycle is immediately put to use as an early pedicab. With a jaunty derby upon his head and his lady love perched on the handlebars, Butch speeds around a farm yard. At the completion of the ride, the sweet lady, Sundance's girlfriend, hugs the bicycling hero, after giving him a bite of a fresh, dew-drenched apple.

This fictional spin around the barnyard contains the four elements we use to define pedicabbing:

- a human powered vehicle,
- a chauffeur who provides the motive force,
- a happy passenger, and
- payment.

An interesting bit of movie trivia related to this particular "pedicab:" from frame to frame, the bicycle gains and loses a set of foot pegs—surely intended to be inconspicuous—at the front axle. Actress Katherine Ross took her early morning ride on a vehicle specially modified for the comfort of a passive passenger.

The time this whimsical Hollywood invention was set in was synchronous with the ascent of more seriously designed pedicabs, plying the streets in search of a greater monetary payoff than a bit of apple and a hug. This paper will explore the design of the vehicles used in pedicabbing, with comments on the advantages and disadvantages of various features.

Caveat: much of the information for this paper was gleaned through primarily English language searches of the World Wide Web and correspondence with pedicabbers by electronic mail. Thus, an inevitable bias has been introduced to the following material.

A conceptual evolution of pedicabs

The above four elements of pedicabbing can be found in many vehicles. A vulgar garden wheel barrow, if used to move a passenger who pays a penny for a spin around the haystack, would be a pedicab. A finely-crafted trishaw used exclusively as a privately operated vehicle on an estate to carry bottles of sparkling water to pool-side guests would not be a pedicab. Hire a chauffeur to do the pedaling, while a riding guest sips the beverage, and presto, the vehicle becomes a pedicab limo.

Examples of things closely associated with but distinct from pedicabs include back-pack or bellypack child carriers and child trailers for personal use, as there is no direct payment.

This paper focusses exclusively on land vehicles. Human-powered watercraft also represent a proven and viable means to transport passengers, and they can be pedal driven, but we have chosen not to address that fascinating topic here.

There may exist a long and logical progression of human-powered vehicles used for the transport of passengers. Regardless of the actual chronology and historical influences, this section will present an evolution of designs which steadily improve to lessen the burden for the wallah (i.e., chauffeur) while increasing the comfort of the passenger.

The patron saint of travelers, Christopher, is frequently depicted as carrying the Christ Child upon his shoulders, across a raging river. In his hand is a wooden staff, which helped him balance while crossing the torrent. This staff could be the very first type of pedicab, the most elemental: merely a device which improves the way one person is able to carry another while walking. "Pedi-" means, after all, foot. Another example can be found in the early part of the twentieth century in India, with potentially much earlier roots. It consisted of a small woven basket in which the adult passenger sat with his knees drawn to his chest. This posture placed the load's center of gravity over the walker's feet. Shoulder straps and a staff for balance complete the "vehicle." The addition of the shoulder straps would lessen the fatigue of the wallah's arm muscles compared to when he (most certainly he) attempted to carry a passenger without the assistance of such a tool.

The next stage of pedicab progress would have been to decrease the amount of weight the wallah carried. This is quickly solved by employing teamwork. The litter, also known as sedan chair or palanquin, consists of a passenger chair (which may or may not be enclosed in a cab) with poles for the chauffeurs (Fig. 1). The poles give two or more chauffeurs a means to lift the all-terrain, all-weather vehicle. Sedan chairs are still very much a part of the modern Western world. Charity events in both the UK and Canada stage sedan chair races and competitions as a way to raise funds for non-profit organizations.

Figure 1. A sedan chair sans passenger.

Step three in pedicab evolution could be considered to be wheels attached to a passenger seat (Fig. 2). A handcart gives one individual the ability to pick up and easily move about great weights with little effort. As Ivan Illich proclaimed, the invention of ball bearings ranks up there with the introduction of fire and the wheel as one of humankind's greatest technological accomplishments. Modern, pneumatic bicycle wheels attached to a jinrickshaw represent a profound mixture of physical principles whose simplicity and elegance are much too easily overlooked and discounted as "primitive."

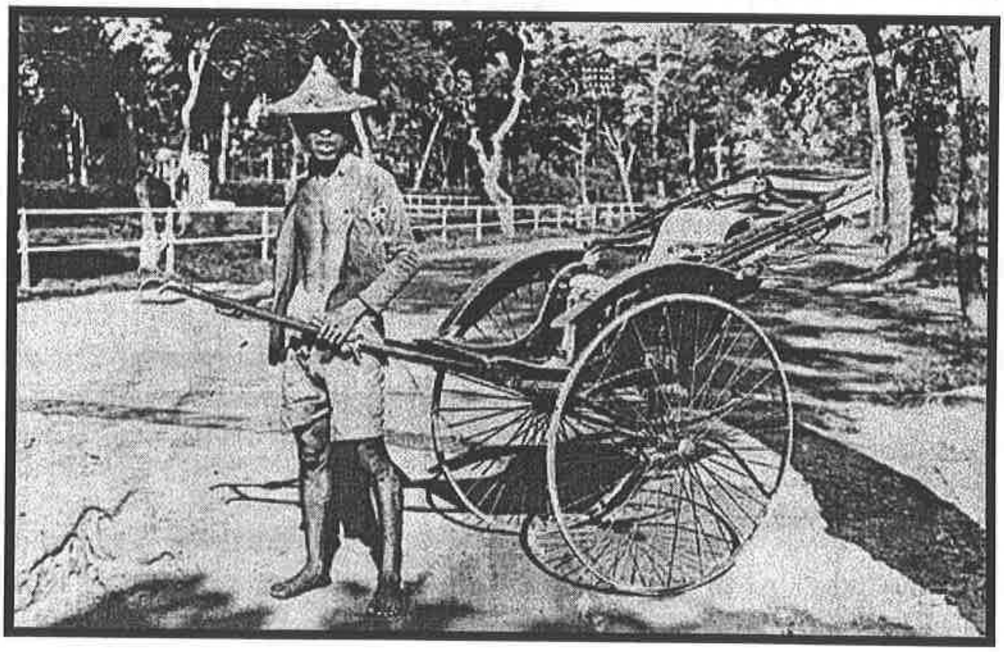


Figure 2. One person and a jinrickshaw can easily do the work of two or more persons and a sedan chair.

Speed multiplying machines increase the velocity of a person's physical effort, such as an hand-operated egg beater or a single-speed bicycle might. Force multiplying machines increase the force of a person's physical effort (at the expense of speed), such as a block and tackle or very low bicycle gears. These two types of simples machines enable a pedicab to do more. Thus the final evolutionary step was for the bicycle to marry the rickshaw, creating a speedy trishaw and other varieties of pedicabs driven with bicycle drive trains (Fig.3). With a good pedicab, one normal human being is able to move half a ton at speeds over 20 km/h—truly an amazing feat when contrasted with the effort of carrying another grown individual in one's arms or on one's back.

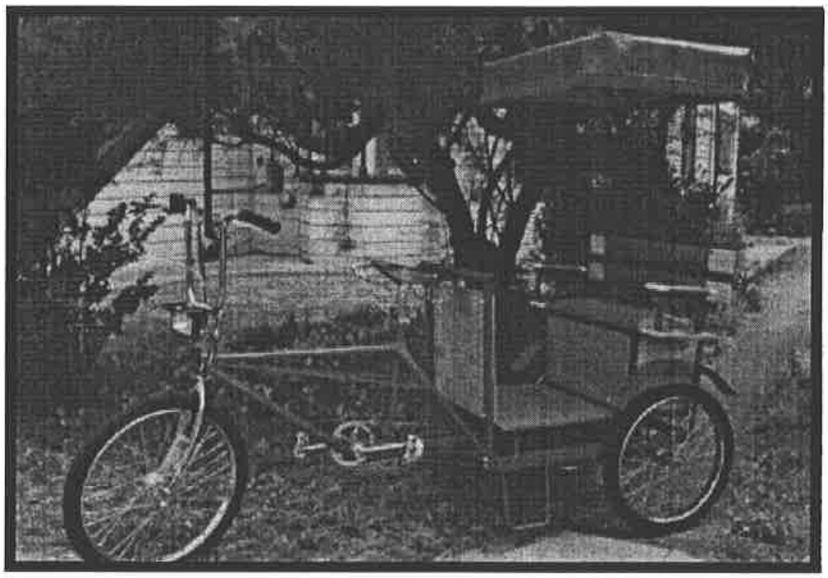


Figure 3. Trishaw made by Rideable Bicycle Replicas, USA. Photo: Rideable Bicycle Replicas.

The design parameters presented here are the product of our experiences in pedicabbing in Europe and North America, as well as our conversations with colleagues on the same continents. While many or most of our comments are probably also valid for pedicabs in less developed countries, they are primarily intended to cover the needs of pedicabbers in more affluent, industrialized countries.

How pedicabs are used

Form follows function, as the old saw goes. Pedicabs can provide unique services, but they are also subject to limitations. In selecting or designing a pedicab, it is helpful to consider some of the following observations common to successful pedicab operations.

Some services are unique to pedicabs. Pedicabs can

- blend with crowds of pedestrians,
- operate profitably over short distances,
- operate in places were motorized transport is banned or impractical,
- provide an environmentally friendly alternative to walking,

• provide a novel experience (the uniqueness of this service has to be experienced to be understood!),
• combine entertainment and practical transport, and
• provide convenient local transportation while promoting a community's traffic calming goals.

Among pedicabs' limitations, they cannot
• easily meld in narrow, non-calmed lanes for motorized traffic,
• operate in bad weather without either special design or discomfort for the chauffeur and/or passengers,
• easily operate in hilly conditions, and
• readily provide comfortable, long-distance travel.

While pedicabs are sometimes used as practical substitutes for motor vehicles or as rapid passenger transportation where motor vehicles cannot travel, the great majority of pedicab income comes from passengers attracted by the vehicle's novel appearance and the unique experience of being pedalled in an open cab. The pedicab's visual presence is also used to provide "color" to a festive event such as wedding, birthday party, or business convention.

Advertising signs make use of the pedicab's public presence and unique appearance. This aspect can bring in as much revenue as rides themselves.

In many pedicab operations, the pedicab is rented out to chauffeurs for either a fixed fee or a percentage of the shift's gross earnings. These chauffeurs can be hard on the pedicabs, as they are not responsible for maintenance of the machines and did not spend money to acquire them. Also, the same vehicle may be used by a large number of different chauffeurs.

Desiderata for pedicabs

While we consider many different types of human-powered passenger transport in this paper, we have the most experience with trishaws and quadracycles. These desiderata apply to those types of pedal-driven pedicabs.

Safety

Above all, any pedicab must be safe. This means the vehicle must be sturdily constructed to withstand both the rigors of normal use and occasional extraordinary loads. People sometimes crowd onto pedicabs in numbers and compactness normally associated with Tokyo subways at rush hour or stunts involving telephone booths in the 1970s. The vehicle must have good reliable brakes, including a parking brake. Bright lights are essential if the pedicab is operated at night, and many are. Turn signals are not necessary—the chauffeur's or a passenger's arm can provide that function—but can be a whimsical extra touch and can free up the chauffeur's hands in difficult steering situations. A bell or horn, the pedicabber's audible signature, warns pedestrians of the approach of the cab, and can help attract passengers. The passengers also need some form of restrain to help them stay in the cab, such as convenient foot rests, arm rests, and/or seat belts.

Comfort

Spending up to twelve hours a shift, with long work weeks, a commercial pedicabber has comfort as a prime concern. And a passenger who spends money for a pedicab ride has the right to expect a highly comfortable ride in return.

For both the chauffeur and the passengers' comfort, a good suspension is needed. This might be as simple as providing thick foam cushions and wide, low-pressure pneumatic tires. Depending on where and when the cab operates, some form of environmental protection may be called for. Most frequently this means installing a sunshade/rain roof, though some commercial pedicab manufacturers have recently experimented with partially enclosed passenger cabs to provide a rain cover.

The passengers need a place to sit, a place to grab (arm rests), and a place to put their feet. It is not unusual that passengers will use another passenger for at least the first two functions, sitting on a friend's lap and hanging on to whatever human limb or part of the pedicab is most convenient. The pedicab should allow ample room for double layers of passengers.

For the pedicab chauffeur, a comfortable seat is of prime importance. For trishaws, large spring-mounted cruiser seats can be rather comfortable over the course of many hours. For recumbent pedicabs, the chauffeur's seat must have a firm back, so that his or her force on the pedals drives the vehicle forward instead of compressing the foam back.

An important part of the chauffeur's comfort (and health) is to ensure the vehicle has low gearing. In India, we have heard that the use of exceptionally heavy single-speed cycle rickshaws has been blamed for causing enlarged hearts, which lead to the premature death of wallahs by the age of 35. With the weight of a pedicab and its passengers, small inclines can become daunting grades. One of us (Etnier) operates with gears as low as 10 gear inches (0.80 m development) and frequently uses the lowest gear.

The more eye-catching a pedicab is, the more likely the operation is to succeed. Any sort of pedicab has a characteristic, exotic appearance, and this helps to attract customers. A well-maintained, brightly colored vehicle will inspire more confidence and interest in sometimes hesitant passengers.

The chauffeur is an integral part of the pedicab service. The more professional his or her appearance and demeanor, the better. The chauffeur's uniform is as much a part of the vehicle as the paint on the frame. Distinctive and/or whimsical dress, like a tuxedo combined with bicycling tights or 1890s fashion and a derby hat, sends the message that the chauffeur is someone who both enjoys the work and takes it seriously.

A pedicab should also have space available for advertising signs. For many pedicab companies, the sale of public advertising can generate a significant portion of the operation's income, and even totally finance the purchase and maintenance of the vehicle.

Speed

Speed is of varying importance to a pedicab operation. As pedicabs frequently are used as an alternative to walking, the cab's velocity need not be overly high to be valuable to the customer. Indeed, much of the time the vehicle will be operated at considerably less than the top speed physically possible—while blending with crowds of pedestrians, while providing a couple cuddling with a romantic tour past fountains and flower gardens, or while "trolling" for passengers with an empty cab.

The subjective sense of speed can, however, be an important part of the joy of riding in a pedicab for thrill-seeking passengers. "Racing" along at a clip of 10-20 km/h often elicits squeals of (nervous) delight from passengers, especially when cornering. The excitement seems to have an appeal similar to that of a roller coaster. Speeds much higher than 20 km/h may be too dangerous, since a sudden stop could injure the passengers, who usually have no seat belt.

Speed is also important when transporting passengers to a specific destination rather than merely riding for the pleasure of touring in a pedicab. Most pedicab operations negotiate the fare with each group of passengers, basing it on the distance travelled and amount of work required, i.e. amount of uphill. In this case, the faster the passengers can be transported, the greater the potential hourly earnings.

There is also a potential pragmatic lower speed limit. If the pedicab operates below walking speed, fewer customers may elect to utilize or benefit from the service. Determining how fast to travel is very much a part of the artistry and responsibility of the chauffeur.

Necessary for speed are stable steering, reasonably high gears, and (except downhill) light construction. The importance of robustness is so great in relationship to speed, however, that weight should never be saved at the expense of solidity.

Advantages and disadvantages of today's pedicab designs

At least eight distinct pedicab types are currently in use around the world: sedan chairs, rolling chairs (and kick sleds), jinrickshaws, passenger trailers, sidecars, delta trikes, tadpole trikes, and quadracycles. (Other multiple-passenger HPV designs such as a tandem bicycle are not included in this listing, as we believe it is unwise to offer rides for hire aboard a vehicle whose safe operation depends in part on the passenger's cycling skills or active cooperation.) This list is not intended to quantitatively define nor limit the reader's imagination. It is our intent merely to suggest the cornucopia of design approaches that exist.

1) Sedan chairs

The easiest to construct and physically most difficult to operate pedicab would be the two poles attached to a chair. The sedan chair is also known as a litter or a palanquin. It requires a least two wallahs on foot per passenger to operate, hence its income generating potential is severely limited. Its speed is confined to that of a brisk trot.

In the sedan chair's favor, it can be operated over any type of road condition, including mud, rocks, plowed fields, stairways, carpet, et cetera. With the addition of an enclosed cab, it can transport the passenger in comfort in any weather. Appearance, suitable material, and design options are virtually unlimited. Obviously, light weight is desirable.

There are no known commercial manufacturers.

Though the most frequent modern use of this type of pedicab is as a part of charity events, as mentioned previously, concerns such as a hotel or theme restaurant may use a sedan chair to transport guests over exceedingly short distances as a form of entertainment.

While we do not have any experience with a sedan chair, we can speculate about its pros and cons. The advantages are:

• no moving parts, thus simple and inexpensive construction and minimal maintenance,
• may be operated in nearly any setting where it is possible to walk,
• provides a comfortable ride and conveys a universally recognized honor to the passenger in a way no other conveyance can, and
• tips could be good if the chair does not tip.

Disadvantages:

• extremely low speed,
• requires at least two operators to operate the vehicle,
• the maximum load is relatively small,
• limited income potential,
• very difficult to operate for persons not gifted with great physical strength, and
• potential for lifting-related injury is high.

2) Rolling chairs and kick sleds

As found in Atlantic City, the traditional rolling chair consists of a forward tricycle wheel arrangement (small wheels, almost the size of those on shopping carts, with the forward wheel on a caster), a padded seat large enough for three adults to sit side by side, a sunshade, and a handle for the chauffeur to push the vehicle at a brisk pace (Fig. 4).

The rolling chair provides passengers an alternative to walking moderate distances on extremely level and smooth ground.

As with the sedan chair, there are no known commercial manufacturers.

Figure 4. Rolling chair tour of the boardwalk.

A closely related passenger vehicle, the traditional Scandinavian kick sled, also deserves mention here. Kick sleds look like small dog sleds and may be used as such. Kick sleds have a single, forward-facing passenger seat. Sleigh-like runners extending from the back of the sled serve as a platform to stand on. The vehicle's operator runs while pushing, then jumps onto the runners to "catch a free ride"—very similar to the operation of a skate board. The only commercial use we are aware of is as a rental vehicle in a very few winter resorts. Commercially constructed kick sleds are available from outfitters who deal in mushing supplies.

Dry-land versions of the kick sled replace the runners with wheels, creating a potentially high-speed rolling chair. Safe steering and braking represent issues which would need to be addressed before using the vehicle for passenger transport.

Other than very limited experience with a kick sled, we have no experience here, either. We offer the following conjectures: Compared to the sedan chair, the rolling chairs are a significant improvement. One operator of moderate strength can transport several passengers. They have a distinctive appearance and minimal maintenance requirements. Rolling chairs' income potential is proven when they are used for short distance touring. The slow speed and the operator's "hidden" position (behind the passenger) can give an enchanting, magic carpet sense to the trip.

The disadvantages of the rolling chair are that its appeal is highly dependent on suitably scenic routes, and it requires a smooth, level surface.

3) Jinrickshaws

"Jinrickshaw " is Japanese for "human-powered vehicle." As the chauffeur can pull and has an unobstructed view of traffic, a jinrickshaw can operate faster and over more varied routes than its cousin, the rolling chair. Jinrickshaws resemble a lighter and smaller version of a horse-drawn gig or cabriolet, a type of two-wheeled cart which enjoyed wide popularity in the latter part of the nineteenth and early part of the twentieth century.

Though there has been a wide variety of designs involving rickshaws over the years, bicycle wheels, especially those with hubs containing ball-bearings, seem to be one of the more significant improvements. A jinrickshaw consist at a minimum of a passenger chair, two wheels, a pair of poles for the runner, and a set of rear-mounted "legs," like immobile kick stands, which prevent the passengers from doing a backwards somersault when the chauffeur is not holding onto the loaded vehicle. Traditionally the passenger seat has been mounted on leaf springs, although with modern paved roads in urban areas, this weight-increasing addition has been becoming less common.

Sunshades for the passenger, though not necessary, add to the charm of the vehicle.

There are several commercial manufactures of jinrickshaws in Canada and the United States.

Figure 5. Full speed ahead on a jinrickshaw.

Once more, our lack of experience with these vehicles will not prevent us from boldly venturing a guess at their properties. Advantages:

• moderate cost and minimal maintenance,
• allows the operator to transport many times his or her weight,
• distinctive appearance,

• may be acceptable for use in areas which ban pedal-driven pedicabs,
• easy to operate, and
• proven high income potential.

Jinrickshaw disadvantages:
• only moderate speed,
• requires significant upper body and leg strength to operate,
• lack of brakes in traditional designs may represent a safety concern on very hilly routes, and
• short effective range.

4) Bicycle passenger trailers
Bicycling writer Wade Nelson informs us that passenger bicycle trailers pulled by a chauffeur on a mountain bike were used in a short-lived pedicab operation in Durango, Colorado in the early part of this decade. Another example is provided by Rideable Bicycle Replicas, a California firm which currently produces two passenger trailers designed to be hitched to their tricycle pedicab (Fig. 6), forming a sort of pedicab train.

Figure 6. Pedicab trailer. Photo: Rideable Bicycle Replicas.

One of us (Snyder) has experimented with pedicab trailers and found they require considerable care to control. As any two-wheeled bicycle trailer, they can tip— both an asset and a liability. If attached to the pulling cycle via an articulated hitch, the resulting vehicle leans with camber without forcing the bicycle into an unnatural lean. The chauffeur of the pulling bicycle can also lean naturally while cornering. However, the trailer can overturn if turned too swiftly.

The weight of pedicab passengers puts considerably greater demand on both the bicycle and the trailer than normal trailer cargo operations. Standard bicycle brakes may need to be upgraded for sufficient stopping power while descending steep grades. And when passengers step onto and exit the vehicle, the tongue of the trailer is subjected to forces much greater than passenger weight. Trailer tongues must be built substantially stronger than if a similar weight of inanimate cargo were being carried.

Trailers have great potential, due to their simplicity and handling characteristics. Simply bolting a chair to a heavy-duty bicycle trailer creates a pedicab. When configured with the load's center of gravity as low as possible, and with an articulated hitch attached near the bicycle's rear axle, a passenger trailer has the potential to carry an adult passenger safely and at relatively high pedicabbing speeds.

Passenger trailer advantages:
• same pulling vehicle can be used with or without trailer,
• higher speed, compared to the previously listed vehicles,
• can operate on a wide variety of road geometries (including side hills), and
• moderately easy to construct.

Passenger trailer disadvantages:
• not in widespread use, so may not be instantly recognized as a pedicab,
• the exceptionally long vehicle is more difficult to handle in some traffic conditions,
• unstable if operated without due care,
• passenger and chauffeur are physically separated, and
• less exotic appearance than other pedicabs types if pulled with a common bicycle.

5) Sidecars

Bicycle sidecars enjoyed a very brief popularity during the 1930s in the West. Nowadays one might spot a custom-built sidehack attached to a child's BMX in imitation of motorized cyclecross racers, or in an antique store, but not too many other places outside of Southeast Asia.

People in Indonesia, the Philippines, and other Asian countries built wide-platform sidecars for either carrying large loads or use as pedicabs around the late 1940s and 1950s.This version consists of:
• a passenger seat wide enough for two adult passengers to sit side by side,
• a large and stable base, set off far enough from the cycle for the chauffeur to operate the pedals unhindered,
• frequently a set of curved tubes to form a forward dash, which also serves to connect the front part of the sidecar to the bicycle top and bottom tubes at points immediately behind the headset, and
• a bolted connection to a point on the bicycle's chain stay on or near the rear hub. The sidecar's hub aligns with the rear axle of the bicycle.

Sidecars may be entirely constructed with salvaged materials (such is frequently the case for Cuban sidecars) or finely crafted using state-of-the-art frame building methods, complete with modernistic ripstop nylon tents which fully enclose the passenger area during periods of heavy rain (Philippines).

Figure 7. Sidecar with portable sunshade.

Though there is no known history of multi-passenger sidecar pedicab vehicles in the West, this design has tremendous potential for a wide variety of applications.

We have not used a sidecar, but we speculate that it has the following advantages:

- Low cost and flexibility—as with the bicycle trailer, only part of the vehicle needs to be specially constructed for and "dedicated" to pedicab use. The bicycle can be used as a normal one-person bicycle when not connected to the side car.
- Though it has 3 wheels, it is a dual track vehicle.
- Length is no greater than the donor bicycle, making it one of the shortest options available.
- The appearance has the potential of being pleasant and "traditional."

We asked Ian Sims, a leading tricycle designer who previously designed motorcycle sidecars, how he thought performance of these vehicles might be. He thought they could be at least as good as delta trishaws.

Possible disadvantages of the bicycle *cum* sidecar are:

- a greater width per number of passengers may make it difficult to pass between the posts that block automobiles from cycle and pedestrian areas and to pass easily through crowds, and
- the variety in bicycle frame geometry would present a challenge to mass production efforts.

6) Delta upright trikes

One of us (Etnier) began his pedicab career by renting delta upright pedicabs (Fig. 8). In most such pedicabs, the passengers sit directly behind the chauffeur on a bench wide enough for two or three people and face forward. Some have a bench facing backwards, also, so there is room for four people without anyone sitting on anyone else's lap.

The rear wheels take most of the weight and must be extremely sturdy. The ones we are familiar with have, for example, 40 very thick spokes or 64 normal spokes per wheel. Even the front wheel should be very solid. Four 90 kg passengers and a rather modest curb can be enough to turn a normal mountain bike front wheel into a pretzel.

Figure 8. One author (Etnier) with a rented Chinese pedicab at Oslo Harbor.

The upright position means that the chauffeur can easily see and be seen, even in quite crowded areas. The vehicle is very agile to maneuver, yet can be stable in cornering. Passengers sometimes express their amazement at the pedicab's high-speed (20 km/h) cornering ability by uttering shrill screams.

A disadvantage of the design is its tippiness. When ascending or descending curbs, it is important to make sure that both back wheels go up or down at once. If they do not, it is surprisingly easy to dump passengers.

The so-called "fanny factor" is also a significant consideration for chauffeurs of upright delta trikes. Passengers are afforded an unimpeded view of the musculature on chauffeur's laboring legs and derriere, and have easy access to the latter. While a male chauffeur may enjoy female passengers' vocal admiration of his physique and the occasional goosing, female chauffeurs with male passengers can feel quite vulnerable. One woman who pedicabbed two summers fantasized about lining her shorts with razors to fend off groping and even blows.

7) Tadpole upright trikes

Tadpole upright trikes eliminate the fanny factor by placing the chauffeur behind and above the passengers. The passengers, in turn, get an unimpeded view of the landscape, similar to that while riding a recumbent with under-the-seat steering. One of us (Snyder) has adapted a Worksman industrial tricycle to pedicab operations (Fig, 9).

Figure 9. One of the authors (Snyder) with his tadpole trike pedicab.

This design, with the passenger box and front two wheels attached to the rest of the vehicle via a vertical headset, has extremely sensitive steering. In some places the safest way to negotiate an inclined surface is to get off and push. A road's camber so small as to be nearly unnoticeable on a bicycle can act almost as a barrier to the tadpole. The manufacture recommends that the vehicle not be driven faster than 13 km/h.

Both upright tricycle configurations can be made in a way to allow them to be used either for passengers or for cargo, an important type of flexibility. The same vehicle might be used both for selling ice cream and other items at times and as a pedicab in other parts of town and/or times of day or seasons. The flexibility is also important for purchasers who intend to try pedicabbing in a new market. If the operation does not pan out, the adaptable vehicle can be used for other types of transport or more easily sold.

While the tadpole's twitchy steering and speed limitation makes it less suitable for some pedicab uses than a delta trishaw, price considerations can make the tadpole more attractive. An industrial tadpole tricycle can be had for under US$1000, while delta trishaws sell for US$1900 or more. Furthermore, the unobstructed view for the passengers and the close contact possible between chauffeur and passengers make the vehicle inherently attractive for slow-speed, guided tours. We have found it possible to talk with passengers with the same feeling of intimacy as when standing behind them with a hand on their shoulder.

8) Quadracycles

Add a fourth wheel to a tricycle and you get a lot more stability. One of us (Etnier) now uses a recumbent quadracycle (Fig. 10) made by Quadracycle, Inc. of Indiana, USA. We believe that the quadracycle design represents a real breakthrough in pedicabbing, for a number of reasons.

There is something about the recumbent quadracycle design that excites people—probably because it looks so much like a car, except the chauffeur is pedalling furiously. Imagine this—you are riding a cycle, and cars honk their horns, people roll down their windows and shout things at you, pedestrians yell out, *and every one of these people is cheering you on!* The tricycle pedicab also is met positively by most people, but not with this level of cheering.

The quadracycle is also more stable. It can go up and down almost any curb at almost any angle without risk of tipping.

Quadracycles can be designed for one or more of the passengers to pedal. The one we use has room for a passenger pedalling next to the chauffeur, and a seat for two or more passive passengers in back. With two people pedalling in front and two to four passive passengers in back, it is possible to take more people more places, and faster. It is possible to pile five or more passengers onto a delta rickshaw—Mel Barron of Rideable Bicycle Replicas reports one imprudent chauffeur taking up to nine passengers!—but with this many passengers, they are uncomfortable, and an incline of any grade presents a nearly insurmountable obstacle. With five passengers on a robust quadracycle, including a strong one up front pedalling, the passengers are more comfortable, and many hills are surmountable. Finally, for many passengers, pedalling adds to their fun.

Figure 10. One of the authors (Etnier) with his Quadracycle by the Oslo Harbor.

The low, recumbent position also leaves the chauffeur much less vulnerable to the passengers. With thighs and buttocks screened and protected by the seat back and rather distant from the passengers in the back seat, we never get groped by excited women anymore. While this protection is somewhat of a disappointment for us, it can make pedicabbing much more attractive for female pilots. The car-like position also makes people think less of cooleys or horses, so people almost never make whipping noises and gestures at the chauffeur's back. This harmless but annoying behavior can be common among passengers on delta trishaws.

The bottom line is that we find the quadracycle a lot more fun to drive than the delta trishaw, and it brings in more than 40% more per hour. The increased earnings are probably a combination of three things: 1) A newer, more attractive appearance than the trishaw previously rented, 2) room for a higher number of comfortable passengers, 3) increased speed and range because of the potential extra horsepower of a second person pedalling.

Note that probably the most significant advantages—greater horsepower and room for more passengers—are unique to "tandem sociable" designs like the Quadracycle. Short wheel base designs with limited weight capacity and room for only one person pedalling, like the Brox and the PickUp, do not share these advantages, although their stability is surely superior to that of tricycles.

The chief disadvantage of quadracycles are their large size, relative to trishaws and other pedicabs. Two wedge-shaped trishaws can also be parked in almost the same amount of space as is required for one quadracycle. Long wheel base quadracycles, especially, can also suffer from low clearance in the middle when going over curbs or other obstacles. They should be designed without a middle set of derailleurs or other vulnerable parts halfway between the front and rear wheels.

All currently produced quadracycles we are aware of are recumbent. Upright quadracycles have been produced previously, but we know of no use in pedicab operations. It is also difficult to imagine that they would have significant advantages over the recumbent quadracycle.

Conclusion

For many pedicab operations, profitability is in part a function of the number of passengers who can be carried at once and the speed with which they can be delivered to their destination. For these situations, a tandem sociable quadracycle with room for two people pedalling seems to be an excellent vehicle. Any of the above designs could be optimal in other situations.

The number of pedicab operations in industrialized countries seems to be growing, but there is only a small number of manufacturers. There is room for design improvement, especially in the area of weight. One pedicabber reports trimming a popular commercial trishaw in weight from its standard 73 kg to 45 kg. The Quadracycle, which we are otherwise quite pleased with, weighs in at 90 kg, and trike designer Ian Sims believes it would be possible to construct something similar at half the weight. We hope that the comments in this paper will help guide the development of new designs and improvement of existing ones.

The Everyday Velomobile: Who uses it and who could use it?

Jürgen Eick, Rüsselsheim

Summary

The everyday velomobile: A street-HPV characterized by weather protection, comfortable seat and luggage space. My contribution to this seminar is based on many years of my own experience as an everyday velomobile user, discussions with like-minded friends as well as the analysis of the customer base of a velomobile manufacturer who has been on the market for the last fifteen years. I will examine the chances for a future widespread use in traffic and categorize velomobile buyers with regard to age ranges, job groups, gender and special living conditions. I will investigate several ways of increasing the sales of everyday velomobiles - at least to a level that will allow these manufacturers to happily continue their developments.

Chances for Velomobiles

In February of this year, Ferdinand Piëch, Volkswagen's CEO, announced in the German Magazine „Stern"[1], that his company will soon introduce a twelve cylinder luxury limousine to the market. He also said that, at the same time, they were in the process of developing a four-wheeled vehicle with capacity for one passenger, at a fuel consumption of 1 litre per 100 kilometres.

Using such seemingly contradictory plans, the car industry is trying to prepare us for the total dependency on motorised mobility. There is no doubt in my mind that this double strategy will continue to increase car industry's success on the world market. The wealthy will be served with a luxury limousine and those with less money will buy a car exactly according to their finances.

Our planet's total supply with cars is pre-programmed. Mr Piëch's announcement of a possible decrease in fuel consumption by factor 6 to 7 per person and kilometre will set those car owners' minds at ease who had feared that petrol supplies would be exhausted prematurely, especially after China's automotive armament.

However, even without this prospect of a decrease in consumption held out to us, there is still no hope of an end to the triumphant progress of individual motor vehicle traffic caused by the exhaustion of oil supplies. Fifty years ago, Germany already had large hydrogenation plants to liquefy coal In South Afrika, for instance, this technology has been developed further to a larger extent and only the slightly higher prices keep this hydrogenation fuel away from the market

Hence, at present, there unfortunately does not seem to be hope for a blip in the increase of car use due to a possible lack of resources. Vytas Dovydenas's optimistic vision of the velomobile as an urban transport system[2], which he presented at the first European Velomobile Seminar in 1993, won't come true. At the very best, there will be several „alibi-projects" here and there In some large cities, there might possibly be nil-emission cars only permitted - in form of electric cars. However, with these electric cars, emissions won't be avoided but simply shifted to power stations - unless the impossible happens and photovoltaics will gain ground soon Therefore, my thesis:

> **Although there are numerous, objective advantages of a good velomobile in comparison with the car or the normal bicycle, its everyday use will be limited to the odd individual.**

I would like to dedicate this Contribution to those individuals, who I call the everyday velomobile users. What is it that makes them swim against the tide and neither join the masses of motorists nor those everyday cyclists who lose ground more and more? Is there a way of increasing their number so that velomobile users will at least see one like-minded person per day - just to help keep up their motivation?

The contributions of the first Velomobile Seminar in 1993 in Farum[3] and those of the second in 1994 in Laupen[4] were mainly dedicated to the velomobile itself. The most important subjects of these first seminars were the design and construction, safety issues, comments about the velomobile's past and conjectures about its future, electric drive support and views about the velomobile's chances in today's traffic.

Meanwhile, within the last four years, engineers have continued to develop the velomobile and manufacturers have produced it in small series. Although good quality is available, there was no steep increase in velomobile sales. Why then, in spite of several undoubted advantages compared to the car as well as the bicycle, are so few people using velomobiles? Couldn't the number of sold everyday velomobiles be increased to at least 2000 or 3000 per year in order to give those few manufacturers who were so commited to pushing ahead its development at least enough work to survive?

Although the velomobile has been defined by others[5,6], I would like to state the essential characteristics of an <u>everyday velomobile</u> once more, partly in agreement with those other definitions:

- <u>Muscular drive</u>, also supported by auxiliary engine, but no driving licence required.
- <u>Weather protection by either full or part fairing,</u> which will protect the passenger from wetness and dirt from above and below.
- <u>Comfortable seat,</u> which will facilitate entering and exiting without danger of soiling.
- <u>Luggage space,</u> which will allow for carrying baggage even for longer holidays.

Who uses a velomobile nowadays?

As far as I am informed, there has not yet been a particularly wide survey amongst everyday velomobile users. Therefore, the sources available to me should not be assessed too strictly. I am based on

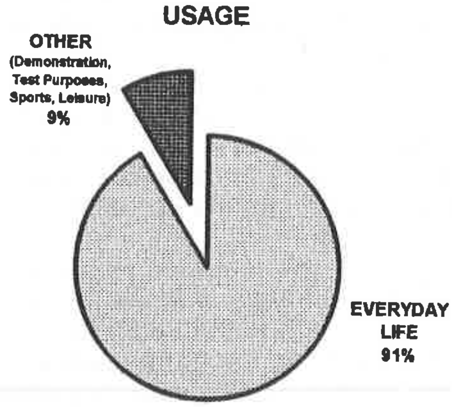
1. my own interviews with everyday velomobile users,
2. asking velomobile producer Mr. C.G. Rasmussen (Leitra) about his own extensive experience and that of his customers,
3. the analysis of a data base of Leitra buyers,
4. my own experience after 9 years of everyday use as well as holidays with the Leitra

Some of you might wonder why there is so much „Leitra". Why be so limited to one brand? Meanwhile, there constantly have been new introductions of the latest models at trade fairs! After the Belgian „Velerique" and the Danish „Hajen", especially the British „Windcheetah", the Dutch „Alleweder" and the Russian „Berkuts" have caused sensations as series products and are likely to have found more buyers than the Leitra.

There are mainly two reasons as to why the Leitra customer seems to be very suitable for a study about the benefits of everyday use. Firstly, the Leitra was intended to be an everyday velobobile right from the beginning and has been developed further in that direction by longterm system improvement. Secondly, its designer and manufacturer, Carl Georg Rasmussen, maintains close contacts with his customers and is very well imformed about their experience. His customer base contains assessable information about 155 customers as well as his own additional information.

Picture 1 shows that the Leitra is mainly bought for everyday use which makes up for 91 %. This shows that everyday use is the most important factor and, at the same time, the aim of developing this vehicle. Naturally, buyers usually in addition want to maintain physical fitness.

The percentage of buyers who exclusively use their velomobile for sports or recreation, as an experiment or for demonstration is comparatively low at 9 %. 11 Leitras, which were bought by bicycle dealers for their customers or themselves to test, already represent part of these 9%.



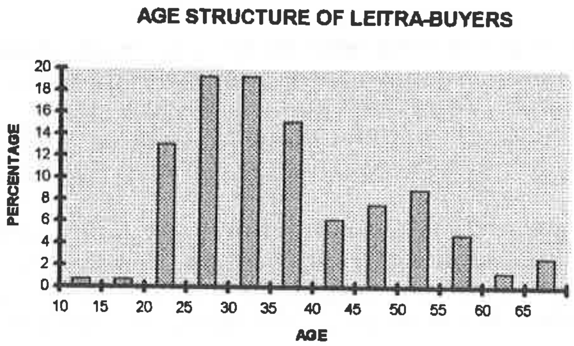
Pict. 1: HOW IS THE LEITRA USED?

Picture 2 shows the age ranges of customers. It is striking that quite a considerable number of buyers seem to fall into the age category between 20 and 25 years. I believe there could be four reasons for this:

- First of all, the buyer has to have considerable financial means at his disposal.
- Secondly, many buyers have spent years considering the advantages that a velomobile may offer compared to a bicycle, before they decide to purchase.
- Thirdly, the buyer's self-confidence has to be quite high which will make him less sensitive to those scornful little remarks often made by pedestrians.
- The fourth reason is that teenagers probably are not too worried about getting cought in a rain shower and getting soaking wet on the way to school or sportsclub. However, an adult on his way to work, wearing clothes for work, will far more appreciate the prospect of arriving there dry, protected by the velomobile, far more.

Thinking about the first reason: The purchase price of a velomobile is comparatively high. The production is carried out only in small or very small series and it requires a lot of manual work. We estimate 150 working hours for a Leitra as an example, but, as the years go by, this manual work becomes more and more expensive. Younger people who might be interested will compare the price for a velomobile with the price they would have to pay for a used car. They will often prefer the latter, as they want to get to their destination for less money and less effort. They also might not yet be aware of the fact that the running costs for a car can soon compensate for the difference in purchase price.

The second reason definitely leads us to age. According to experience, there often is a period of several years between the first interest in a velomobile and the decision to actually buy one. Therefore, a younger person will already have reached the age category of 20 to 25 by the time he decides to buy.



Pict. 2: HOW OLD ARE LEITRA-BUYERS?

With regard to the third reason, most everyday velomobile users know from experience how often especially younger pedestrians will virtually be in stitches with laughter when they see a velomobile. It should be hard to find any youngsters who will be prepared to lay themselves open to this everyday situation in dealings with other youngsters. This reason for the lack of interest in younger people would immediately be dropped if it was suddenly "trendy" to own a velomobile instead of a mountainbike or moped. The tables could be turned if, for instance, the bicycle industry took possession of the idea of the velomobile and started a necessary, expensive advertising campaign to promote the velomobile and, even better, managed to win over the media. In my opinion, however, this is unlikely to happen within the forseeable future.

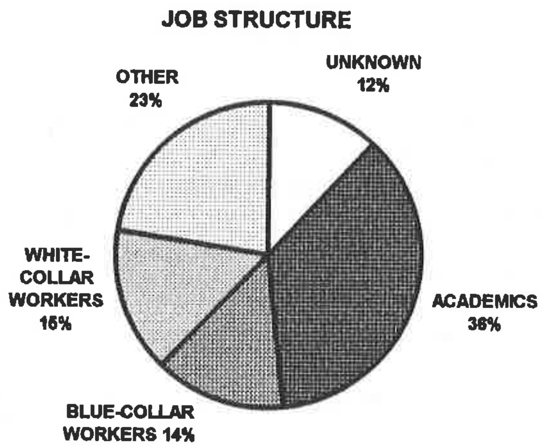
As you can see from **Picture 2**, most Leitra buyers belong within the age range of between 20 and 40. At that age, people usually have the required financial means at their disposal. They have started work, often after completing university. In most cases a family will have been started and people search for an activity as a balance for work. Perhaps the idea to experiment with a special means of transport appeals.

Above that age range clearly less buyers can be found. At the ages between 40 and 45 years, vocational demands are often especially high, so that there is less time to spend on activities that are not directly connected to family and securing the vocational existence.

It is only later on in life that people can start turning their attention back to other things. Some people might disfairing the possibility to conserve their physical efficiency with the help of a velomobile. Nowadays it is a well-known fact that regular but moderate physical training, especially at an advanced age, will keep people healthier than discontinuous physical high performances. The velomobile offers a comfortable way to exercise in everyday life. A particularly attractive reason to chose the velomobile rather than the bicycle, is the independance with regard to weather.

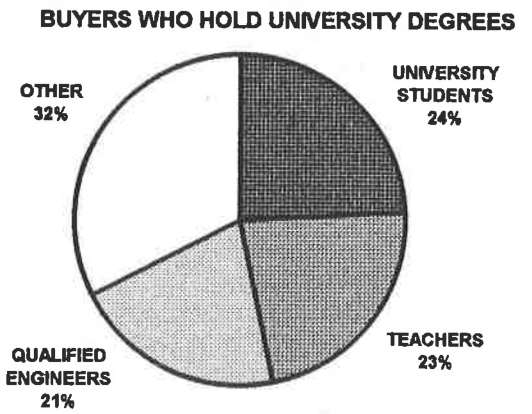
So it is altogether quite easy to reconstruct and explain this age structure for Leitra buyers shown in **Picture 2.**

Picture 3 shows the categories of job titles that Leitra buyers hold. Those with the longest education at school and university represent the largest percentage. This group of academics was, therefore, examined more closely and shown in its composition in **Picture 4**. From this we can see that university students, teachers and qualified engineers are represented in approximately the same proportions. The assumption that for many the search for a way to daily physical exercise has lead to the velomobile, applies especially to this job category. Many of these people have to sit down during most of their working day and welcome the possibility of daily exercising without having to spend extra hours in the gym or on time consuming bicycle trips at the weekends.



Pict. 3: JOB STRUCTURE OF LEITRA-BUYERS?

Let us have another look at the "womens quota". Only 6% of all Leitra customers are women. However, just one in five women has bought a velomobile independently, ie without her husband, partner or son being a velomobile customer as well.



Pict. 4: BUYERS WITH UNIVERSITY DEGREES

Experience has shown that we will find a very strong environmental conscience within all of these age and job groups. Most velomobile buyers want to do their own bit to keep traffic pollution as low as possible, but without having to put up with inconveniences, especially in cold seasons and bad weather.

After examining this manufacturer's customer base, we can conclude without doubt that the buyer's motivation basically complies with his first expectations: When he decided to start the serial production of the Leitra 15 years ago, he was looking towards the same purchase motivations which still basically dictate the purchase decision nowadays. At the same time, it has become absolutely obvious that the number of Leitras sold is far smaller than the number that could have been produced.

This takes me to the second part of my contribution: What keeps those people from buying the velomobile who, according to their attitudes and interests, could easily be potential buyers? Or, in other words:

Why are there not more everyday velomobile users?

Too little advertising for velomobiles

Velomobiles are generally not very well known yet. Therefore, we have to find ways to increase the public knowledge. The velomobile manufacturer's advertising budget is far too low to start promotional campaigns the likes of those that have been carried out to promote, for example, roller blades. Thus, it is essential for manufacturers to appear as participants or organisers of events, which demonstrate velomobiles. I doubt that bicycle fairs are particularly appropriate places to do this. At large trade fairs like the IFMA or INTERCYCLE in Cologne or the EUROBIKE in Friedrichshafen, it becomes apparent that many visitors only examine the demonstration models so very closely because they are planning to build a velomobile themselves. Although this sort of interested person knows the market very well, he is not a potential buyer. HPV-events like the European Championship here in Roskilde or last year's Worldchampionship in Cologne are much more suitable for introducing people to the velomobile and perhaps awaken their interest in a purchase. However, as many people as possible should be attracted as, after such an HPV-event, usually only about one in a hundred written inquiries leads to an order.

Velomobile manufacturers should definitely try to establish contacts with those numerous projects and workshops at schools and universities dealing with the construction of velomobiles. Readyness to consult young people surely must be a good means of advertising. As an example, a German university student took up a manufacturer's offer of a placement in model-making and synthetic resins processing with composite materials, which took him to Denmark and lead him to buy two Leitras.

Velomobiles are expensive

It is easy to explain the high price for a velomobile:

- Small numbers,
- a lot of manual work during the manufacturing process,
- expensive models and forms for plastic elements,
- high prices for additional components and
- customers' special requirements

keep the level of pricing high.

With regard to the first reason mentioned, the small numbers, no explanation is necessary - this event has been organised in order to abolish it.

The second reason, the relatively large part of manual work, is mainly a result of the small numbers of individual velomobiles. As mass production is unlikely to be expected in the forseeable future, manufacturers are trying to lower these manual work costs, using several different strategies. As a rule, the buyers have the opportunity to save some of the purchase price by assembling the parts themselves or at least by supporting the assembly of their velomobiles. Alleweder has practised the first version - you could perhaps call it do-it-yourself (DIY)-assembly with required skills as a craftsman - which keeps the purchase price comparatively low, whereas Leitra prefers the second version in which the buyer helps with the assembly and which has been a success for many years.

In order for the customer to build the velomobile himself, there has to be a relatively simple vehicle concept with prefabricated components as well as the buyer's own craftsmanship. This is the only way to prevent the instructions delivered with the components from becoming too extensive and their production and up-dating from becoming too expensive. If the manufacturer does not carefully plan and formulate these instructions, he might later even get into trouble with Product Liability Regulations. One unavoidable concomitant of this production concept is that the buyer has no flexibility regarding the use of drive components according to his own wishes or even the use of differing fairing or luggage space versions. I know a few Alleweder customers who gratefully received the comparatively cheap Flevobike product range for DIY-assembly and put together their own velomobiles.

It would probably be quite a job to produce an instruction for the DIY-assembly of the Leitra. Some confident enthusiasts who apparently like finicky jobs have tried to put together their Leitras themselves even though there were no instructions, but usually failed to succeed. It is, however, highly recommendable to help with the assembly. It not only enables everyday care, maintenance and repairs later on, it also allows for the consideration of special wishes, especially regarding drive trace and brakes. Workshops, where the manufacturer instructed several customers at the same time, were another successful way of assembly. At these workshops, new ideas were developed and put into effect. One direct result of these intensive contacts with the customers seems to be the very large variety regarding drives and brakes as well as the outer appearance of the velomobile. There are many ways of combination offered to the buyers - not only in colour sceme but different fairings, luggage boxes and suspension systems. Unfortunately, one rather unwelcome aspect of this concept is its higher price, which will probably prevent many an interested person from buying.

I have deliberately chosen these two vehicle concepts in order to rate the possibilities of lowering the velomobile prices or at least explain its high prices to the buyers. One could almost call Alleweder and Leitra antipodes with regard to the philosophies based on their concepts. On the one hand, there is a deliberately simple design with the chance to build a robust vehicle cabin, using the skills and abilities of a craftsman and premanufactured components, thus enabling the buyer to replace a large percentage of the purchase price with his own work. On the other hand there is a vehicle which offers many ways of combination and although these can be adapted by the owners themselves, this process will be time consuming and cannot be carried out without intensive instructions.

There is another hypothetical possibility which has not yet been practised: The manufacturers could put their heads together and find out which components might fulfil their mutual requirements regarding size and quality. As an example, they could agree on a uniform rim size, maybe even on a normed gear and break system. The development of a purchasing co-operative would allow for lower purchase costs for these components.

Another way of increasing the turnover might be the creation of a network of dealers which would include all competing products on the market. If these dealers could fall back on an existing pool of velomobiles that have already been built, long waiting times could be prevented and buyers could be served immediately after their decision to buy a velomobile and use it straight away. Of course, dealers would have to keep special parts in stock to ensure availability and fast repairs.

There is another, indirect way of cost reduction which should definitely be mentioned: The velomobile as an advertising medium. A short while ago, the chemist in my home town became the proud owner of a small car with electric drive which is used exclusively for the local delivery of medication. He managed to create an advertising medium which is supposed to suggest: a close connection between exhaust-free transport and medical welfare by medication. If his choice had been a velomobile, not only would he have an advertising medium that is at least as suitable, but, moreover, there would be no parking restrictions and he could park at nearly everybodies' front doors. He also would have got away with a cheaper vehicle. There are some velomobile users who use their vehicle successfully as an advertising medium and who gain quite a lot of money that way. If manufacturers and dealers advertised this aspect more, perhaps the number of potential buyers could be increased.

Susceptibility to repair and service

I would like to point out another reason for the caution of those who might be potential buyers. This reason might not have received the necessary attention of those involved in the discussion within the HPV-Scene. It is the reliability of today's everyday use velomobiles.

A person buying a car would be very surprised if the salesman expected complete knowledge about the technical side of his vehicle as a necessity. Nowadays, the buyer can expect defects to appear extremely rarely. However, should there be a breakdown anyway, the breakdown service is happy to help him out there and then.

As opposed to this, the velomobile buyer has to be armed with extensive know how. He will soon realize that inspection, maintenance and repairs are necessary concomitants of his everyday use of a velomobile. It is only natural, that a heavily used racing or mountainbike needs a lot of care and attention and this is accepted by their buyers without any complaints. There are even some mountainbikers who are proud if the rims of their hyperglide gears already need replacing after 1500 kilometres. To them it is a proof of their own efficiency and of rising to their own sporting challenges. The everyday velomobile user, on the other hand, won't be very happy at all about early wear and tear of components as it comes along with costly and time consuming repairs. His reason for buying the vehicle was that he wanted to get through bad weather, ice and salted roads in winter, broken glass and dust in spring and summer with as little time spent on maintenance and repair as possible. It is hardly to be expected that he is willing to spend more time than necessary caring for his velomobile. To him it is not a sports facility for leasure times but an item of practical use, which he will particularly learn to appreciate if he doesn't have to spend too much time on it. Unfortunately, today this is not possible yet. Although frames and fairings will survive long periods of time without special care and attention, in the case of gears, breaks, wheels and, sometimes even bearings, maintenance or renewal periods are a lot shorter. If they are not well prepared for this, many potential everyday velomobile users will lose their love for their vehicle soon after its purchase. Being well prepared also means that buyers should receive carefully worked out, written instructions to tell them after how many kilometres to replace which parts in order to avoid breakdown during travel.

Transport after breakdown

It can be particularly unpleasant for an everyday velomobile user to break down whilst being on a holiday trip away from home - especially if that damage cannot be repaired there and then. Although the chances to be able to load the velomobile onto a train have improved within the last few years - thanks to bicycle compartments with wider doors (for example in the German Intercity-trains) - how is one going to get to the train station?

In Denmark,the solution to this problem is the membership of an organisation called Falck. Falck is responsible for fire fighting, ambulance service and breakdown service for cars. One of their information leaflets says that help is at hand if a cyclist cannot continue the ride due to accident/breakdown with irreparable damage of his bicycle or because of illness. The bicyle will be transported to the nearest workshop and the owner will be taken either home or, if necessary, to the nearest hospital. The annual bicycle insurance fee amounts to about DM100 and does not, however, include any minor damages.

There is another question to be asked: What sort of a workshop will deal with repairing a velomobile? If a person cannot or does not want to carry out the repairs himself, it is always advisable to build up a good relation with a well-running repair workshop.

Chances created by a new regulation of the German road traffic act

Considering the sort of provisions that would have to apply in order to see more velomobiles in everyday life, we can't disregard the traffic regulations. Especially in the Netherlands, the regulation that only vehicles with a maximum width of 75 centimetres are permitted on bicycle paths, has had a strong influence on the Alleweder concept. This results in a very low seating position which then leads to a small area of cross-section and, therefore, lower air resistance. Thus, speed is increased, which will be particularly attractive to younger buyers. Being the owner of a Leitra, I am often asked whether I was afraid to be overlooked in traffic. The average potential buyer will naturally be investigating the traffic safety of the vehicle. It will be easier to convince him, offering a vehicle with the necessary width in order to position the rider as high as possible, in fact, high enough to be on an eye level with car passengers. According to the amendments to the German road traffic act, there will have to be a revision of bicycle paths which had to be used hitherto. After that, velomobile users won't be obliged to use many of those cycle paths anymore, which do not have the necessary width or surface smoothness. Due to this, velomobile users will be allowed to use smooth street surfaces a lot more in future. Using streets will automatically increase the importantance of visibility. On the other hand, some of those who have so far been put off by uneven cycle path surfaces (which present a particular problem to velomobiles with their small wheels) might finally decide to purchase a velomobile after all.

This brings us to the question of whether the regulations regarding traffic registration should include a special definition for the velomobile or if we should just retain the present regulation, which does not differentiate between velomobiles and bicycles. I would personally probably be in favour of the existing German regulation, according to which bicycles are permitted to have more than one track. The track width is not limited but logically derives from the maximum width permitted for bicycle trailers which is 1000 millimetres.

Velomobiles for the disabled

There is one possibility with regard to the everyday use of velomobiles which has only been discussed very little and which is very important: The velomobile can facilitate the lives of many disabled people. At any rate, 8,5 % of all sold Leitras have been bought by or for disabled people, who, for a range of different reasons, cannot use a one-track vehicle. In Germany, many disabled people use tricycles in the shape of bicycles which are extremely unwieldy and not very steady. What is more, these tricycles are not equipped with a weather protection. A robust velomobile which does not easily topple over and which is designed for easy entering and exiting, for instance, would be very suitable for disabled people.

It might put off other buyers to praise the everyday use velomobile as a vehicle for the disabled. Maybe health insurances could be won over to cooperate or velomobiles could be made available for rehabilitation centres in order to increase the level of knowledge amongst disabled people.

Step-by-step purchase of a velomobile

First experience has shown that some participants of our project "Velo" at the local polytechnic love cruising around the block on the assembled chassis of a Leitra. Without the fairing, the vehicle is not only very lightweight and nimble, but also not particularly expensive. It might well be an interesting possibility to change the chassis into an all-weather-vehicle by buying the fairing later on. Thus, we might awaken a young customer's interest early on. It is probably only later on in life, that there will be a need for full fairing for weather protection and to decrease air resistance. By then, the customer might have saved enough money to transform his FUN-Mobile into a real velomobile. There would have to be more opportunities for test rides provided. Perhaps theme or leasure parks might be suitable sites for this.

For a family with average income, the price for an everyday velomobile is considerably high, whether it is paid for in money or in work. It is, in fact, so high that it might question the purchase of a second car. Such a possible family conflict could be solved by purchasing the separate elements in stages. The acceptance in the family might be increased even further if the vehicle could be used by several family members. To enable this, the distance between seat and pedal bearing should be adjustable.

It would be a lot easier to adapt to the requirements of different family members if the velomobile had several, easily exchangeable rear elements: That way lockable luggage room, children's seat with windscreen or aerodynamic rear part could be interchanged easily.

Reasons why velomobile users might not want to advertise the velomobile

Whoever followed publications on velomobiles within the last few years will have noticed that my contribution contains only very few thoughts and suggestions that have not yet been published somewhere else in the past. I have tried not to be lead by unrealistic wishes, but to somewhat soberly judge the prospects for a not very rosy future of the velomobile and its manufacturers. I would like to repeat the wish I have mentioned in the beginning: It would give a velomobile user like me great pleasure and a rush of motivation to see a like-minded person at least about once a day.

In July 1996, we took part in a velomobile tour to the European HPV Championships in Leicester. One of the participants was the designer of a beautiful tricycle who came from Bremen. At the end of an eventful tour day, we all sat together in an English pub and discussed how we could better the world by getting more people to use velomobiles. He asked whether it wasn't also the appeal of doing something special that made us use velomobiles in everyday life. „Would we", he asked, „still enjoy using the velomobile in everyday life as much as we do if it suddenly became just as ordinary as driving a car.

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Velomobile - a missing link in traffic

Joachim Fuchs

Velomobiles - fully faired recumbent bicycles for everyday use - are compared with cars and bicycles as fast and effective means of transportation. Due to their great dissimilarity, a method is presented to calculate the attainable average speed. This speed is denominated effective average speed in this article. It is defined as the covered way divided through the overall time for riding, obtaining the vehicle and maintenance. It is pointed out that the results are based on numerous assumptions. The article shows that velomobiles rank highest with respect to these calculations.

Introduction

Traffic is a subject everyone is concerned with - and everyone spends a lot of his or her time in traffic. A common goal is to cover a distance in a short time. Besides, comfort is also an important point for most commuters.

Today's traffic is dominated by cars. They offer in the eyes of their users a maximum of comfort and speed. But what is speed?

Speed in a physical manner is simply the distance a vehicle covers divided through the time needed for that distance. But mobility cost money, and a car is the most expensive means of transportation compared to a velomobile and a bicycle. People earning enough money can afford that mobility easily. Nevertheless, a part of their income is spent for that purpose. During the time needed to earn the money for purchase and maintenance, the vehicle has to stand still (assuming the vehicle is not the mean with which the money is earned - for example taxi drivers). Of course, people with a higher income work shorter, with a lower income longer for purchase and maintenance costs.

The way to calculate the real costs of cars and other vehicles is the following. One should focus on the effective average speed. This - as used herein - is the distance a vehicle covers divided by the overall time necessary for that distance: earning the money for the purchase and maintenance of the vehicle.

There are several parameters that influence the effective average speed: the total distance, the average speed, the net income (it was said that people have to purchase and maintain their vehicle; the time needed depends on the income), the maintenance costs, the life time of the vehicle and so on.

The vehicles presented here are used for quite different purposes. Velomobiles have the advantage that they keep the rider dry and warm in winter (as in a car). The seat is comfortable and there is space for baggage even for holiday trips. In addition, some are significantly faster than normal bikes. Velomobiles have the positive characteristics of of both cars and bicycles. could fill that gap in traffic between cars and bicycles. Although the velomobile development is more or less still in the hand of courageous private persons, many vehicles have covered uncountable kilometers and have proved to be an outstanding alternative mean of transportation for everyday use.

The small-scale production of velomobiles causes higher costs compared to a normal bike (but one should keep in mind that velomobiles represent a higher quality of vehicle).

The central question is, whether or not the effective average speed of a velomobile is levelled out by the higher costs of purchase.

Calculations

The following table compares the above mentioned parameters of cars, velomobiles and bicycles. The lines are numbered, and comments to the assumptions are listed beneath.

Annotations to the input of the table:

Lines 2-6:

The average distance of car drivers is a value supplied in the literature [1]. The velomobile distance is based on the experience of the author. It is assumed that bicycles do not achieve that distance because they are not used in bad weather. There are some transportation tasks - especially those of longer distances in a narrow time limit, that can only be done with a car; velomobile and bicycle riders will take the train for that purpose. The additional costs are calculated in line 3 to 6. The train average velocity was not taken into account to keep the calculations simple. The result would be more advantageous for the velomobile and the bicycle. The overall distance is set to the same value of 14200 km.

1		car	velomobile	bicycle	calculation	source
2	distance driven per year [km/a]	14200	10000	8000		literature/assumption
3	additional distance with public traffic per year [km/a]	0	4200	6200		calculation
4	total distance per year [km/a]	14200	14200	14200	=L2+L3	calculation
5	costs for that distance by train, half price reduction [DM]	0	525	775	=L3*0.125	calculation/assumptions
6	fix costs of the half price reduction [DM]	0	240	240		actual price
7	average velocity [km/h] (mph)	40 (25)	25 (16)	20 (13)		assumption
8	purchase costs [DM]	33500	14000	2000		literature/assumption
9	life expectation [a]	10	10	10		assumption
10	proportional worth after life expectation	0.01	0.3	0.05		assumption
11	depreciation per year [DM/a]		980	190	=(L8-L8*L10)/L9	calculation/assumptions
12	support of car per year (including fuel, repair etc.) [DM/a]	6936				literature
13	costs of the driving licence per year, 50 years use [DM/a]	40	0	0		assumption
14	maintenance bicycle/velomobile per year [DM/a]		293	218	=SUM(L15:L21)	calculation/assumptions
15	tyres		70	60		assumption
16	chain		50	50		assumption
17	cogs		60	60		assumption
18	fairing		50	0		assumption
19	cables		8	8		assumption
20	lighting		25	10		assumption
21	brakes		30	30		assumption
22	total costs per year [DM/a]	6976	2038	1423	=L5+L6+L11+L12+L13+L14	calculation/literature
23	price per km [DM/km]	0.49	0.14	0.10	=L22/L4	calculation/assumptions
24	net income per month [DM/month]	3200	3200	3200		assumption
25	payment per hour [DM/h]	21.8	21.8	21.8	=L24*13/(220*8)	calculation/assumptions
26	necessary time for earning the total costs of ownership per year [h/a]	319.7	93.4	65.2	=L22/L25	calculation/assumptions
27	time needed for obtaining official authorisation	2	0	0		assumption
28	driving licence	1	0	0		assumption
29	maintenance, repair	5	20	15		assumption
30	tank	2.4	0	0		assumption
31	cleaning	4	4	3		assumption
32	time needed for maintenance per year [h/a]	14.4	24.00	18.00	=SUM(L27:L31)	calculation/assumptions
33	effective average speed [km/h] (mph)	20.6 (12.88)	20.7 (12.94)	17.9 (11.18)	=L4/((L4/L7)+L32+L26)	result

Line 7:

The average velocity is based on personal experiences of the author. Pushing the vehicle does not affect the average velocity and is an advantage in comparison to a car.

Most rides of the author are made in flat areas, although there are some trips in hilly areas. This is typical for those users who live in larger towns. (In Europe, almost every larger town is situated in a flat area). In steep areas, the average speed of the velomobile would be almost the same as that of a normal bike.

Line 8:

The purchase costs of the car is the average value of all bought cars in Germany. The velomobile of the author is not commercial available, the purchase costs of the velomobile were taken from the "Leitra", a velomobile from Carl Georg Rasmussen, Farum, Denmark.

Line 10:

The vehicles are not worthless after the lifetime. The proportional worth after lifetime is given in line 10. It is assumed that velomobiles are relatively highly sought after so they can achieve reasonable high prices. This is also due to the fact that in contrast to cars, worn parts are replaced regularly.

Line 12:

The support costs of cars is taken from literature [1]. The value includes purchase, fuel costs, repair and insurance costs.

Line 13:

It is assumed that a driving licence costs 2000 DM and is used for 50 years.

Line 14:

The sum of the maintenance costs of bicycles and velomobiles depend strongly on the components. A drum brake for example lasts more than 25000 km without maintenance (experience of the author) while rim brakes need regular maintenance.

Line 23:

The price per kilometre is just an informational value that is not needed for further calculations. Note that the result shows that bicycles are cheaper than velomobiles. Because of the higher average speed, the effective average speed is higher for velomobiles.

Line 24:

The net income is not that of the author...it is a free variable and variation of this value gives interesting results that are not the subject of this article.

Line 27:

The time needed for obtaining official authorisation is calculated because getting the car certificate and passing the car check requires additional time.

Line 29:

The values for velomobiles and bicycles are based on the assumption that all maintenance is done by the driver himself. For cars, most of the maintenance is done by professional staff, which is taken into account in the maintenance costs (line 12).

Line 33:

The average speed of public transport is assumed to be 25 km/h for velomobiles (long-distance journeys with between smaller towns with trains are somewhat slower than by car) and 20 km/h for bicycles (it is assumed that cyclists use public transport also within the city limits, for example when the weather is bad).

About the calculations:

Literature data to the effective average speed of bicycles and cars is reported in Seifried, [2]. Nevertheless, it is almost impossible to find consistent literature data for bicycles, velomobiles and cars. The calculations done in this article do not claim to be exact in a strong sense. The results depend on the assumptions, and it was the aim of the author to set them in a "reasonable" manner. The mathematics are shown in the column "calculations" so everybody can easily calculate with own assumptions.

There could be further parameters to put into the calculations, for example pollution costs, risk of injuries etc. The aim of the present article is to keep the calculations as simple as possible.

The literature data were taken from German sources valid for 1996. Although it would be interesting to get European data, each country uses different statistical sources that can not be compared in each case.

The costs are given in DM (German marks). The rate of exchange to Euro is not fixed at present (April 1998).

Comment on the results of the effective average speed

To the personal view of the author, there are three winners:

The "bad winner" is the car. It has the advantage to be promoted by means of the tax which is the case in most countries all over the world. It is a slow mean of transportation, as the calculations show. The result would be better for the car if the assumed income is higher.

A "good winner" is the bicycle. It is simple and a good mean of transportation for short distances. In hilly areas, the bicycle could be the winner concerning the average velocity. The aerodynamic advantage of the velomobile is then levelled out, but there is less comfort with a normal bicycle.

The "best winner" is the velomobile. It offers an overall speed advantage for many different riding conditions. Since most larger towns are situated in flat areas, velomobiles are good concerning aerodynamic drag.

The velomobile - unknown to the most part of traffic users as now - offers the opportunity to close the gap between cars and bicycles. It is up to future generations to comment whether the velomobile is just that kind of vehicle missing in traffic.

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Further informations: Ivan Illich: several publications, translated in different languages

Human-Powered Vehicles for Third-Agers as a Mode of Local Transport

The Third European Seminar on Velomobile Design, Roskilde, Denmark, 5th Aug. 1998

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Abstract ---
Cycling fits well into any plans for a future transport framework. It offers a widely accessible, convenient and environmentally-friendly means of making local journeys, especially in urban and suburban areas. And it is a healthy, enjoyable, economic and efficient means of travelling. Much of the considerable potential for cycling is derived from the existing journey patterns of other modes. 72% of all trips are less than five miles in length. Half are less than 2 miles. Combined with public transport, cycling can offer a door to door alternative for longer trips.
Cycling could be a better choice of local transport for Third-Agers. However, the vehicles have to be thoughtfully designed by taking into account the loss in physiological effectiveness due to the ageing process. A postal questionnaire survey technique was used to collect data. A questionnaire to understand Third-Agers' attitudes to cycling as a daily mode of transport was designed and distributed to about 300 members of the Thousand Elders panel, established by the Centre for Applied Gerontology, University of Birmingham, UK. The members of the panel are people aged 55 years and over who live independently in the community and come from various socio-economic backgrounds. Two hundred and fifty-five completed questionnaires were received and the responses were analysed using the SPSS statistical package. The implications of the results of the investigation are: (i) Third-Agers' mobility patterns including the frequency of using a car, using public transport, walking and cycling, (ii) attitudes toward cycling, and (iii) problems of cycling.

1 Introduction

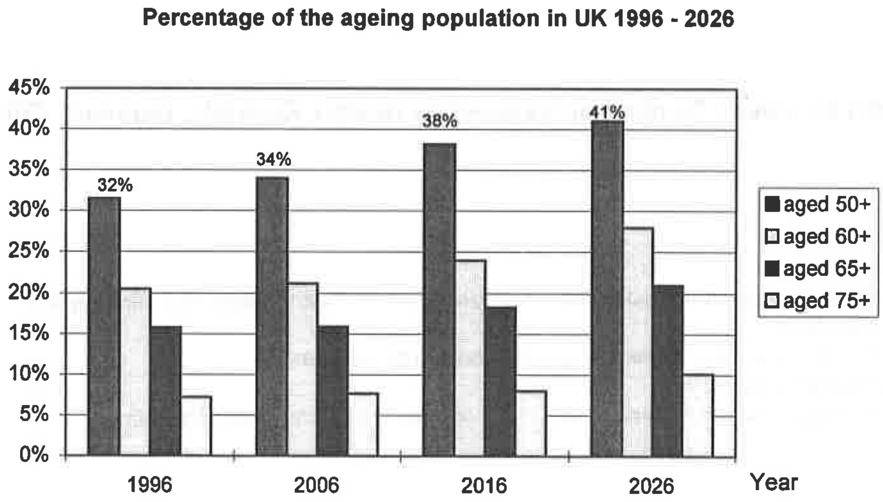
'By the time we reach the third decade of the 21st century, half the adults in Europe will be aged 50 or over.'[1] Of a world total of 355 million people over 65 in 1993, more than 200 million are in the developing world, where they make up 4.6% of the population, with more than 150 million in developed countries, where the proportion is 12.6% (WHO, 1998).

The 20th century is the 'motor age'. Driving in travel is part of normal life for a majority of people as drivers or passengers. Transport planning and urban transport policy have tended to focus on vehicle travel rather than other modes of travel such as cycling and walking. As some local authorities and designers around the world start providing cyclists with cycle-friendly infrastructure and a diversity of cycle design for sustainable transport choice, people aged 50 and over should not be ignored.

1.1 Ageing population in the United Kingdom

Age Concern England (1996) gives details of the population in the United Kingdom for the years 1996, 2006, 2016 and 2026 covering men and women of 50 years of age and over (Figure 1):

Figure 1: Percentage of the population aged 50 and above in the UK, 1996 - 2026.



Source: Adapted from Age Concern (1994): Fifty plus- population and other projections.

In the UK (1991), the elderly comprised 18.4 % of the national population, up from 16.4 % in 1971 and almost three times the proportion at the turn of the century. Over the twenty years to 1991, the actual number of elderly people is estimated to have grown by 16.6%, in other words, one extra person for every six in 1971. The figures for the 75 and above group are even more striking: their numbers goes up from 2.6 to 4.0 million, an increase of 53%. In other words, an extra person in 1991 for every two in 1971, and their share of the total population goes up from 4.7 to 7.0% (Champion, Wong and Rooke, 1996).

The Third Age has become an important stage in the life-cycle. People are giving up full-time work at an earlier age and are living longer. It would seem important that this stage in the lifestyle is an active one, and that we should be concerned to promote the conditions which permit an active old age. Third Age is a stage in the life-cycle where needs and abilities differ from earlier stages, and it is often found that these different needs and abilities are not very well catered for.

1.2 Definition of Third-Agers

In the belief that birthdays are poor indicators of social attitudes or health, most titles in the field of social gerontology eschew them as much as possible. It is becoming customary to use a 'status' construct for such studies, dependent upon where a person is located in the social life-cycle. The usual frame of reference for this is as follows:

- the First Age is the age of childhood and socialisation;
- the Second Age is the age of paid work and family-raising;

[1] Roger Coleman, DAN co-ordinator, from his lecture: 'The Future is Old', delivered 10 May 1996 at 'de Balie' in Amsterdam, at 'Young Industrial Designers Trigger Industry' conference.

- the Third Age is the age of active, independent life beyond work and parenting;
- the Fourth Age is the age of eventual dependence (Midwinter, 1991).

People might be, and are, in the Second Age when they are 70 years of age, in that they- politicians, actors, for instance - are still working full time; they might be in the Third Age at 50 years of age, their workdays finished and/or their children grown up and left home.

1.3 Problems in mobility among Third-Agers

The following information from the UK Department of Transport (1996) contrasts the mileage and journey figures for different main modes of travel.

Table 1: Mileage and journey figures for different modes of travel.

MODE	% miles travelled	% journeys made
Walk	3	29
Car/van	**81**	**59**
Local bus	4	6
Bicycle	1	2
Rail	5	2

Source: Department of Transport UK (1996). Journey mode and distance travelled 1993/95.

Car availability

Among people in the Second Age, the most important determinant of mobility is car availability, which in turn is very closely related to social class, income, and sex. Ageing adds further dimensions to these differences in mobility.

Firstly, health and personal capabilities decline with age. Driving a car becomes more dangerous; climbing into a bus becomes more difficult; hills, steps, ramps, and road crossings become more difficult when walking.

Secondly, retirement from work brings a reduction in income. Further reductions in real income may occur if an old person is relying on a pension which does not keep pace with the increase in prices. In these circumstances it is difficult to maintain and run a car or to replace it when its life expires. It also becomes expensive to travel by bus unless concessionary fares are available (Robson, 1982).

Access to car driving depends upon ability to operate a car and to deal with road conditions. A car which runs at a speed of 30 (or usually more) miles an hour demands rapid reaction times which older people cannot always easily attain. The attitude of other road users is another barrier for elderly people as drivers.

It should be emphasised that this decline in mobility does not necessarily mean a decline in the number of journeys, for this is determined more by needs. The more likely results of declining mobility are shorter journeys and greater effort (Robson, 1982).

Public Transport Services

The major change since the 1980s in commuting by public transport in the UK has been the rapid decline in travel by bus. This period has seen the deregulation of the bus industry: bus usage has been in long-term decline, but the policy changes certainly seem to have done nothing to turn this around. Adoption of similar policies for the rail industry in the 1990s is thus understandably controversial.

Access to public transport depends upon the cost and availability of services, particularly in rural areas. The existence of pensioners' bus passes and other concessionary schemes reduces the impact of fare increases on many retired people. 93 % of pensioners in 1989/91 lived in areas where concessionary travel fares were available (Department of Transport, 1993).

In some parts of the country, bus services can be infrequent and unreliable. In rural areas, facilities are far less likely to be within walking distance - nearly a third of households did not have a bus stop within 6 minutes' walk (Department of Transport, 1993)

1.4 Exercise and ageing

The ability to perform physical activity usually declines with age. What is not clear however, is how much of this deterioration is an inescapable part of ageing rather than a result of disuse. Much of the data documenting these changes was obtained from a largely sedentary population. It may therefore be a measure only of lack of physical activity and not ageing per se. Exercise appears to offer protection against several of the diseases of ageing and is a factor in maintaining good health in the elderly. However 73% of individuals above age 65 do not exercise regularly, compared with 56% of the 30-

year to 44-year age group. Older women appear to be especially sedentary. Ideally a strength and fitness program should start early in life and be maintained with necessary modifications into old age. It is, however, beneficial to begin even late in life. Some very old individuals have achieved impressive increases in muscle strength through progressive resistance training, and there is ample evidence that major increases in cardiovascular fitness can be achieved by the elderly (Spreadbuly, 1993).

Traditionally the objective of traffic management has usually been to maximise capacity for motor vehicles, but this is changing. In future, there will be a need to avoid motor traffic capacity considerations, pre-empting the provision of cycle-friendly traffic management and design. Cycling provision should be given full consideration in delivering improved efficiency of road use, better safety and reduced environmental impact, because bicycles use road capacity more efficiently than private motor vehicles (Department of Transport UK, 1996a).

Cycling can contribute to a wide range of sustainable benefits: reduce pollution, enhance local environments and improve the health, especially of Third-Agers. Cycling which can offer door to door trips, could be a better choice in local transport for Third-Agers. However, the physical ability of older adults, which affects the use of facilities that they need, may decrease with age. Slowing down means that roads have to be crossed with care and that vehicles have to be thoughtfully designed.

2 Research methods

To enable the Third-Agers to remain mobile independently and enjoy a reasonable quality of life, they should be able to take control of their own transport decisions. This investigation will explore Third-Agers' experience in driving and their attitude toward cycling including daily transport needs.

A questionnaire was developed by the School of Design Research at the University of Central England in consultation with specialists in the Centre for Applied Gerontology at the University of Birmingham. The questionnaire contained 22 questions with 110 decisions for each respondent. It collected information on:

1. mobility patterns by frequency of: using a car; using public transport; walking; and cycling,
2. use of and attitude toward cycling, and
3. difficulties when cycling.

Questionnaires were sent out to 300 members selected at random from the Thousand Elders panel (Nayak, 1995). The members of the panel are people aged 55 and over who live independently in the community and come from various socio-economic backgrounds. Two hundred and fifty-one completed questionnaires from the Thousand Elders were received and were analysed using the Statistical Package for Social Sciences (SPSS).

The age distribution of the survey respondents is given below (Table 2).

Table 2 : Age groups in the investigation.

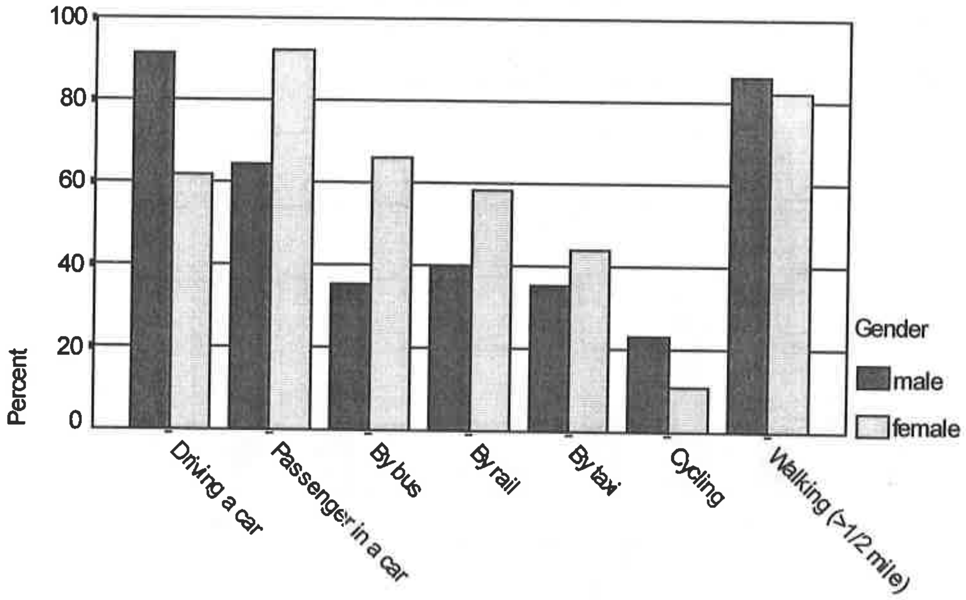
Age groups	Number of respondents	Percentage sample
50 - 54	7	2.7
55 - 59	23	9.0
60 - 64	80	31.4
65 - 69	73	28.6
70 - 74	72	28.2
Total	255	100.0

3 Results and discussion

3.1 Mobility patterns

Among the variety of transport used for daily life, the ageing population tend to walk and use a car more than other types of transport.

Figure 2: Types of transport used for daily life of the survey respondents in the last 6 months.



Driving a car

The survey respondents are not only devoted to driving (77.4%), but also drove frequently. Among 192 respondents, 98.1% of them did drive weekly or more often. 62.2% of males and 43.8% of females actually drove daily. This does not imply that Third-Agers drive a car without difficulties.

Being a passenger in a car driven by someone you know

In the last 6 months, 78.1% of the respondents in the investigation rode in a car driven by someone he/she knew. Frequency of riding in a car among these correspondents was fairly equally distributed from daily to less than once a month.

Travelling by public transport (bus or rail)

Half of the respondents had used public transport - either bus or train - in the last 6 months. 52.8% of them used the bus weekly or more often, while 66.1% of them used the train less than once a month. Females tended to use the bus more than males did.

According to Age Concern (1994), only 3% of people aged 50-74 travel by train once a week or more, while 63% never or rarely do so. 91% of people over 74 use the train twice yearly or less.

Travelling by taxi

39.0% of the respondents had used a taxi in the last 6 months. However, most of them did not use taxis frequently; 78.4% of them used taxis less than once a month.

The taxi provides an accessible transport service for those Third-Agers who do not have the use of a car, and cannot use public transport. For those who have access to cars and public transport, a taxi can be seen as a occasional supplement to the transport available to them.

Cycling

17.1% of respondents had cycled in the last 6 months. Frequency of cycling among these correspondents is equally distributed from daily to less than once a month. Compared to other types of transport Third-Agers used, cycling was relatively less frequently used.

Walking (more than half a mile)

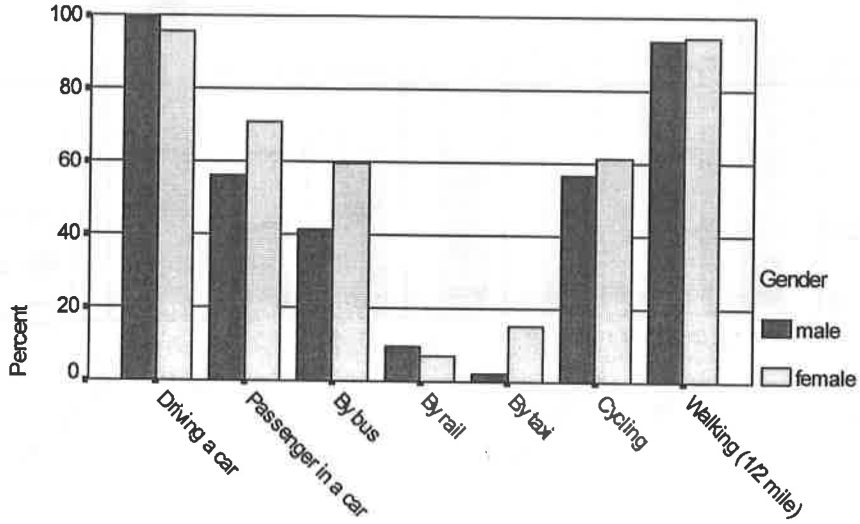
People walk for many reasons; going to work, for business, leisure, health or domestic purposes. Walking (more than half a mile) was the most popular method (84.7%) of transport among the survey respondents. 37.7% of the respondents walked daily and 94.1% weekly.

According to the Department of Transport (1996b), walking along the public highway accounts for 29% of our journeys, including 82% of journeys less than a mile. In mileage terms, it accounted for 3% of distance travelled. Furthermore, most trips by vehicle - be it a bus, car or tram - involve walking at both ends.

Frequency of use of transport

Among the survey respondents, of those who drove a car in the last 6 months, 55.2% drove daily; 98.4% drove weekly or more frequently. Of those who walked, 37.7% of them walk daily and 94.1% of them walked weekly or more frequently. Surprisingly, of those who used cycles in the last 6 months, 18.6% of them cycled daily and 58.2% cycled weekly or more frequently (Figure 3).

Figure 3: Transport used weekly or more frequently.



3.2 Use of cycles

Cycling could be a better choice in local transport for Third-Agers. However, their attitude toward cycling and the problems they experienced have to be identified to enhance future transport policy management and vehicle design.

People who own a cycle and have used it in the last 6 months

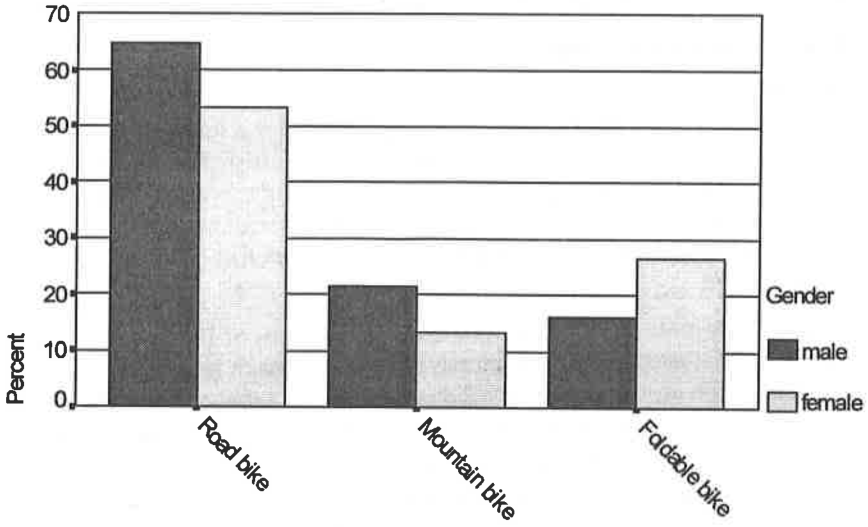
According to The Department of Transport (1993), only 10% of pensioner households own a cycle and cycling mileage by pensioners has halved between 1975/76 and 1989/91. However in the current investigation, 29.7% of the ageing population own a cycle and 20.9% have cycled in the last 6 months

More elderly people own cycles today. 40.2% of males and 18.5% of females have one or more cycles. The number of males is double the number of females who used cycles in the last 6 months.

Types of cycle used

61.5% of the cycles used by survey respondents were road bikes which was the most popular type of cycle. Surprisingly, 19.2% of the cycles used by respondents were mountain bikes which are supposed to be a youngster's choice. A mountain bike demands much pedal force and is usually ridden in an uneasy posture for the ageing population. Older people's mountain bikes might have been bought when their owners were younger. Foldable bikes comprised 19.2% of the cycles used by survey respondents. For those who need to store or transport cycles in a narrow space, foldable bikes are alternatives. Figure 4 indicates that females are more in favour of foldable bikes than males are.

Figure 4: Use of 3 most popular types of cycle.



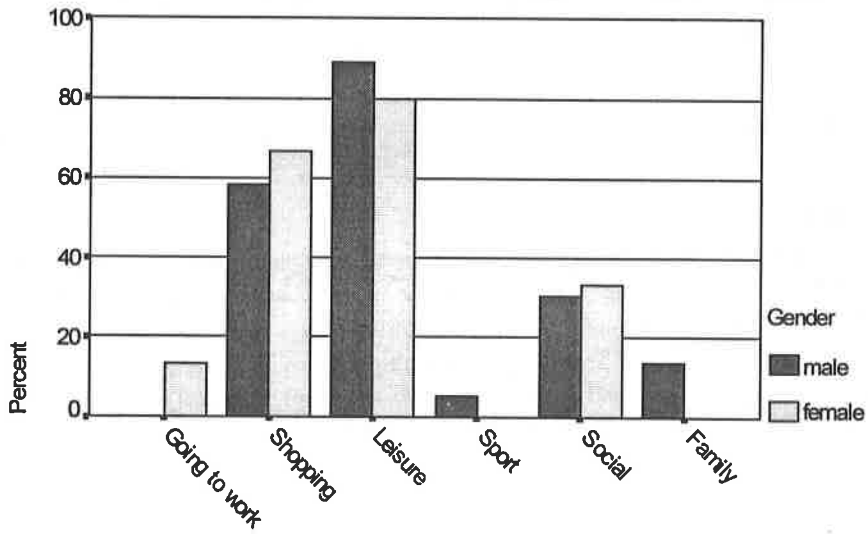
Purpose of cycling

Those who cycled in the last 6 months, used a cycle for leisure (86.3%) most frequently, followed by shopping (60.8%) and social purposes (31.4%). Very few of them used a cycle for sport or work (3.9%) (Figure 5).

According to the Department of Transport (1993), most cycle journeys are for commuting/business (41%) or leisure (31%).

On average they (Third-Agers) have more time available than younger households, and are prepared to travel longer distances to shop. They also have more money for comparison goods. Shopping becomes more of a leisure activity than a chore (Morgan, 1992).

Figure 5: Purpose of cycling.



Needs of load carrying

As the ageing population usually used cycles for leisure, shopping and social reasons, 54.5% of them believe that being able to carry a load is important when cycling. On this subject, different gender and age groups agree. Meanwhile, we found that 59.3% of the survey respondents were not fully satisfied with the load carrying capacity of the bicycle.

In the investigation, the respondents gave their opinion about occasions on which they carried the greatest load. A majority of 88.6% of the respondents believed that they needed to carry a load on a shopping journey, followed by family (24.9%) and leisure (22.3%) journeys.

Cyclists of other age groups use knapsacks (backpacks) for carrying loads. This does not apply to the ageing population due to difficulties in putting it on and taking it off. It would be useful to have a storage device or compartment designed on a cycle to meet their needs.

Speed of cycling and journey length

Speed of cycling

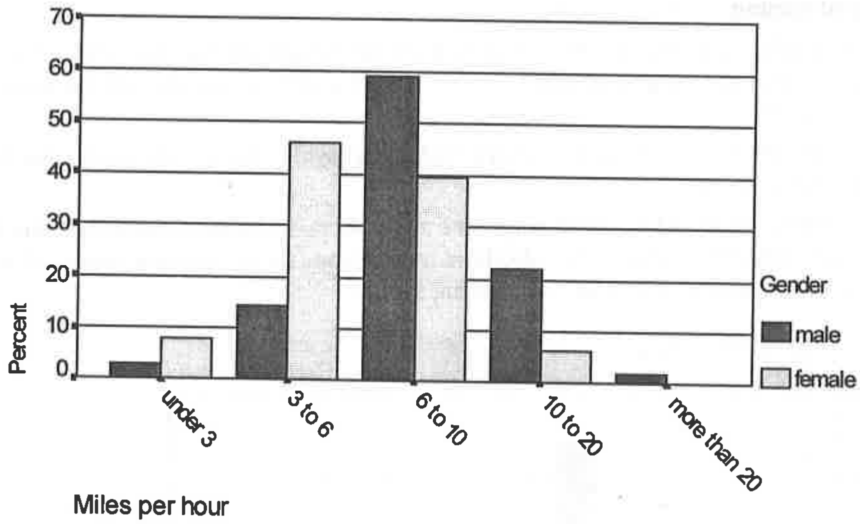
When cycling, 51.8% of the respondents believed that riding at a speed of 6 to 10 miles per hour (10 to 16 km per hour) is suitable for people of their age. This consisted of 59.4% of males and 39.1% of females. However, 46.9% of females prefer to cycle at a lower speed of 3 to 6 miles per hour which is about double the average walking speed. Only 11.4% of the respondents thought that a speed over 10 miles per hour was applicable to the ageing population (Figure 6).

According to Faria,IE and Cavanagh,PR (1978):

The maximum steady-state energy value (for exercise durations of 10 minutes or more) for the average individual levels off at about 0.3 hp[2]. Even this represents a much greater power output than most of us would care to maintain during touring or riding to the office. A figure around 0.1 hp is probably a more reasonable value for a non-exhaustive bicycle ride that lasts for an hour or so.

At 10 miles per hour, the cyclist would have a power output of 0.13 hp, which requires more than a comfortable power output for the average individual.

Figure 6: Highest comfortable speed (miles per hour) of cycling.



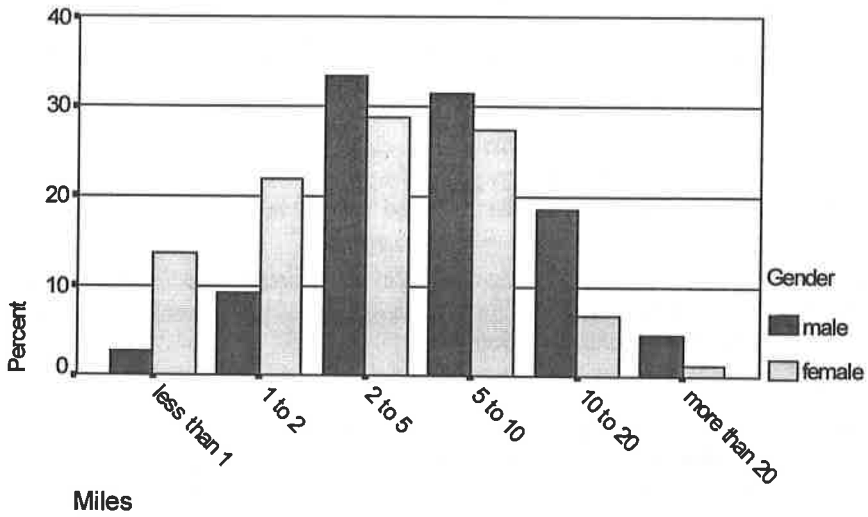
Journey length

Up to 83% of the respondents thought that a journey of less than 10 miles was applicable to older people. However, 35% of females preferred to cycle within 2 miles, which is the distance covering more than 35% of the existing journeys in the UK (Figure 7).

According to the Department of Transport, the existing journey patterns show that 72 % of all journeys are less than 5 miles in length; half are less than 2 miles. Hence, for local transport in either urban or suburban area, the cycle is potentially capable of carrying Third-Agers to almost anywhere needed in daily life.

[2] 1 hp = 746 watt

Figure 7: Comfortable longest journey for cycling (miles).

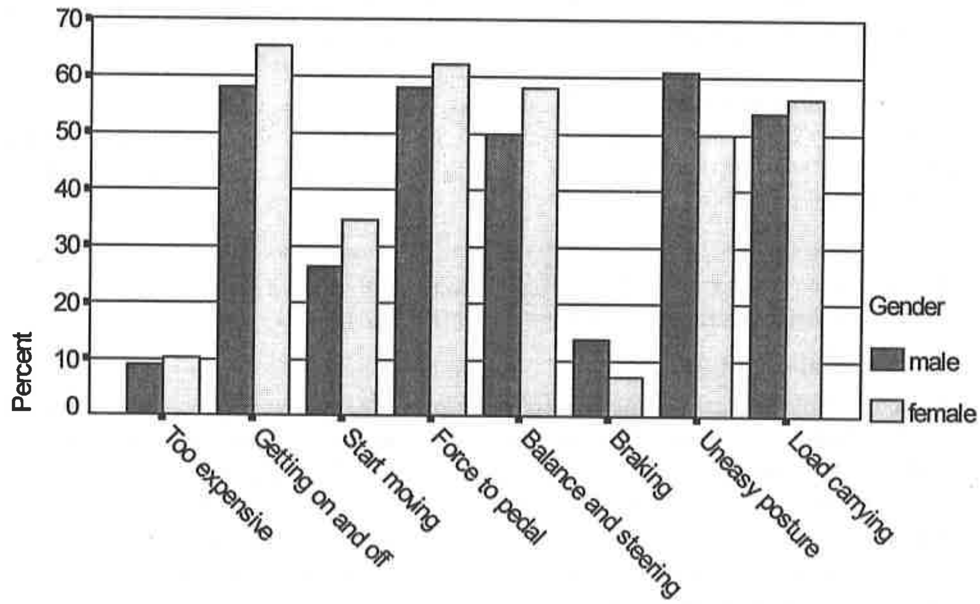


3.3 Difficulties of dealing with cycle

Within the category of 'the Third-Agers' capability of cycling', the most prevalent concerns are 'Getting on and off' and 'Force required to turn pedals', followed by 'Uncomfortable posture', 'Keeping balance and steering' and 'Load carrying' (Figure 8).

The physical skills of an individual usually peak between the early twenties and the mid-thirties. One of the major reasons for a decrease in physical performance during adulthood is a reduction in muscle strength. Muscular strength and the ability to maintain maximum muscular effort have both been found to decline steadily during middle adulthood. By age 30, about 70% of a man's 175 pounds is muscle. Over the next forty years, he loses ten pounds of that muscle as cells stop dividing and die. To illustrate : by age 45, the strength of a man's back muscles declines to approximately 96 % of its maximum value, and by age 50, it declines to 92 %. Most men in their late fifties can only do physical work at about 60 % of the rate achieved by men who are 40 (Rybash, Roodin and Hoyer, 1995).

Figure 8: Difficulties of dealing with cycle.



Too expensive

There are relatively fewer respondents (9.6%) who think it is too expensive to cycle than those (64.2%) who think to drive a car is too expensive. There are no distinctive differences between age groups or gender.

To most Third-Agers, cycling is something affordable when it is needed.

Getting on and off a bicycle

Getting on and off appears to be the most serious concern in cycling: 61.2% of the respondents felt that it was difficult to get on and off a bicycle. In another investigation by the same authors, coincidentally, 62.1% of the respondents reckoned 'getting in and out of a car' their second biggest (night driving is the 1st) problem when driving a car.

Getting in and out of a vehicle, including car and cycle, is considered a difficult process for the survey respondents. These factors provide designers with opportunities of making it easier to get in and out of vehicles when designing for elderly people.

Start moving

There were 30.1% of the respondents who thought that starting to move a cycle was somewhat difficult for elderly people. More females than males thought so. The age group of 60 to 69 tended not to think starting to move was a difficulty for them compared with other age groups.

It requires a certain degree of adeptness to start moving a bicycle smoothly. In spite of the difficulty of keeping balance when starting to move a bicycle, the force required to overcome the static friction of the mechanism could be a serious problem for older people.

Force required to turn pedals

It is not a surprise that 60.3% (second to 'getting on and off a bicycle') of the respondents considered cycling as heavy work for elderly people. Cycling at a speed of 10 miles per hour without hills and wind resistance requires 5 W/kg energy expenditure (Abbott and Wilson , 1995) which applies to walking at a speed of 4 miles per hour. Taking the additional resistance of hills and wind drag into account, it requires a much effort to move the cycle. A power-assisted system may be essential for human-powered vehicles that are designed for the Third-Agers living in hilly or windy countries.

A small kitchen mixer is likely to have a power output of about 0.1 hp which if applied might double the power of our average cyclist. A sealed 12 volt battery, which weighs under 6 lb., can power a 0.1 hp motor on the cycle, taking a typical cyclist along for about 5 miles without pedalling. If the cyclist pedals while using the power assistance, the battery will last even longer.

Keeping balance and steering

It was found that 54.5% of the respondents in the investigation believed keeping balance and steering when cycling was difficult, especially females of whom 58.2% believed so, compared with only 50.0% of males.

When bicycling, one might lose his confidence if he or she cannot keep the moving cycle stable. Anyone who cannot easily keep balance while cycling, will never gain complete confidence. Hence, a proper adaptation for cycling balance might be not only physically but also psychologically essential to the ageing population.

Braking

Braking when cycling seemed not to be a problem (10.5%) for most respondents. Males and younger age groups tended to think braking was a problem when cycling.

Uncomfortable posture

Uncomfortable posture was the 3rd highest rated difficulty when dealing with cycles, comprising 56.0% of total respondents. 48.3% of the respondents who used road bikes thought uncomfortable posture was somewhat of a problem for elderly cyclists. The rates went up slightly to 50.0% and 55.6% for those who used a mountain bike and those who used a foldable bike.

Those who cycled tended to think uncomfortable posture was one of the major concerns for elderly cyclists. Those who did not use a road bike, mountain bike or foldable bike tended to have an optimistic view about the problem of uncomfortable posture. Males (60.9%) outnumbered females (50.0%) by 10.9 % in the problem of uncomfortable posture when cycling.

The recently introduced recumbent cycle seat is an alternative to the traditional bicycle saddle. Besides this, the effect of the addition of a suspension system on a cycle has to be analysed.

The main reasons that make Third-Agers use a cycle less frequently than younger adults are 'Getting on and off' and 'Force required to turn pedals', both of which can be solved by innovative design and up-to date technology.

4 Conclusion

Cycling offers a widely accessible, healthy, convenient and environmentally-friendly means of making local journeys, especially in urban and suburban areas. Cycling at moderate speeds enable older people to take full control and could be a better choice of local transport for Third-Agers. A clear recommendation arising from this survey is that a cycle-friendly infrastructure and thoughtfully designed human-powered vehicles can offer a better choice in local transport to the ageing population.

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A Simple Trike with a Roof
– for Elderly People in Denmark

by Per Lindhardt

Abstract:

The paper presents the design considerations behind a simple trike aiming at elderly peoples'' daily needs and their use of the bicycle-path-system in danish suburbs. The paper further reports on reactions from the public so as to conclude on a wider acceptance of 3 wheeled bicycles.

1..The Problem.

First and foremost challenge to designers of velomobiles for a danish public is to be on a par, not with automobiles but with current normal bicycles so as to enjoy the safety provided by our numerous bicycle-paths adjacent to the roads —yet, on three wheels!

Next comes the requirement of meeting this challenge by affordable means i.e. with a simplicity on a par with current bicycles and while relying on same easily available, mass—produced components.

Finally comes the challenge presented by existing velomobile solutions for improved w eather protection as compared with the one offered by normal bicycles.

As to fairing this issue may well be neglected in regard of the speeds elderly people can realise.

2. Specification of Concept.

Basic suitability for our bicycle-path-system is provided, if a trike is built within the limits given by law for current two-wheeled bicycles, i.e. with an overall width of the vehicle not in excess of 70 cm.

Further in regard of elderly drivers (and their knees!) seat height should not be lower than about 40 cm and seat should be taken before lifting any leg from the ground is required.

As to the efficiency of pedalling, advantage should be taken from recent designs of recumbent bicycles, where reactions to pedalling forces are obtained from the support of the entire back of the driver - up to his shoulders and from the steering handles, as realised for instance with Bjällby Recumbents.

With the above requirements meet, tilting stability will be a major concern to deal with. Therefore, the vehicle must be given leaning properties, i.e. be felt like a two-wheeled bicycle, but with its three wheels trusted as a car!

As to the requirement of simplicity, a model should be taken from the classical solution for loadcarrying trikes, represented today by Christiania-bikes, or as shown on Figure 1 with only 3 items involved: a frame with a normal transmission arrangement, a frontwheel-carriage -- and a seat. Or an articulated vehicle with a single steering tube to give a fixed relation between radius of turning and leaning angle of the frame.

3. Concept Tuning.

The assembly of the items of Figure 1 is shown on Figure 2. Weight 19 kg.

A number of look-alike versions of this concept were built and tested over 2-3 years, meaning, that the design proces merely resembled a tuning-in--or an evolution proces if you like. In actual fact a proces of discovering the priorities of the problems to solve.

The most serious obstacle thereby encountered was the tilting risk at a very frequent type of maneuvring namely the passage from the right side of the road via a short ramp to the adjacent bicycle-path, i.e. at an oblique angle of attack -- and with the frame upright!- or what is so easily done on two wheels. While still being able to turn at a radius of about 2,5 m.

The measures and characteristics to realise this capability are shown on Figure 3 and with the critical situation demonstrated on Figure 4. Somewhat surprising this capability is rather enhanced if load on the back wheel is 40--50 % of the total weight of the vehicle.

Figure 4 further shows how the steering gear opens like a door for easy access. One just walks "into" the vehicle and takes seat before lifting the legs to the pedals. The inspiration to this solution was derived from the winning project of the bicycle-design competition in Copenhagen 1996, although the connection may be hard to see.

Now, with the design tuned-in on the above considerations alone, it is interesting to compare the leaning angle of the frame at turning with the natural leaning angle on a normal 2-wheeled bicycle.

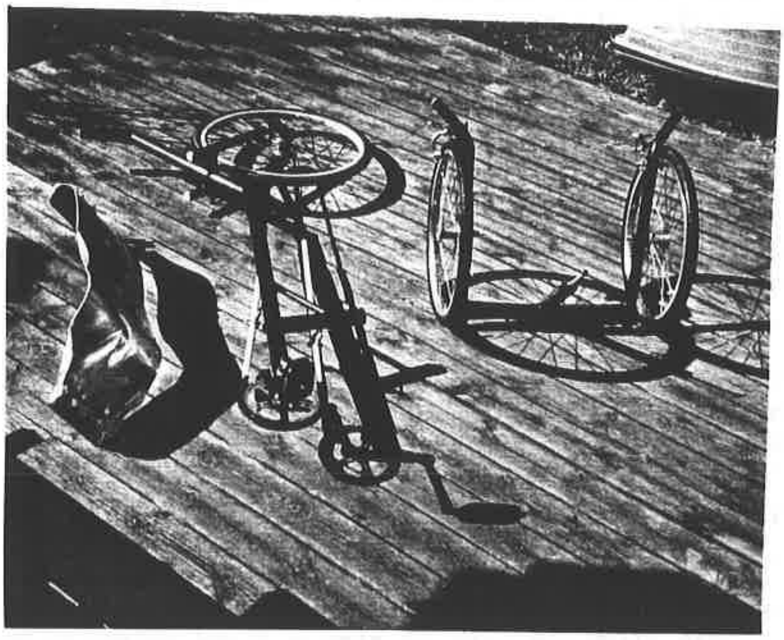


Figure 1

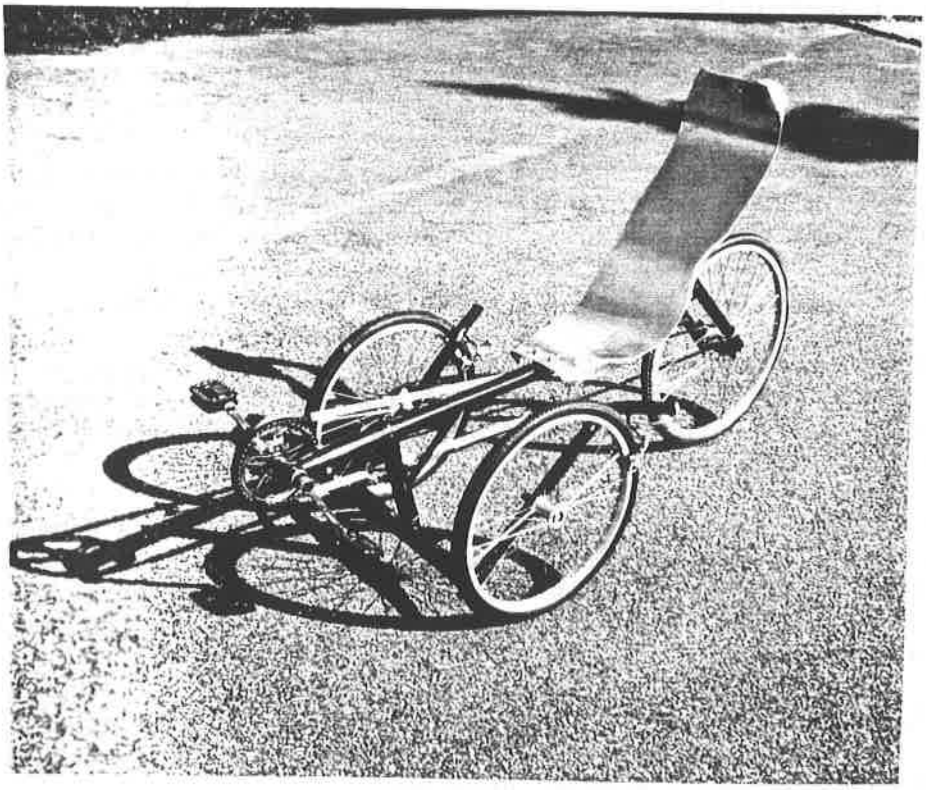


Figure 2

A small exercise on Figure 3 here reveals, that the driver feels exactly as on two wheels at a speed of 1,43 m/s at a radius of turning of 2,5 meters --gently increasing to a speed of 1,56 m/s at a radius of turning of 20 meters. Thus, when turning a corner at a speed of 5,2 to 5,6 km/h, as a cautious driver would do, the bicycle-feeling is perfect and the car stability margins are unimpaired. At higher speeds the driver will naturally lean the body inwards and so the vehicle can be trusted as a car at normal manuevring,--with important reservations how--ever : Never approach a ramp with the foremost frontwheel up first! - and take care of deep holes in the ground ! - or tilting will be an imminent risk!

This vehicle has its peculiarities --as others have--to learn and master automa--tically.

4..Steering Philosophy.

Most velomobiles have steering mechanisms derived from automobiles so as to have independence of steering forces from other forces and in particular from those from the ground. Trikes as the Christiania-bike use the inertia of the loaded frontwheel-carriage to obtain a similar independence.

In the present case adjustable Coulomb-friction in the sleeve bearing of the steering tube was used for a long period to obtain a similar independence of steering forces from ground forces--and fairly satisfactory. once stick-slip problems had been overcome by lubricating the steering tube bearing with a cop--per--grease (to avoid seizure).

However,with the small track-width of 61 cm and with an arm of same magnitude from steering handles to steering tube, such added friction was not only found unnecessary but even disturbing.

Firstly because an obstacle hitting one frontwheel would cause the frame to lean to the safe side in regard of tilting —or a property one just needs to trust.

Secondly because the unsafe feeling from a frontwheel loosing ground contact when the frontwheels hit obstacles almost simultaneously, could be avoided by just letting the steering whir freely and by using the hands to damp and correct the ground influence only.

Finally because thus leaving the impetus to steering to the ground would help to avoid the situations where obstacles are meet with the foremost frontwheel up first —as mentioned in the preceding section.

As can be derived from Figure 3 the pointing of the steering tube to the ground about 10 cm ahead of the line between the contact points of the front wheels means, that the vehicle will understeer, i,e. centrifugal forces on the vehicle at turning will tend to reduce the steering angle applied. Therefore, no risk of steering in—stability at high speed exists. Moreover, the individually operated frontwheel—brakes can be activated differently without but small extra steering forces to apply.

Yet, one hand at least must be kept on the steering gear as with most vehicles, and with both hands on, pedalling efficiency is improved by involving the entire body of the driver as with normal bicycles.

5..Comfort Features.

The interest in a minimum of width in regard of traffic also allowes for taking the vehicle through most doors and for hauling it up stairs so as to be stowed away in vertical position as shown on Figure 5.(a roller skate wheel to add aback if rolling the vehicle in vertical position is desired).
Pushed along on pedestrians walks the vehicle can be steered by tilting the frame.

As to the requirement for transporting shopping goods Figure 3 (and 6) shows how two baskets can be mounted for carrying almost unlimited weight without jeopardizing the tilting stability of the vehicle.

Figure 6 finally shows what can be done for protecting the driver against the wet and windy Danish climate.
Thus two T-pieces can be attached to the frame for mounting a hard-top of say plexi-glas —or a tent, hinged to the T-pieces so as to be swung aside at mounting the vehicle —somewhat like if "going to bed"..

Often it may be preferred just to take a shelter along for occasional rain-showers and then a simple rain-cape can be hooked to the T-pieces like a hammock instead. The whole to be easily stowed away onboard in fair weather.

As shown on Figure 5 the vehicle is prepared for the mounting of a small auxiliary engine --to use if allowed in non-EU-countries !?

6..Market Prospects.

The author has used vehicles of the concept presented over a period of 3 years on daily shopping tours in a township of some 20000 inhabitants --also to obtain some impression on the marketing prospects for the proposition.

This impression has recently been supplemented by a report from a project in our nabourtown of Allerød,where the community summer 1997 bought 15 trikes of traditional design (2 wheels back) to lend to elderly citizens for periods of 6 months. This independent initiative came from Jerrik Gro Jensen of the urban planning consultancy Anders Nyvig,Hørsholm,Denmark.

The authors impression has been that the elderly citizens of Birkerød, aimed at, invariably regarded the proposition as an aid for disabled (to pity!)- while children of age between 5 and 15 frequently marvelled at the sight of such a "cool" bicycle!

The report from Allerød (of same size as Birkerød) indicates, that of the 35 being interested at all, the average age was 76 years and with 70% of those involved in the project beyond the age of 70..

So the disappointing impression received by the author may well be due to his being too young —or too old ? for marketing ?

It seems that one has to be close to the age of 80 before it is more "cool" to drive a trike than a wheelchair ! - and that the market would then be confined to lending or leasing arrangements —..

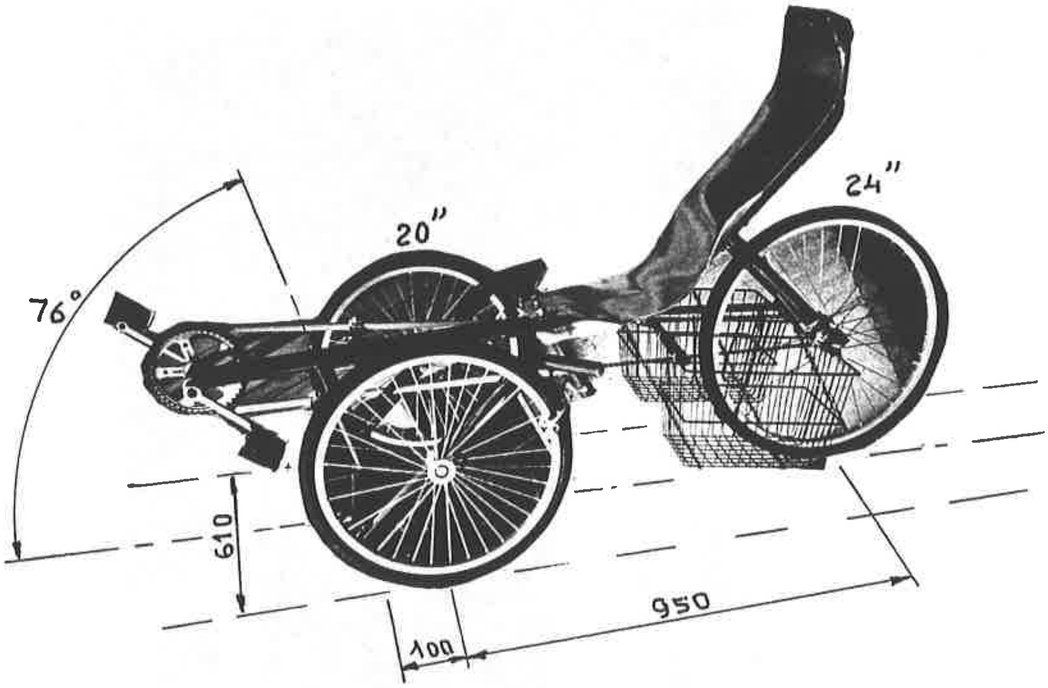


Figure 3

Figure 4

Figure 5

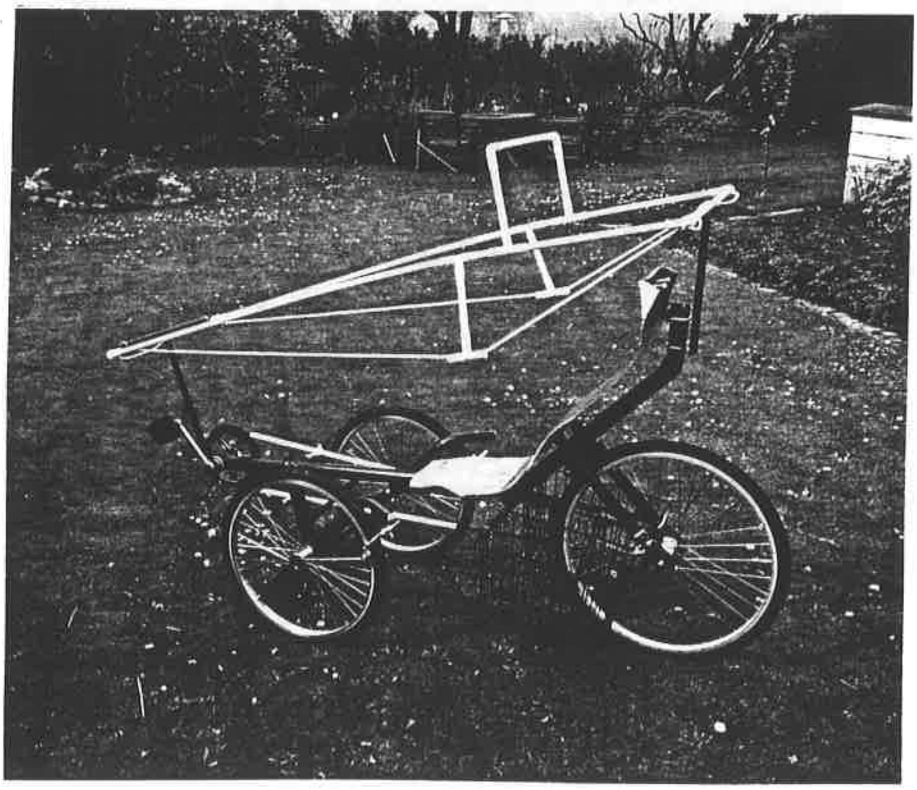


Figure 6

7..Conclusion.

The author believes to have found a happy compromise between a bicycle and a tri-cycle or to have united the best features of both types with a minimum of draw-backs.

Yet, the aiming at the demands of elderly people in their 60ies has been proven to be a downright failure in spite of all logic because the mere proposition of driving on three wheels seems to violate dignity and self-esteem of this age-sensitive target group.

Presented as a velomobile solution the concept might on the other hand lack the sophistication required by a public of all-weather bicycling enthusiasts.

Therefore,the proposition presented may well have to await its proper time of changed public attitudes or changed economic conditions.

Till then its simplicity may serve as a model from which to judge future advancements of the art.

—o—-

THE DESIGN OF ADVANCED HUMAN-POWERED VEHICLES/VELOMOBILES AND PRODUCT-LIABILITY LITIGATION: CAN THEY CO-EXIST IN THE LIGHT OF APPARENTLY OUTRAGEOUS US CASES?

David Gordon Wilson

ABSTRACT.

Much publicity is given to "horror stories" of seemingly excessive judgments against apparently ethical manufacturers after they have been sued by unscrupulous people pretending to be victims of what is claimed to be deficient design. However, these reports are far from representative of the actual situation. It is pointed out in this paper that the other side of this story is that product-liability litigation is decreasing quite markedly in the US; that this form of litigation brings about major improvements in product design and in the safety of the public; and that it is possible to avoid most negative impacts of such litigation by striving for, and documenting, excellence in the design and manufacturing of products, by clearly warning users of dangerous situations, and by putting trust in insurance that is standard for the industry.

INTRODUCTION.

Background.

In many areas of modern life we are driven by what we know of extreme cases: only these are reported by news organizations. Here is a recent example (disguised so that your author does not get sued! I was an "expert witness" for one of the manufacturers involved).

"Bill", a young American, bought a regular "road" bicycle for recreation. He found that he liked biking, and hearing that sew-up tires are used by racing cyclists and would enable him to go faster, bought new wheels and tubular tires and had them installed on his bike. One day he went with a group of friends on a ride that included the summit of a small mountain. While pausing at the top he joked to his friends that he had bad brakes, showing that with the brake levers fully squeezed against the handlebars he could move his bike easily back and forth. He then said "Last man down the mountain buys the beers!" and rushed off down the steep, rough, bumpy, asphalt road with the others in hot pursuit. The road had signs showing a speed limit of 35 km/h, and, after about a kilometre, a warning of a sharp S-bend. The person who was closest behind Bill said that as he approached the bend his cycle-computer was registering about 75 km/h and that Bill was out of sight ahead of him. He braked to get around the bend and saw that Bill had hit a stone wall and was lying on his back some distance from his bicycle.

Bill had severed his spinal cord and was, tragically, a quadraplegic from then on. He gave his bike to a family member, who, after having the front wheel and fork replaced, used it regularly. Bill confessed at some point that the accident was his fault. However, after over a year he (or possibly his insurance company) decided to try to get some money through the courts, and his lawyer sued the bicycle shop that sold him the bike, the bicycle manufacturers, and the supposed manufacturers of the rims and the tires (the actual wheel and tire had been disposed of). One would have thought that these companies would have had a very strong case. Yet one by one they, or rather their insurance companies, all "settled out of court", meaning that they agreed to pay large sums to the plaintiff to avoid the far-larger costs of going to trial. They also may have felt that, however strong their case, the sight of this young man sitting paralyzed in a wheelchair, with his wife and child, would be enough to make an American jury decide that these insurance companies were rich and Bill and his family had already been punished terribly. To award him a large settlement even though he was at fault could be possibly some form of jury-administered social justice.

The present status of product-liability litigation in the US.

Cases like this seem to be typically American. In what is considered to be a free-enterprise system (but is in fact increasingly regulated) the absence of a socialist health-care and welfare system seems to give credence to reports of juries leaning to the "left". They are drawn largely from the lower end of the economic spectrum because professional people try to find reasons to be excused from jury service. However, contrary to popular belief, jurors do not overwhelmingly sympathize with individual plaintiffs at the expense of companies. According to Jury Verdict Research reported in Business Week on November 8, 1993, defendants won 57 percent of the products-liability suits in 1992. Popular opinion also paints a picture of a flood of products-liability litigation. In fact, products-liability lawsuits were less than 1 percent of the total state and federal caseload in 1994[1]. (There is a huge backlog of lawsuits awaiting trial in most US jurisdictions, but most cases are suits between businesses and suits between family members, particularly divorce cases). The number of product-liability lawsuits is also in sharp decline, having dropped 40 percent between 1985 and 1991. Insurance premiums covering product liability dropped 45 percent between 1987 and 1993[2].

There is also concern regarding so-called "punitive damages" awarded by some courts. These are imposed for particularly egregious cases in some states (punitive damages are not allowed in many states, including Massachusetts) and are derived from ancient Roman and English law[3]. In fact, apart from the special and shocking case of asbestos liability, the awarding of punitive damages is very rare in the US, under ten cases per year. A velomobile/HPV manufacturer would have to be very delinquent, or exceedingly unlucky, to be included in this number.

The remaining fear of liability lawsuits.

So far I have given some details of the type of case that strikes fear in the heart of small manufacturers who are concerned that one such lawsuit could put them out of business; and I have also tried to show that much of the concern is exaggerated. However, I should describe how lawsuits come about and are adjudicated or settled in order to give manufacturers of velomobiles, particularly those outside the US, an understanding of the risks and rewards of exporting to the United States.

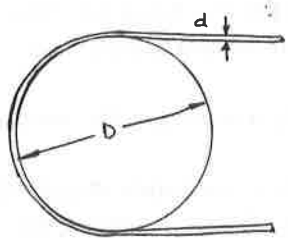
The US is a country where even a poor person can sue the world's largest corporation. To do so she/he needs to persuade a lawyer who specializes in this type of case that her/his injuries or other harms are sufficiently serious to justify taking action. The lawyer will generally do this on a "contingent-fee" basis: that is, she/he will charge the client nothing for his/her services, but will take 25 - 33% of any monetary award. This has the socially desirable consequence that people of limited wealth are given full access to the courts in cases where they have been harmed. Although occasional large awards receive a great deal of publicity, juries are generally hard-headed and reasonable in awarding damages.

Most cases, however, do not go to trial. The early stages of a lawsuit are taken with "discovery", a process in which each side is required to make available all relevant written records and all relevant people to give depositions. So-called expert witnesses are hired by both sides to add weight to the testimony. The discovery process can be a time-consuming, disruptive and costly time for a manufacturer, although the attorneys' and experts' costs are usually handled by the insurance company. The opposing lawyers can demand, however, all drawings, sketches, notes and other records that have any possible connection with the injury to the plaintiff. Each item considered actually relevant is labelled as "Exhibit A, B etc." During this period the attorneys for each side are assessing their situations and their likelihood of winning or losing in the trial. At some point the lead attorney on one side will contact the lead attorney on the other side and say something like the following. "As a result of discovery and depositions we have an overwhelming case, and your side is likely to have to pay large sums if we go to trial. My client has expressed a willingness to settle out of court for a payment of X dollars." Sometimes the other attorney accepts the offer with alacrity. More often there is a period of negotiation, as in a market anywhere. In under ten percent of cases agreement is not reached, and a trial date is set. This may be several years after the suit is filed.

I believe that this procedure is fair and leads to social justice in the large majority of cases. It is difficult to be fair in cases where a life has been lost or serious permanent injury has resulted from a product defect. Suppose, for instance, a promising young person just married and just launched on a promising career is permanently confined to a wheelchair because the fork of a new bicycle snapped in normal use. No amount of money could compensate this person and her/his spouse and family for the terrible change in the quality of their lives for perhaps the next fifty years. The medical-care costs alone could amount to a huge sum. Such cases could be regarded as the norm in malpractice lawsuits against the medical profession, which takes extraordinary steps to prove that every decision and procedure taken has been for the best. A whole battery of very expensive tests will often be specified for a minor ailment, purely to ward off a suit against supposed malpractice in the event that a patient's recovery is not all that might be expected. The manufacturer of a human-powered vehicle does not need to go to these extremes. However, she/he must likewise take very conscientiously, and document in some way, the design and manufacture of any component the failure of which could cause, with reasonable probability, serious injury or death.

Manufacturers in countries where liability litigation is rare might well react with some alarm at having to take major precautions to avoid being sued, and to face unwelcome prying into their design, manufacturing and business practices if they are sued. These seem to be the price we pay to have markedly safer products in the US (and increasingly the safety advances achieved in the US partly through liability lawsuits have been adopted in Europe and elsewhere). Consider the alternatives.

It is claimed above that the quality of design and manufacture is enhanced by the possibility of liability litigation. There is, however, some question about the benefits that occur if a case is settled out of court, because of the secrecy that is more marked in the US than in, at least, Britain. (My professional field is turbine design, and the catastrophic failure of a turbine in Britain is followed by a full exposure of the causes, and the steps taken to cure the problem, in papers presented to the Institution of Mechanical Engineers. This public airing seldom occurs in the US, except in the case of airline crashes.) However, I believe that the message does get broadcast. An example is a case in which I served as an expert witness. A linesman working on overhead wires while on a truck-mounted aerial ladder was severely injured when the ladder suddenly collapsed, dropping him to the pavement. The cause was relevant to safety in HPVs: the ladder was operated by wire ropes that passed around several sheaves (figure 1). The sheave diameter was only seven times the wire diameter. The standards set by the wire-rope manufacturers are that the sheave/rope diameter ratio should be 72 for long life, with 42 being an absolute minimum. At a ratio of 7, the rope was bound to have a very short life before metal fatigue caused it to fail without warning. (The parallel with HPVs is that bicycle brakes and gear-shift cables are taken around pulleys and bends with a diameter ratio of far less than 42, and also fail periodically without, usually, any warning.)



Sheave Diameter Factors

Rope construction	D/d ratio: For ropes subjected primarily to bending stresses	General purpose: Recommended	General purpose: Minimum
6 x 7	72	63	42

From a guide by Armco Steel.

Figure 1 Sheave/rope diameter ratios.

When the lawyers for the two sides agreed on an out-of-court settlement, I became very disturbed that workers would be killed or injured because now, it seemed, the information about the extreme hazard that these ladders and booms posed would not be made public. The attorneys agreed with me that my professional engineering ethics outweighed my expert-witness responsibilities, and allowed me to try to send warnings of the extreme danger of these ladders to unions and other places. However, I believe that the manufacturer recalled the trucks faster than did any actions resulting from my warnings: the company did not want to face the rash of lawsuits that it now knew would be certain to come. Liability litigation had worked! Why doesn't it work to give us safe brake cables? I have had many cables, and handlebars, and cranks break, but fortuitously never at a critical time. If I had, there would have been a strong probability of a fatal accident, and, because bicycle accidents are usually not investigated with any degree of seriousness, the cause would not have become known.

Would it be better without lawyers willing to sue?

Contrast the recent US situation with that in Britain when I last lived there, in the 1960s. As an example, on one occasion I went to the National Health doctor specified for my district after I had had a sore throat for several weeks. With very few questions he told me to lower my pants, and jabbed a needle into my right buttock. By the next day the sore throat had cleared up magically. But my right leg grew huge and red and hot and very itchy. I could sleep at night only by lying in a tub of cold water. I went back to the doctor twice during the next two weeks as the swelling spread over the rest of my body, increasing my weight 17 kg. He waved me airily away. "It will go down!" he said. At about that time I had to fly to Boston to be introduced to the firm that had just hired me. My new boss met me at the airport: I was trying to disguise my sorry condition. From a distance of 20 m he cried out "What's the matter with you, Dave? You look as if you have a penicillin allergy!" He rushed me to his doctor, who said that I could have been dead in another 24 hours because the swelling was closing off my airways, and he treated me expertly so that I was fully recovered within five days.

There are several other similar anecdotes that I could tell about medical care in Britain, at least one occurring to a friend relatively recently. To me, there is one principal conclusion: physicians there have, or had, absolutely no concern about being sued. In the apparent absence of any other form of control they had absolute power. And absolute power corrupts. I have no doubt that many cases of malpractice were quietly swept under the rug. That leads inevitably to another rather startling conclusion: Britain has too few lawyers pursuing malpractice cases. They may not take cases on a contingent-fee basis, and they are also liable to face payment of costs if they lose a case. I am sure that this is also true of many other countries. Another conclusion is that the perceived (not necessarily the real) costs of medical care will undoubtedly seem lower in Britain than in the US.

If I had to choose between just these two alternatives, I would unhesitatingly take the US system, even though it makes engineering design and production a little more expensive. It produces a far safer society. If this were a paper about the reform of liability and malpractice law I could quote several authors who have proposed improvements that should bring about a happy compromise between these two alternatives (Linowitz[4], Bok[5]). But this paper is about the impact of the existing US system on the design of advanced human-powered vehicles. This is the topic of the next section.

IMPACT OF LIABILITY LAWS ON HPV DESIGN.

The perceived impact of liability laws in the late 1970s on the design of the Avatar 2000, which we believed to be the first recumbent bicycle to be produced for general sale since the 1930s, was the following. The initial impetus for the design was my concern for safety[6], because I had seen many reports of riders of regular "road" bicycles being severely injured or killed after going head-first over the handlebars on applying the front brakes too hard, or riding into a grating or hole in the pavement, or having baggage or a stick get caught in the front wheel, for examples. It seemed to me to be safer to go feet first. It was easy to list, in addition, other virtues that would improve safety: the near-impossibility of catching one's pedals on the road; the great improvement in the ability of the rider to see forward and to the side; the improved braking capability on both wheels; the shorter reaction time resulting from the hands being on or close to the brake levers at all times; and the lessening of injuries because riders are closer to the ground than when on road bikes. There were, and are, a few negative aspects to recumbents: the view to the rear is more circumscribed unless one uses a rearview mirror; and it is difficult to recover from a skid because of the low centre of gravity and the attendant rapidity with which one is "dumped" on the ground. The "safety balance" is clearly in favour of the recumbent. However, we knew that we would not receive large cheques from grateful riders who felt that our bicycles had saved them from serious injury. We would be more likely to be sued for larger amounts in those few areas in which our design might be worse than that of upright bicycles. (Designers of three- and four-wheeled vehicles have other advantages and disadvantages, of course).

We responded to this dilemma was in three ways:

1. we made the bicycle as safe as practicable;
2. we gave prolific warnings about possibilities of danger; and
3. we took out an insurance policy that was standard for (small?) bicycle manufacturers.

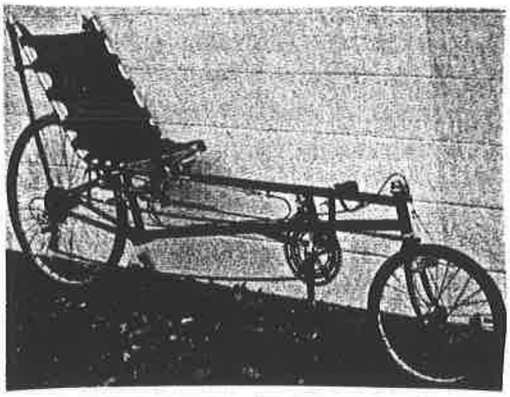


Figure 2 The Avatar 2000

We discussed the positive and negative features of the bicycle design with the insurance representative, who felt comfortable in giving Fomac, manufacturers of the Avatar, a policy that would apply to manufacturers of regular bicycles. There was an indication that, if the Avatar turned out to be as much of an improvement in safety as we claimed, our rates might even be reduced. This gave an added incentive, if one was needed, to increase safety in our design wherever possible. As mentioned above, insurance rates for liability have in fact dropped markedly since that time.

THE INSURANCE INDUSTRY.

Insurers are therefore major players in liability litigation, frequently almost taking the place of the defendants in pretrial organization of the defense and in the trial itself. Their role is that of insuring against risks to businesses, and of doing it in a way that is least costly to manufacturers (otherwise they would go to other insurers) while making a profit themselves. Insurers have a major stake in litigation, and have an obligation to ensure that any settlement is not greater than the limits of the insurance that has been purchased by the manufacturer. An insurer (meaning an individual agent or the firm she or he represents) may decide to settle out of court even though many may believe the case to be defensible, as in the example quoted above, simply to avoid the continuing high costs of attorneys and expert witnesses and the large amount of time that its own personnel will be spending on defending the suit.

An insurer might also be behind Bill's late decision to bring suit. If he had a policy that covered the medical consequences of accidents, his insurance company could well have contemplated the enormous lifetime costs of providing medical and other services and have taken the decision to institute the suits. Sometimes American courts play out dramas in which one family member may bring suit against other family members, a seemingly highly distasteful procedure. The suit may, however, be required by provisions in small print in the insurance policies, not by any previous ill-will in the family. There is, therefore, economic justification for this type of suit. It would be better if a system could be devised that was not so wasteful and invidious for the parties involved: a large proportion of any funds transferred from the defendants to the plaintiffs goes to legal costs, and the proceedings are likely to split families apart.

EDUCATION AND LITIGATION.

Design education has been helped by liability litigation. At M.I.T., and I'm sure at most universities, concern about the impact of litigation on engineering has led to an much-increased emphasis on engineering ethics and our responsibilities to society. The disaster to the Challenger space shuttle was a shock that brought about changes, particularly after it was found that engineers who had been fighting to have the launch put off because of what seemed to them obvious flaws in the low-temperature performance of some seals had been overruled by policy-makers, some of whom were also engineers. Our students are shown a videotape of a talk by one of the "whistle-blowing" engineers involved in the Challenger case, and many are moved to tears. We examine other case-studies for lessons to be learned. For instance, one of the first skyscraper fires occurred in a New York building on the 37th floor, far too high to be reached by ladders. The first group of firemen decided to take the elevator to the 38th floor, break through the ceiling and spray water on the fire. However, the elevator stopped on the 37th floor, the doors opened automatically, and all were killed. The elevator was one of the first to be operated by heat-sensitive buttons, and these naturally stopped it where the fire was blazing. We ask our students how it was that in the several years required to invent, develop and manufacture this elevator-control system, no one in the company making them, nor in the architectural engineering offices specifying the use of the buttons, ever considered what would happen in the case of a fire. It seems likely that one or more people did think of this possibility, but were overruled. One obvious conclusion is that, like the British physicians mentioned above, no one was concerned about being sued for malpractice. Yet it is surely malpractice to design and install a device that, although it works wonderfully for every expected use, will kill or injure in an unexpected, but not unlikely, situation.

Can concern for safety go too far?

Designs analogous to heat-sensitive buttons for elevators can be found in many areas. Only a few years ago we drove cars that had rigid steering columns ready to pierce drivers' chests even in a low-speed collision. Now we have cars in which the driver and occupants are surrounded by air bags and restrained by belts and protected by a passenger compartment that will allow people to walk away from a frontal collision at 60 km/h and higher. Some research has found that some drivers like to operate their vehicles at an exciting level, a level at which they perceive a certain degree of danger. Give them seat belts and airbags and their average speed increases so that they feel the same degree of safety or danger. On the other hand, there is in the US at present an enthusiasm for huge sports-utility vehicles, partly because they are much more likely to survive, along with their drivers and passengers, in collisions with regular automobiles. The safety of others, including pedestrians and riders of HPVs, has thereby decreased. There is, therefore, an optimum level of safety engineering. This level should be found by estimating the benefit-cost ratio of any proposed change, evaluated over the whole affected population, not just the users of the new system[7]. The "benefit" side of such analyses require the invidious decision on what value to put on human lives saved. Perhaps it is justifiable to avoid this thorny question by using, instead, the expenditures that could be predicted as having been avoided in litigation lawsuits. In either case, benefit-cost analyses would indicate that some proposed safety measures had gone too far. It is also certain that safety aspects of bicycles, regular and recumbent, would be found to have not received enough attention. We cheerfully ride bicycles with brakes that wear fast and don't stop us safely, on rims and tires that can explode at at least a thousand times the frequency of those on motor vehicles, and so forth. There are several ways (research and development, industry standards and government regulation being three) whereby improvements in our HPVs can be attained. We may have to depend on a fourth way: liability litigation.

CONCLUSIONS.

The threat of US liability litigation has been exaggerated, especially with regard to human-powered vehicles. The many US manufacturers of recumbent bicycles and other velomobiles are not being overtaken by a flood of lawsuits. The quality of design and manufacture of the great majority of vehicles is very high, some of this high quality undoubtedly having been brought about by the desire of the designers and manufacturers to be able to stand up in court to defend their work. Liability-insurance rates for manufacturers have actually fallen as a result of the increased safety brought about by lawsuits and by regulation, and the insurance companies take most of the impact should a suit be filed. Finally, if a suit is filed and goes to trial, the great majority of US juries make fair and reasonable awards.

ACKNOWLEDGMENTS.

Attorneys Neil Sugarman and Phillip M. Davis were kind enough to read early drafts of this paper and to give valuable advice and documents that I have incorporated in the final version. My spouse Ellen Wilson also gave much-appreciated criticism. I am most grateful for their help.

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The Danish Bicycle Design Competition 1996

by Johannes Lund *)

To help the bike to get a break-through as a **practical integrated** means of transport, **Danish Cyclist Federation, Association of Danish Designers** and **The Danish Ministery of Traffic** arranged a **Design Competition** in May 1996.
As a member of the organizing group and the jury, I will report on and comment the thoughts and work behind the competition and its preparation. Besides I will present and discuss some of the ideas entering the competition.
The result of the competition was rightly criticized from many sides. I will present my own points of view of both the negative and the positive outcome of the competition and what we can learn from it when we plan similar events in the future.

Background
As part of the Cultural Capital 1996 a Bicycle Culture Week was held in Copenhagen from the 5th to the 12th of May. Among the projects in the planned program was a Bicycle Design Competition. The competition was announced during the Bike Culture Week, May 8th, 1996, and concluded with the awarding of the prizes on the 29th of November that year.
The final co-sponsors, who also cooperated in looking after the practical details of the competition, were: The Ministry of Transport, The Association of Danish Designers and The Danish Cyclist Federation.

Why a Design Competition?
The three sponsors had rather different motives for backing the competition:
The Ministry of Transport saw its participation as one of several initiatives aimed at replacing 4% of all car trips with cycling or walking trips by the year 2005 [1]. The Ministry favoured focussing on the production of better and more functional equipment, especially resulting in improved safety. Emphasis should be on better accessories for the traditional bicycle; there was skepsis about calling for new bicycle concepts.
The Association of Danish Designers entered enthusiastically into its function as co-organizer. The bicycle had not been the subject of a design competition in Denmark before and this was an obvious chance to show that the word design did not simply mean superficial esthetic form, but also functionality.
Danish Cyclist Federation's point of view was that the development of the bicycle in the direction toward an integrated, practical vehicle lagged far behind the comparable development for cars: Why are bicycle lights not a built-in feature? Why is there no lockable baggage compartment on a bike? Why do cyclists put up with getting oil on their clothes and hands? DCF was looking for creative ways of countering the cyclist's traditional "enemies": rain and flat tires. Moreover it was calling for a complete rethinking of the concept of the human powered vehicle.
The final competition description incorporated the wishes of the partners in the following way:

Theme 1 - the improvement of the traditional bicycle. With 4 subthemes: baggage, lights, weather protection and safety.
Theme 2 - development of a human-powered vehicle, which is superior to the traditional bicycle.

The competition description states that "to be eligible for a prize an entry must not only solve one or more of these problems, but also have a production-friendly design, which will appeal to buyers, so that an economically viable production can quickly be achieved. In addition emphasis will be placed on the environmental soundness of solutions, viewed from a life-cycle perspective ("cradle to grave" concept)".

Financing
The Ministry of Transport, DKK 800,000. Copenhagen Cultural City 1996, DKK 100,000. The

*) *(Member of the design competition jury and the planning group)*

Green Fund [2]), DKK 200,000. The Ministry of Cultural Affairs' Design Fund, DKK 100,000.
Winther Cykler A/S (bicycle manufacturer), DKK 10,000.
Total budget, DKK 1,210,000 [3])

Total amount of prize money: DKK 500,000. (1 first prize of DKK 250,000., none of the other prizes to be less than DKK 25,000.)

The Course of the Competition
The competition was planned and carried out as a series of stages. The purpose of the stages was to further qualify the participants by increasing their awareness of the qualities and the deficiencies of the bicycle.

The first stage (June-August) consisted of sending background material about the current state and potential of the bicycle to the registered participants. These included the publication "Bicycle Encycleopedia", rules for bicycle design and equipment, a description of typical bicycle problems, as well as an invitation to the subsequent stages.

The second stage was a seminar held on the 26th of August in Copenhagen. Here the strong and weak points of the bicycle and the rules for bicycle design and equipment, as well as factors pertaining to the protection of product ideas were presented.

The third stage consisted of 3 arrangements in September 1996 with the aim increasing the participants' knowledge about product requirements, material technology, bicycle production and marketing. The three were a visit to the Institute of Product Development at the Technical University of Denmark, a visit to the FORCE institutes, and finally a visit to the Kildemoes Bicycle Factory.

The fourth stage was the actual bicycle design competition, to which the entries had to be submitted no later than November 15th, 1996.

The purpose of the first three stages was to give the participants the best possible prerequisites for becoming acquainted with basic knowledge and experience of the construction of bicycles, in order to achieve the best results without wasting time getting experience which could be contributed by others.

The Entries
The competition material submitted was subject to the following requirements:

- Entries should be anonymous and not previously published.
- No more than 4 drawings in A3 format or 1 in A1 format.
  The scale may be 1:1, 1.2, 1:5 or 1:10.
- Model or prototype may be submitted.
- A text that describes the problem and the suggested solution. No more than 4 pages in A4 format. Entries may be submitted in Danish, Swedish, Norwegian or English.

132 Entries were received. The entries had not been divided into categories beforehand and all were judged in one series. After the judging the entries were categorized as follows:
Accessories 63, Improved bicycle 55, New vehicle 14. 22 entries were accompanied by prototypes, 16 by models. The remaining entries were presented by means of drawings and text alone.

The Jury
The jury, the names of whose members were published when the competition was announced,

consisted of: 3 designers, a bicycle shop owner, the managing director of a bicycle factory, the chairman of the Danish Cyclist Federation, a representative from the Ministry of Transport, a professional bicycle racer, a well-known television journalist [4]).
An engineer, who is an expert in vehicle construction, was attached to the jury as adviser.

The judging of the entries took two full days. The entries were displayed in random order in the room in which the judging took place. Out of the total prize money (DKK 500,000.) the jury was to award one first prize of DKK 250,000. and up to ten further prizes. Within the limits of the remaining sum of DKK 250,000. the jury could itself decide the number and amount of these prizes, with the stipulation that no prize under DKK 25,000 be awarded.

The Prize-winning Entries
The jury awarded prizes to five entries: First prize DKK 250,000, Second prize DKK 125,000, Third prize DKK 75,000, Special prize DKK 25,000 Special prize DKK 25,000.

All the prizes were awarded to entries in the new means of transport and the improved bicycle categories. None of the entries in the accessories category were qualified. Either they were not convincing enough or they were already known to at least one of the jury members. The prizewinning entries are shown below together with excerpts of the judges' remarks:

1st prize. This visionary project aims to get non-bikers started biking. Points particularly worthy of mention:
-Only partially closed fairing protects while allowing for ventilation.
-Enclosed luggage compartment.
-Integrated lighting, combining diode/dynamo and halogen reflector.
-Ease of parking in small space (can be parked upright on rear wheels)
By using recyclable materials, improving user safety and improving the construction of the child's seat this project could be further developed.

2nd prize was awarded to this well-designed and detailed, highly realistic project, which further develops familiar principles from Danish cycling tradition. A carrier cycle is redesigned to transport children and luggage. The aerodynamic form of the front compartment for two children and the rear luggage compartment underline the simple and unified construction. This sturdy bike requires little space to turn. The handlebars are comfortable to use and act as a roll-over bar for the protection of children in case of accident.

3rd prize was given for a project which gives particular consideration to the transport of luggage. Traditional bicycles have a flat carrier to which luggage can be strapped. In this project luggage, bags, boxes, etc. are secured from above. Shopping bags can be hung from protruding fixtures and secured at their base. A briefcase fits between two components. There is also provision for drainage and unwieldy luggage.

One of two special prizes went to a design recognized as an innovative total concept and a production-friendly, knock-down design aimed at user assembly. The judges were not convinced that the teflon-coated windscreen would be completely effective. This three-wheeled bike has been conceived as competition for the car, as far as comfort goes, but in fact the dimensions could be reduced to advantage.

A special prize was also given for another innovative total concept, which gives new form to the traditional bicycle, with a luggage compartment positioned underneath. This competitor has tackled the inevitable problems of the rearwheel steering, but the judges had doubts about the stability of the vehicle and the efficacy of the steering mechanism.

The Subsequent Debate
The awards occasioned a number of critical articles in the press. Engineers in particular challenged the results, claiming there had been too much emphasis on design or form and too little on functionality. The debate reflected a traditional controversy between designers and engineers. One of the motives behind the design competition was to encourage engineers and designers to integrate the viewpoint of the other side into their own approach. How well this has succeeded only time will tell. But one thing is certain, because of the competition the bicycle is now a subject which many engineers and designers now think about and work on and that is positive in itself.

My Personal Evaluation of the Project
The bicycle design competition was a pioneering project with no experience from similar competitions to build on. The development of bicycles and Human Powered Vehicles has been too much characterized by an engineering approach, often with a pronounced lack of emphasis on form. A greater focus on form and design, suitability for mass production and the use of environment-friendly materials are fundamental prerequisites for the acceptance of alternative vehicles, such as faired bikes etc., outside enthusiast circles. All the same it seems to me that the Danish design competition tended to concentrate too much on form. This was primarily because it was based on principles which are no doubt appropriate for the designing of pill bottles and coffee pots, etc., but must be regarded as less fortunate when it comes to stimulating the development of such a complex object as a bicycle. The following points should be considered when planning future projects:

1. It must be quite clear whether form or functionality is to have the highest priority in the adjudication. Either the vehicle's esthetic appearance is chosen as the essential criterium with the hope that the neccessary function will be satisfactory within the framework of the outer form. Or the functionality of the vehicle is chosen as most important, in which case design and appearance must adapt to functionality.

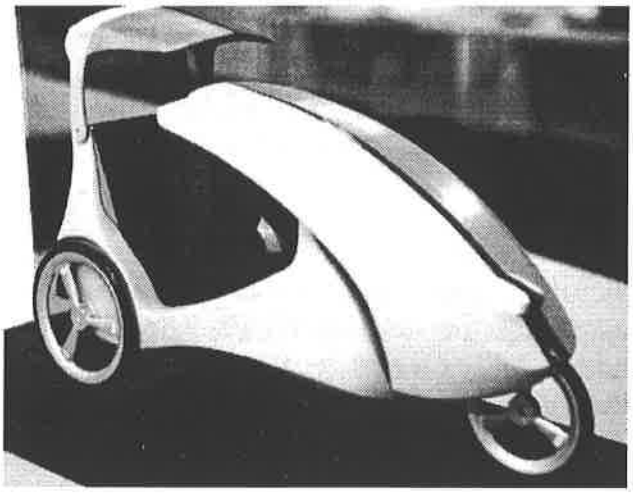
2. On the nine-member jury (in practice seven, due to two withdrawals) three judges, including the foreman, had a background as designers. This was an absolute minimum for the Association of Danish Designers, who wanted at least four and it was a fight to the finish in the planning phase to get them to accept a jury with only three. There should be at least one (better two) bicycle builders with experience in building alternative as well as ordinary bikes in the jury.

3. The submission of prototypes, at least when the entry is a complete bicycle, should be an absolute requirement. Models will not do, because both the builder and the judges tend to ignore unsolved technical problems connected with a model. On the other hand mistakes and inadequacies will show up clearly when a fullscale prototype is tested.

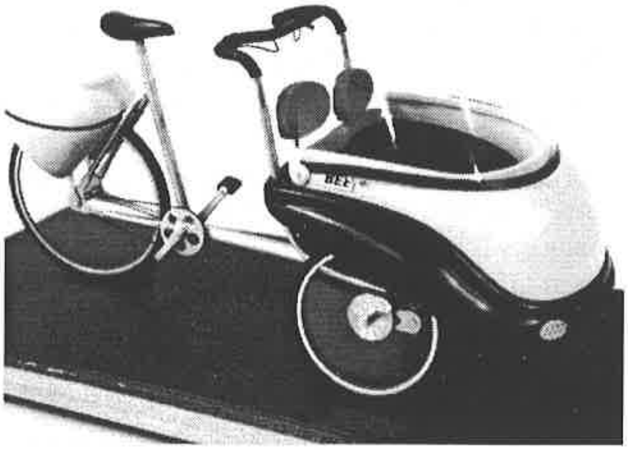
4. More time should be allowed for the judging of entries. Two days are not long enough to judge the many complex details which must work together in order for a vehicle or an accessory to function. A solution could be that the jury hold two meetings 8-10 days apart. Between the two meetings experts could be called in to judge technical details.

5. The rationale for judging complete vehicles and accessories in the same competition should be reconsidered. In any case awards should be made in two or more categories (e.g. accessories, improvements to the traditional bicycle, new vehicles).

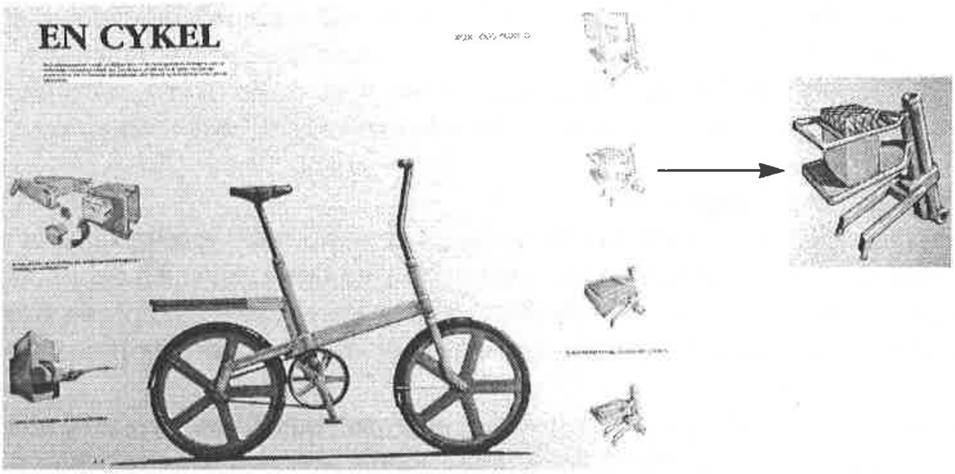
6. Although there has to be a limit somewhere, the requirement that entries have not been made public is much too restrictive. In the first place it is difficult for the judges to know if the individual entries have been made public. In the second place it is unclear when an object has been seen before



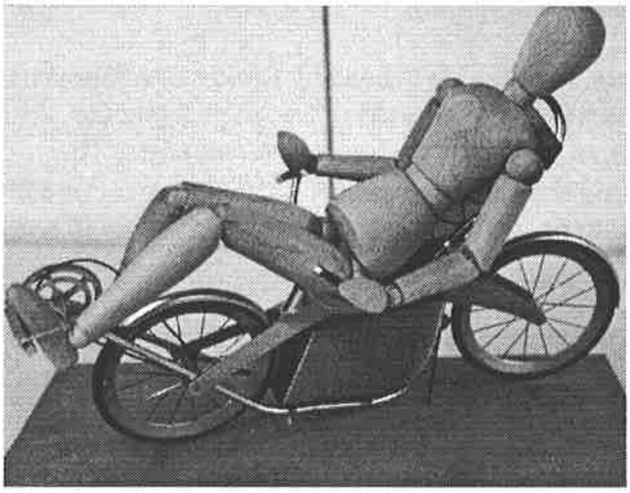
1st prize: 250.000 dkk



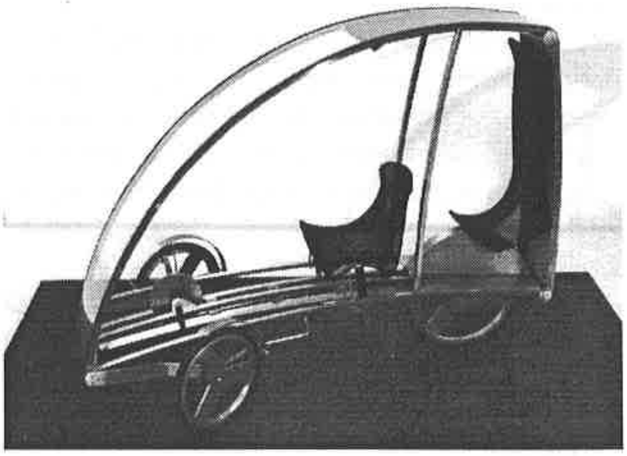
2nd prize: 125.000 dkk



3rd prize: 75.000 dkk



Special prize: 25.000 dkk



Special prize: 25.000 dkk

and when it is in fact new. In the third place many of the best bicycle innovations are already in use, although often so few have been built that they can be seen as prototypes or a test series. The builders of these have just as much need of the stimulation and help that is connected with participation in a design competition as someone who creates on the drawing board.

What happened to the Entries Afterwards?
It is important that the entries in a competition like this one are not simply forgotten after the prizes have been awarded. All the entries in the Danish Bicycle Design Competition have subsequently been looked at and evaluated by the Innovation Department of the Danish Technological Institute (DTI) with a view to preparation for production and suitability for mass production. The report of this evaluation was presented about ¾ of a year after the prize awarding. It contained a very brief "Yes/No" evaluation: Was the item qualified for further development and/or production or was it not. No reasons were given in the written report.

Danish Cyclist Federation was not satisfied with this, nor did they agree with the selections made by DTI. DCF therefore took the initiative to a meeting with DTI and representatives from the competition organizers, where all 132 entries were discussed and more thoroughly evaluated. Also individual hints and ideas how to carry on with the projects were given to their creators. The meeting resulted in a report with 33 selected entries, whose creators should be contacted. At the present moment (30 May 1998) I am not aware of further results from these contacts.

Inspiration from the design competition.
Anyway, although the competition itself has been fairly critizised, it did inspire some of the participants to continue with bike development and to arrange other events. An exhibition took place in Copenhagen about half a year after the competition. Here selected proposals from the competition were exhibited, many of them now with models and even working prototypes.

One of the participants, a Copenhagen designer, has with great enthusiasm presented an idea about a travelling bike-exhibition. Around 25 – 30 new bike-designs and -consructions should be presented at an exhibition, travelling around in all Europe. All items should be presented as prototypes, some of them even made ready for trial runs by the audience. Serious initiatives are taken to raise money for the project .

Conclusion
The competition itself cannot be considered a succes. Nor have we seen any further developments of any of the prize winning entries. One of the aims with the competition was to promote the synthesis between design and function and the dialogue between designers and engineers. The competition certainly made both categories focus on bike-development for a certain time. For a few of the participants the competition even succeeded to be an "eye-opener", inspiring them to work with bike development in the future.

The competition gave a base of knowledge and experience about the complexity in this kind of evaluation process, about what to do and, especially, **not** to do, which can be of great value for all promotors of bikes and velomobiles in the future.

Footnotes:
[1] The Danish government's goal in their Traffic Plan "Trafik 2005".
[2] The Green Fund is a state foundation which, on the basis of applications supports initiatives for the benefit of the environment.
[3] Approx. $ 200,000
[4] The last two withdrew from the jury shortly before it was to meet and therefore did not participate in the judging.

Designing a Practical Velomobile for the Next Century

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ABSTRACT

After nearly thirty years of development, the modern practical velomobile has yet to achieve an appreciable market impact. This may be due to engineering and design criteria that has been internally driven rather than customer focused. All aspects of design, manufacturing, and marketing must be evaluated if the practical velomobile is to move into the mainstream in the twenty-first century. Critical design criteria must include styling, cost, performance, comfort, visibility, stability, and safety. These areas are addressed with review of previous work, suggestions for future development, and modeling of design factors to determine relative impact on achieved average speed in real-world environments.

INTRODUCTION

The basic design criteria for modern practical velomobiles have been debated and evaluated for nearly thirty years. The first modern design competition was organized by David Wilson and the journal *Engineering* in 1967-1968 (Whitt and Wilson, 1982). While there has been much interest by both bicycle commuting enthusiasts and the popular press a market has failed to develop for practical velomobiles (PV) beyond the most avid bicycle commuters. Predictions from the eighties and early nineties of mass markets of PVs has failed to materialize. Why hasn't the concept of PVs caught on and how do we change that as we move into the next century?

How do we create the market for a product that is almost unknown to most potential consumers? The low number of production vehicles in the world means that most people have never seen or heard of a PV. We as a community need to find ways to promote the concept beyond the small group of enthusiasts that find their way here, usually after much searching. We tend to attract those that have already begun to utilize bicycles as a commuting vehicle. They progress from bicycle to velomobile. How do we attract the vast majority of commuters that currently drive an automobile that would probably not consider riding a bicycle? The change will only come if we approach the problem from a holistic viewpoint; combining design, manufacturing, and marketing that is consumer driven. The viability and practicality of the concept has been proven by the Leitra and Alleweder in a niche market. How do we expand upon these designs to move to the next higher plane of market penetration?

DESIGN

The design phase and especially the initial concept and formulation steps involve a small percentage of the total cost of a project, yet have the greatest impact on the overall cost of the final product. It is imperative that the design of a practical vehicle be thought out very carefully. Jim Kor (1994) described the PV as a metastable design; a design that balances between a bicycle and an automobile. The book *Making Niche Marketing Work* (Linneman and Stanton, 1991) stresses the need to focus, focus, focus when working with small markets. As engineers and designers we must carefully define what our PV will and will not be. It is not possible to design something for everyone. Market research and understanding of the niche we are designing for is important to stay in the stable region of the metastable environment. For this paper a practical velomobile (PV) is defined as an HPV that protects the occupant(s) from the environment and is primarily used for short commuting trips.

Some of the common factors that must be addressed in the design process include comfort, stability, crash protection, visibility, reliability and serviceability, style, and cost.

Comfort

The primary driving force for the design and use of PVs is rider comfort in all conditions. A PV must provide weather protection, adaptability for extremes, and a pleasant environment with which to ride. Protection from rain and cold are the primary factors that motivate users to purchase a PV. However, once the user begins to utilize the PV on a regular basis the ability to adapt to the changing environment becomes an important factor in long term satisfaction. For this reason the authors believe that the most viable solution will come from PVs that are of the cabriolet (convertible) or targa style. These styles offers the advantages of rain, snow and cold-weather protection, while providing a quick method of adapting to warmer conditions.

Most of the current commercially available PVs are from Northern Europe, where rain and cold protection are the most import factors. To penetrate markets outside this region will require designs that adapt to a wider variety of weather conditions. The two extreme conditions for a PV are cold and humid and hot and humid environments. Figures 1 and 2 indicate the daily average low and high temperatures in Copenhagen, Denmark; Frankfurt, Germany; and Columbia, Missouri, and Boston in the United States. The intercontinental climates of the United States has more extremes of both high and low temperatures as well as generally high humidity during both periods. The Central USA has temperatures on average of 5 degrees cooler in the winter and nearly 10 degrees hotter in the summer. In these summer time conditions, adapting to the heat will be critical.

Adapting to all types of conditions requires the use of several adjustable ventilation systems. The Leitra fairing (Rasmussen, 1994) has a very good system of ventilation. For hot environments air flow that is ducted over the feet and legs may need to be added as well. Some have suggested that the ability to leave the fairing off is adaptability. The authors feel that this option should be considered as last option in that this leads to having to predict the weather rather than adapting to changes as they occur. The use of a cabriolet style fairing with the possibility of lowering or storing the front windscreen could add to the overall flexibility of the fairing system.

Figure 1. Average Daily Minimum Temperature

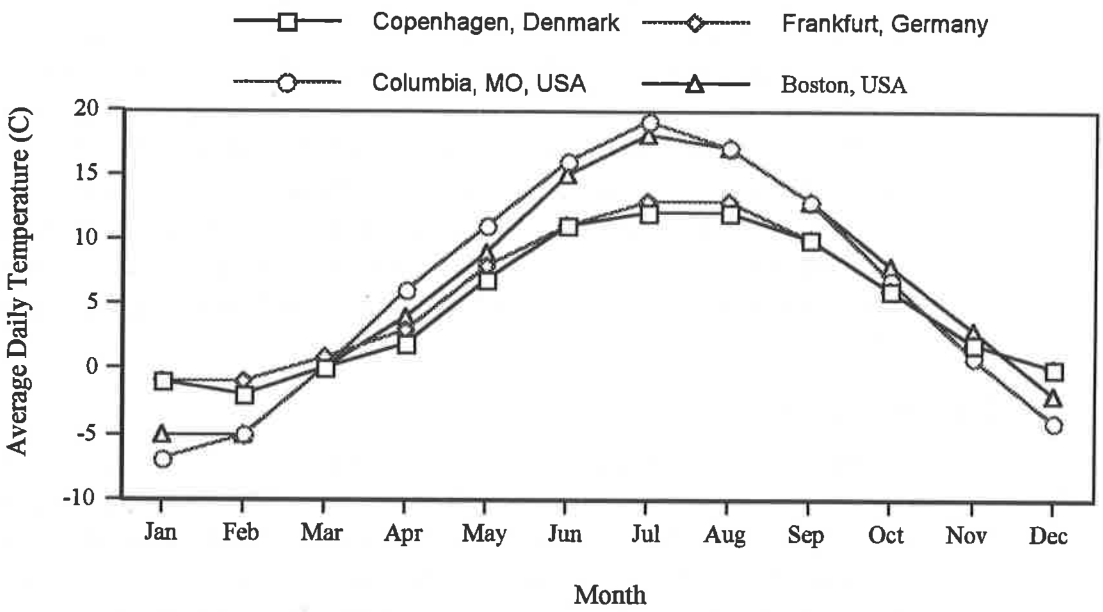
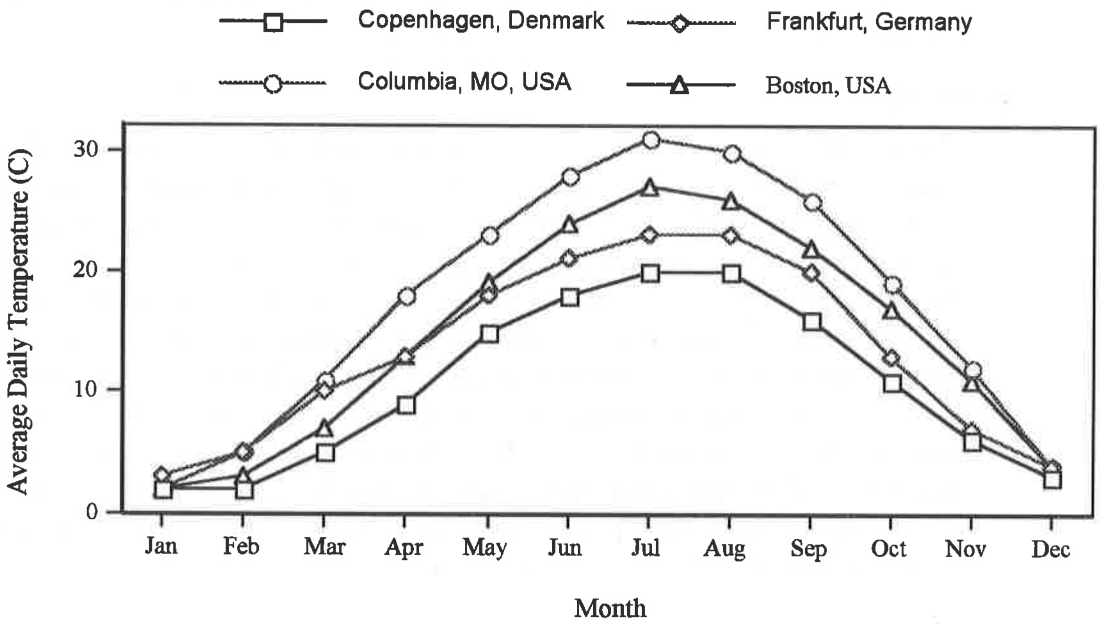


Figure 2. Average Daily Maximum Temperature



The PV must also be comfortable from a noise aspect as well. One of the most common comments about current PVs is that they make a "unique" sound. Generally this is a rumble or "oil can" sound that is objectionable. Research and design studies must be conducted to minimize the resonant sounds produced by a PV. Providing suspension for the vehicle and shock mounting for the fairing will provide increased comfort for the rider, sound dampening, and reduce vibrational fatigue on the fairing.

Stability

The PV design must provide stability and predictability for the rider in all conditions. If weather protection is a primary factor in design, the use of at least three wheels is required to provide directional stability (Dovydénas, 1993). The trend is for riders to attempt to use two wheels for streamlining a traditional recumbent, then to realize that after several "near misses" in strong wind conditions that at least one additional wheel is required. In addition to the additional wheel, design of the body must include provisions to help with directional stability (Fuchs, 1993). The solution may require the addition of vertical stabilizer surface on the rear of the body (Sims, 1997) or possibly a rudder interlinked with the steering system to counteract the yaw produced by most PV bodies that have substantial surface area in front of the front wheel(s).

Crash Protection

Crash protection is a critical factor in the design. This was extensively discussed in the *Second European Seminar on Velomobile Design* (1994). The fairing must provide protection on the outside of the shell, but care must also be taken to ensure smooth or padded surfaces and seat belts on the inside to prevent harm to the rider in sudden deceleration. The designer must be sure to review and learn from automobile design case studies from the 1960's and 70's. Areas near the riders head and chest need to be smooth to provide as much spreading of force as possible to the largest possible surface area. Materials such as safety glass and glass fiber, kevlar or spectra layer(s) over carbon fiber must be chosen that do not become sharp objects on breaking (Rasmussen 1994, Stuart 1998).

Visibility

To ensure safe operation, a velomobile must provide good visibility in all conditions. Rasmussen (1986) reported that visibility at night was a serious problem after initial trials with polycarbonate windscreens. Polycarbonate wind screens tend to spread the light internally through fine scratches making forward visibility difficult when illuminated by headlights or low sunlight in the direction of travel. The author (tat) has experienced this problem in flying gliders with polycarbonate canopies in the direction of the sun late in the day. The effect is near blindness in the direction of travel. The use of glass provides a surface hard enough to be cleaned with a wiper without scratching the windscreen. The other problem is windscreen fogging due to condensation. A flow-through system must be provided that sweeps air along the inside of the glass and exits from the cockpit to minimize the build up of moisture in the cabin. An auxiliary fan system should be considered for situation where relative velocity of the vehicle to the outside air is minimal.

The amount of glass in the windscreen should be kept as small as possible due to weight considerations. Combinations of glass and lighter transparent polymeric materials can be utilized to provide visibility in critical directions while minimizing overall weight effects. Bubble type canopies should be avoided to minimize solar insolation. In a non-moving vehicle with large sloping canopy the internal temperature can rise to 50 C in a few minutes.

Reliability and Serviceability

The practical velomobile needs to be as reliable as possible. Designs should attempt to minimize the damage to parts by water, road grime and salt. Enclosing the drive train should be done if at all possible. Wheels should be easy to access and repair. Front tires on two-in-front trike designs can usually be repaired or replaced on the vehicle. Using one size on all wheels helps to reduce the number of spare tubes and tires required to be carried in the tool kit.

Performance

A practical velomobile should perform at least similarly to a good hybrid commuting bicycle. To understand the dynamics of different bicycles under real-world conditions a time-step simulation program was developed to predict the average speed of different HPVs under several different scenarios. An energy-balance equation is utilized to describe the net energy of an HPV with time:

$$E_{net} = E_{in} - E_{out} + Accumulation \qquad (1)$$

The total energy at any given time is a function of the power input, braking force, and drag forces including; aerodynamic , rolling resistance, and gravitational. Therefore a derivative equation can be written for the energy change with time:

$$\frac{dE}{dt} = \eta P - B - \frac{1}{2}\rho v^3 C_d A - C_r mgv - mgsv \qquad (2)$$

where:

P = power input of the rider (W)
η = mechanical efficiency of the drive train
B = braking force applied (W)
ρ = density of air at 15 C and sea level (1.226 kg/m^3)
v = velocity of the PV (m/sec)
C_d = body drag coefficient
A = frontal area of the PV (m^2)
C_r = rolling friction of the tires (N/kg)
m = mass of the PV and rider (kg)
g = acceleration due to gravity (9.81 m/s^2)
s = slope (positive for uphill/ negative for downhill)

Utilizing numerical integration the total energy in the system can be calculated at any point in time. This method is similar to Kirshnar (1995), but includes the energy required for braking. By assuming all net energy is in the form of kinetic energy (KE), the speed and distance traveled by the HPV can be calculated. This approach does not ignore potential energy, only assumes that net energy can not be stored in that form. The potential energy is accounted for in the time derivative (equation 2) as the gravitational resistance term:

$$\text{gravitational resistance } = mgsv \qquad (3)$$

Where the velocity multiplied by the slope is equal to the net change in height (h). The term reduces to the standard form for potential energy:

$$\text{potential energy} = mgh \qquad (4)$$

To find the velocity at any given time the equation for kinetic energy (equation 5) is solved for v (equation 6):

$$KE = \frac{1}{2}mv^2 \qquad (5)$$

$$v = \sqrt{\frac{2KE}{m}} \qquad (6)$$

The model assumes no angular kinetic energy of rotation from the moving parts on the PV, such as wheels, cranks, sprockets and chain. At normal speed these values should be less than 1.5% of the total kinetic energy of the PV (Whitt and Wilson 1982).

Rider power input was assumed a constant value over time, except when braking. In the simulations an input value of 125 watts is assumed with a 95% efficiency to achieve an effective input of 118.75 watts of power. This is a reasonable value to use for a commuting vehicle for a trip of thirty minutes or less (Whitt and Wilson 1982, and Dovydėnas 1993. Future enhancement to the models could include physiological equations that more closely mimic human output with varying terrain and rider abilities. Braking force was assumed to be a constant value of 800 watts when applied. When the brakes are applied in the model the negative value reduces the total energy until the net energy is equal to zero.

To examine the effect of real-world conditions on average speed four scenarios were evaluated as well as maximum theoretical speed. All scenarios were a simulated eight kilometer commute. This distance corresponds to a value where bicycles can achieve similar speeds to those of automobiles and nearly 50% of all automobile trips are this distance or less (Whitt and Wilson, 1982).

Scenario 1: A level trip with 5 equidistant stops.

Scenario 2: A trip with sine wave shaped hills with a period of one kilometer and height of 25 m. This give a maximum slope of 8%.

Scenario 3: Scenario 2 with 5 equidistant stops.

Scenario 4: Scenario 3 with height of 32 m and 5 equidistant stops. This give a maximum slope of 10%. Defined as hills/stops in the graph.

Five different types of HPVs were evaluated utilizing hypothetical performance data for each type (table 1). These values represent approximation from the literature (Whitt and Wilson, 1982, Staubach, 1993 and Rhinne and Wollschläger, 1994) and the authors' assumptions of reasonable values for a PV based on personal design research. Frontal area and aerodynamic drag coefficients are given when available, effective frontal area values, $A \bullet C_d$, are given from literature values. The values for the recumbent, RB, is for a short wheel base with panniers.

Table 1: Frontal Area, Drag Coefficient, Mass and Rolling Resistance Values

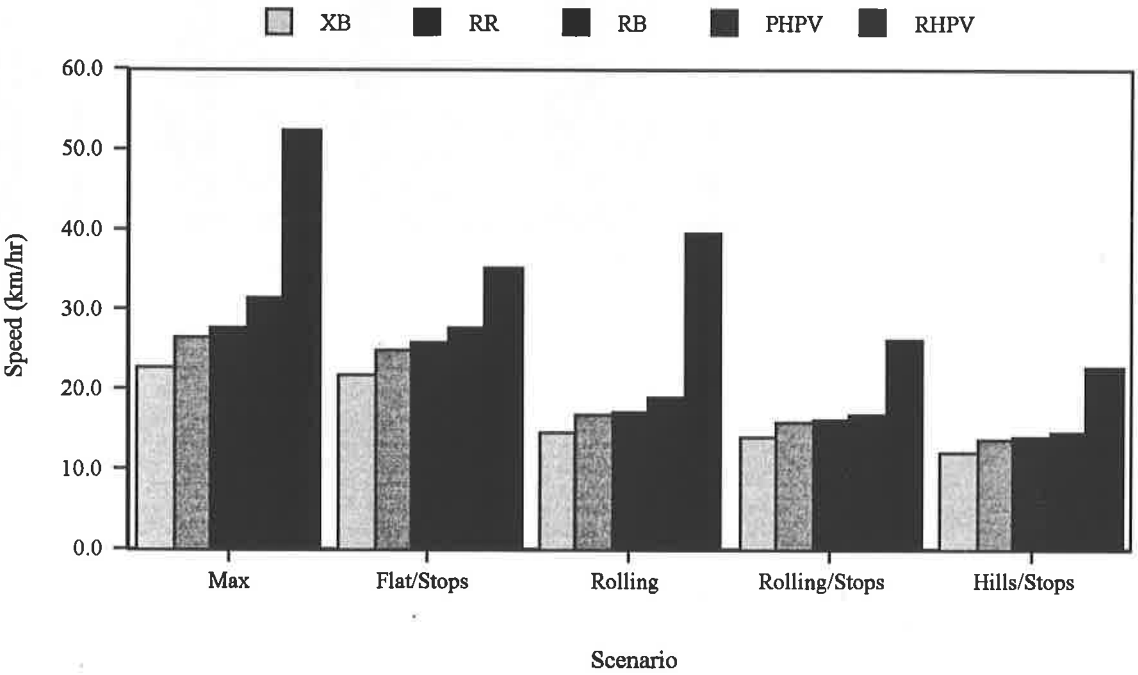
HPV Type		A	C_d	$A \bullet C_d$	M	Cr
		m^2		m^2	kg	

Hybrid Bike	XB			0.60	12	0.0050
Road Racing	RR			0.42	6	0.0030
Recumbent	RB			0.35	10	0.0030
Practical HPV	PHPV	0.65	0.30	0.20	23	0.0045
Racing HPV	RHPV	0.45	0.09	0.04	17	0.0030

Data from the simulation is presented in Figure 3. Maximum speed predictions indicate that the racing HPV is much faster than any of the other types of HPVs by nearly 40%. As real-world effects of hills and frequent stops are added, the difference in speeds for all types of HPVs is minimized. If actual waits at stop signs and traffic lights were added the difference would be even less. These simulations help to remind us that the overall achieved average speed on any trip is greatly influenced by traffic patterns and the route selected.

The sensitivity of the practical HPV to weight (Figure 4) and Cd•A values (Figure 5) was explored to help establish the effects of these parameters on actual achieved average speeds. Values that were 25% more and less than the original values were used in the simulation.

Figure 3: Average Speed Data for Simulated Scenarios



The effect of increasing or decreasing the PV weight on overall performance was approximately 2% (2.23% ± 0.86%). This indicates that weight under the simulated conditions had very little effect on average speed. Weight primarily will become critical in areas with very steep hills. The simulation allowed unconstrained maximum speed, which will tend to minimize the effect of weight. Future modeling might include setting a maximum speed, then the extra mass downhill would not contribute such an extent to the overall speed. While the average speed values would seem to indicate that weight is not a critical factor in design, it is always important to remember subjective speed as perceived by the rider is an important design factor (Schmidt 1994). A nimble PV with rapid acceleration may still be a very significant subjective consideration when purchasing a PV.

The effect of increasing or decreasing the Cd•A values 25% on overall performance was 7.22% ± 2.19% for the scenarios. The increase in effect of Cd•A values compared to the sensitivity to change in mass is not surprising considering the Cd•A is multiplied by the cube of the velocity in the aerodynamic drag equation. Designers should work to minimize the cross-sectional-area and drag-coefficient terms, but recognize that the fairing must still be practical, stylish, and easy to use.

Figure 4: Effect of PV weight on average speed

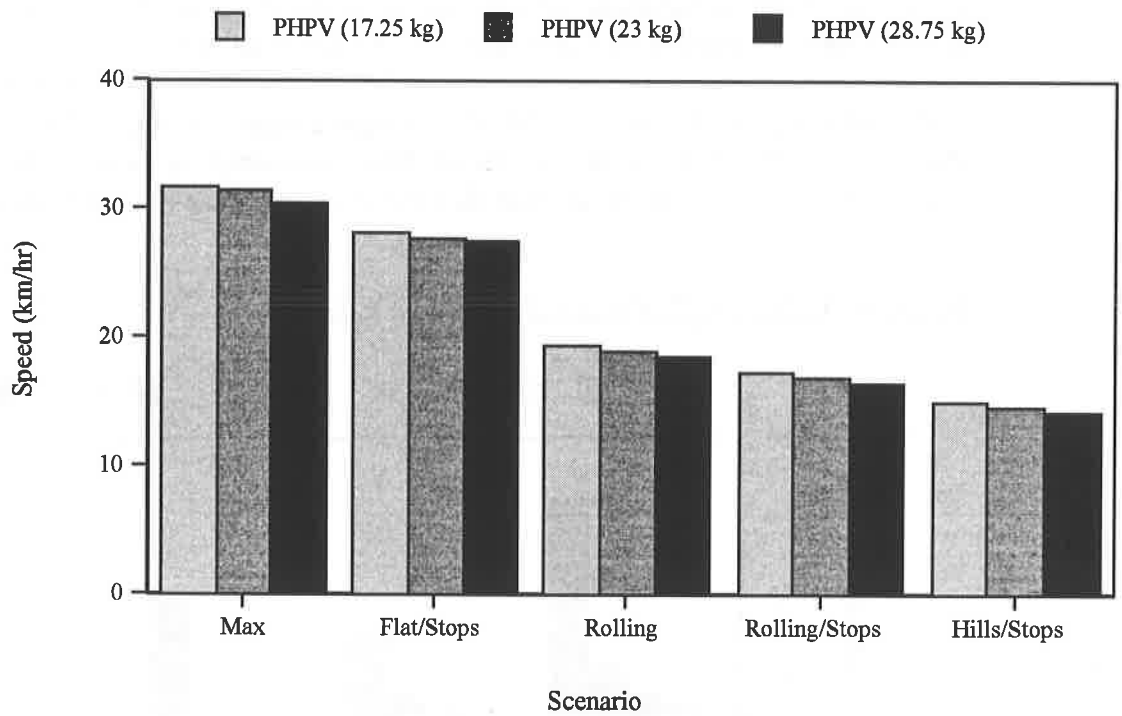
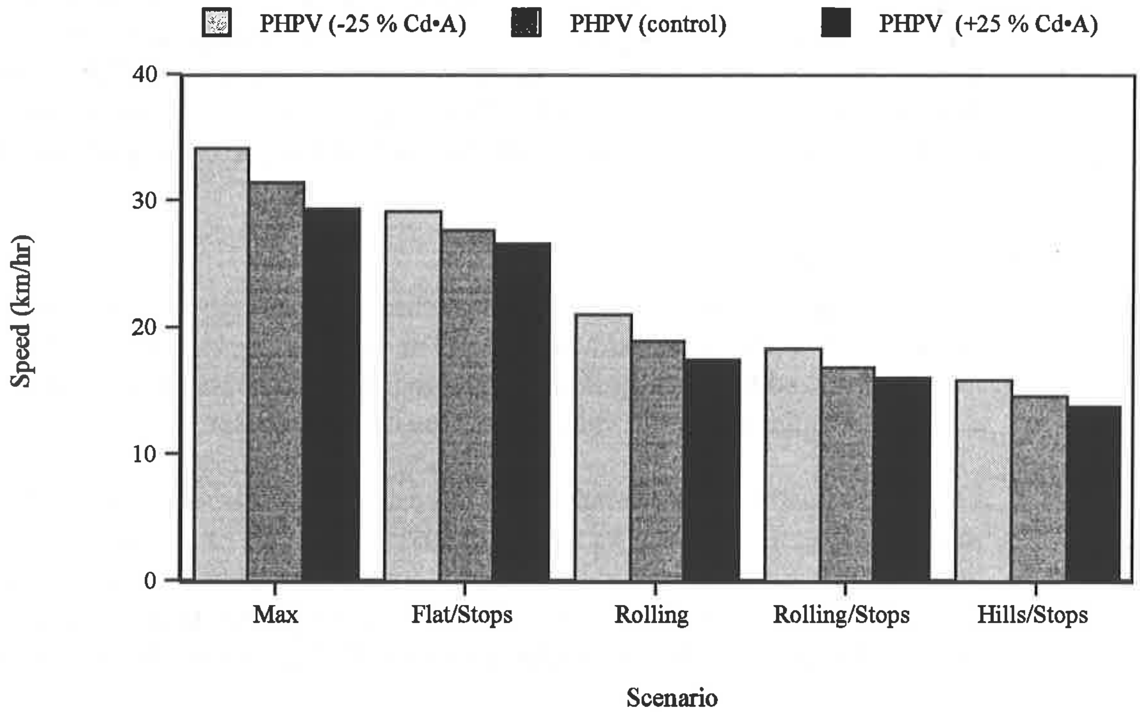


Figure 5: Effect of PV Cd•A values on average speed



Style

One of the least written about, yet most important design factor is style. For most individuals a PV is a luxury, rather than a necessity. Daniel Irányi (1994) wrote:

> "If, on the other hand, you show a HPV with fairing, its **appearance** has to compete with cars or at least motorbikes. Unfortunately it is exactly these two products, along with some consumer products like walkmen or sports-equipment, that set the standard regarding styling and design.
>
> You will never get an 'average consumer' to buy a vehicle that makes him look like an idiot. This decision is unconsciously emotional and happens within a split second, it is therefore much stronger than rational arguments."

These words are critical to any advance of PVs into the mainstream markets. The major limitations of producing PVs for a larger market are not technical, but perceptual. Most of the current products look as if they were designed by engineers. The authors are both engineers so we recognize the limitations of engineering training. Engineers design for performance and functionality, but unfortunately a byproduct of these is often boring styles. We encourage you to seek out artists and industrial designers to collaborate with to design a product that not only a mother (or engineer) would love and instead make a product the consumer must have.

One area that could benefit from styling immediately is lighting. Most PVs on the market do not have lights integrated into the fairing. In contrast automobiles have stylish lights that are an integral part of the design.

Cost

In order to establish a much larger market for PVs the cost of the final product must be reduced. Currently, the retail cost is approximately $6000 USD (~9000 CHF) for a complete PV. Our research indicates that to make significant market penetration the price will need to be nearly half of that value. Assuming a retail markup of 50% (Brunkalla, 1994) the manufactured cost must approach $2000 USD (~3000 CHF) including manufacturing profit margins. This will require significant improvement in current manufacturing efficiencies.

MANUFACTURING

We are caught in the dilemma of not being large enough of a market to take advantage of economy of scale in manufacturing. The only opportunities we have are to design for manufacture and simplifying designs for production and assembly. This includes utilizing parts that can be molded or CNC milled to reduce labor and costs.

From the initial designs on napkins, every piece and subassembly should be considered from a manufacturing as well as a performance standpoint. Use of as many standard parts as possible helps to keep the costs as low as possible. Specialized parts can be beneficial if they provide a long term payback or provide an increase in performance that is not available with standard parts. An example of this is the cast aluminum fittings for the Windcheetah.

MARKETING

Marketing is as important as engineering and design in the creation of a new category of product. We are not just selling other widget to a consumer that knows what to do with it. We must educate and promote the concept so that it becomes part of the popular culture. The critical step in establishing the market for practical velomobiles will be making them an "in thing". They need to be perceived as a trend that is coming. The designs must have that "cool" or "wow' appeal. We are selling a concept that is a "want", rather than a "need" and therefore must find a way to drive consumer demand.

Currently, most of the PV users come from a bicycling background. We must learn to market to the current driver of automobiles who would probably not think of riding a bicycle to work. Several areas that can be used to market the practical velomobile include benefits to health, environment, and economics.

With the aging of the general population in many countries the opportunity exists to market PVs as moving exercise equipment. In the US many exercise products are sold each year just because of the perceived health benefits, yet most are never used more than a few times. A PV can become part of a regular exercise program saving the cost of driving to a gym, then riding a stationary recumbent cycle.

The next generation will be even more aware and concerned about the environment than our current generation. Young children are being exposed to the concept of "green" living at an early age. What better way to promote the concept than to provide an alternative to one of the most wasteful products we use, the automobile.

Finally, the cost benefits of utilizing a PV should be calculated and used as part of the marketing strategy. In the United States, most families have at least two cars and often more. If a family can reduce the number of cars they own, the cost benefit can be significant. The reduction in cost of buying, depreciation, insurance and operating costs for fuel, oil, tires, and maintenance can be substantial. The payback period would be very short and the long-term savings significant to a family.

CONCLUSIONS

Despite thirty years of development and research, practical velomobiles have failed to make a significant impact in the global market. The limitations to sales do not appear to be technical, but primarily style and cost. These can only be addressed by a complete evaluation of the process involved in developing a practical velomobile including the design, manufacturing and marketing components. These problems appear to be exasperated by the lack of investment capital available to fund human-powered projects (Stuart, 1998). Gross *et al.* (1983) described the investment and engineering effort required to produce a practical velomobile as similar to that made in producing an automobile. The fact that this community is willing to share freely of ideas and technical information provides reason to believe that as a collective we may see the dream become reality of a practical velomobile being a common sight in the twenty-first century.

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Tuning velomobiles for everyday use

by Anselm Kiersch

Abstract:

Velomobiles suitable for everyday use are desperately needed as an altrenative to the steadily increasing motor traffic. In the process of designing such velomobiles many decisions and compromises between different technical solutions have to be made in order to consider the various aspects of everyday-demands. For this kind of decision making an evaluation procedure is presented, that is inspired by system analysis. It is based on 40 functional criteria, that are defined out of a functional context and listed up in a table, that is used for evaluation. This might be helpful for getting an overall view over everyday demands, for regarding the velomobile as a whole and for committing all technical decisions to a single goal: the suitability for everyday use. Three exemples are given concerning 3- and 4-wheel-velomobiles, different kinds of fairings and differential gear.

The global dilemma of motor traffic

From a global point of view the increasing waste of energy by motor traffic is the most challenging task for environmental politics in the years to come. Progress has been made in many fields like recycling, reduction of pollution of the air, rivers and oceans, protection of landscapes, trees and rare animals, saving of energy in the industry, in power stations, in heating of houses etc. But CO_2-pollution caused by motorised individual traffic is still increasing dramatically, because all the progress the motor industry has made in increasing the kilometres to the litre has been eaten up by the growth of traffic itself and there is nothing, that indicates, that this will be different in the near future. The most important reason for this is probably, that changes in a more sustainable direction in this field of environmental politics will deeply interfere with personal habits of car drivers, that represent a large majority of the population in industrialized countries. Such changes are therefore very unpopular and difficult to implement in democracies, because politicians, who merely dare to talk about changes in a serious manner, are punished for this immediately by going down in opinion polls.

Therefore it may be more effective not to restrict motor traffic directly, but to make alternatives to it like public transport and *cycling* more attractive in order to convince more and more people, that there are many occasions, where a car is not the most efficient way of getting from A to B.

Using velomobiles for low distance transport

Most of the tours, people are going by car on a daily basis, are under 8 km, which is a distance, that easily can be made by using a bike as well. Now one could think, that people find it too exhausting to ride a bike, but considering how many people nowadays are going to fittnesstudios to do some exercise, it is hard to imagine, that this is the only reason, why there are so few going by bike. Besides common prejudice and image problems there may be three main reasons for that:

- The bad *traffical conditions* cyclists usually are facing on the roads (cars are driving at high speed very close to cyclists and not taking notice of them, when turning of; traffic lights are discriminating cyclists for keeping the motorised traffic fluent; highly polluted air and much noise are more disturbing for cyclists, than for car drivers etc.).
- Compared to a car it is more *uncomfortable* to ride a bike (no protection against bad weather, no suspension ...)
- Too little *capacity for transportation* of children and luggage on normal bikes

The first point remains a challenge to streetplanners, that should pay more attention to the demands of cyclists in order to improve their conditions (e. g. in restricting the maximum velocity of cars in narrow streets, building more cycle paths and more high speed cycle routes for commuter traffic, physically separated from car traffic etc.). The two other points however are challenges to engineers, to build velomobiles (VM), that are comfortable, flexible and secure in traffic, and that have a suitable transport capacity, so that the riders can use them in a broad variety of *everyday* situations. Such human powered vehicles will be a serious alternative to cars in low distance transport and as such they will be a very important contribution to the solution of *global problems* like waste of energy and other natural resources, greenhouse effect etc. and *local problems* like noise, diseases caused by air pollution, car accidents, cut up of landscapes etc. caused by individual motor traffic.

Designing velomobiles for everyday use

In order to get a VM *suitable to everyday use* it is important, that *all* the technical solutions, that are chosen or invented during the design process, are committed to this goal. The goal itself is however more difficult to describe, than other technically or physically more well defined goals like e.g. low weight or low c_w, because there are much more aspects, that have to be considered, and many of them are difficult to quantify. But even when a number of characteristics or criteria is found, that should be fulfilled in order to achieve that goal of suitability to everyday use, then it will still be difficult to keep them in mind all together while designing a VM. Therefore,it might be an advantage to have a standardized procedure for evaluation of technical solutions, that can be a guideline to the designer for making decisions between different technical solutions during the design process.

Such an evaluation may also help the designer to develop the VM in a more balanced way, where *all* demands for everyday use are considered equally according to there importance. This will prevent the construction process becoming a "slave" of only a few one-sided goals like e.g. c_w-reduction and high speed. Furthermore the evaluation will avoid, that the designer is choosing some favourite solutions because of technical fascination or technical perfection, without noticing, that they may not be very important for the ordinary customer. Such technically fascinating solutions may on the contrary have some side effects, that even reduce the suitability for everyday use, when the VM is considered as a whole (see e. g. the example 3 below).

In the following a standardized *evaluation procedure* for decision making between all kinds of alternative technical options is proposed. It is inspired by some results of systems theory and therefore this theory will be outlined in a few words before getting into details with the evaluation procedure itself.

Wholeness and goal seeking - principles taken from systems theory

According to systems theory systems are so called "organized complexities", where a number of laws can be applied. In our context only two laws are to be considered: the law of *wholeness*, that says, that the whole is more than the sum of the parts, and the law of *goal* *seeking*, that says, that systems are developing after a certain goal (Skyttner 1996). A VM as a physical object is not a system itself, but looking at it in a functional way, considering it together with the rider in various traffical situations fulfilling different tasks of transportation etc., it becomes a subsystem of the system of traffic in general and as such it can be investigated by systems theory. Frederic Vester has developed a method and some tools for system analysis mainly aimed at the question of how systems can be stabilized (Vester 1990). It is impossible to make a system analysis of VM's here, but some element of it like e.g. criteria matrix and the way of thinking in *functional* terms can be useful for our purpose. In system analysis according to Vester elements (in our case the evaluation criteria) are defined according to their own functional context and to their functional relations to each other and not primarily out of technically or economically predefined data. This makes system analysis a real interdisciplinary method, where the behaviour of elements taken from such different areas of life like technology, life style, economy, health, politics etc. can be investigated in *one* system using the same method to all elements, because it makes them compatible to each other in focussing on their functionality and cybernetic behaviour.

For the same reason the proposed evaluation procedure will deal with a set of *evaluation criteria*, that are not defined as a set of standardized technical data, but according to the function, each criterion is fulfilling in the "velo-mobile-system" as a whole, i.e. the complex of functional interactions and conflicts, that occur between the VM, the rider and the (traffical) environment.

Examples:

- The "weight of the VM" regarded as a physical quantity is not a criterion on its own, but it is a factor or indicator for two other criteria. It is functioning first as a restricting factor to the criterion, that describes the function of "how easy the VM can be born, lifted up and turned around by one person alone", and second as the "mass, that makes the VM heavy to ride", because "it is increasing rolling resistance, it has to be accelerated each time after stopping, and it has to be lifted up to a higher level when riding uphill." In both cases the physical quantity "weight" is the same, but it stands in a different functional context. The first one is important for the flexibility of the VM, and the second one is important for its easy-to-ride qualities (see categories below).
- The "suspension" is not just meant as a technical device, but as the function of "how well the rider is protected against shocks caused by bumpy roads". That depends both on a "sufficient suspension" as a technical device and on the "diameter of the wheels".

Unlike Vesters system analysis however the proposed evaluation procedure will not focus on the stability of the system (that would require a complete analysis of it), but it will have to be regarded as a possibility to see the VM as a *whole* when applying *all* criteria to *all* the technical decisions made during the design process, and to commit all decisions to one single *goal*: the VM's suitability for everyday use.

The evaluation procedure

If a VM shall be ready to compete with a car in short distance transport, the goal of design will be, that it is flexible and easy to ride like a bike on the one hand, and that it is secure, weather protected, comfortable and large in transportation capacity like a car on the other hand. Together with some general criteria regarding technology, economy, acceptance and design this is resulting in 9 main categories, under which 40 *evaluation criteria* are defined, that are important for everyday use of VM's. Their *name*, their functional *definition* and some *indicators* for further explanation of the functional background are listed up in the appendix.

The categories are[1]:

1.	security	*Sicherheit*	(criteria 1 - 5)
2.	flexibility	*Flexibilität*	(6 - 9)
3.	easy to ride	*Leichtgängigkeit*	(10 - 13)
4.	weather protection	*Wetterschutz*	(14 - 18)
5.	riding comfort	*Fahrkomfort*	(19 - 25)
6.	transportation capacity	*Transportkapazität*	(26 - 29)
7.	maintenance	*Wartungsfreundlichkeit*	(30 - 32)
8.	costs	*Kosten*	(33 - 36)
9.	design, image, acceptance	*Design, Image, Akzeptanz*	(37 - 40)

The 40 Criteria are listed up in the *evaluation table* below, that is the main tool in the evaluation procedure. It is used as followed:

Step 1: Putting the question

As explained above the evaluation is aught to be a guideline for decision making between different technical options. It can be used both to very specific questions, like e.g. whether the position of the bottom bracket (Tretlager) should be rather 35cm or rather 38cm above the ground, and to more general or basic questions, like e.g. whether a VM should have 3 or 4 wheels. (A specific question can however only be answered, when the technical environment, where the decision has to be made, can be specified to the same degree, to which the question is put. Therefore it is not possible to answer the first question generally without having the surrounding technical data like height of the seat etc.). If there are more than two options, then they have to be subdivided into several "pairs" of options. When using the evaluation table, the decision, that is to be evaluated, has to be put in a question, that has the following logical form:

How much is the function of criterion C increasing or decreasing, when option A is implemented *instead of* (logical: AND NOT) **option B?**

In order to make it possible to compare the technical solutions A and B in that way regarding every single criterion, the criteria are defined in a functional *direction,* e.g. not "mass" but "low mass", and not just "weather protection" but "high (=effective) weather protection". These directions are marked by arrows (↑ or ↓) in the evaluation table. Furthermore the criteria are all defined in the very direction, that is positive to the main goal, i.e. that increases the VM´s suitability for everyday use.

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[1]In the following things will be listed up in German as well in order to avoid misunderstandings. If there are bad translations, the German terms should be chosen as the right ones.

Step 2: Direct evaluation according to the criteria

After the question is put the evaluation process can begin. The question has to be rated according to every single criterion C in the evaluation table, i.e. it has to be estimated, what happens to the VM regarding C_1 ... C_{40} , when option A is chosen instead of option B. The result of this rating is given in numbers b_1 ... b_{40} (*Bewertung*) ranging[2] from +3 to -3. They are standing for:

"C is increasing very much ...	⇒	b = (+3)
"C is increasing ...	⇒	b = (+2)
"C is increasing a little...	⇒	b = (+1)
"C remains constant ...	⇒	b = (0)
"C is decreasing a little ...	⇒	b = (-1)
"C is decreasing ...	⇒	b = (-2)
"C is decreasing very much ...	⇒	b = (-3)

...when A is implemented *instead of* B."

Using the evaluation table that way one should not hesitate to use the number "0", when the effect is very little. Thus the number "0" is usually getting the one, that is used most.

Step 3: Evaluation according to the criterias importance

Not all the criteria are equally important for everyday use. Therefore every criterion is related to a predefined factor of importance (F). In the next step all the results of the direct evaluation b_1 ... b_{40} are multiplied by the factor F_1 ... F_{40}, that belongs to the respective criterion C_1 ... C_{40}. The results are the evaluation points according to the importance g_1 ... g_{40} (*Gewichtung*):

$$b_1 \cdot F_1 = g_1$$
$$b_2 \cdot F_2 = g_2$$
$$\vdots$$
$$b_{40} \cdot F_{40} = g_{40}$$

[2]Practical work with system analysis has shown according to Vester, that it is useful to choose the numbers used for evaluation between +3 and -3, because if it they are less (e.g. +2 to -2), then they are not precise enough, and if they are too many (e.g. +5 to -5), then they are getting unmanageable, because the numbers are getting too close to each other, and it will often be hard to say, whether an effect is e.g. rather +3 or rather +4. But it is possible of course to use higher numbers also. The strength of this method however is not, that the effects to the different criteria can be quantified very precisely, but that there are so many criteria each decision has to be confronted with, that they are taken from very different and usually incompatible areas concerning everyday use, and that all the criteria are functionally committed to one single goal.

Step 4: Calculation

Based on the evaluation points $g_1 \dots g_{40}$ the final result of the evaluation R is calculated as followed:

$$R = \frac{S_1}{S_2} = \frac{\sum_{i=1}^{40} g_i}{\sum_{i=1}^{40} |g_i|} = \frac{g_1 + g_2 + \dots + g_{40}}{|g_1| + |g_2| + \dots + |g_{40}|}$$

S_1 is the sum of $g_1 \dots g_{40}$, and S_2 is the sum of the absolute values of $g_1 \dots g_{40}$.

Step 5: Conclusion

The resulting value of R is interpreted as followed:

1 > R > 0,7	⇒ It is *strongly recommended* to choose option A instead of option B ...
0,7 > R > 0,3	⇒ It is *recommended* to choose option A instead of option B ...
0,3 > R > 0,15	⇒ Option A *tends* to be better than option B ...
0,15 > R > -0,15	⇒ The choice between option A and B is up to personal preference ...
-0,15 > R > -0,3	⇒ Option B *tends* to be better than option A ...
-0,3 > R > -0,7	⇒ It is *recommended* to choose option B instead of option A ...
-0,7 > R > -1	⇒ It is *strongly recommended* to choose option B instead ot option A ...

... when the VM shall be optimized for everyday use.

Example 1:

Option A: A 4-wheel VM with full solid fairing; between the rear wheels is a major square space for transportation so the fairing does not taper to a point at the rear side.

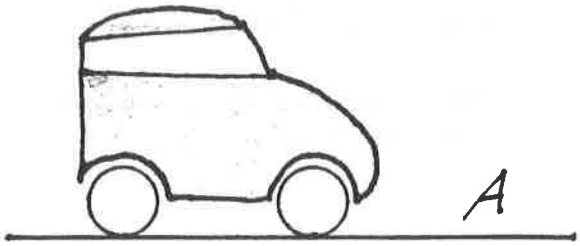
Option B: A 3-wheel VM like the Leitra with two wheels in front and the fairing tapering to a point at rear side.

Result (see next page): R= 0,22 ⇒ Option A tends to be better than option B.

In the evaluation table one can see, that B is better regarding easy-to-ride and low pricing qualities, whereas A is better regarding transportation and security.

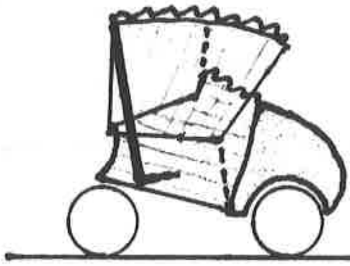
Example 2:

Option A: A full fairing out of glass fibre composite with a windscreen in front like:

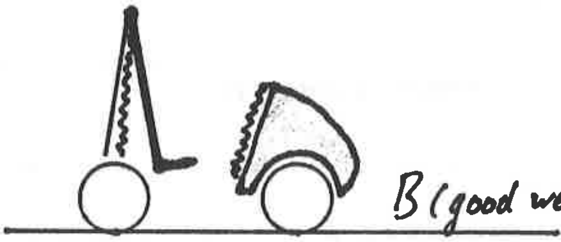


A

Option B: A half fairing of GFC at the front side and a fairing out of fabric, that can be tilted up in bad weather and that is covering the head of the rider, the sides and the rest of the front side close to the riders face, but without a windscreen:



B (bad weather)



B (good weather)

Result: R = -0,07 ⇒ The decision between A and B may be up to personal preference.

In the evaluation table one can see, that B is better in comfort, transport and low pricing categories,whereas A gives better weather protection and security except active visibility.

Example 3:

Option A: VM with differencial gear.

Option B: VM without differential gear.

Result: R = -0,59 ⇒ It is recommended to choose option B, i.e. not to use differential gears in VM´s, in order to achieve maximum suitability for everyday use.

If anybody is going to use the proposed evaluation procedure for designing a VM, the author would be pleased to get a response on , whether the procedure is useful in practical work and how it may be optimized as a guideline to the design process of VM´s for everyday use.

Literature:

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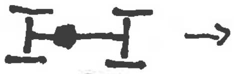
Evaluation Table:

Option A: 4 - wheel VM 

Option B: 3 - wheel VM 

No	Functional criteria	F	b_{1-40}	g_{1-40}	Comments
1	Roll over stability ↑	4	3	12	
2	Braking behaviour ↑	3	1	3	
3	Safety in collisions ↑	4			
4	Passive visibility ↑	3			
5	Active visibility ↑	3			
6	Width ↓	3	2	6	
7	Turning circle ↓	2	-1	-2	
8	Lift-up-alone ↑	2	-1	-2	
9	Length ↓	1			
10	Air resistance ↓	3	-2	-6	B: fairing tapering to a point rear side
11	Rolling resistance ↓	2			
12	Weight ↓	3	-2	-6	
13	Gear resistance ↓	1			
14	Protection: - rain ↑	3			
15	- fine precipitation ↑	2			
16	- splash-water ↑	1			
17	- cold ↑	2			
18	- sun and warming up ↑	2			
19	Suspension ↑	3			
20	Ventilation ↑	3			
21	Comfortable posture ↑	2			
22	Comfortable get in/out ↑	2	2	4	front wheels no hindrance (A)
23	Noise ↓	1			
24	Freedom to move ↑	1			
25	Simple operation ↑	2			
26	Transport: big luggage ↑	3	2	6	
27	- heavy luggage ↑	2	3	6	
28	- children ↑	3	2	6	
29	Adjustable to height ↑	2	2	4	A can tolerate shifting center of gravity
30	Wear and tear ↓	2			
31	Easy to repair ↑	2			
32	Simple technology ↑	1	-2	-2	
33	Cheap to buy ↑	4	-3	-12	
34	- to maintain ↑	2			
35	- to dispose ↑	1			
36	Security against theft ↑	1			
37	Smart design ↑	2			
38	Ecological material ↑	1			
39	Sporty image ↑	2			
40	Not too unusual ↑	2			
	$S_1 = g_1 + g_2 + \ldots + g_{40} =$			17	$R = \frac{S_1}{S_2} = \frac{15}{75} = 0{,}22$
	$S_2 = \lvert g_1 \rvert + \lvert g_2 \rvert + \ldots + \lvert g_{40} \rvert =$			77	

Evaluation Table:

Option A: VM with full GFC-fairing and windscreen

Option B: with GFC-fairing at the front and tiltable fabric-fairing, no windscreen

No	Functional criteria	F	b_{1-40}	g_{1-40}	Comments
1	Roll over stability ↑	4			
2	Braking behaviour ↑	3			
3	Safety in collisions ↑	4	3	12	
4	Passive visibility ↑	3			
5	Active visibility ↑	3	-2	-6	windscreen misted up, rain at night (A)
6	Width ↓	3			
7	Turning circle ↓	2			
8	Lift-up-alone ↑	2	-2	-4	A more unhandy
9	Length ↓	1			
10	Air resistance ↓	3	2	6	B fairing only used in bad weather => only „2"
11	Rolling resistance ↓	2			
12	Weight ↓	3	-1	-3	
13	Gear resistance ↓	1			
14	Protection: - rain ↑	3	1	3	
15	- fine precipitation ↑	2	2	4	
16	- splash-water ↑	1			
17	- cold ↑	2	2	4	
18	- sun and warming up ↑	2	-2	-4	A: fairing warmed up
19	Suspension ↑	3			
20	Ventilation ↑	3	-2	-6	
21	Comfortable posture ↑	2			
22	Comfortable get in/out ↑	2	-1	-2	
23	Noise ↓	1	-2	-2	
24	Freedom to move ↑	1	-2	-2	
25	Simple operation ↑	2	1	2	
26	Transport: big luggage ↑	3	-2	-6	luggage cannot stik out (A)
27	- heavy luggage ↑	2			
28	- children ↑	3			
29	Adjustable to height ↑	2			
30	Wear and tear ↓	2	1	2	
31	Easy to repair ↑	2			
32	Simple technology ↑	1			
33	Cheap to buy ↑	4	-2	-8	
34	- to maintain ↑	2			
35	- to dispose ↑	1			
36	Security against theft ↑	1			
37	Smart design ↑	2	2	4	
38	Ecological material ↑	1			
39	Sporty image ↑	2	2	4	
40	Not too unusual ↑	2	-2	-4	feeling narrow and locked in (A)
	$S_1 = g_1 + g_2 + \ldots + g_{40} =$			-6	$R = \frac{S_1}{S_2} = -0{,}07$
	$S_2 = \|g_1\| + \|g_2\| + \ldots + \|g_{40}\| =$			88	

Evaluation Table:

Option A: VM with differential gear

Option B: VM without differential gear

No	Functional criteria	F	b_{1-40}	g_{1-40}	Comments
1	Roll over stability ↑	4			
2	Braking behaviour ↑	3			
3	Safety in collisions ↑	4			
4	Passive visibility ↑	3			
5	Active visibility ↑	3			
6	Width ↓	3			
7	Turning circle ↓	2			
8	Lift-up-alone ↑	2	-2	-4	it is heavy
9	Length ↓	1			
10	Air resistance ↓	3			
11	Rolling resistance ↓	2			
12	Weight ↓	3	-2	-6	
13	Gear resistance ↓	1	-3	-3	two chains, more ball bearings
14	Protection: - rain ↑	3			
15	- fine precipitation ↑	2			
16	- splash-water ↑	1			
17	- cold ↑	2			
18	- sun and warming up ↑	2			
19	Suspension ↑	3			
20	Ventilation ↑	3			
21	Comfortable posture ↑	2			
22	Comfortable get in/out ↑	2			
23	Noise ↓	1			
24	Freedom to move ↑	1			
25	Simple operation ↑	2			
26	Transport: big luggage ↑	3			
27	- heavy luggage ↑	2			
28	- children ↑	3			
29	Adjustable to height ↑	2			
30	Wear and tear ↓	2	-2	-4	second chain is very little
31	Easy to repair ↑	2			
32	Simple technology ↑	1	-2	-2	
33	Cheap to buy ↑	4	-3	-12	
34	- to maintain ↑	2			
35	- to dispose ↑	1			
36	Security against theft ↑	1			
37	Smart design ↑	2	2	4	car like
38	Ecological material ↑	1			
39	Sporty image ↑	2			
40	Not too unusual ↑	2	2	4	not turning to one side
	$S_1 = g_1 + g_2 + \ldots + g_{40} =$			-23	$R = \frac{S_1}{S_2} = \frac{(-23)}{39} = -0{,}59$
	$S_2 = \lvert g_1 \rvert + \lvert g_2 \rvert + \ldots + \lvert g_{40} \rvert =$			39	

Appendix:

No	Name	Functional definition	Indicators and explanations
1	Roll over stability ↑ *Kippstabilität* ↑	The stability of not rolling over to one side in curves or to the front when braking hard	Low centre of gravity Long distance from the centre of gravity to either side and to the front of the polygon, that is defined by the points, where the wheels are touching the ground
2	Braking behaviour ↑ *Bremsverhalten* ↑	Efficiency of braking and that it is possible to steer the VM when braking hard	Wheels, that are not in the center line, braking equally hard Steering wheels not blocking too early All wheels able to brake Wheels with most weight on it braking hardest
3	Safety in collisions ↑ *Aufprallsicherheit* ↑	That the rider is not getting hurt, when the VM is colliding with something, especially cars	Height of the seat not too low ⇒ the riders head and chest out of the range of bumpers (*Stoßstangen*) No hard things in front of the rider (e.g. handlebars/*Lenker*) A fairing, that can spread the collision energy to a broader surface
4	Passive visibility ↑ (being visible) *Sichtbarkeit* ↑	How well other traficants can see the VM	Height of the VM Conspicuous colors Good lightning set, representing the width of the VM
5	Active visibility ↑ (quality of vision) *Sichtverhältnisse* ↑	How well the rider can see out of the VM	High seat Hight of the bottom bracket low compared to height of the seat Possibility to look all the way (360°) round (evt. rear-viev mirror) Visibility not reduced by bad weather (rain, windows misted-up)
6	Width ↓ *Fahrzeugbreite* ↓	Possibility to get through narrow passages	under 80cm ⇒ VM is getting through every normal door 80 - 95cm ⇒ VM is still getting through front doors 95 - 110cm ⇒ VM cannot pass normal doors ⇒ it cannot be repaired inside in the winter (garages exepted) over 110cm ⇒ VM is getting problems with cyclist-infrastructure
7	Turning circle ↓ *Wendekreis* ↓		

No	Name	Functional definition	Indicators and explanations
8	Lift-up-alone ↑ *Alleine zu heben* ↑	How easy the VM can be born, lifted up and turned around by one person alone	Low weight The form of the VM makes, that it is easy to bear it alone
9	Length ↓ *Fahrzeuglänge* ↓	Space used for parking and transpotring the VM	<180cm ⇒ parking sideways to cars (*Querparken*) is possible 180 - 220cm ⇒ parking sideways to cars is getting difficult >220 ⇒ parking sideways to cars is impossible
10	Air resistance ↓ *Luftwiderstand* ↓		Low front surface Form of the VM close to the ideal drop-form (low c_w)
11	Rolling resistance ↓ *Rollwidwestand* ↓		Great diameter of the wheel Great tyre-width combined with high pressure and little tread
12	Weight ↓ *Fahrzeuggewicht* ↓	The mass, that makes it heavy to ride	The mass is increasing rolling resistance The mass has to be accelerated each time after stopping The has to be lifted up to a higher level when riding uphill
13	Gear resistance ↓ *Getriebewiderstand* ↓	Resistance caused by the chain, gear and ball-bearings (*Kugellager*)	Better only *one* chain[3], that should be protected
14	Protection: - rain ↑ *Wetterschutz: - Regen* ↑	The rider protected against coarse and heavy precipitation (rain, hail /*Hagel*)	The velocity the precipitation is falling down with is high compared to driving velocity
15	- fine precipitation ↑ - *feiner Niederschlag* ↑	The rider protected against fine and light precipitation (snow, drizzle /*Nieselregen*)	The velocity the precipitation is falling down with is low compared to driving velocity
16	- splash-water ↑ - *Spritzwasser*↑	Protection against water coming from below from the wheels	
17	- cold ↑ - *Kälte* ↑	Protection against cold wind	

[3]A vast majority of bicycles is maintained badly and there losses of energy caused by dirty, rusted and old (i.e. too long) chains are considerable compared to the other types of losses. Taking for granted, that the standard of maintenance will not differ very much, when a VM is used by people, who are not VM-enthusiasts, then these losses will be doubled by two chains.

No	Name	Functional definition	Indicators and explanations
18	- sun and warming up ↑ - *Sonne / Aufwärmung* ↑	Protection against warming through direct sun radiation and warm fairings	
19	Suspension ↑ *Federung* ↑	How well the rider is protected against shocks caused by bumpy roads	Sufficient suspension, especially the wheels that are bearing most Great wheel diameter
20	Ventilation ↑ *Lüftung* ↑	Cooling the rider	
21	Comfortable posture ↑ *Körperhaltung* ↑	The rider sitting and riding in a ergonomic and comfortable posture	General ergonomical criteria Variable back (*Rücklehne*)
22	Comfortable get in/out ↑ *Ein/-Ausstiegskomfort* ↑	Easy to get in and out of the VM	Low at the point where to climb through (*niedriger Durchstieg*) Seat not too low
23	Noise ↓ *Lärmbelastung* ↓	Little disturbance caused by noise	A problem of solid fairings
24	Freedom to move ↑ *Bewegungsfreiheit* ↑	Enough space around the rider	Space enough to lean into the bend Space enough not to get the feeling of being locked in
25	Simple operation ↑ *Einfache Bedienung* ↑		
26	Transport: big luggage ↑ *Transport: großes* - ↑		A big and joint space for transportation Possibility that the luggage can stik out of the VM
27	- heavy luggage ↑ - *schweres Gepäck* ↑		
28	- children ↑ - *Kinder* ↑		Capacity for two children and a purchase would be desirable for everyday-family-use
29	Adjustable to height ↑ *Körpergrößenvariabel* ↑	VM adjustable to the riders height	

No	Name	Functional definition	Indicators and explanations
30	Wear and tear ↓ *Verschleiß* ↓		e.g. full protection of the chain; rubber tyre
31	Easy to repair ↑ *Einfach zu reparieren* ↑		Easy access to parts, that often are worn out
32	Simple technology ↑ *Einfache technik* ↑		Simple technology is usually less susceptible to faults
33	Cheap to buy ↑ *Preiswert im Kauf* ↑		
34	- to maintain ↑ - *im Unterhalt* ↑		
35	- to dispose ↑ - *in der Entsorgung* ↑		
36	Security against theft ↑ *Diebstahlsicherheit* ↑		
37	Smart design ↑ *Flottes design* ↑	Attractive to buy and to be seen with	
38	Ecological material ↑ *Ökologisches Material* ↑		e.g. hemp instead of glass fibre and biological degradable plastics in stead of epoxy resins in composite materials; bamboo instead of poly-urethan foam for suspension etc.
39	Sporty image ↑ *Sportliches Image* ↑	Positive image as a condition for a broad acceptance of the VM	Not the image of a vehicle for physically disabled or elderly people
40	Not too unusual ↑ *Nicht zu ungewohnt* ↑	Easy for the rider to get used to the VM	Use and operation of the VM similar to that of a bike or a car, i.e. well-known to a broad population

SINGLE TRACK VEHICLE DYNAMICS

THE EFFECT OF FRAME GEOMETRY ON HANDLING QUALITIES

by **William B. Patterson**

Introduction

The objective of this treatise is to provide the designer qualitative information as to the effect of frame geometry on handling qualities. The equations of interest are:

Control authority -- The partial differential of frame roll rate with respect to handlebar (control) movement

Control spring -- The partial differential of control force with respect to control movement

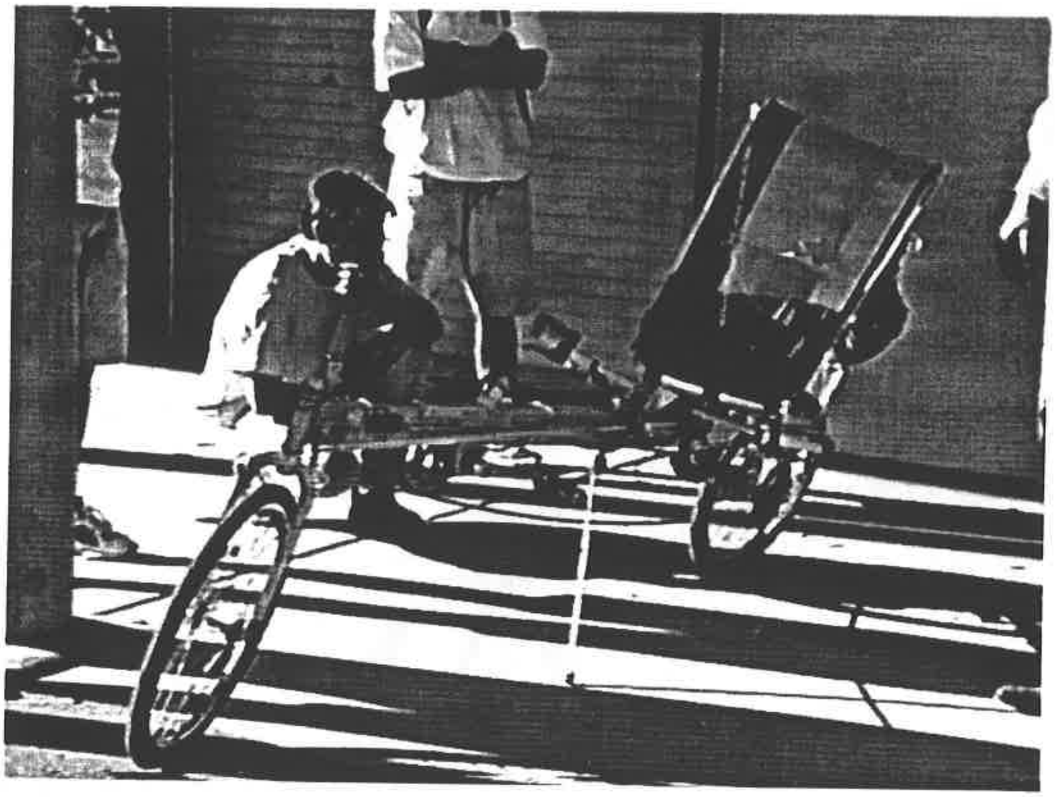
Fork flop -- The partial differential of control force with frame roll angle

Control sensitivity -- The partial differential of frame roll angle with respect to the rider's intention. The intention function is a start at estimating the relationship between control movement and control force applied by the rider.

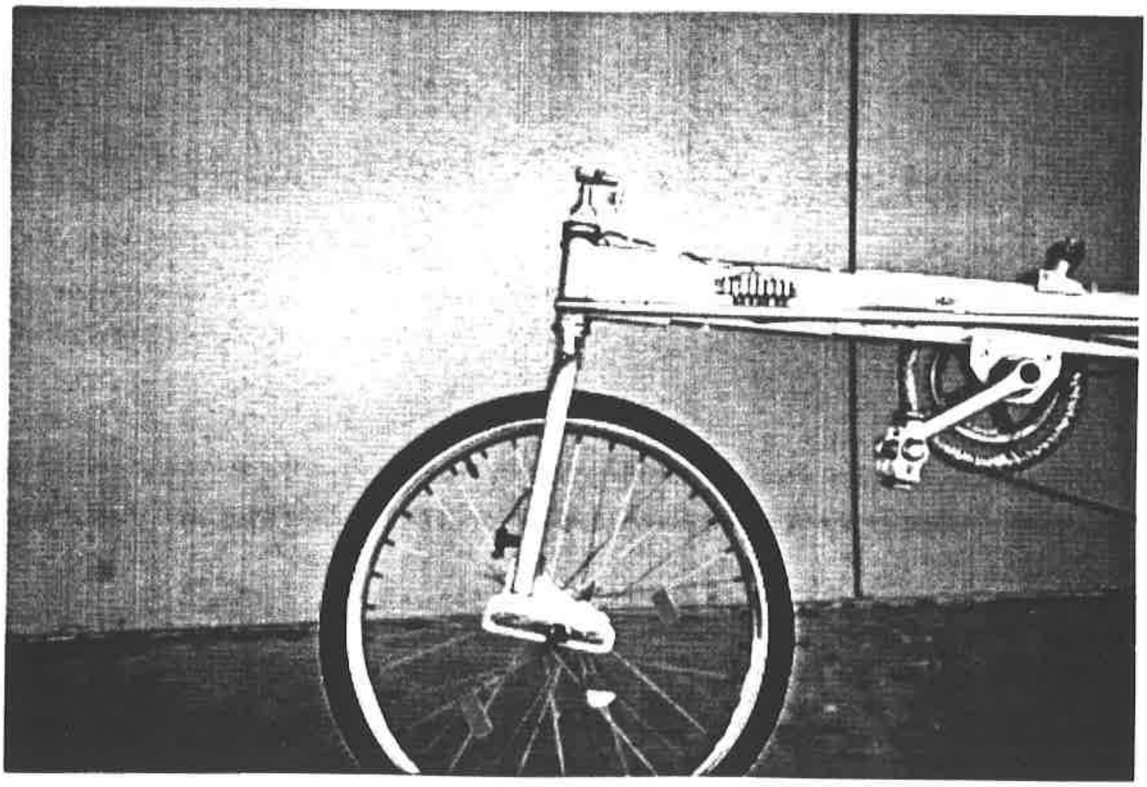
The problem was approached by using variable geometry bicycles and complicated dynamic computer programs. The melding of the bikes and the program allow us to determine which dynamic terms were most important to the designer. Only these terms are included in the "simplified equations" presented here.

Background:

The whole process started when my students asked for the equations that could tell them how geometry changes specifically affected the handling of their HPV racers. We referred to Jones ref. 2 and Lowell and McKell, ref. 3 to no avail. The hands free stability approach, provided no direct advice to the designer. We then embarked on a series of variable geometry bikes starting in 1984 ref. 1.



The Adjustable Linear is used to demonstrate how changes to the front-end geometry can affect the handling qualities of the bike.



Details of the variable front end. We have a 2 position headtube angle and variable rake

The "Killer" uses brake cable in the steering system and has been dubbed killer by the students.

The response of the cycle, are changes to speed, direction and attitude. The intention of the rider is communicated to the vehicle through the throttle/pedals, brake, body position and the handlebar. The throttle can change both the bikes speed and its attitude, accelerating tends to correct the roll angle. The brake reduces speed and the body can be shifted on the vehicle to correct attitude and cg position in the vertical and for and aft directions.

Two wheelers are complicated, certainly too complicated to grasp totally in a first attempt such as this. In order to simplify the problem we will reduce the number of controls that we investigate. We will assume that the vehicle is in a constant speed constant rate of turn, and that the rider remains fixed on the bike. This requires us to study only the effect of the handlebars. Since the handlebar controls direction and attitude, we will choose to study only attitude. Attitude control can be the control of the roll angle, the angular velocity or the angular acceleration. Angular velocity control has been determined to be the method that the rider affects control of the vehicle.

Control authority

This first part of the study is to determine the response of the cycle to steering position inputs. We will denote this as control authority. Later, we will consider force feedback on the controls.

The angle that the front wheel turns relative to the ground is not the angle that the handlebar is turned. It is changed by the frame roll angle and the headtube angle. The effective steering angle is found with the line of nodes (intersections) of the ground plane and the plane of the front wheel.

Two coordinate systems are used. The primary system will be an xyz-axis with its origin at the contact point of the rear wheel. It will be translating and yawing with the bike but not rolling as the frame rolls from side to side. The rotation rate of the axis system will be the turn rate of the cycle. A second axis system will be aligned with the front axle and the head tube. It rolls with the bike frame and turns as the cycle is steered.

TERMS

Body Rotation

θ rotation about the x-axis roll

β complement of the head tube angle

S fork offset (rake)

Wx rotation rate about the roll axis

Wz rotation rate about the yaw axis

B horizontal distance of the cg from the rear wheel

Ax angular acceleration about the roll axis

Q torque about the steering axis

m mass of the bike and rider

Geometry

A wheel base

T trail

h height of the center of gravity cg

Rt tire carcass radius

R front wheel radius measured from axle to the center of the tire carcass

Rh handlebar radius

Fh force required by the hands

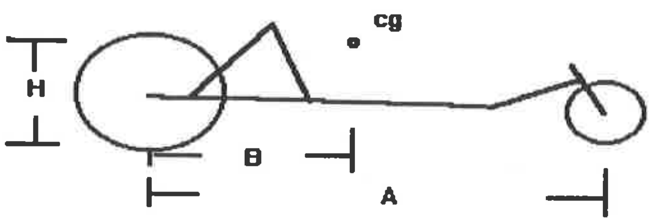
g acceleration of gravity

Steering Input

δ rotation about the headtube .

γ angle of the line of nodes to the x-axis (the ground)

SIDE VIEW
A wheel base
B horizontal distance to cg
H vertical distance to cg



For brevity, cos = C, sin = S.

We assume that the cycle is rolling and yawing to the left. The positive y-direction. This is accomplished using standard coordinate transformations. You are encouraged to carry out this operation for yourself.

The secondary axis system is first rotated about the I-axis with a negative $-\theta$. This accomplishes the roll of the frame about the x-axis..

$$\begin{matrix} I' \\ J' \\ K' \end{matrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & C\theta & -S\theta \\ 0 & S\theta & C\theta \end{bmatrix} \begin{matrix} I \\ J \\ K \end{matrix}$$

$$I''' = I$$
$$J''' = C\theta \bar{J} - S\theta K$$
$$K''' = S\theta \hat{J} + C\theta K$$

The new axis system is now rotated about the J'"-axis for an angle of negative $-\beta$. This is the complement to the head tube angle. The complement is used so that all angles are acute.

$$\begin{matrix} I'' \\ J'' \\ K'' \end{matrix} = \begin{bmatrix} C\beta & 0 & S\beta \\ 0 & 1 & 0 \\ -S\beta & 0 & C\beta \end{bmatrix} \begin{matrix} I''' \\ J''' \\ K''' \end{matrix}$$

$$I'' = C\beta I + S\beta \quad S\theta J + S\beta \, C\theta K$$
$$J'' = C\theta J - S\theta K$$
$$K'' = -S\beta I + C\beta \, S\beta J + C\beta \, C\theta K$$

The axis is now rotated about the K"axis by the steering input δ.

$$\begin{matrix} I' \\ J' \\ K' \end{matrix} = \begin{bmatrix} C\delta & S\delta & 0 \\ -S\delta & C\delta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{matrix} I'' \\ J'' \\ K'' \end{matrix}$$

$$I' = C\delta \, C\beta I + (+C\delta \, S\beta \, S\theta + S\delta \, C\theta)J + (C\delta \, S\beta \, C\theta - S\delta \, S\theta)K$$ Equation 1

$$J' = -S\delta \, C\beta \, I + (-S\delta \, S\beta \, S\theta + C\delta \, C\theta)J + (-S\delta \, S\beta \, C\theta - C\delta \, S\theta)K$$ Equation 2

$$K' = -S\beta \, I + C\beta \, S\theta \, J + C\beta \, C\theta \, K$$ Equation 3

We have now defined a coordinate system aligned with the plane of the front wheel. The J' axis is parallel to the axle and the K' axis points up the head tube.

The effective steering angle is formed by the line of nodes, the intersection of the plane of the front wheel and the ground, and the x-axis. This line is found by J' cross K. Be aware that it is not a unit vector because J' is not normal to K.

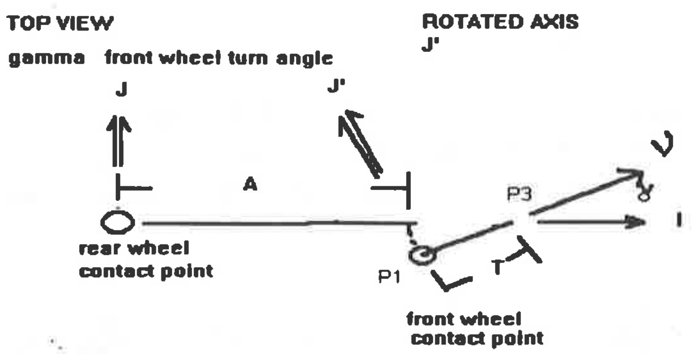
$$J' X K = \begin{vmatrix} I & J & K \\ -S\delta\, C\beta & (-S\delta S\beta S\theta + C\delta C\theta) & -S\delta S\beta C\theta - C\delta C\theta \\ 0 & 0 & 1 \end{vmatrix}$$

This cross product defines a vector in the ground plane that is contained in the plane of the front wheel. We denote this line of nodes as "ν".

$$\nu = (-S\delta\ S\beta\ S\theta + C\delta\ C\theta)\, I + S\delta\ C\beta\ J$$

Now the effective steering angle is

$$\tan\gamma = (S\delta\ C\beta)/(-S\delta\ S\beta\ S\theta + C\delta\ C\theta) \qquad \text{(Equation 4)}$$



We can now equate the sideward motion of the front wheel to A times yaw rate of the frame.

$$V \tan(\gamma) = A\ Wz$$

$$Wz = (V/A)(\tan(\gamma)) \quad \text{(Equation 5)}$$

CONTROL COUPLING

The aircraft designer does everything possible to de-couple aircraft controls. The elevator should change only pitch, the aileron only roll and the rudder only yaw. Bicycles and motorcycles don't have that luxury. The handlebar is used to control both turn rate and roll rate. The control must be coupled to do both jobs for the rider. When the bike is turned, 3 coupling mechanisms are possible. Angular impulse angular acceleration and linear impulse. These coupling terms are not additive, only the predominate term need be considered.

Angular impulse.

This is a weak response of the frame to the change in the angle of the front wheel. When the front wheel is turned left, its angular momentum vector is turned backwards. The total angular momentum of the vehicle is conserved so the bike should roll to the right. This is a weak interaction and is believed to be only important to perhaps BMX bikes while airborne. A bike or motorcycle that has a very massive front wheel compared to the total mass of the vehicle may have a significant angular impulsive control coupling, most vehicles will not.

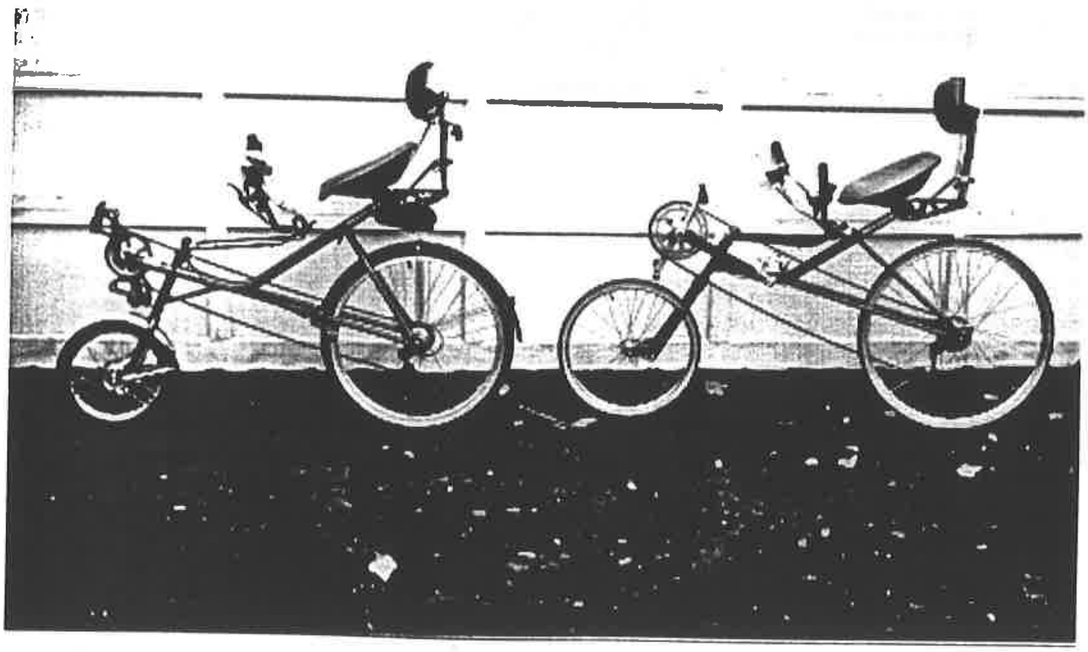
Linear impulse.

Most bicycles and motorcycles will have this as the predominate control coupling term. The center of gravity of the bike will tend to continue in its current state when the front wheel is turned. This conclusion allows us to estimate roll rate as a function of turn rate. A small $d(\alpha)$ will cause a small yaw rate d(Wz) to the left. The bike will then roll the right with a small roll rate d(Wx). We can equate the tangential roll velocity so that. :

$$B \cos(\theta) d(Wz) = h\ d(Wx)$$

$$d(Wx) = (B/h) \cos(\theta)\ d(Wz) \quad \text{(equation 6)}$$

We see that the term $(B/h) \cos(\theta)$ indicates the yaw/roll coupling that allows us to keep the bike upright, and control direction wit only one set of controls. A roll to the right is caused by a turn to the left. Our model assumes a fixed cg on the bike frame and a constant velocity.



Advanta courtesy of Clive Buckler

Roll acceleration

Roll acceleration can be the predominate mechanism if "B" is reduced. Computer models of bikes with cg near the rear wheel contact point indicate that such bikes will be difficult to control at low speed because roll acceleration is a weak interaction. If B is negligible, the models show that only bikes with very high seating positions would be easy to ride at low speeds. The American Star bicycle of 1880 was a machine that placed the rider very near the rear wheel contact point. It's interesting to note that the seating position is very high. A current bicycle is made with a similar configuration, the Advanta. It also has a very high seating position.

Simplified equations.

The roll rate and yaw rate with respect to control motion can be simplified for the use of the designer. In this case, we are finding a differential which predicts control authority. This is a measure of the bike's response to actual motion of the rider's hands, without consideration of the forces involved. The following expressions are excellent as pointers to the effect of geometry changes on handling qualities. They are neither complete nor extremely precise, but they are very useful. The first simplifying assumption is that the bike is riding in a straight line. This greatly simplifies the turn and roll equations, because we can neglect θ, the requirement to find the handlebar turn angle δ and the consequent complication of the angular equations. So:

$\theta = 0$
$\text{Cos}(\theta) = 1$
$\text{Sin}(\theta) = 0$

A small turn angle is input $\delta = d(\delta)$

so that $\sin(\delta) = d(\delta)$ and $\cos(\delta) = 1$

also $\sin(\gamma) = \tan(\gamma) = d(\gamma)$

$\tan\gamma = (S\delta \ C\beta)/(-S\delta \ S\beta \ S\theta + C\delta \ C\theta)$ (Equation 4)

The turn angle is just the small (differential) deflection from zero. Equation 4 becomes

$d(\gamma) = \text{Cos}(\beta)\, d(\delta)$

$Wz = (V/A)(\tan(\gamma))$ (Equation 5)

As we input a small steering deflection to bike traveling in a straight line, we generate a small yaw rate. Equation 5 becomes:

$d(Wz) = (V/A)\, \text{Cos}(\beta)\, d(\delta)$

$d(Wx) = (B/h)\cos(\theta)\, d(Wz)$ (Equation 6)

So the roll equation can be determined for a bike that is riding in a straight line.

$d(Wx) = (B/h)\,(V/A)\, \text{Cos}(\beta)\, d(\delta)$

YAW AUTHORITY

$d(W_z)/d(\delta) = (V/A)\cos(\beta)$

ROLL AUTHORITY

$d(W_x)/d(\delta) = (B/h)(V/A)\cos(\beta)$

If we include the effect of handlebar width, so that we are finding roll rate with respect to hand movement.

ROLL CONTROL AUTHORITY

++

$d(W_x)/(R_h\, d(\delta)) = (B/h)(V/A)\cos(\beta)/R_h$ (Equation 8)

++

This is magic equation number one for the designer. It indicates the major geometry terms that determine the riders control authority, which is a linear function velocity.

$K V/R_h$ where $K = B\cos(\beta)/(A\,h)$

COMMENTS

The terms B, h, A and the head tube angle are very important design considerations. They are, of course, not the only ways that a designer can affect controllability. We control machines by applying a deflection and or force to the controls. Control forces will be discussed later.

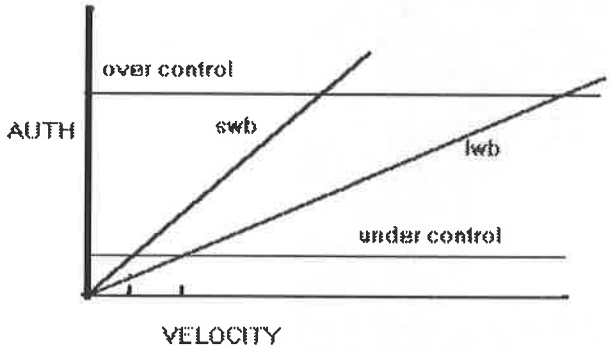
A preferred value for control authority is different for each designer and individual rider. Any new vehicle is a compromise. Reliance upon normal "safety bicycle" front end geometries, is obviously, an error.

The designer can change control authority by noting the values in the roll equation

$B\cos(\beta)/(A\,h\,R_h)$

A control authority plot illustrates the difference between a Long Wheelbase (lwb) bike and a Short Wheelbase (swb) bike.

CONTROL AUTHORITY PLOT



A short wheelbase (swb) bike will have a steeper slope for the control authority function simply because "A" is smaller. We should expect that such a bike will attain adequate control authority at a lower speed. Therefore, the swb bike should win the slow race over the long wheelbase (lwb) bike. This is shown by the intersection of each authority plot with the under control line on the graph. Actual values for the 'under control' line vary greatly with each rider and the rider's experience with the machine. Some riders can do 'track' stands so the under control line would be at zero.

We should expect that an 'over control' line exists that would limit the speed of each machine, with the swb reaching a maximum speed before the lwb. We know that this is not generally true, because another mechanism is at work. As the bike goes faster the force needed to move the controls increases. We must determine this force to see how it allows the bike or motorcycle to attain very high speeds without having the bike or motorcycle becoming over sensitive. With this knowledge in mind, we have been able to determine, roughly, that a response of 8 degrees/ second of frame roll rate for each 1 cm of control motion is too much for a normal rider. It is very difficult to measure this term directly, because a bike with no feel will also have no fork flop to help us ride comfortably at any speed.

This long wheelbase cruiser won't have a problem with over control

CONTROL FORCES

The change in handlebar torque with respect to steering angle is the basis for the 'feel' of the bike. It is most important to understand the total force on the handlebars is of little consequence. Whether we need to hold the bike into a turn or the hold force away from a turn is easily learned and compensated by the rider. The aircraft term for the constant force is 'trim'. The constant force is only trimmed out when the aircraft remains in one flight condition for an extended period of time. The perceived 'spring constant' in the control system is the important term for the pilot/rider.

US Air Force flying qualities directive Milspecs are vague to say the least.

A linear or smoothly varying response to control deflection and force is desirable.
Ref section (4.1.12)

I take this to mean that the forces on the controls should be of the form.

$F = K0 - K1\,dX$
Ref section (4.2.7)

The pilot knows that it's the control spring rate/spring constant K1 that is the important term here. The trim K0 is of little consequence.

One method to determine the torsional spring rate is to place the vehicle in a constant rate constant speed turn. The forces at the front wheel contact point can then be estimated. Next, we deflect the handlebar steering angle by a small amount to the left. The vehicle will experience a change in yaw rate to the left and a roll rate and acceleration to the right. The change in vehicle state will change the forces on the front wheel contact point. These new forces and the new dynamic state will change the torque by a small amount. The change in torque with respect to the change of steering angle is the torsional spring rate. The process is not a time history such as used for a stability analysis. It also simplifies the dynamic analysis because the front wheel assembly has no motion relative to the frame, These limitations are not so great because the front wheel assembly moves very little at speed. For the more complex case, please refer to #5.

FRONT WHEEL CONTACT POINT

Our next task is to determine the position of the contact point of the front wheel as the handlebar is turned and the frame rolls. It is essential to have this information when finding the feedback forces on the handlebar. Any vector from the head tube axis to the contact point will suffice. First models assumed a knife-edge tire, and were inadequate. Changing front tire width changes the very handling qualities that we are trying to predict. We must redefine trail to include the tire size. We measure the trail to a plane just above the ground plane. It is the distance from the ground to the center of the tire cross- section "Rt".
The point can be found by moving T Cβ in the -I' direction then downward Rt, this is from P1 to P_o in the illustration. This is a vector perpendicular to the head tube axis to the wheel center. We can also proceed from intersection of the head tube axis and the revised ground plane by going T Cβ in the -I' direction then T S β in the K' direction, and downward in the Rt direction, from P2 to p_o. .

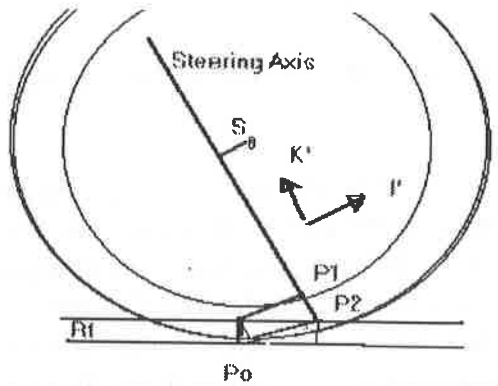
The vector from point P1 on the steering axis to the front wheel contact point is:

$$-T\,C\beta[C\delta\;C\beta I + (+C\delta\;S\beta\;S\theta + S\delta\;C\theta)\,J + (C\delta\;S\beta\;C\,\theta - S\delta\;S\theta)\,K]\;-Rt.\,K \quad \text{(Equation 9)}$$

where $T\;\mathrm{Cos}(\beta) = R\;\mathrm{Sin}(\beta)\;-S$

For greatest accuracy, measure R from the axle to the center of the tire carcass cross section and Rt from the center of the carcass to the ground while the rider is seated with his/her feet off the ground.

The thickness of the tire is significant. Many bikes and motorcycles have a tire which has carcass radii of the same order of magnitude as the trail.



Front Wheel Geometry

A vector is used to find the restoring torque on the controls. P1 is convenient because its direction is in the - I' unit vector direction. We can then add the vector for the vertical distance from the tire center to the contact point Po. Both the front normal force that supports the cycle and the steering friction force that turns it act through this point. We will now will use this geometry to determine control forces and their effect on the rider.

Fork Flop

A classical concept of a human controller is to observe an error, determine the proper response and then carry out that response. The control loop is closed by having the rider continue to observe the reactions of the vehicle and make additional control inputs. A more direct and visceral process can take place in the proper environment. An example is the pitch control of a light aircraft. The force on the controls increases as the control is displaced. It always tends to return the control the trimmed position.. The pilot can feel the controls and that feel constitutes the observation and response. The process of feeling the vehicle condition through the controls, bypasses cognition and becomes a purely physical, almost automatic, response.

Most single-track vehicles exhibit a handlebar torque with respect to frame roll angle. This is the disconcerting tendency for the wheel to flop over when we try to wheel the bike by holding the seat. It is an autopilot while we are riding, because it tends to turn the bike in the direction of a fall. It also allows riders to sense frame angle through their hands rather than their eyes. We have tested numerous riders on bikes with minimal fork flop, 15 % cannot ride a bike without some fork flop.

Simplified Equation

The designer is interested in the geometry factors that influence the bikes 'feel'. We are not interested in absolute precision or completeness in our equations. In this case we chose to look at a bike that is traveling in a straight line and experiences a minimal roll deviation. We assume that the bike is starting to roll to the left, and is not yawing. Therefore the only force on the front wheel is the normal force, which can be found by summing the moments about the rear wheel contact point.

$$F = mg\ B/A \quad K$$

the trail vector becomes

$T = T\,Cos(\beta)\ \text{-}I' \quad \text{-}Rt\,K$

Where I' is the unit vector pointing to the forward of the front wheel

The wheel has not turned so δ is zero. Equation 9 becomes.

$T = -T\,Cos^2(\beta)\,I \ \ -T\,Cos(\beta)\,Sin(\beta)\,d(\theta)\ J \ \ + [-T\,Cos(\beta)\,Sin(\beta) - Rt]\ K$

$K' = -Sin(\beta)\ I \ \ + Cos(\beta) d(\theta)\ J \ \ + \ Cos(\beta)\ K$

now the moment d(Q) is:

d(Q) = K' dot T cross F

$d(Q)/d(\theta) = -T\cos(\beta)\,(B/A)\ mg$

We can take handlebar width into account by remembering the $Fh = Q/Rh$

FORK FLOP

++

$d(Fh)/d(\theta) = -T\cos(\beta)\,(B/A)\ mg/Rh$ (Equation 10)

++

This is magic equation number 2. The wheel flop force is felt by the rider and actually provides additional sensory input as to the bikes roll angle error. Many riders find it difficult to ride bikes that have no fork flop control reaction to roll errors. Experience from building and testing several variable geometry bikes make it clear that the minimum value for this term is 2 Newtons per degree of frame roll angle. As in everything, more is not better. Large values of fork flop can generate disconcerting handlebar forces at low speeds.

Remember that the magnitude of $T\,Cos(\beta)$ is $R\,Sin(\beta) - S$

Control Spring

The change in handlebar torque with respect to steering angle is another sort of 'feel' for the bike. One method to determine the torsional spring rate is to place the vehicle in a constant rate constant speed turn. The forces at the front wheel contact point can then be estimated. Next, we deflect the handlebar steering angle by a small amount to the left. The vehicle will experience a change in yaw rate to the left and a roll rate and acceleration to the right. The change in vehicle state will change the forces on the front wheel contact point. These new forces and the new dynamic state will change the moment by a small amount. The change in moment with respect to the change of steering angle is the torsional spring constant. The process is not a time history such as used for a stability analysis. It also simplifies the dynamic analysis because the front wheel assembly has no motion relative to the frame. The rider seldom moves the front wheel assembly to any great extent, at speed. For the more complex case, please refer to #5.

A detailed derivation of the spring equation is more that we can cover in this paper see ref. 6.

The control spring 'constant' is of a form:

$$d(Q)/d(\delta) = K1 - K2\ V^2 \qquad \text{(Equation 11)}$$

We can neglect the angular momentum of the wheels below 25 km/hr to get;

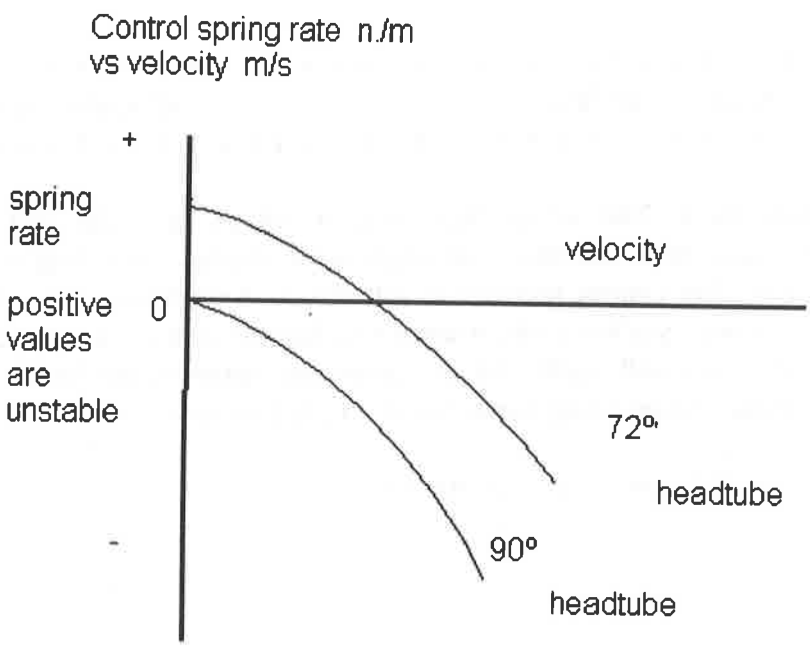
$$K1 = mg(B/A)(T\ Cos(\beta)\ [\ Sin(\beta) + T\ Cos(\beta)/A + Rt\ Sin(\beta)/A\ ]$$

now T/A and Rt/A are very small so that:

$$K1 = mg(B/A)T\ Cos(\beta)\ [\ Sin(\beta)\ ] \qquad \text{(Equation 12)}$$

And K2 is

$$K2 = (\ T\ Cos(\beta) + Rt)\ m(B/A^2)Cos(\beta)\ Kx^2 / (\ h^2 + Kx^2\ ) \qquad \text{(Equation 13)}$$



The upper curve of the control spring curve is characteristic of most 72 degree headtube bikes. The lower curve is that of a vertical headtube bike.

We would prefer our control spring 'constant' to have a negative sense throughout the velocity range, so that we can apply force in the same direction as we are move the controls. The plus sense of K1 means that controls will feel unstable at low speeds. The front wheel will tend to continue to deviate when the handlebar is turned. Happily, this occurs only at very low speeds and the rider quickly learns to compensate. Why do you suppose that the new rider needs to be held up to reach a speed above the intersection point? Mitigation of the unstable low speed control problem is solved in safety bikes by the handlebar stem. The hands are forward of the steering axis and generate a proper control spring simply by their position. Recumbent riders bemoan "tiller" steering. Having the hands behind the steering axis exacerbate the unstable control problem.

K1 has the term Sin(β) as one of its multipliers. Bikes with vertical headtubes (Sin(β) =0) will have a K1 very nearly zero and should be much easier to ride a low speed. Experimentation confirms this. See ref. 4. The German study found that bikes with nearly vertical headtubes and bent back forks were easier to ride.

The Mountain Climber

The above bike was designed to be an off road mountain climber. To this end, it has a short wheelbase and forward cg to provide high control authority at low speed. It also has a vertical fork for benign stable handling qualities during low speed climbs. The cg will need to move backward for them to get back down the hill.

Sensitivity

The following theory is presented as trend information only. It has not been validated by large numbers of test vehicles. A vehicle operator, whether a pilot, driver or rider, transmits intentions through the controls by moving them and/or applying force to them. A bike rider tends to move the handlebars at low speed, but then tends to think of applying control pressure at higher speeds. This occurs because the control authority increases as a function of velocity while the control spring constant increases as a function of velocity squared. This is really a good thing, because, without increasing force, the bike would be too easy to over control at high speed.

We will assume the most simplistic human model, an addition of force and displacement.

Intention = Displacement + Force

The following operation may appear a little bizarre, but then, any attempt to place the human in the equation will be strange. This only drives home the reason that the physicists are so determined to stay with hands free stability.

d(intention) = Rh d(δ) + Ka d(Q)/Rh (Equation 15)

Ka is a constant of proportionality and is different for each rider. A good first approximation is 20 Newtons for each cm of control displacement. The differential of roll rate with respect to the rider's intention becomes sensitivity.

Ka = 1/2000 meters/newton

d(Wx)/d(int) = d(Wx)/(Rh d(δ) + Ka d(Q)/Rh)

dividing the numerator and denominator by d(δ)

d(Wx)/d(int) = [d(Wx)/ d(δ)]/ (Rh + Ka d(Q)/(d(δ) Rh)

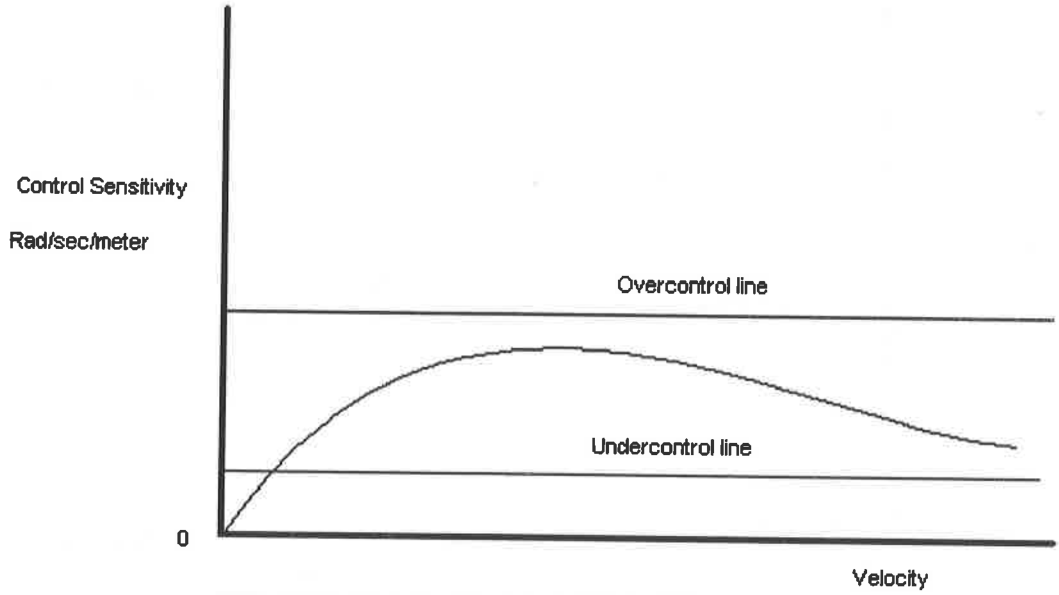
We assume that the dynamic terms of the front fork/wheel are negligible so that the hands must apply a force in the opposite direction of the control spring. From our equations for authority and control spring we have:

++
d(Wx)/d(int) = K V/[Rh +(Ka/Rh)(-K1+K2 V^2)] (Equation 16)
++

Ka from equation 15

K1 and K2 from equation 11

This is our final magic equation. It has a characteristic shape with a maximum value that normally falls at a velocity around 17 km/hr. Some riders find that sensitivity values higher than 8 deg/sec of change of roll rotation for each cm of control displacement, too high for comfort.

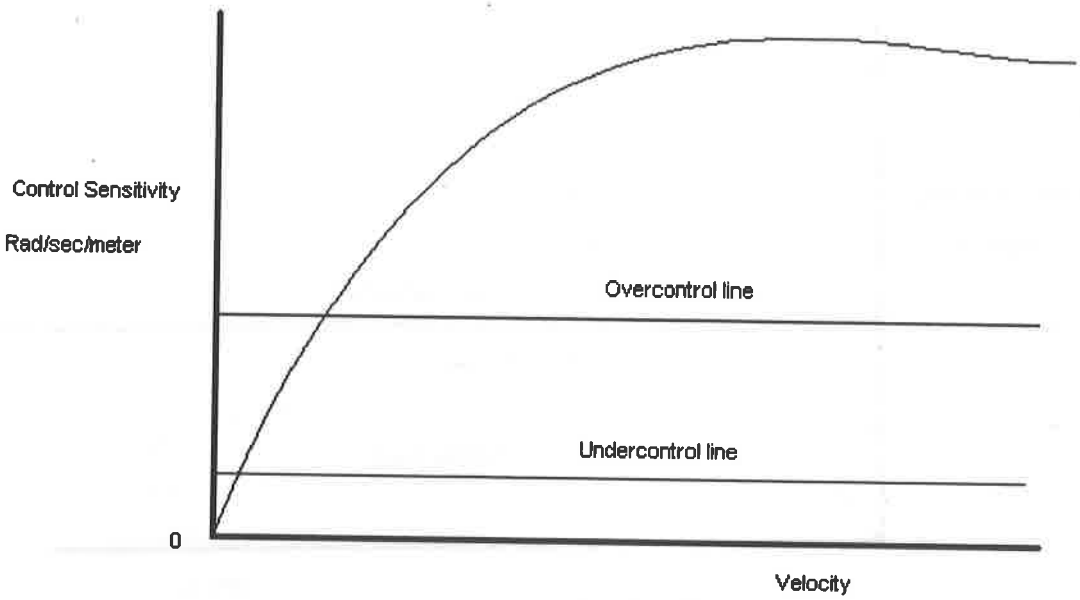


SENSITIVITY PLOT OF A PROPER BIKE

The intersection of the sensitivity line with the lower and/or upper limit lines determine the minimum and maximum comfortable riding envelope of the bike being designed. It is easy to insure that the over-control value is not exceeded, by careful attention to the control force equations. Some bikes will have the sensitivity maximum at higher speeds. If this should occur, it is important to include wheel momentum and rederive the equations

The bike designer changes the control feel by changing the value of the control spring K2. If very light control forces are desired, then great care must be taken to keep the sensitivity low enough for easy control throughout the velocity range. Many HPV racers have been built with very small values for trail at the front wheel. Consequently, they have a sensitivity plot that passes through the upper limit line, similar to the authority plot, and quickly become too 'twitchy'.

The following plot is normal for many bikes that come to my attention. They were designed to an 81-degree castor angle and use a small front wheel. This results in front wheel trail that is too small. The result being, that fork flop and the control spring rate are inadequate. The simple solution is to bend the front fork backward to increase Trail which increases K2 and fork flop. A new rider has a very difficult time on a bike without fork flop at any speed. Over sensitivity at high speed is similar to playing a video game with the mouse sensitivity turned up to max.



OVERSENSITIVE BIKE WITH TOO LITTLE TRAIL

Bikes that will spend a great deal of time at low speed should have higher authority k and very small or negative K1, so that the controls are stable at such speeds.

The idea of considering handling qualities before stability when designing bicycles is certainly controversial. We have built many bikes by referring to these equations, and they have been easily controlled. A prime example of hands off stability vs. handling qualities is the rear steered bike. We have built several rear steered bikes with supposedly minimal instability. Yet, track bikes ridden backwards are much easier to ride and have better handling qualities.

The idea of using highly simplified equations to emphasize the important geometric values and their relationship to handling qualities is also very different. It accomplishes my goal of allowing anyone with a calculator to predict handling qualities. The designer shouldn't need a Ph.D. or a working knowledge of Laplace transforms to find a proper front fork rake and headtube angle. Equation 13 directs the designer to the truly important geometry terms, K2 the control spring rate is a very important value for the prediction of bicycle and motorcycle handling qualities.

I hope that this will encourage further discussion and experimentation. Many alternate approaches to problem solving should be attempted.

PROUDFOOTS
Happy members of the ME 441 bike design class

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Stability of Faired Recumbent Tricycles

Ian Sims, Greenspeed.

ABSTRACT
Aerodynamically faired Human Powered Vehicles are the most efficient vehicles ever built for personal transport, and offer the possibility of a safe, healthy, non-polluting alternative to the motor car, which is causing an increasing amount of pollution, social alienation, sickness, injury, and death on our planet. However, many faired HPVs are difficult to control at speed in windy conditions, which can make them dangerous, or at least frightening for a novice to ride.

This paper examines the effect of steering geometry, and the effect of fairing shape on stability in cross winds. Practical experiments were made with a Greenspeed recumbent trike, of the type used by the author for everyday transport in the suburbs of a large city. They show how simple changes to fairing shape can have a profound effect on aerodynamic stability, and give some guidance to builders of fairings for three wheeled HPVs.

BACKGROUND

Greenspeed first began building recumbent tricycles in 1990 after a prototype was used by the author in the 1990 Great Victorian Bike Ride from Bairnsdale to Melbourne. This ride covered 530kms with approx. 4,000 participants. So many people were interested in the trike, and impressed by their brief test ride, that it was decided to start producing Greenspeed trikes for sale to the public. In 1992 a faired Greenspeed trike was entered in the 1992 Energy Challenge in Sydney - see fig. 9. It covered the full course of 153.5 kms at average speed of 28.8 kph though Sydney traffic and 40 degree C heat. It won its class from two other unfaired trikes, which averaged 16.0 and 11.1 kph, and did not complete the course. It also recorded a faster average speed than 7 of the eight electric vehicles entered.

Subsequent testing by National Roads & Motorists' Association showed the faired trike only had 1kg force total drag at 60kph, and a hill roll test against an unfaired trike produced 69kph for the faired trike, V 45kph for the unfaired trike.

However the high demand for unfaired Greenspeed trikes prevented further development of the faired trike, and Don Elliott of D&H Enterprises was commissioned to design and build full fairings for Greenspeed. While these fairings met the criteria of having a pleasing appearance, and have had some racing success, there have been concerns with stability at speed in cross winds.

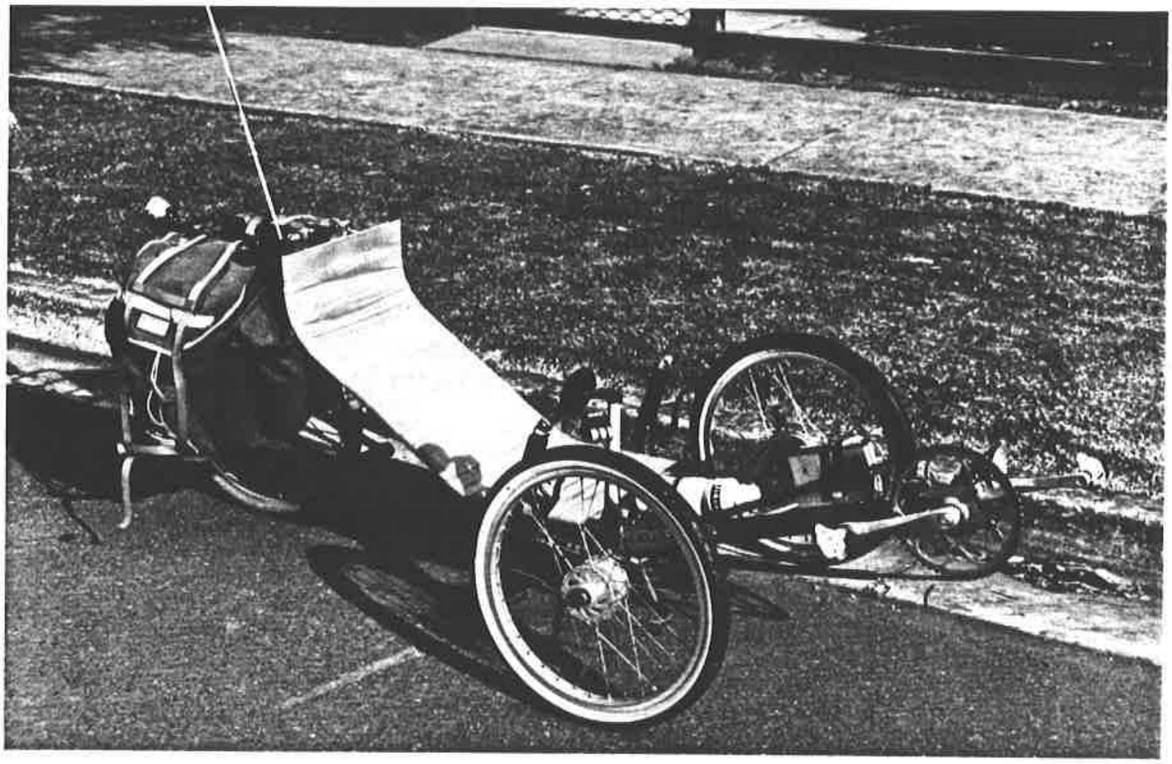

Fig. 1.
Greenspeed GTS 20/20 Sports Tourer tricycle as used by author for commuting in Melbourne, Australia.

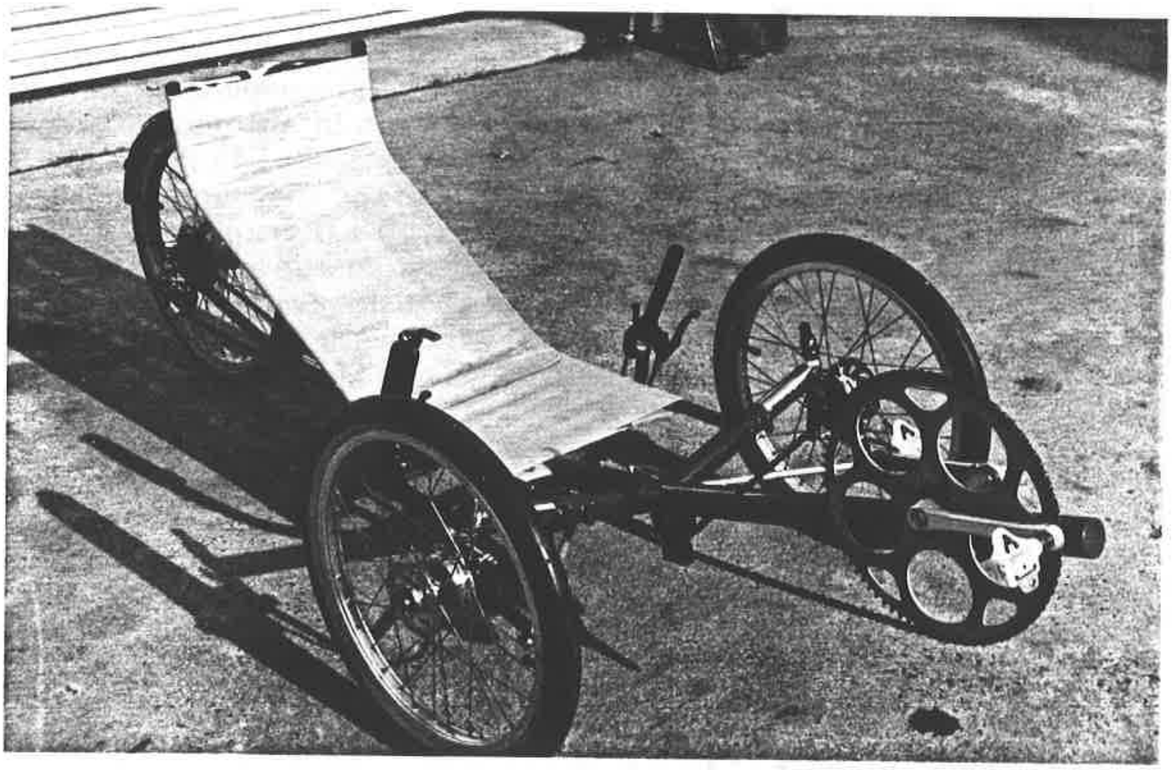

Fig. 2.
GTR 20/20 built with adjustable castor for fairing experiments. Note 80t chain, Schulmpf mountain-drive, and Sachs 3x7 rear hub, giving a gearing range from 15 to 193 inches.

TEST MACHINE

The basic machine used for these tests was the Greenspeed GTS 20/20 Sport Tourer recumbent tricycle - see fig 1 and "Sports Tourer Tricycle - Standard Specifications".

While these trikes are not as popular as the Greenspeed GTR 20/20 Touring Trikes (40 GTSs V 200 GTRs built by June '98) they have been used as base model for a number of fully faired prototypes, and have been the most popular choice for schools competing in the 24 hr Australian pedal prix events, which often have 100 teams competing. The numbers of GTS kits supplied to schools, and numbers build by schools to Greenspeed plans have not been recorded.

TEST CIRCUIT

This was a 2.25 km course of suburban streets in the Mountain Gate estate, Fern Tree Gully, Victoria, AUSTRALIA -see Fig 3. From the corner of Ashton Rd, Mountain Gate Drive climbs moderately to Lydford Rd, where it drops steeply to Kevin Ave., and then climbs steeply to Conn Street. The rest of the course, Adele Ave, and Ashton Rd, is combination of gentle down grade, level road, further gentle down grade, and level road, enabling a speed of approx. 40 to 60 kph to be maintained, depending on rider and machine. The houses are the typical Australian single story brick veneer, set on large block of land, (see fig 4) giving rise to currents of wind between the houses, and much stronger currents through the side streets and across the open areas of the school grounds and the park, on windy days.

STEERING GEOMETRY

The standard steering geometry on Greenspeed solo trikes is 11 degrees of castor, which gives 48mm of trail - see drawing "Greenspeed GTS 20/20 Sports Tourer". This is a lot more that is common in Automobile practice where a typical figure is 3 degrees of castor or less. The 11 degrees was selected to give a reasonable amount of "feel" in the steering for such a light vehicle (100kg laden weight compared with 1,000 kg for a car). However if one pushes against the side of the trike, the steering will turn in the direction of the force, and it was felt that this could be a contributing factor to instability in cross winds with a fairing. Thus a Greenspeed GTS 20/20 was constructed with adjustable caster by using a telescopic cross member- see Fig. 2.

This was initially set up with 0 degrees of caster, but it was found that it felt unstable on the road, with the trike "pulling itself" into the corners! Then 3 degrees of caster was tried with a number of riders. While most riders agreed this gave a lighter steering than the standard set up, one rider was unable to detect the difference, thus 3 degrees for castor was used for the stability tests. With the caster set at 3 degrees, the steering on the trike would not move when the trike was pushed sideways.

TESTING

We have a small number of days in the year of continuous gusty high wind, when it has been found that it is almost impossible to hold the fully faired trike (fig 6) in one lane of a road at over 50kph, when the wind was blowing from the side. Thus one of these days of high wind was selected for the testing.

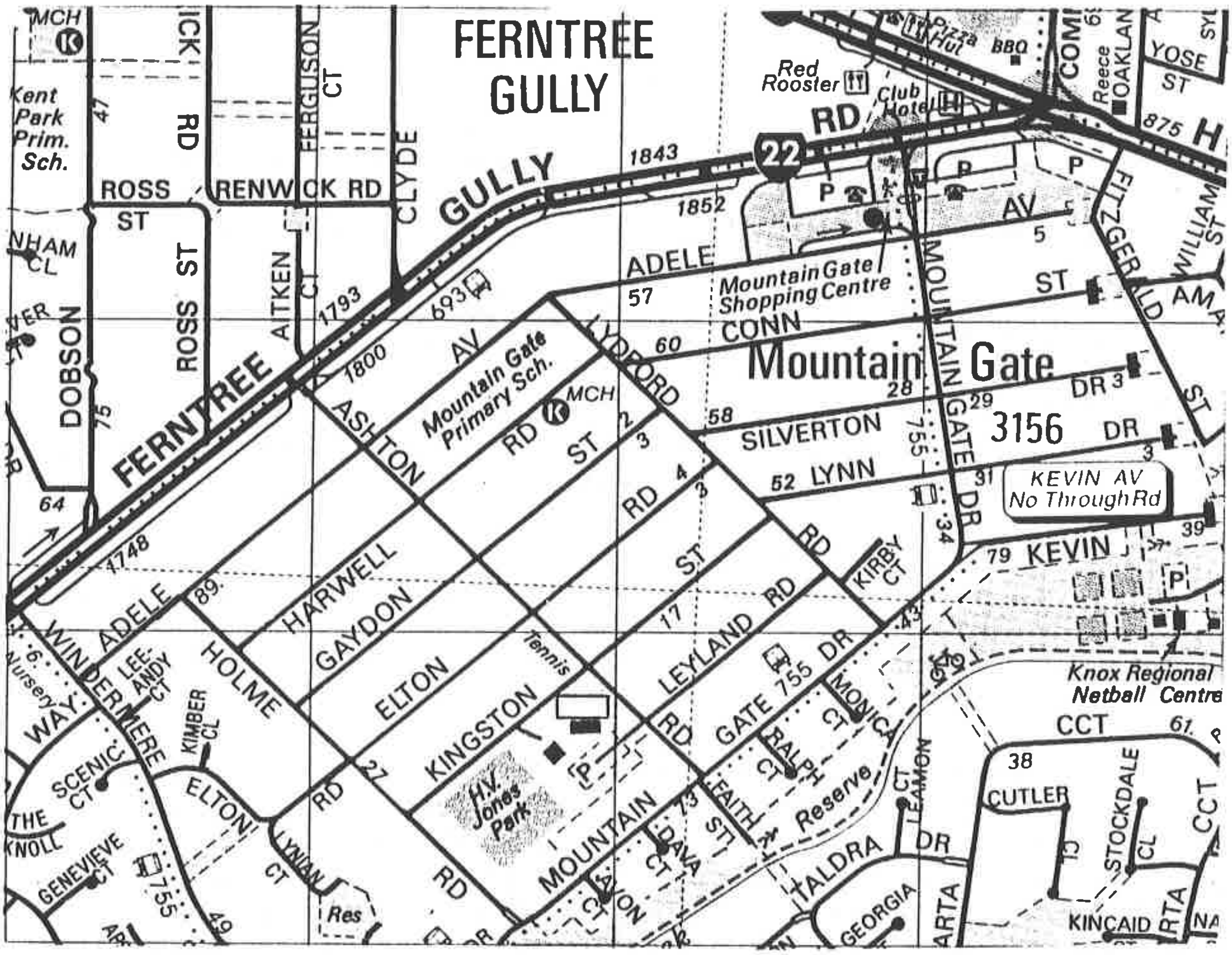

Fig. 3. The test circuit in Mountain Gate, Fern Tree Gully, AUSTRALIA.

Fig. 4. Typical Australian brick veneer house in the steeper part of Mountain Gate Drive, Fern Tree Gully.

1st a run was made around the circuit with the bare trike- see fig. 8. Like the standard Greenspeed trikes, there was absolutely NO sensitivity to the strong side winds - the trike behaved as if there was no wind at all. Next the trike was ridden around the course with just the front wheel discs fitted - see fig 5. There was very noticeable effect. It took a fair amount of concentration to hold the trike on course. This was in line with previous experience with discs, i.e. they effect the steering.

Thus as the steering geometry modifications appeared to have NO effect on stability, i.e. the behaviour was no better. It seemed that the instability was totally unrelated to the steering geometry!

This prompted the attachment of a piece of plywood about 30cm x 60cm (approx. same area of the wheel disc) to the rear rack to act as a tail fin. The effect was a DRAMATIC improvement. The handling reverted to approximately that of the bare trike - it was quite easy to keep the trike on line.

The next experiment was to ride the same circuit again with a fully faired trike. This was another Greenspeed Sports Tourer with a "Targa" Reflex fairing, with front screen, rear section, and detachable roof, but no side screens. see fig, 6. This trike had been successfully raced from Adelaide to Melbourne via Broken Hill, as a solar assisted HPV by the fairing manufacturer, Don Elliott, in early 1997. It achieved the maximum top speed of the race of 90.4kph, and completed the 1,467km course in six days to achieve 2nd place in the '97 Sunrace.

Fig. 5. Greenspeed GTS 20/20 Sports Tourer with front wheels discs - steering effected by cross winds.

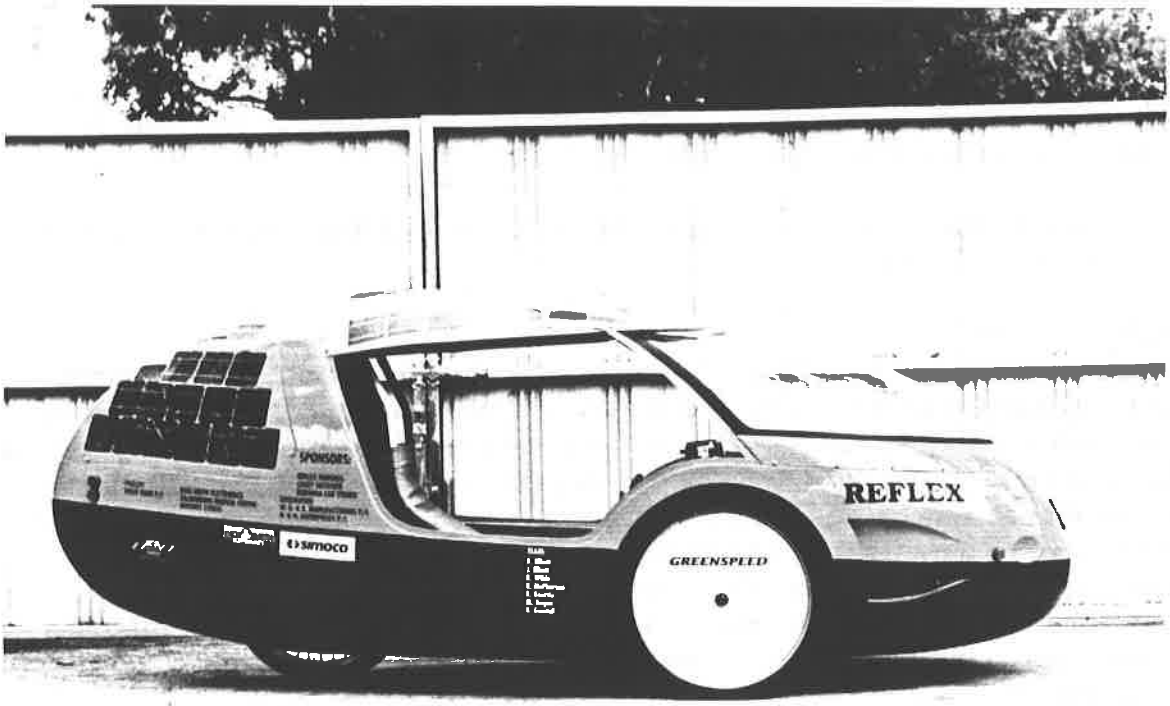

Fig. 6. Sports Tourer with "Targa" Reflex fairing - stability effected by cross winds.

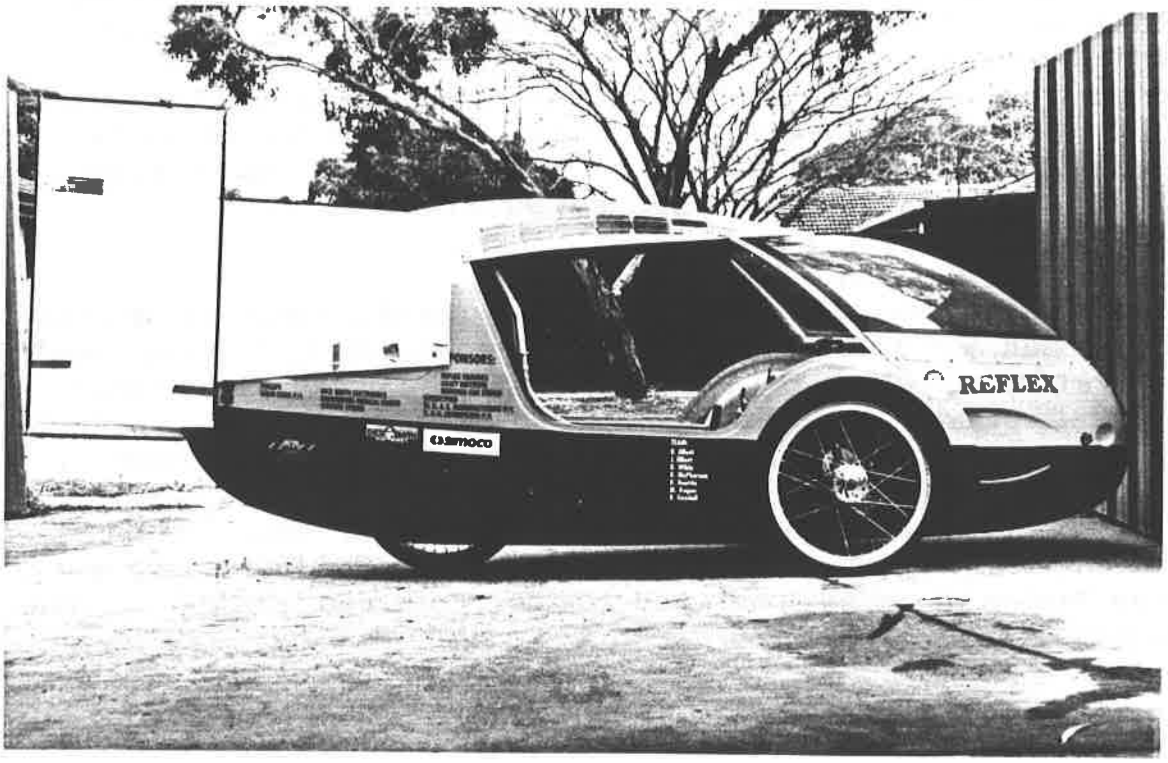

Fig. 7. Reflex fairing with "Corflute" tail - stable at speed in strong cross winds.

Again the steering was effected by the wind, and it was found quite difficult, if not impossible to hold a straight line on the road at speed. A tail fin was then constructed from "Corflute" and taped to the rear of the vehicle. It measured approx. 50 x 80 cm see fig 7.

Again there was a significant improvement in stability - almost like the wind was not there!

DISCUSSION

While we do not see tail fins on cars unless they are land speed record attempt machines, cars weigh about ten times the average HPV, and are thus not effected to the same degree by side winds. On the other hand, tail fins are used universally by aircraft to maintain directional control, and it appears that it is ESSENTUAL to have a larger area in side view behind the centre of gravity, than in front, so that directional stability can be maintained in side winds. One could consider an HPV being pushed sideways by the wind, but with enough tail area, it steers back into the wind, compensating for the sideways displacement away from straight running.

MATHAMATICAL MODEL

The question is how much tail area is needed? I am not going to attempt to provide a mathematical model for stability, as that was given by Andreas Fuchs in the 1st European Seminar. Andreas had some concerns about too much tail area causing an HPV to be steered into the path of a truck by it's "bow wave". Some approximation of the tail area used can be made from the side photographs and the fact that the loaded weight distribution is 1/3 on each wheel. The tail fin on the Reflex fairing increased the side area rear of the CG from 52% (unstable) to 67% (stable). Of course the amount needed for a particular HPV will depend on many factors including the overall shape of the HPV, and how the wind flows over it. Thus practical experiments may yield the best results.

FUTURE DEVELOPMENTS

Due to other practical problems with fully enclosed fairings, e.g. interior noise, vision, weight, etc., Greenspeed is now developing "three-quarter" fairings of the type used in the Energy Challenge, in conjunction with D&H Enterprises. A mould has been taken off the original mounds for the nose cone, and Don is producing a number of prototypes for further testing. These tests should provide guidance for the manufacture of a complete "hard shell" fairing of the "three-quarter" or "head-out" type, with sufficient tail area to provide stability. It is hoped this fairing will retain most of the aerodynamic and weather protection advantages of the full fairing, without the noise, vision, and weight problems.

Fig. 8. Bare Sports Tourer without wheel discs - completely stable at speed in strong cross winds.

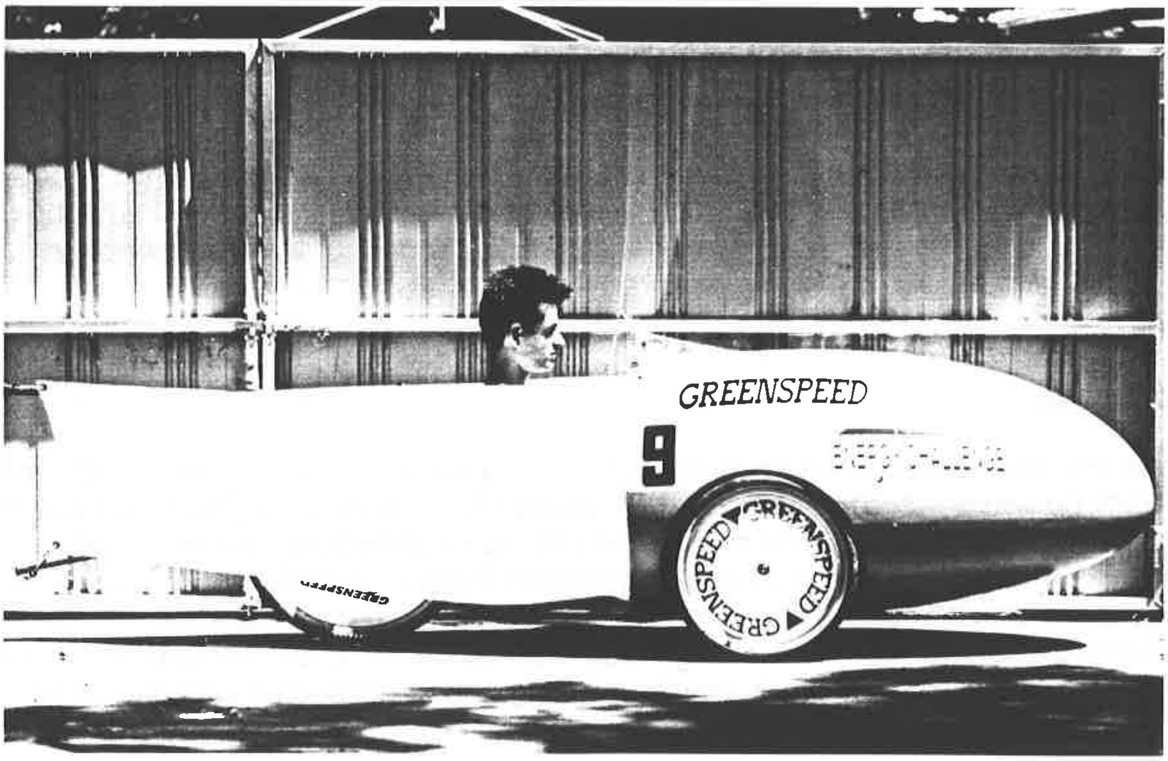

Fig. 9. Early Greenspeed GRT 20/26 Touring Trike with fairing as used in 1992 Energy Challenge - nose cone now being used to develop "3/4" or "head up" fairings.

Trim of aerodynamically faired single-track vehicles in crosswinds

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ABSTRACT

This paper is about minimizing the disturbing effects of steady crosswinds on single-track vehicles (velomobiles and hpv / bicycles / motorcycles). A solution of the static problem 'aerodynamically faired single-track vehicle in crosswind' is presented.
The Cornell Bicycle Model (Cornell Bicycle Research Project) describes the physical behavior of an idealized bicycle (single-track vehicle) at no wind. Other equations in a previous paper describe the torques on fairings due to aerodynamic forces which induce lean of single-track vehicles and lead to steering-action. These equations are combined with those of the bicycle model to describe the conditions for equilibrium at some lean but zero steering angle. Parameters affecting equilibrium are mass distribution, vehicle- and fairing geometry and the relative position of fairing and vehicle structure. Faired single-track velomobiles whose parameters are such that the equilibrium-equation ('trim equation') is fullfilled could be easier to ride in steady crosswind than those designed at random.
Because the trim equation derived in this paper does not describe the dynamic behavior e.g. of a velomobile coming from a no-wind situation into one with steady, alternating or impulse-input crosswind, further investigations will be needed for even better hpv- or other single-track vehicle design.

1. Introduction

Bicycles with disk wheels or other lifting surfaces and aerodynamically faired single- or multi-track human powered vehicles may be safely ridden in low and steady crosswind. But when the speed and direction of the wind change in unsteady patterns, today's lightweight, aerodynamically faired vehicles become hard to control. Multi-track vehicles may remain rideable because mainly one degree of freedom, rotations about the yaw-axis, has to be controlled, whereas single-track vehicles need to be controlled in the two degrees of freedom roll and yaw (yaw-roll-coupling) and may become very difficult to handle.

It is therefore important to increase understanding of the statics and the dynamics of these latter vehicles. This paper is about the statics of single-track vehicles in steady crosswind; it presents conditions for equilibrium at some lean angle and at zero steer angle. Solutions of the dynamic problem, where angular velocities are not zero, may be derived in later work.

A single-track vehicle can be compared to a great extent with a sailing-boat. There, trim also needs to be achieved in order that the boat neither turns away from the wind nor very quickly turns into the wind. Yet, the comparability of single-track vehicles and boats is limited in that a boat at zero speed may return from high rolling angles whereas a single-track vehicle returns to vertical only when speed is not zero.
Riders of faired velomobiles (single- or multi-track) know that lift may help to compensate drag (of any form: due to slope, to rolling resistance or air-flow). In order to gain a lot of energy from the wind by maximizing lift as much as possible, it would be necessary to increase the lateral area. But this is in conflict with the wish to ride the velomobile on narrow and on public streets as safely as possible.
The main intention of this paper is not to explain sailing with velomobiles, but to describe the statics of single-track vehicles in crosswinds in the hope that safer velomobiles may be designed in the future. Therefore, here, minimization of the lateral area of the fairing is suggested.

The main problem in the static case is the location of the center of pressure relative to the center of mass and the wheels of the vehicle. The center of pressure is the center of the aerodynamic forces acting on the vehicle, whereas the center of mass is the center of the gravitational forces (Fuchs, 1993 and 1994).
If the vehicle was airborne and if the center of pressure lay behind the center of mass, the nose of the vehicle would turn into a lateral wind (airborne vehicles rotate around axis through the center of mass). If, conversely, the center of pressure was in front of the center of mass, the vehicle's nose would point out of the crosswind.
Since land vehicles are (hopefully!) seldom airborne the behavior of the suspension has to be taken into account. Cooper (1974) explains : „ *... In terms of response to the wind, I don't feel that you want a lot of weathercock stability* (note by AF: far rear center of pressure location), *that is, you should try to use as small a vertical tail as possible* (note by AF: in contradiction to Bülk 1992 and 1994). *To initiate a right turn on a motorcycle you have to initially steer left. Following this line of reasoning, if a sidewind from the right hits a motorcycle with weathercock stability, it will cause the motorcycle to turn right into the wind. But the aerodynamic rolling moment and the lateral acceleration due to path curvature will cause the motorcycle to lean left getting you into real trouble. I think what you want is a careful balance of aerodynamic roll and yaw moment such that the wind vector will tend to force the motorcycle out of the wind but this tendency will be balanced by the lateral acceleration produced by the curvature of the path which will roll the motorcycle into the sidewind. From these arguments it's clear that you don't want to follow the dictates of aircraft or of four-wheel cars. You must consider the aero sufaces and the chassis together because a surface vehicle has tires which are doing things at the same time the aerodynamic forces are acting.*"

When the angle of attack (angle between the lifting body and the relative wind) increases due to rotation of the vehicle, the center of pressure location changes and moves towards the tail. Therefore, one should not simply talk about 'the center of pressure'. But since velomobiles are often faster than the wind, the relative wind mainly comes from ahead (see below, angle of attack). For this case, and when the fairing is made from thin airfoil sections, 'the center of pressure' is usually the one at small angles between the relative wind and the vehicle main plane and then the center of pressure position is fairly constant.

Gloger conducted crosswind-experiments in real scale (Gloger, 1996). From the results he concluded that for good handling of a single-track vehicle the center of lateral area of a fairing should be far front and low. This finding is compatible with the low weathercock stability suggested by Cooper (see above). Low weathercock-stability is equal to a center of pressure location near the nose, possibly in front of the center of mass.

Up to now, no analytical proof or simulation (numerical solution) existed that demonstrates mathematically what was guessed by Cooper and what was suggested by Gloger after the interpretation of the results from his crosswind experiments. In this paper, the first analytical approach known to the author was tried in order to find a solution to the statics of the crosswind problem and to derive the location of the center of pressure that would require minimal rider action ('equilibrium center of pressure location').

A bicycle model (by members of the Cornell Bicycle Research Project, see below) was modified by the author with the terms for the aerodynamic forces. The resulting equation allows the designer to trim a single-track vehicle so that it keeps its course in a steady field of crosswind. In order for trimming to be possible, a designer needs to know the position of the center of pressure in dependence of the angle of attack. With a method given in Fuchs 1993, two extreme positions may be estimated (at small angles, and at about 90 degrees). In wind tunnel experiments the center of pressure locations of between 0 and 90 degrees angle of attack could be determined.

So far no experimental validations - e.g. in a way Gloger performed his crosswind-studies - of the aerodynamically modified Cornell bicycle model exist. But there is qualitative evidence for the correctness of the model (see further below).

2. Bicycle model

(Box 1)

Extracts from the Cornell Bicycle Model

Cornell Bicycle Research Project
(Summary by Andreas Fuchs)

Some readers may know about the Cornell Bicycle Research Project (CBRP) due to a paper by Olsen and Papadopoulos in Bike Tech (Olsen and Papadopoulos, 1988), a journal which is no longer being published. There, the equations of motions of a bike model having rigid knife-edge wheels („ideal tires“), rigid rear frame with rider being immobile relative to it, and a rigid front assembly consisting of a steerable front fork with front-wheel, stem and handlebar, were published.

Thanks to personal communication with Andy Ruina the author of this paper has access to a unpublished report (Papadopoulos 1987) that contains sections about sidewind-effects (p. 10 and p. 19). Andreas Fuchs combined equations from Papadopoulos's 1987 report with equations about the aerodynamic torques and found the results of interest for the hpv community. Therefore, below there follows a short summary of the relevant equations of the Cornell Bicycle Model with reference to the unpublished report (personal communication with Papadopoulos, starting October 1996).

According to Hand (1988), cited by Papadopoulos (1987), the unmodified Cornell bicycle model was compared to bicycle models by earlier authors (see ref. cited at the end of this box 1) and the Cornell bicycle model was found to be consistent with some, whereas it was inconsistent with others. But confidence in its correctness is increased by the fact that the equations of motion were derived using two diverse approaches. The equations of the Cornell bicycle model are consistent with those by Whipple (1899, with typographical corrections), Carvallo (1901), Sommerfeld & Klein (1910), Döhring (1955), Neimark & Fufaev (1967, potential energy corrected), Sharp (not the paper, but the dissertation 1971, minor algebraic correction) and Weir (Dissertation, 1972).

The Structure of the Cornell Bicycle Model

A bicycle model consist of a set of equations describing the dynamics of this single-track vehicle, the equations of motion. In the Cornell Bicycle Model, their derivation starts with the formulation of the following four equations for :
F1) The total lateral forces that lead to the lateral acceleration of all mass points, that is the whole bicycle (total x-force; originally, the bicycle moves along the y-axis)
F2a) The total moment about the heading line of the rear assembly required for the acceleration of all mass-points in a general lateral motion (total χ-moment by external forces; see figure A below)
F2b) The total moment about a vertical axis through the rear wheel contact point required for the acceleration of all mass points in a general lateral motion (total θ-moment by external forces)
F3) The total moment exerted by external forces about the steering axis (total ψ-moment)

In the case of the Cornell bicycle model, the equations of motion are linearized and therefore are valid only for small angular deflections from the upright state of the single-track vehicle.

'Reduced Equations of Motion'

To study the motion of the bicycle itself, if one is not interested in the position of the vehicle in the x-y-plane (positive directions: x to the right, y forward, z up) and the heading θ, two equations to solve for the lean angle χ and the steering angle ψ would suffice. By using relations between all the angles and the lateral acceleration (acceleration in the x-direction), x and θ and their time derivatives may be eliminated. The side force in the front-wheel contact point may be eliminated from the set of four equations also by combining F2b) and F3). Three equations, equation F1) and the two 'reduced equations of motion' (lean- and steer-equation), remain:

Lean equation:

(I) $M_{\chi\chi}\ddot{\chi} + K_{\chi\chi}\chi + M_{\chi\psi}\ddot{\psi} + C_{\chi\psi}\dot{\psi} + K_{\chi\psi}\psi = M_{\chi}$ (p. 17, Papadopoulos 1987)

Steer equation:

(II) $M_{\psi\chi}\ddot{\chi} + C_{\psi\chi}\dot{\chi} + K_{\psi\chi}\chi + M_{\psi\psi}\ddot{\psi} + C_{\psi\psi}\dot{\psi} + K_{\psi\psi}\psi = M_{\psi}$

χ lean angle of the rear assembly, to the right
ψ leftwards steer angle of the front assembly relative to the rear assembly
$M\chi$ tipping (or supporting) moment (usually 0)
$M\psi$ steering moment exerted by rider

All terms on the left side in the equations consist of indexed coefficients M, K and C, dependent on physical parameters of the rider- bicycle-system, multiplied with the lean- or the steer-angle or their time-derivatives.

Both the lean- and steer-equations are to be found in other letters also in Olsen and Papadopoulos (1988).

Crosswind

A sidewind creates forces acting on some point of the front assembly and on some point on the rear assembly (Remark by Fuchs: the respective centers of pressure).

These forces create moments $(M\chi)_w$ and $(M\psi)_w$ ('w' for wind): $M\chi$ tends to tip the bicycle, whereas $M\psi$ steers due to the forces acting in the points on the front and rear assembly.

If at zero lean the center of pressure of the rear assembly (rear frame and rider) would be vertically above the rear wheel ground contact point, lean occurs, but there is no steering. If the center of pressure of the front assembly (fork, wheel, stem, handlebar) lies on the line between the front-wheel ground contact point and the intersection of the steering axis with the vertical line through the rear wheel ground contact point, no steering occurs, but bicycle-tipping results.

Condition for equilibrium in steady crosswind

For a steady response to the wind with steering angle ψ=0, the equation

(III) $\frac{K_{\psi\chi}}{K_{\chi\chi}} = \frac{(M_{\psi})w}{(M_{\chi})w}$ (p. 10, Papadopoulos 1987)

has to be fulfilled. This equation results from dividing (I) and (II) and setting all angular accelerations, angular velocities and the steer angle to zero.

The indexed coefficients of the equations of motion are as following (p. 16, Papadopoulos 1987):

(IVa) $K\psi\chi = g\nu$

(IVb) $K\chi\chi = -gm_t h_t$

According to lists and figures in Papadopoulos (1987) and Hand (1988) the parameters are (Abbreviations, see below):

V) $\nu = m_f d + \frac{c_f m_t l_t}{c_w}$ (Hand 1988, p. 29)

In detail:

VIa) $d = h_f \sin\lambda + l_f \cos\lambda - c_f$ (Hand 1988, p. 27)

If the center of mass of the front assembly is in front of the steering axis, then d > 0.

VIb) $m_t = m_r + m_f$ (Hand 1988, p. 29)

VIc) $l_t = \frac{m_r l_r + m_f(c_w + l_f)}{m_t}$ (Hand 1988, p. 29)

The parameters $K\psi\chi = g\nu$ and $K\chi\chi = -gm_t h_t$ have the following physical significance:

$K\psi\chi$ is the sum of two terms, $gm_f d$ and $\frac{gm_t l_t}{c_w} c_f$. Both terms are due to mass-forces acting on the front assembly when the bike is leaned, when $\chi \neq 0$: gm_f is a vertical mass-force acting on the lever d and $\frac{gm_t l_t}{c_w}$ is another vertical mass-force acting on the lever c_f (proportional to trail). For equilibrium, the steering-torque induced by these gravitational forces needs to be counterbalanced by lift acting in the center of pressure.

$K\chi\chi$ is due to the total mass-force gm_t acting on the lever $h_t\chi$ [$\sin(\chi) \approx \chi$ for small angles] and is the tipping moment due to gravitation.

Abbreviations in the Cornell Bicycle Model

g	gravitational constant, ≈ 9.81 m/s^2	
mf	mass of front assembly	(Hand 1988, p. 29)
cf	measure for trail, $cf = trail \cos \lambda$. cf > 0, also in case of mirrored front-wheel geometry.	(Hand 1988, p. 51)
cw	wheelbase	(Hand 1988, p. 21)
ht	height of center of mass of rider-bicycle-system	(Hand 1988, p. 53)
hf	height of center of mass of front assembly	(Hand 1988, p. 51)
λ	steering axis tilt (from vertical)	(Hand 1988, p. 21)
lf	horizontal position of front assembly center of mass, forward of front-wheel ground contact point	(Hand 1988, p. 51)
mr	mass of rear assembly	(Hand 1988, p. 29)
lt	horizontal position of system center of mass, forward of rear wheel ground contact point	(Hand 1988, p. 53)
lr	horizontal position of rear assembly center of mass, forward of rear wheel ground contact point	(Hand 1988, p. 49)

Table a Parameter designations

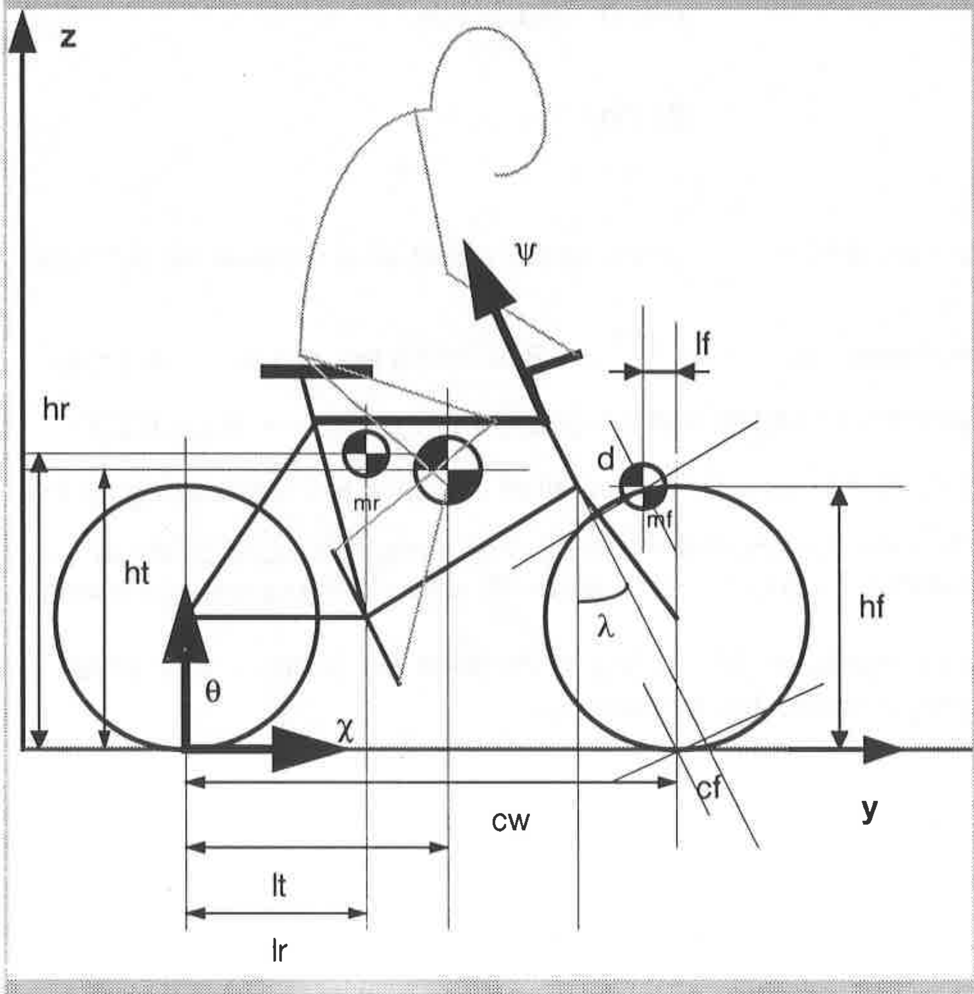

FIGURE A Main dimensions on a bicycle according to the Cornell Bicycle Model
Here, $c_f > 0$, $l_f < 0$, $d > 0$.

References of CBRP, published:
Olsen, John, and Papadopoulos, Jim. Bicycle Dynamics - The Meaning Behind the Math. Bike Tech December 1988

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(End of Box 1)

3. Normal force and true angle of attack

Lift is usually defined as acting against gravity. On faired velomobiles, the lifting surface is vertical so that when the word 'lift' is used here, actually a predominantly sidewards force is denominated.
Lift and drag combine to the total aerodynamic force. The component perpendicular (normal) to the centerplane of the fairing is called normal force:

1a) $$N_i = \frac{\rho}{2} v^2 c_{Ni} A_i \qquad i = 1,2,3$$

ρ density of the air
v airspeed of the relative wind (vectorial sum of vehicle-groundspeed and windspeed)
c_{Ni} coefficient of normal-force
A_i reference area
For lift: Often, the lateral area of fairing is used (for drag: often the cross-section of the fairing is used). On how to transform coefficients: See Fuchs 1993

[The equation for the normal-force is formally similar to the one for drag.]

The relative wind is the vectorial sum of the vehicle groundspeed and the speed of the crosswind relative to the ground. The faster the hpv (the higer its propelling power and the smaller its drag), the smaller the angle of attack. Yaw-, roll- and pitch-rate also influence the angle of attack (Cooper 1974): Upon taking these rates into account, we arrive at the 'true angle of attack'. In this paper, however, only the static case is considered, all angular velocities are zero and therefore the true angle of attack is the angle with which the relative wind approaches the fairing.

For small angles of attack, the coefficient of the normal-force is approximately the same as the coefficient of lift:

$$1b)\quad c_N = \frac{dc_N}{d\alpha}\alpha \approx \frac{dc_L}{d\alpha}\alpha = c_L$$

$dc_N/d\alpha = c_{N_\alpha}$	slope of lift-angle of attack-curve
α	angle of attack (angle between the centerplane of the fairing and the relative wind)
c_L	coefficient of lift

In Fuchs (1993) the magnitude of the lift-alpha-slope is given in dependence of the airfoil / fairing thickness. For thin, symmetrical airfoils, the linear approximation may be used in an interval of -10 ≈< α ≈< +10 deg.

4. <u>The center of pressure locations</u>

Most single-track velomobiles can be described as consisting of two lifting surfaces (see Fig. 2):

1. The vehicle body including main fairing, top (covering the rider's head) and possibly faired rear wheel
2. The steered front-wheel which produces considerable lift if faired or if the wheel is a trispoke

Fuchs (1993) is on how to estimate the location at which the normal force ('lift') acts for small angles of attack ($0 < \alpha < 15$ degrees) and large angles of attack ($\alpha \approx 90$ degrees). This location is called center of pressure CP.

4.1 Center of pressure (CP) of the vehicle excluding the front-wheel but including the possibly faired rear wheel (fairing, body)

n3	distance between the nose of the fairing and the CP of the fairing (excluding the front-wheel)
δ3	height of the CP of the fairing (excluding the front-wheel)
A3	reference area of the vehicle (for lift: the lateral area) excluding the wetted area of the front-wheel
N3	normal force on the fairing (excluding the front-wheel)

According to Fuchs (1993), for common fairing geometries of supine recumbents, the CP is located at about 1/3 body length from the nose of the fairing for small angles of attack and slightly more than ½ body length for large angles of attack. If the top covering the head is fairly small relative to the rest of the fairing, then the CP lies just below half the vertical extension of the fairing (not the whole vehicle!).

Fairing center of pressure relative to the rear wheel

With the definitions of a bicycle's geometry (→ Box 1, Fig. 1), the position of the CP of the fairing relative to the rear wheel, rh, is (See also Fig. 2):

2) $rh = cw + w - n3$

w	distance between the nose of the vehicle and the front-wheel ground contact point

4.2 CP of the faired front-wheel

n2	horizontal distance between the nose of the vehicle and the CP of the faired front-wheel
δ2	height of the CP of the faired front weel
A2	'wetted area', area of the faired front-wheel exposed to wind (for lift: the lateral area)
N_2	normal force acting in the wheel-CP ($N_2 = 0$ if wheel unfaired)

Remarks:
- If the front-wheel is not faired and does not produce lift, then A2 = 0
- If the faired front-wheel is only partially exposed to the airstream, then: $A2 < R^2\Pi$, R: front-wheel radius

Wheel center of pressure relative to the rear wheel

With the definitions of a bicycle's geometry (→ Box 1), the position of the CP of the wheel relative to the rear wheel, rhw, is (See also Fig. 2) :

3) $rhw = cw + w - n2$

w	distance between the nose of the vehicle and the front-wheel ground contact point

Assuming the front-wheel to be a flat plate, the CP-location can be estimated using an integration method in Fuchs (1993).

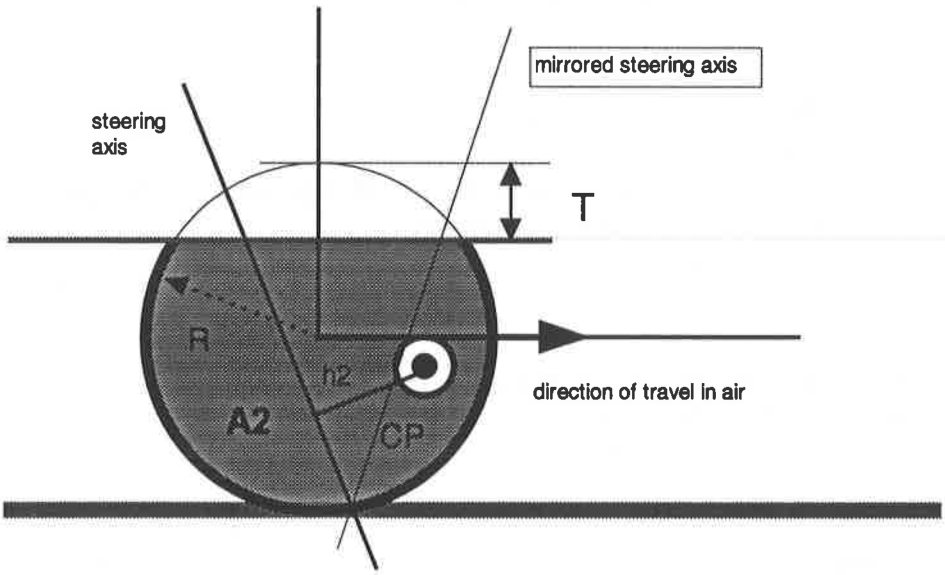

Figure 1 CP-location of a faired front-wheel with radius R. The wheel may be hidden in the fairing by the distance T. When the CP is in front of the steering axis (as in this figure) then h2 > 0.

Distance between the front-wheel CP and the steering axis

The distance between the steering axis and the front-wheel-CP is given by:

4) $$h_2 = \cos\lambda \left(w - n_2 - \frac{cf}{\cos\lambda} + \delta_2 \tan\lambda \right)$$

h_2 distance of the faired-wheel CP to the steering axis (positive if CP in front of the steering axis)

w distance between the nose of the vehicle and the front-wheel ground contact point

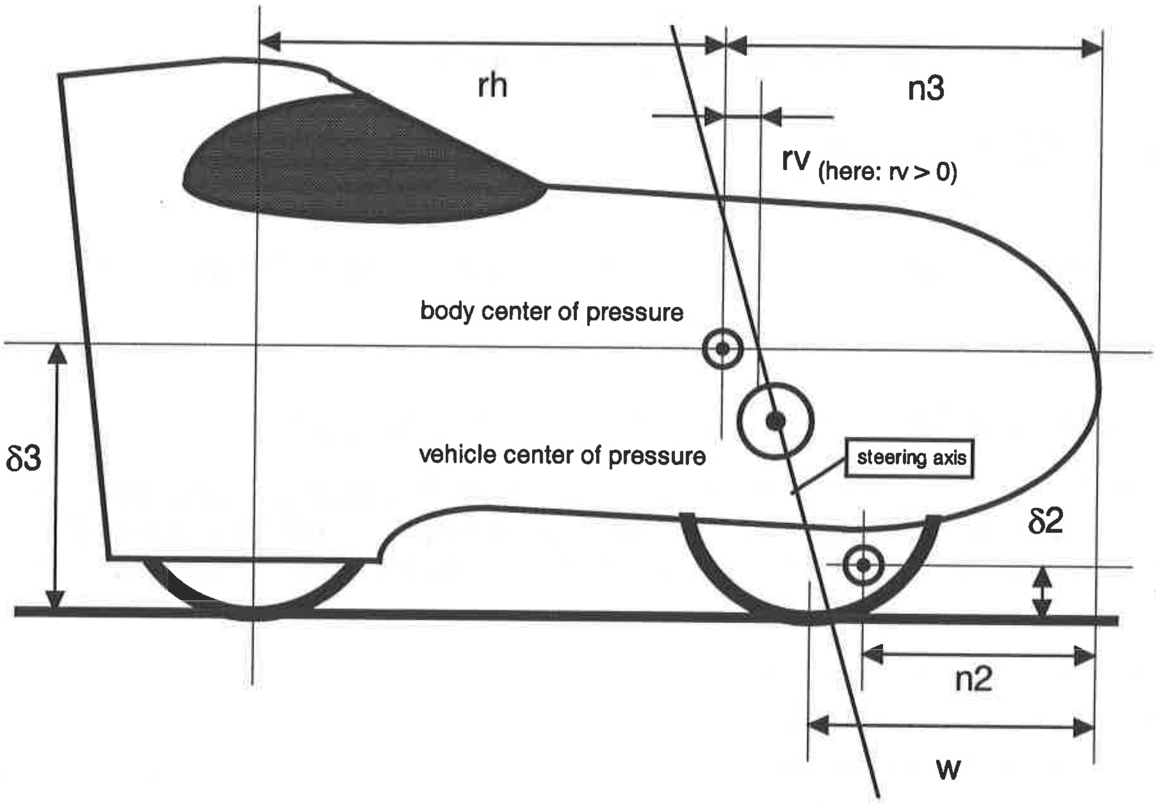

Figure 2 Definitions of the position of the body center of pressure, the position of the faired wheel center of pressure and the position of the fairing relative to the bicycle inside.
Here, the symbol 'circle with dot' does not represent a vector pointed towards the reader, but is simply the symbol for center of pressure.

4.3 Center of pressure location of the whole vehicle

n1	distance between the nose of the fairing and the CP of the vehicle
δ1	height of the CP of the vehicle
A1	reference area of the whole vehicle (for lift: the lateral area)
N1	Total normal force on vehicle

The CP of the vehicle is determined by the CP of the fairing and the CP of the faired front-wheel:

$$A1 = A2 + A3$$

$$N1 = N2 + N3$$

5) $$n1 = \frac{n2N2 + n3N3}{N1}$$

$$\delta 1 = \frac{\delta 2N2 + \delta 3N3}{N1}$$

The lift-curve-slope of the whole vehicle can be derived from

$$6)\quad c_N\alpha 1 = \frac{c_N\alpha 2A2 + c_N\alpha 3A3}{A1}$$

If the front-wheel is unfaired, A2=0, then A1=A3, N1=N3, n1=n3, δ1=δ3 and $c_N\alpha 1 = c_N\alpha 3$.

5. <u>Introduction of the aerodynamic terms into the Cornell Bicycle Model</u>

Aerodynamic terms using the formulaes of the two preceding chapters were combined with the equations F1, F2a, F2b and F3 of the Cornell Bicycle Model (See box 1); the aerodynamic terms were added on the side of the external forces of the formulaes F1 to F3:

Formula F1, X-force (lateral forces) :
Force due to 'lift' on fairing: $+N3$
Force due to 'lift' on faired front-wheel: $+N2$

Formula F2a, χ-moment (moment relative to a horizontal forward axis) :
Moment due to 'lift' on the fairing: $N3\delta 3$
Moment due to 'lift' on the faired front-wheel: $N2\delta 2$
(Since for small lean angles δ and N are approximately perpendicular, we do not use the cross-product: sin(90 deg) = 1!)

Formula F2b, θ-moment (moment relative to a vertical axis through the rear wheel ground contact) :
Moment due to 'lift' on the fairing: $-N3rh$ **(negative sign!)**
Moment due to 'lift' on the faired front-wheel: $-N2(cw + w - n2)$ **(negative sign!)**

Formula F3, ψ-moment (moment relative to the steering axis) :
External forces do not directly create moments at the steering axis, but indirectly due to the forces in the front-wheel contact. Therefore N3 does not appear in the equation for ψ.
Moment due to 'lift' on the faired front-wheel: $-N2h2$ (negative sign if h2 > 0)

From the four modified equations the 'modified reduced equations of motion', now including the aerodynamic terms, were derived as described in box 1. From these modified reduced equations of motion, in a further step an aerodynamically modified equation III was derived (Condition for equilibrium in steady crosswind):

6. Trim equation

Equation (III), now modified with the aerodynamic terms, is as follows:

$$7)\ \frac{K_{\psi\chi}}{K_{\chi\chi}} = \frac{M_{\psi} - N_2\left[h2 + \frac{cf}{cw}rhw\right] - N_3\frac{cf}{cw}rh}{M_{\chi} + N_2\delta_2 + N_3\delta_3}$$

$K_{\psi\chi}$: Equation IVa (Box 1)
$K_{\chi\chi}$: Equation IVb (Box 1)
M_{ψ}: Steering moment by rider
M_{χ}: Supporting moment (e.g. supporting side-wheels)

The terms with N2 describe the moments due to 'lift' on the front-wheel and those with N3 the moments on the main fairing, the top and the eventually faired rear wheel.

Putting into equation 7) all the detailed geometrical and aerodynamic relations yields the **'faired single-track vehicle trim equation'** 8) :

'Faired single-track vehicle trim equation' 8) :

$$8)\quad \frac{m_f d + \dfrac{c_f m_t l_t}{c_w}}{-m_t h_t} = \frac{\left\{\dfrac{M_\psi}{\frac{\rho}{2}v^2}\right\} - \alpha c_{N\alpha 2} A_2 \left[\cos\lambda\left(w - n_2 - \dfrac{c_f}{\cos\lambda} + \delta_2 \tan\lambda\right) + \dfrac{cf}{cw}(cw + w - n2)\right] - \alpha c_{N\alpha 3} A_3 \dfrac{cf}{cw}(cw + w - n3)}{\left\{\dfrac{M_\chi}{\frac{\rho}{2}v^2}\right\} + \alpha c_{N\alpha 2} A_2 \delta_2 + \alpha c_{N\alpha 3} A_3 \delta_3}$$

This trim equation aplies to states of single-track vehicle near upright (small lean angles) with zero steer angle (See box 1 for details about the bicycle model). If the trim equation is true, then equilibrium is established: As long as no disturbance alters the state of the vehicle, it will go straight, with some lean but zero steer angle. The trim equation is valid only if the speed of sideslip is much smaller than the component of the crosswind perpendicular to the vehicle heading.

The significance of the abbreviations may be found elsewhere in this paper:

a) Influence of rider ($M\psi$) → Box 1
b) Variables describing the mass distribution → Box 1
c) Variables describing the 'bicycle geometry' → Box 1
d) Variables describing the lift-distribution on the body and the faired front-wheel: Chapters 3 and 4
e) Possible moment $M\chi$ by e.g. supporting wheels or fins which produce roll-moments → Box 1

6.1 The trim equation and effects that affect trim

- The trim equation (8) is arranged similar to equation III of box 1 to show the resemblance.
The velomobile designer may rearrange it according to his wishes.

- The equilibrium is independent of the gravitational acceleration and, if the steering-moment $M\psi$ and the supporting moment $M\chi$ are zero, the equilibrium is also independent of velocity : $\frac{\rho}{2}v^2$ (the dynamic pressure) then cancels on the right side of the equilibrium equation.

- At equilibrium, body-CP-locations near the center of mass are only reached at the far extremes of the parameter ranges. Generally, the equilibrium center of pressure locations lie front of the center of mass.

- In the case where $M\chi$ and $M\psi$ are zero, in formula 8) the angle of attack α factors in such that the result is 1. If the center of pressure did not move in dependence of angle of attack, trim would thus be independent of α.
For small angles of attack (typically: $0 < \alpha < 10$ degrees), the center of pressure of thin symmetrical airfoils does indeed not move much. Therefore, for that small region of angle of attack the above expression can be considered valid on the whole range of about 10 degrees so that the parameters describing the CP-locations (n_1, δ_1, n_2, δ_2, n_3, δ_3) do not have to be varied. But since outside the range $0 < \alpha < 10$ degrees even for thin airfoils the CP-location depends on angle of attack α, it is factored in to remind us of that fact.
How insensitive the CP-location is with respect to α for thicker symmetrical airfoils common on hpv fairings should / could be measured in wind tunnel experiments.

- Trim depends on the lift-curve-slopes $c_{N_\alpha 2}$ and $c_{N_\alpha 3}$ which in turn depend mainly on airfoil thickness. Faired wheels are relatively thinner airfoils than bodies: They therefore produce more lift per degree angle of attack than bodies. See Fuchs, 1993.

- The supporting moment $M\chi$ is in the case of single-track vehicles without side-wheels non-existent and thus equal to zero.
But a moment exerted by the rider on the handlebars, $M\psi$, may exist, although the rider is unnecessarlily stressed by a non-zero steering moment. Trim should be established so that $M\psi = 0$ for the most common angles of attack.
If $M\psi > 0$ (the rider pulls on the left side on the handlebar and pushes on the right side), then n3 reqired for equilibrium becomes smaller and the equilibrium center of pressure location moves forward compared to the case where $M\psi = 0$ (remember: The sign convention is such that the wind blowing from left to right blows in the positive lateral-x-direction). Conversely, if the rider turns the handlebar to the right ($M\psi < 0$) the equilibrium center of pressure location moves back, n3 needs to become larger.

- In the case of an unfaired front-wheel (and vanishing moments), A2=0 and δ2 as well as n2 are not defined. All terms including A2 and n2 vanish and the trim equation becomes much simpler and shorter:

$$9)\ n_3 = \left[- l_t - \frac{c_w}{c_f} \frac{m_f}{m_t} d \right] \frac{\delta_3}{h_t} + w + c_w$$

In the case of a lifting wheel (A2 ≠ 0 and δ2, n2 defined), two cases have to be distinguished:

a) Standard front-wheel geometry

Since the CP is in front of the steering axis (h2 > 0, see Fig. 1) the front-wheel is steered out of the wind (e.g. on a triathlon bike with a trispoke front-wheel or a track bike with a disk front-wheel). Trail exerts a moment due to lift on the main fairing N3 that also pushes the steering axis out of the wind. Therefore, the moment by lift required for equilibrium could be smaller; with a constant N3, the lever between the main body center of pressure and the center of mass may become smaller and the cp may therefore be further away from the nose of the fairing (bigger n3).

An elegant way to get rid of the disturbing moments on a faired front-wheel is to fair the whole wheel with the main fairing. This is what Brichet did when designing 'Nilgo III' (Fehlau 1996, p. 128).

Another way to minimize the moments on the front-wheel is to add tail fins at the rear-side of the fork, that is, to redistribute the lift on the front-wheel assembly such that the center of pressure lies on or behind the steering axis. But this method yields more lift - due to increased lifting area - on the front-wheel alone.

Note: When the steer angle ψ is not zero, the angle of attack of the exposed front-wheel area A_2 is different from the angle of attack of the body. Thus, lift on the front-wheel alone may increase or decrease. This alters the lift distribution on the vehicle and therefore the CP moves (mainly up or down). Putting the whole front-wheel inside a fairing fixed to the body avoids this vertical shift in the vehicle-CP-location.

b) Mirrored front-wheel geometry

h_2 (see Fig. 1) may be minimized by choosing a mirrored front-wheel geometry, where the steering axis tilts forward instead of rearwards. Read more on this in Gloger 1996.

6.2 Application of the the 'trim equation':

The trim equation (8) is basic for the lateral stability of faired single-track vehicles in crosswind (at small lean angles, at zero steer angles). The trim equation may be used in numerous ways: E.g. for a given faired single-track vehicle, if the location of the center of pressure in dependence of the angle of attack α is known, the trim equation may be rearranged to calculate the moment Mψ in dependence of α required on the handlebar to keep the vehicle moving with zero steer angle.

The variables in the 'trim equation' can be classified in five groups:

a) Influence of rider ($M\psi$)
b) Variables describing the mass distribution
c) Variables describing the 'bicycle geometry'
d) Variables describing the lift distribution on the body and the faired front-wheel
e) Possible moment $M\chi$ by e.g. supporting wheels or fins which produce roll-moments

The trim equation may be true after any set of variables from these five groups has been varied. A designer of velomobiles, wishing to establish equilibrium at certain conditions (that is at a certain angle of attack α) could now optimize his vehicle e.g. according to the following steps :

A) Define the position of the rider. Since the rider is the main mass, this defines the mass distribution of the vehicle to a high extent
B) Optimize the bicycle geometry for good handling also in no-wind situations (Patterson 1997)
C) Tune the lift distribution in such a way that the 'trim equation' 8) is true. Then trim is established at a certain angle of attack[1]

The lift distribution may be varied by the following actions :

- redistribution of the lifting area (for minimum sidewind sensitivity, the lateral area A1 = [A2+A3] needs to be as minimal as possible)
- add lift-producing devices as small as possible (e.g. small fins or a fairing around a front-wheel that steers inside) to achieve a desired CP-location. Even though total sideforce will increase, handling may improve
- add devices that create disturbance to the airstream so that lift and sideforce vanish

To tune a velomobile the designer wants to know what changes will have what influence. The important parameters may be identified by calculating e.g. the sensitivities of the horizontal fairing CP-location n3 with respect to any other parameter / design variable x_i:

10) Sensitivity of n3 with respect to design variable: $x_i = \left.\frac{\delta n_3}{\delta x_i}\right|_{\text{Vehicle}}$

The subscript 'Vehicle' signifies: Only x_i is varied; all other parameters are held constant at the vehicle's nominal values.

(An example of this variation is shown in Fig. 3. There δ3 has been varied to get the curve 'cp-locations'. The sensitivity of n3 with respect to δ3 is the slope of this curve.)

Increasing the wheelbase, the rear center of mass height, or the trail, moves the equilibrium CP-location backwards. Moving the rear center of mass location forward relative to the rear wheel ground contact or moving the fairing CP up shifts the equilibrium body-CP-location forward.
Changes of the steering tilt angle do not have dramatic effects on the equilibrium CP-

[1] At angles of attack of about 10 to 15 degrees, thrust due to lift is maximal; a velomobile could be tuned, for example so that a zero steer angle results at this region of angle of attack!

location.

Trail and rear center of mass height have strong influence on the equilibrium center of pressure postion in a positive way and the fairing CP height and rear center of mass forward position have strong influence in a negative way.

One may even think of applications of the trim equation (8) that at first sound like Science Fiction: Measure the angle of attack of the relative wind using a vane and automatically adjust e.g. the bicycle geometry or the lift distribution while riding such that trim is always established !

7. Evidence for the validity of the trim equation

No extensive validation of the aerodynamically modified Cornell Bicycle Model has been made, e.g. in an experiment similar to the crosswind-experiment by Gloger (1996). But a simple, illustrative experiment and the single-track velomobile 'Aeolos' by Joachim Fuchs demonstrate the (qualitative) validity of the trim equation (8):

7.1 A Simple Experiment (See also Milliken 1989)

Instructions: Lean a bicycle towards yourself to simulate lean against a crosswind. In this case, the crosswind would come from your side of the symmetry plane of the bicycle. Push the frame away from you at various horizontal locations such that the front-wheel aligns with the frame (steering angle zero degrees).
Question: Where do you have to push: more toward the back or more on the front of the frame?
Results: Most likely, you will find it easier to align the front-wheel with the vehicle's main plane when you push somewhere near the steering axis (usually near the front of the bicycle).
Interpretation: The push by your fingertip is similar to a lift-force by the crosswind. The location where you push is near the equilibrium location of the center of pressure.

7.2 Aeolos - an example for a minimal crosswind-sensitive hpv

According to Joachim Fuchs (Fuchs Joachim, 1996) his fully faired single-track streamliner *Aeolos* can easily be ridden in crosswinds. The following text by Joachim Fuchs originates from the HPV CD 1997 (pictures of Aeolos may also be found on the HPV CD 1997):

„The construction is focused on little side wind sensitivity because it is known that race recumbents are difficult to control. Nevertheless, Stefan Gloger (DESIRA II) showed in his PhD work that this problem can be overcome. My plan was to reduce the lateral area of the rear part of the fairing. The centre of pressure is then closer to the front of the vehicle. The wind takes influence on the steering in a way that the rider must not react actively. The only thing he has to do is to hold the handle with a slack grip. Even in gusty and strong winds, the vehicle finds its own way and leans into the wind by itself."

In order to check the state of trim of Aeolos, the longitudinal position of the center of pressure of the fairing, n3, was calculated using the trim equation (8). Those parameters that are not known were estimated from reasonable assumptions (Aeolos front-wheel is unfaired). In Fig. 3 the lateral area of the fairing and the wheels are shown. The locations of the center of pressure CP (small angles of attack) and the center of lateral area CLA (center of pressure at angles of attack near 90 deg) were estimated by using methods in Fuchs (1993). Known masses and a foto of the frame permitted an estimation of the position of the center of mass.

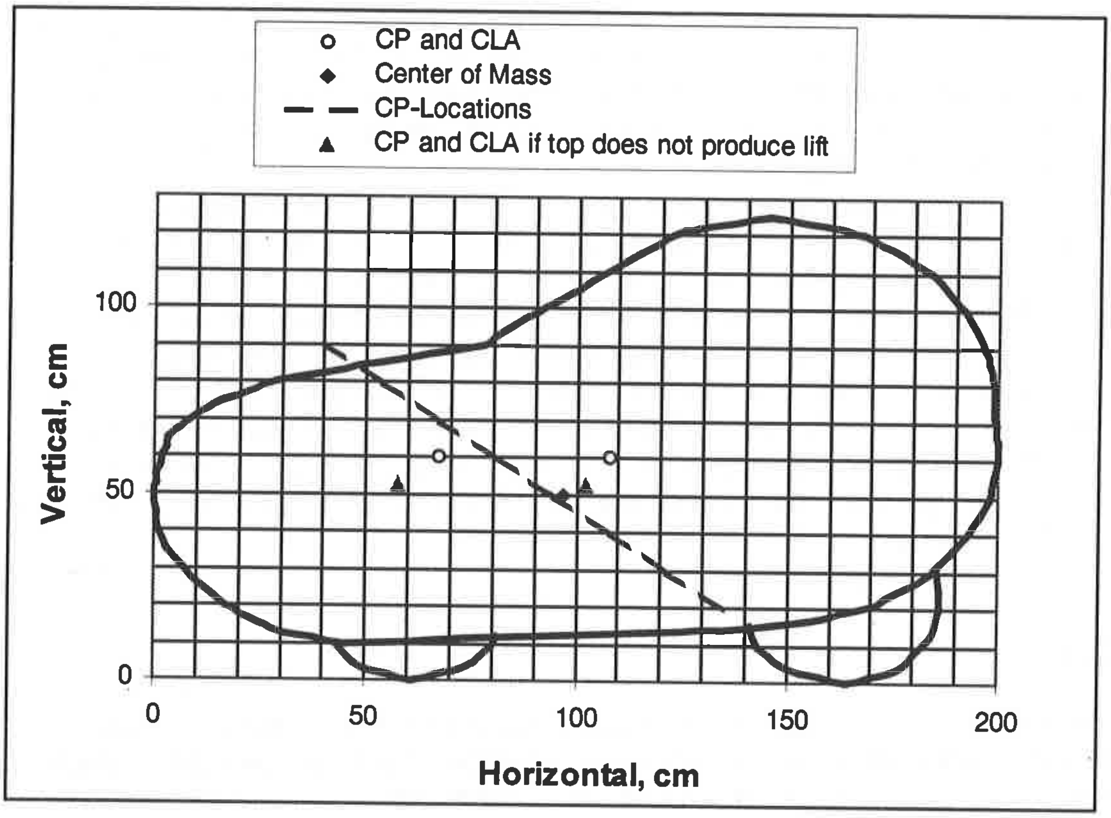

Fig. 3 Aeolos sideview shows the relative position of the center of mass, the estimated centers of pressure for small and large angles of attack (the latter being probably near the center of lateral area) and the possible equilibrium positions of the center of pressure (cp-locations).

If the height above the ground of the fairing center of pressure is $\delta 3 = 0.60$ m, for equilibrium a body-CP-longitudinal location of $n_3 = +0.81$ m behind the nose of the fairing is calculated. This longitudinal position is in front of the center of mass.
The center of pressure height $\delta 3$ was then varied, and by using the solver of a worksheet, corresponding longitudinal positions were calculated (or one may use equation 9). The results are plotted in Fig. 3 as the line 'cp-locations'. This line shows that a vertical displacement in up-direction of a fairing needs to be accompanied by a horizontal displacement towards the front of the vehicle. Otherwise, equilibrium is no longer assured.

The line of 'cp-locations' crosses the shortest line between the estimated centers of pressure (CP and CLA) for small and large angles of attack. This is an indication that the Aeolos-fairing is already positioned quite optimally relative to the person and the recumbent inside. Joachim Fuchs arrived at this technical solution after having considered the results of the crosswind experiment by Stefan Gloger (Fuchs Joachim 1996).
The line 'cp-locations' crosses the line between the estimated centers of pressure CP

and CLA near the center of pressure at small angles of attack CP. This indicates that Aeolos will need no steering input when the relative wind comes from angles of attack of less than 45 degrees (about 15 to 30 degrees).
If the exact locations of the center of pressure and corresponding angles of attack were known (e.g. by wind-tunnel experiments), the parameters of Aeolos could, with the help of the trim equation, be varied such that Aeolos is trimmed at a defined angle of attack.

Very probably the design of Aeolos would be worsened by adding a tail or a long nose. In both cases, the centers of pressure would move away from the line of statically optimal center of pressure locations (line 'cp-locations') and the vehicle would turn into the wind or out of the wind. The rider of the worsened Aeolos would have to compensate for that by steering action.
Matt Weaver's 'Cutting Edge' ultra-streamliner has a very long nose (Weaver, 1991). Matt states that in sidewinds he had to gently steer out of a lean into the wind. This can be interpreted in the following way: The nose is so long that the actual center of pressure lies in front of the line of possible equilibrium center of pressure locations (derived by using the parameters of the mass distribution and the parameters of the suspension geometry). This leads to steering action and to rolling into the wind. If the actual center of pressure was higher above ground, that is nearer to the line of the cp-locations, then the tipping moment due to sidewind would also be higher and thus would work stronger against the lean. As a consequence, Matt would not have to roll out of the wind as much by steering.

8. Conclusions

The equation to calculate the equilibrium location of the center of pressure for zero steering angle in crosswinds - the 'trim equation' - has been derived. Using it, a single-track velomobile designer may trim his vehicle to achieve good handling characteristics under certain conditions (angle of attack); the torque that has to be exerted by the rider onto the handlebar may be minimized. But the fact that a vehicle is in trim at certain angles of attack does not assure safe handling in any situation that may be encountered in windy conditions on the street.
For the first time it was mathematically shown that static stability of single-track vehicles in crosswinds is achieved when the center of pressure is in front of the center of mass[2] (Hucho 1994).

What has not been discussed in this paper are the dynamics of the transition from one state of crosswind-influence to another state of crosswind-influence. This would require further research.

9. Suggestions for further research

- Wind tunnel experiments to determine the wandering of the CP with angle of attack so that estimations are no longer needed.
- Investigations concerning the importance of the human as a controller. Gloger's crosswind-experiment (Gloger 1996) shows that there is a difference in vehicle reaction to crosswind dependent on the familiarity of the rider with a certain vehicle.

[2] Further investigations, not reported here, indicate that the height of the center of pressure above ground should not be much more than the height of the center of mass.

Joachim Fuchs text about how to handle Aeolos is another hint to the importance of the rider.

- Theoretical investigations of the dynamics, since it is not only important to establish equilibrium at certain conditions, but (for safety) it is even more important how equilibrium is approached from any state the vehicle is in!
- Simulations of fully-faired (single-track) vehicles to study the dynamics in dependence of various forcings by crosswind: Impulse input (wind gusts), step input (coming from a no-wind region into a region with steady crosswind), and periodical as well as variable crosswind-patterns. Rigid-body simulation tools such as 'Mechanica' could be used.
- Estimations to determine the relevance of aerodynamic damping: hpv's are lightweight and their fairing lateral area may be huge. It is therefore possible that aerodynamic damping is important for mainly the yaw movement.
- Validations of simulations by measuring vehicle behavior in different crosswind-patterns.

Acknowledgements

'Many thanks' go to Andy Ruina for providing copies of documents about the Cornell Bicycle Model.
Jim Papadopoulos's comments were essential for the derivation of the trim equation as can be followed in this paper - Thank you very much, Jim ! Having copies only of the final result, Jim also derived the trim equation and arrived at a result similar to that of the author.
Thanks go also to Joachim Fuchs for providing Aeolos data (no, Joachim is not my brother!).
In an early stage of this work, Joachim Fuchs, Stefan Gloger and Bill Patterson contributed many important ideas. With Theo Schmidt, the author was able to conduct valuable discussion about sailing with faired hpv's.
Thanks go to David Picken for checking the text.

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Minimizing aerodynamic drag of a fully faired racing recumbent

Frank Lienhard

Fully faired recumbent bicycles are well suited for high speed racing. A fundamental goal is to achieve a maximum of efficiency with human powered vehicles. This means that the aerodynamic drag as a main factor of resistance has to be minimized. The present paper describes the results of tests with a full-size model in a wind tunnel.

Investigations of Dr. R. Bannasch [1] at the Technical University of Berlin have shown that certain kinds of penguins show extraordinarily little hydrodynamic resistance. This was the starting point to test this result in practice on fully faired racing recumbents in a wind tunnel.

In the current investigations, a full scale model was tested in a wind tunnel to improve the aerodynamic drag of a fully faired recumbent. The model was first mounted above the ground plate to measure the drag of several yaw angles without differences in the shape of the recumbent. The smallest value of aerodynamic resistance was used as a start for the next measurement. The first investigations showed that the best results were obtained at small positive angles (0 to 3°).

Reducing of the ground clearance lead to a reduction of drag, however, an expected ground effect was not observed within the parameters used in this experiment. Nevertheless, the influence of the ground clearance was small (approx. 10% when lowering the model 15 cm). A significant reduction of the aerodynamic drag was only achieved by applying a long, fin-shaped tail to the fairing.

At a yaw angle of 2 degrees, different patterns were found at the separated air streams. On the wind side, the stream is almost laminar while on the lee side the stream detached in the rear part of the fairing.
The improvement of the reduction of the drag and their results were:

Version	c_d
Original	0.07
Connected wheel fenders	0.05
with a long fin at the tail of the fairing	0.03

Note: The proportion of the model compared to the wind tunnel was not ideal. All results can be compared with one another, while the absolute values are assumed to be 30% too low.

Aerodynamic forms in the literature

In most applications, the relative length/width proportion is lower than 5, which is the approximate value of the present fully faired recumbent. Rotational symmetric forms have cd values of 0.043 to 0.045 [2]. Spindles with length/width proportions of 3 can be as low as 0.04 [2]. Results of measurements of penguins show that they have drag coefficients of only 0.02 [1].

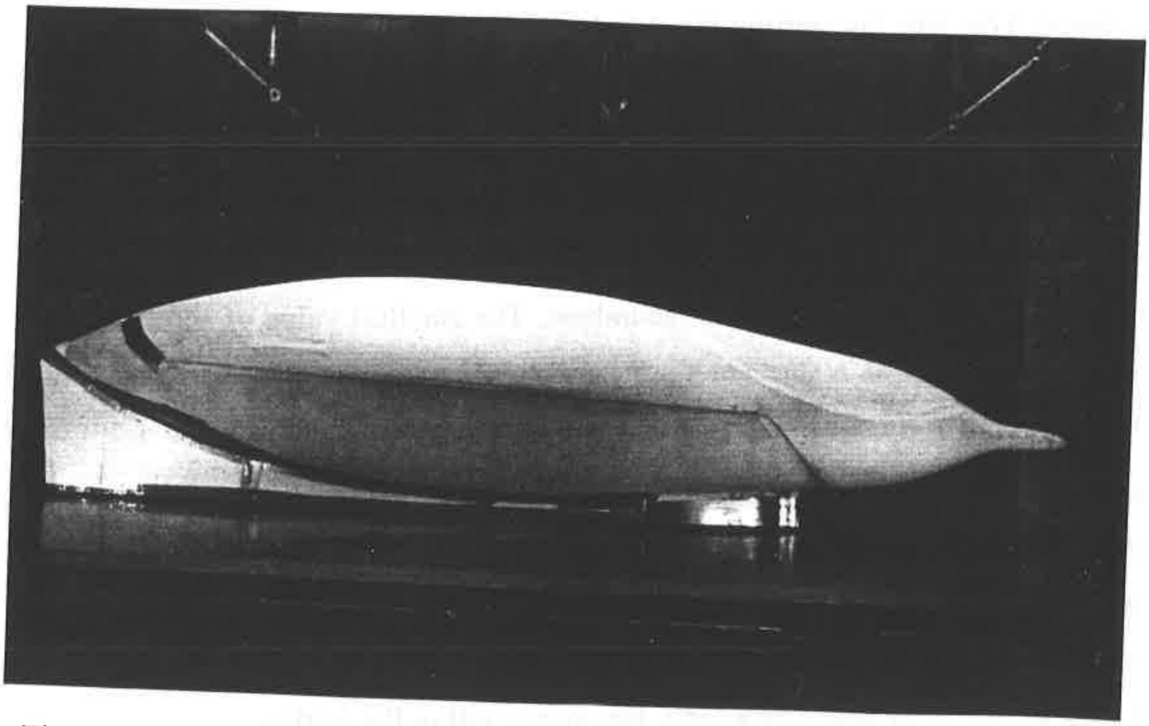

Fig. 1: Final and drag optimized form. It could be modified in seat height because of space problems between feet and front axle.

Parameters of the wind tunnel

Measuring distance: 3.5 m

Wind speed: 20 m/s

Power: 110 kW

Grade of turbulence: 0.2%

Diameter of the inlet tube: 1.2 m

Parameters of the fully faired recumbent:

front area: 0.25 m^2

total length: 2.7 m

width: 0.5 m

height of the body: 0.5 m

overall height of the vehicle: 0.75 m

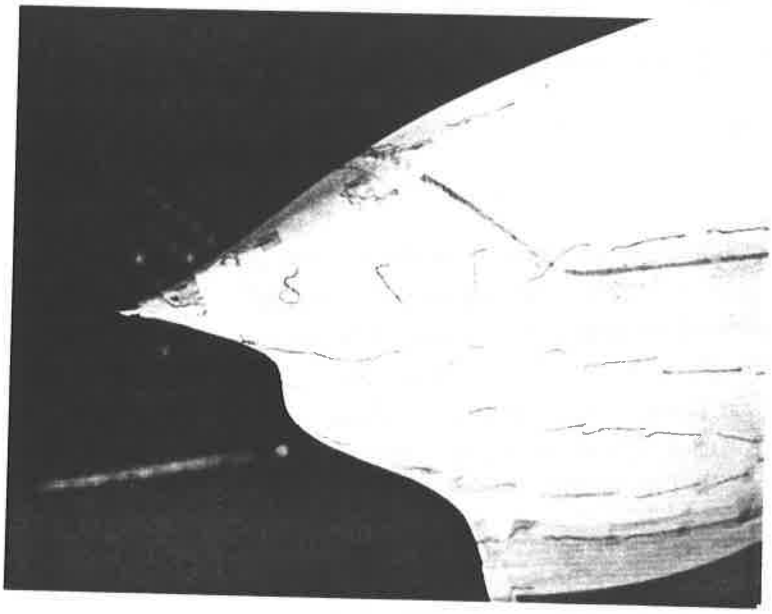

Fig. 2: 0° yaw angle, detaching of the stream shown in detail view of the (tail part of the fairing).

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Titel: **Investigation of the passive safety of Ultra Light Vehicles**

Modellversuche zur passiven Sicherheit von Leichtfahrzeugen

Authors: Stefan Gloger, Harald John

Abstract:

More than hundred crash tests vehicle to vehicle were executed with model vehicles of a car and a velomobil. Those crash tests validated the *May Bug Principle*, that was introduced in the first and second velomobil seminar. The results are showing, that a velomobil design is possible, that gives a good passive safety to the driver even in severe accidents. This design is a round or elliptical structural front, a stiff structure around the driver for side colissions and a driver restraint system that avoids contact of the driver with parts inside the velomobil. The results are similar for two and four wheelers.

1. The May Bug Principle

The May Bug Principle for velomobiles was introduced in the first velomobile seminar and furthermore explained by the author (1, 2). The main item is, not to transform all the kinetic energy of a vehicle during an accident by deformation but to change the moving direction of the vehicle and transform only a small part of kinetic energy at least by friction. The precondition of this behaviour is a rounded structurel shape. To verify this, a number of experiments were executed.

2. Experiments

The testing was done for typical (high frequency) bycicle accidents as well as for very severe ones (3, 4) (*Figure 1*).

2.1. Test Station and Vehicles

The test station is buil t of an accelerator that moves one or two vehicles. (*Figure 2*). The accelerating force comes out of a rubber rope that is normally used to start model-sail planes. To start the vehicles simultaneously the accelerators are connected by a cable. The maximum speed possible is 30 km/h.

The vehicle models were scaled 1:5. So the mass has to be scaled 1:125 because its a function of volume. So the mass of the velomobil model is 800 g for the two wheeler, 1000 g for the four wheeler and 11 kg for the car. The mass distribution of the vehicles axis's can be changed as needed. The velomobile model is built as a frame with additional fairing. The frame is adjustable as a 2- or 4-wheeler. The stiffness of the fairing was varied in four steps. We used a form similar to the DESIRA-2 and DESIRA-quattro (2). The car model was rigid (4 mm glasfibre epoxy layers on hard foam) representing the worst case of car stiffness (*Figure 3*).

2.2. Parameters and Measurements

In addition to the vehicle parameters different collision types were tested and the speed was varied. After all 144 different crashes were simulated. The crashes were filmed by a video camera (High 8). The maximum acceleration inside the velomobile was measured to get an idea of the crash severeness. The measuring device was placed at the "head" of the drivers seat in the direction of the highest impulse.

HPV auf unbewegten PKW

HPV in PKW-Flanke, 45°

typischer Rechtsabbiegeunfall,
Autofahrer übersieht HPV , "toter Winkel"

schräger Frontalaufprall

typischer Linksabbiegeunfall,
Stoßstangenhöhe relevant

HPV in PKW-Flanke

"Kreuzungsunfall"

PKW auf unbewegtes HPV

Überrollen

HPV wird z.B. durch den Aufprall in den Gegenverkehr geschleudert

Heckaufprall

Autofahrer will überholen, bricht wegen Gegenverkehr ab und fährt auf

---

PKW und HPV bewegt

Dynamischer Seitenaufprall

"Kreuzungsunfall"
Aufprall in den vorderen, mittleren oder hinteren Teil der HPV-Seite

Dynamischer Frontalaufprall

Anordnungen: 30°schräg, Offset,
gerade mit 100% Überdeckung

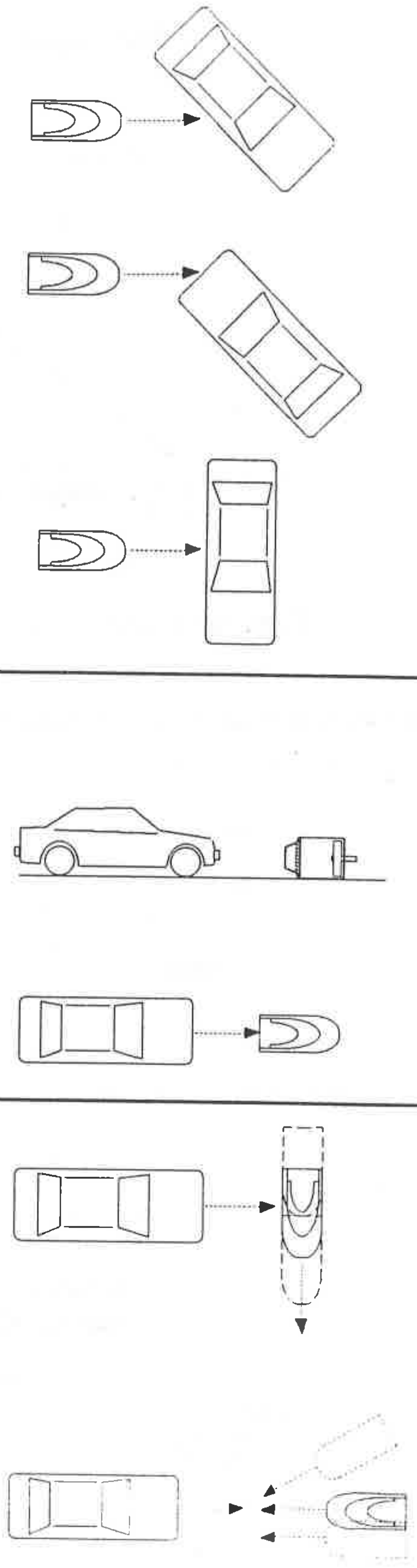


Figure 1: Investigated collision types

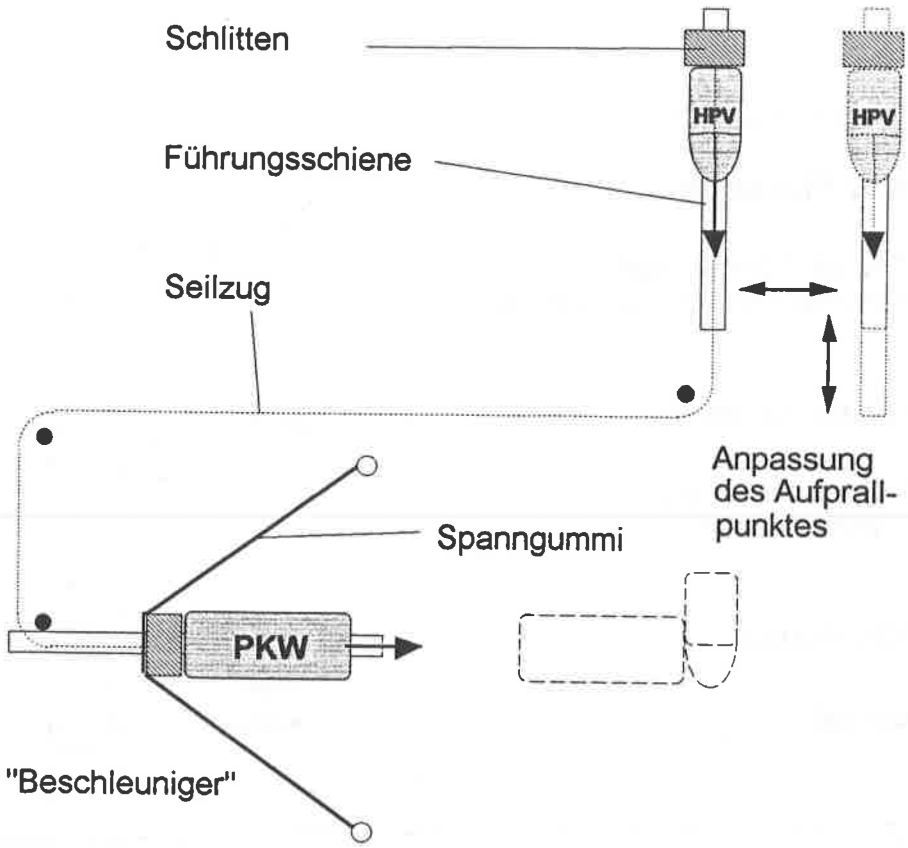


Figure 2: Accelerator for two vehicles

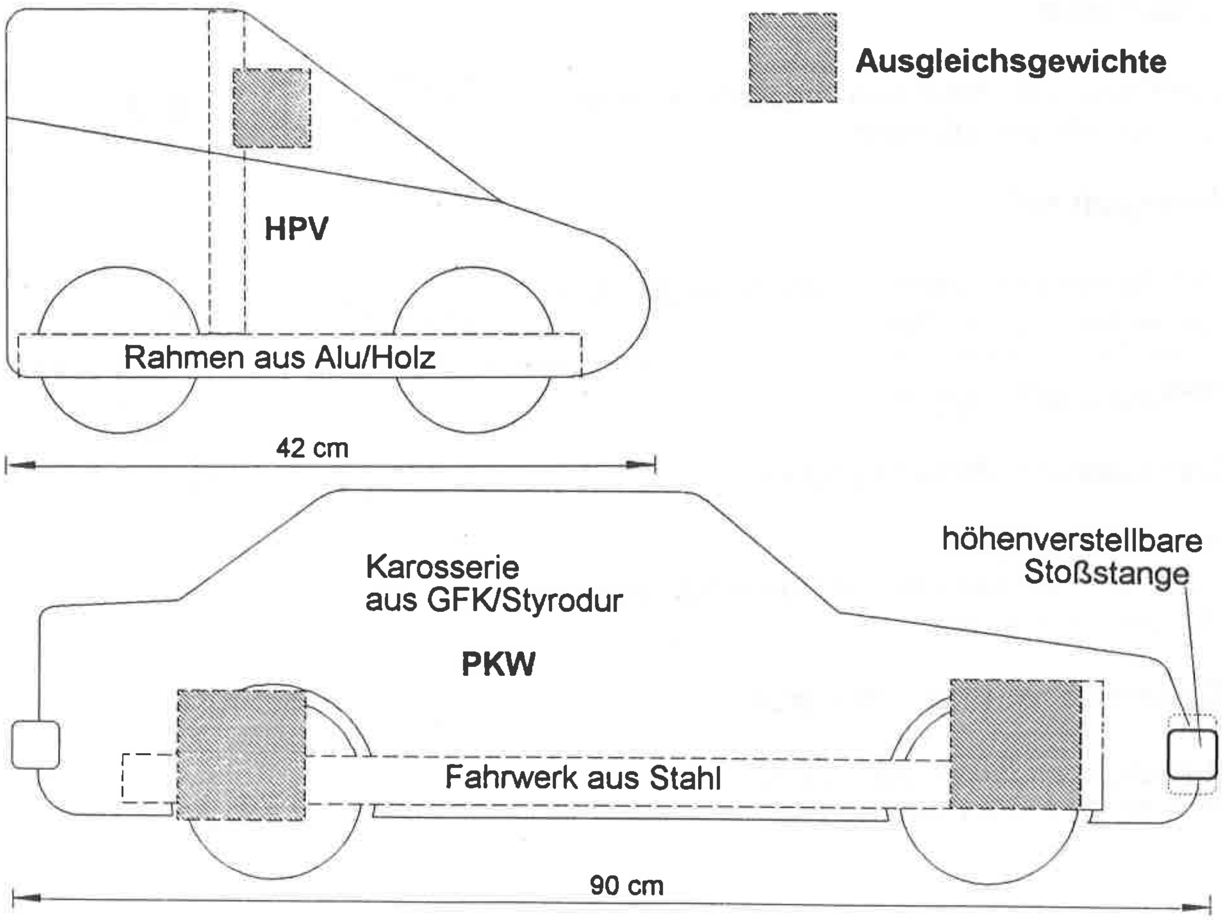


Figure 3: Test vehicles

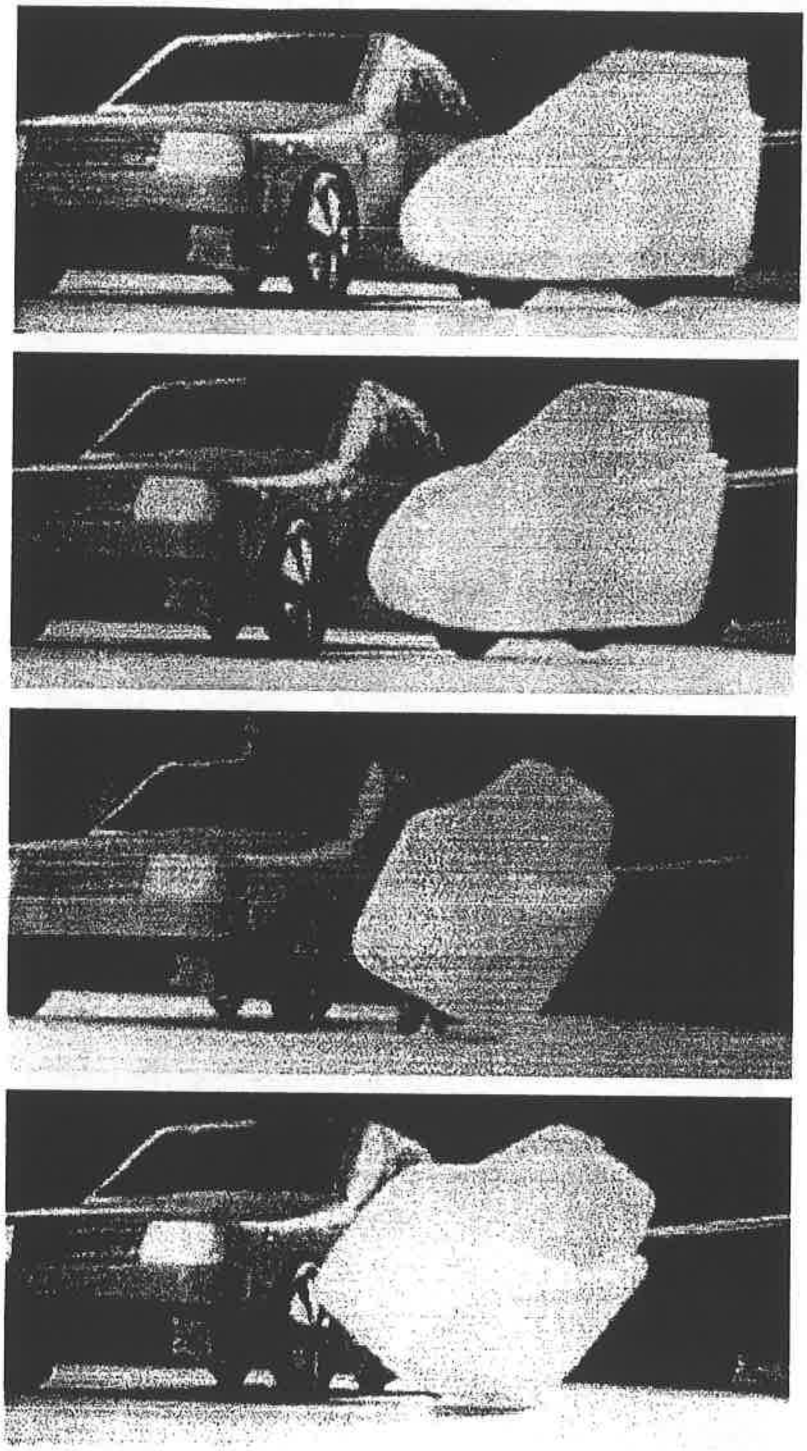


Figure 4: Vehicle movement during a side impact with 45 degrees impact angle, soft fairing and 20 km/h

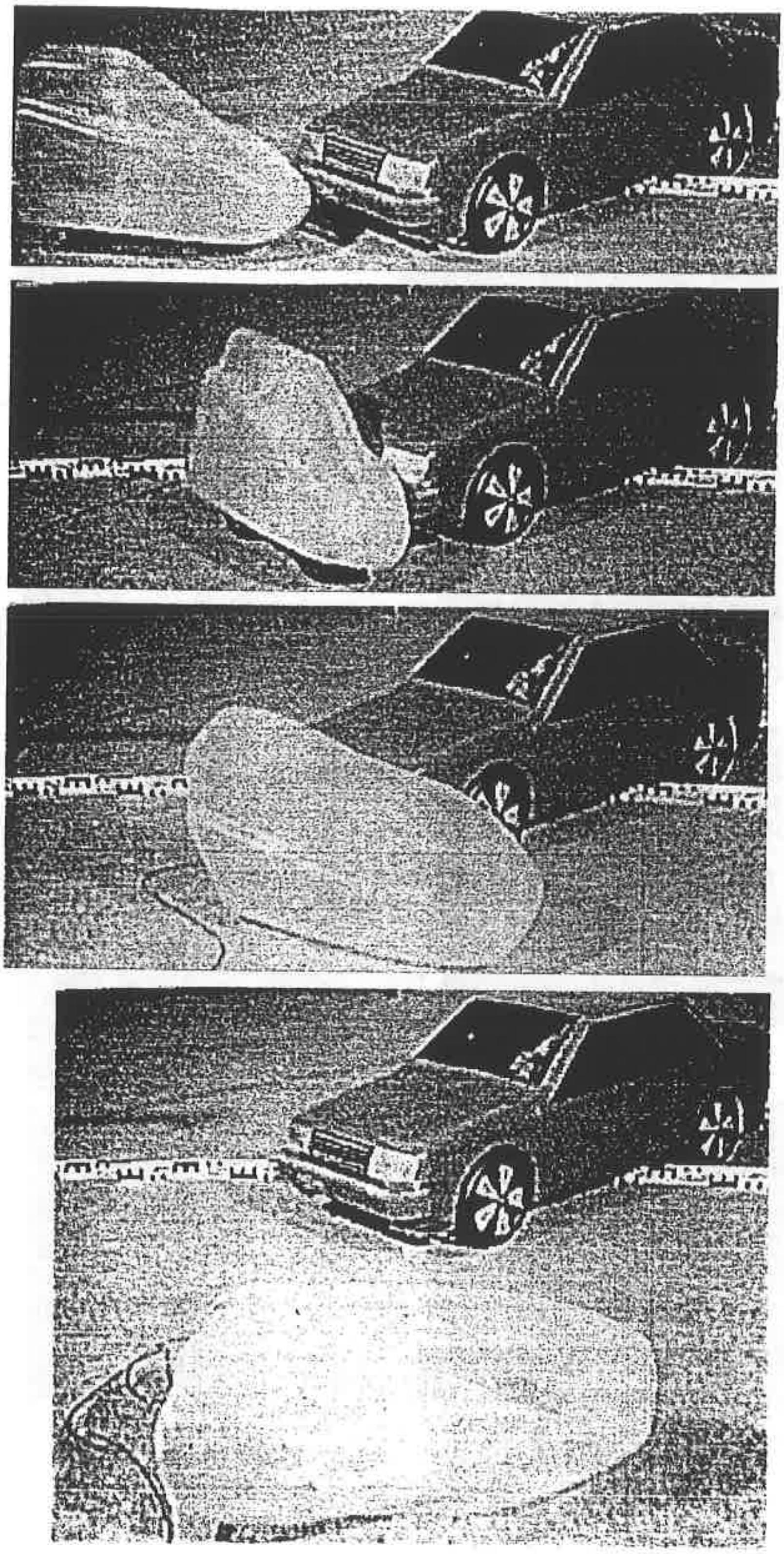


Figure 5: Vehicle movement during frontal impact, 45 degrees, soft fairing and 20 km/h

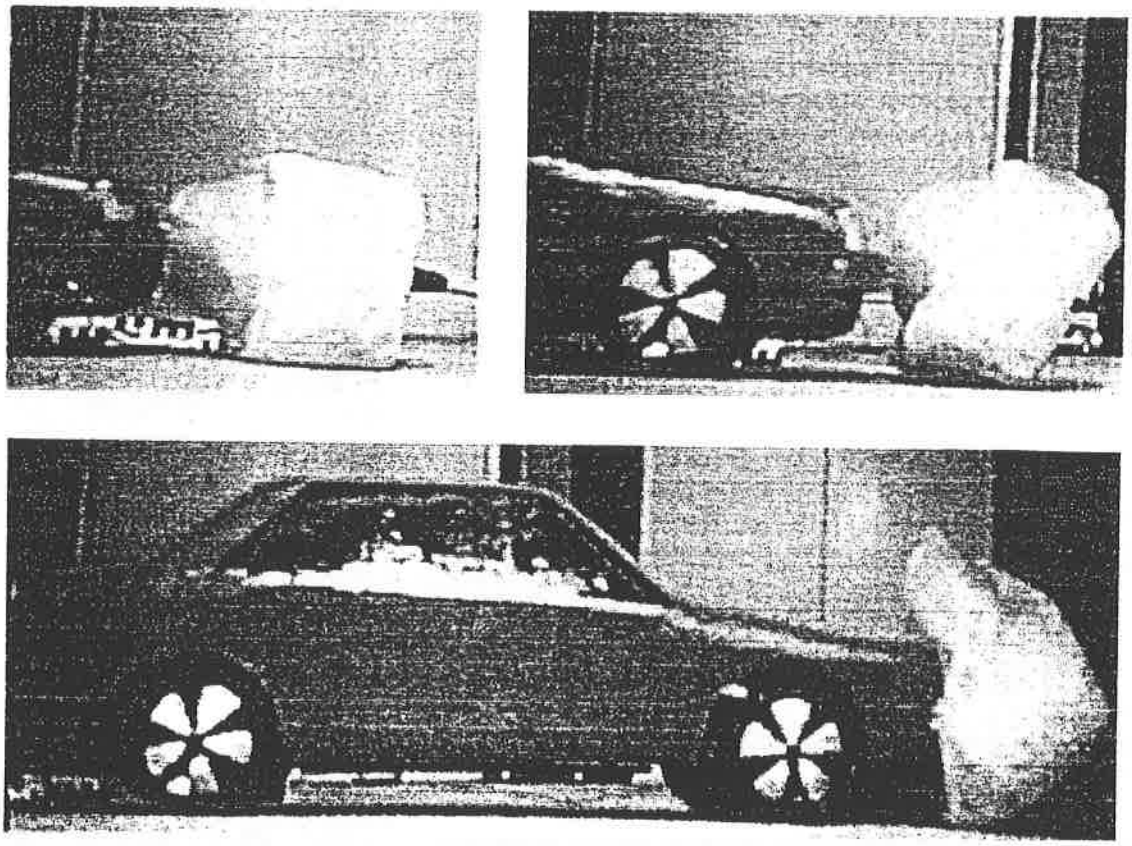


Figure 6: Overroll test with soft fairing, moving against a wall

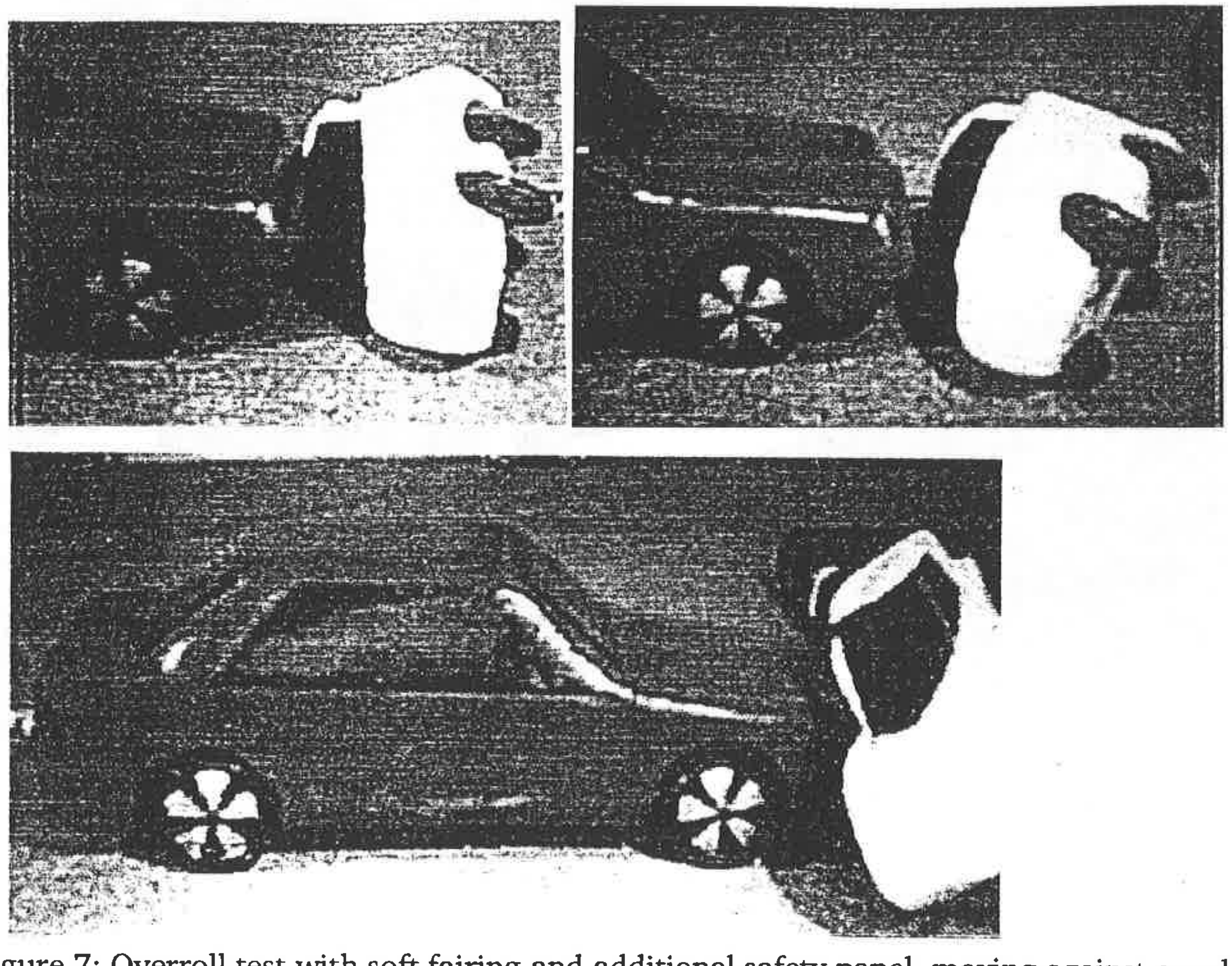
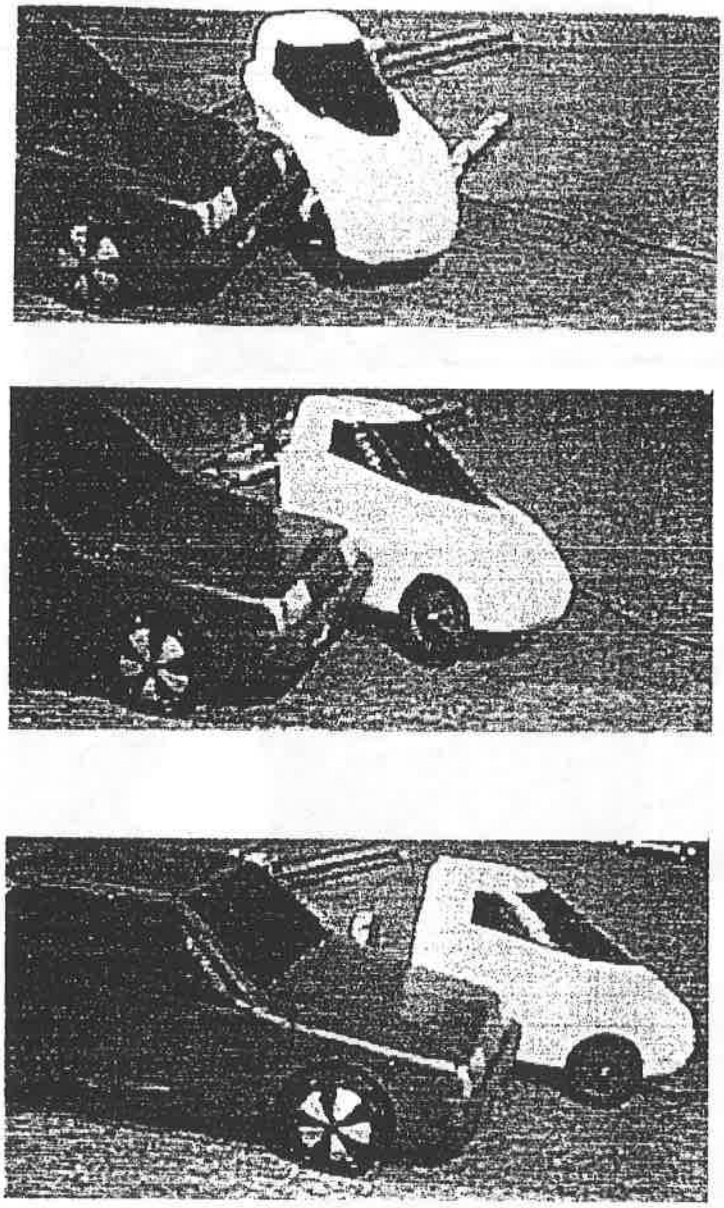


Figure 7: Overroll test with soft fairing and additional safety panel, moving against a wall



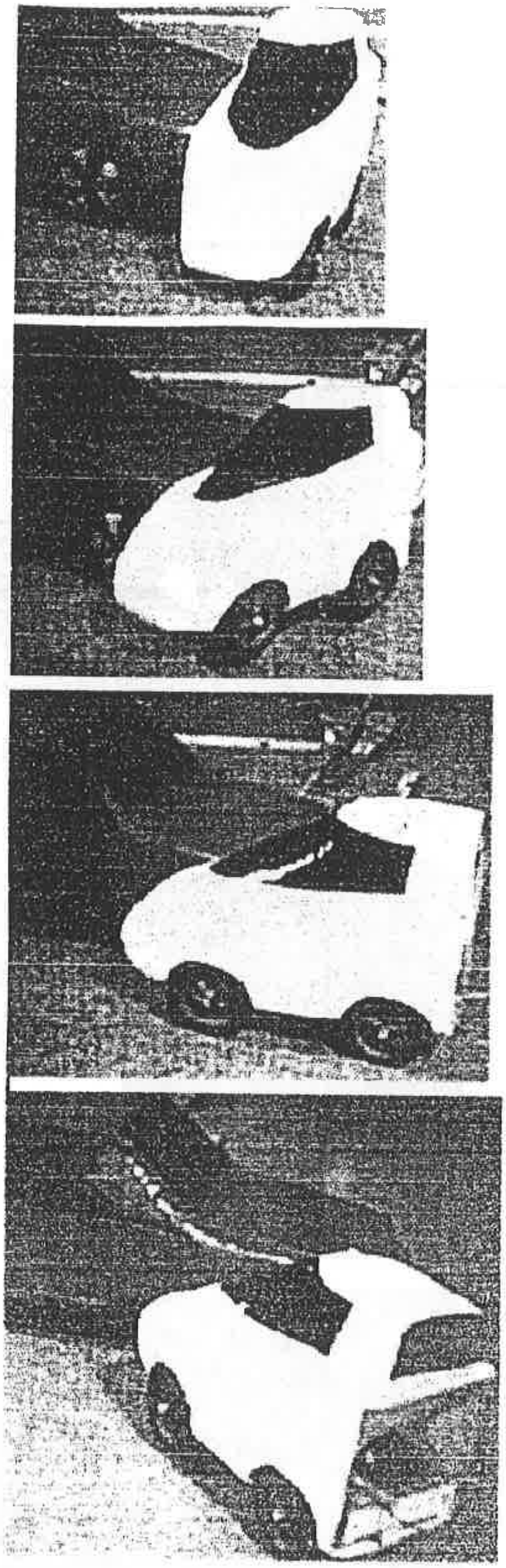


Figure 8 and 9: Dynamic side impact more front (left) and more rear (right)

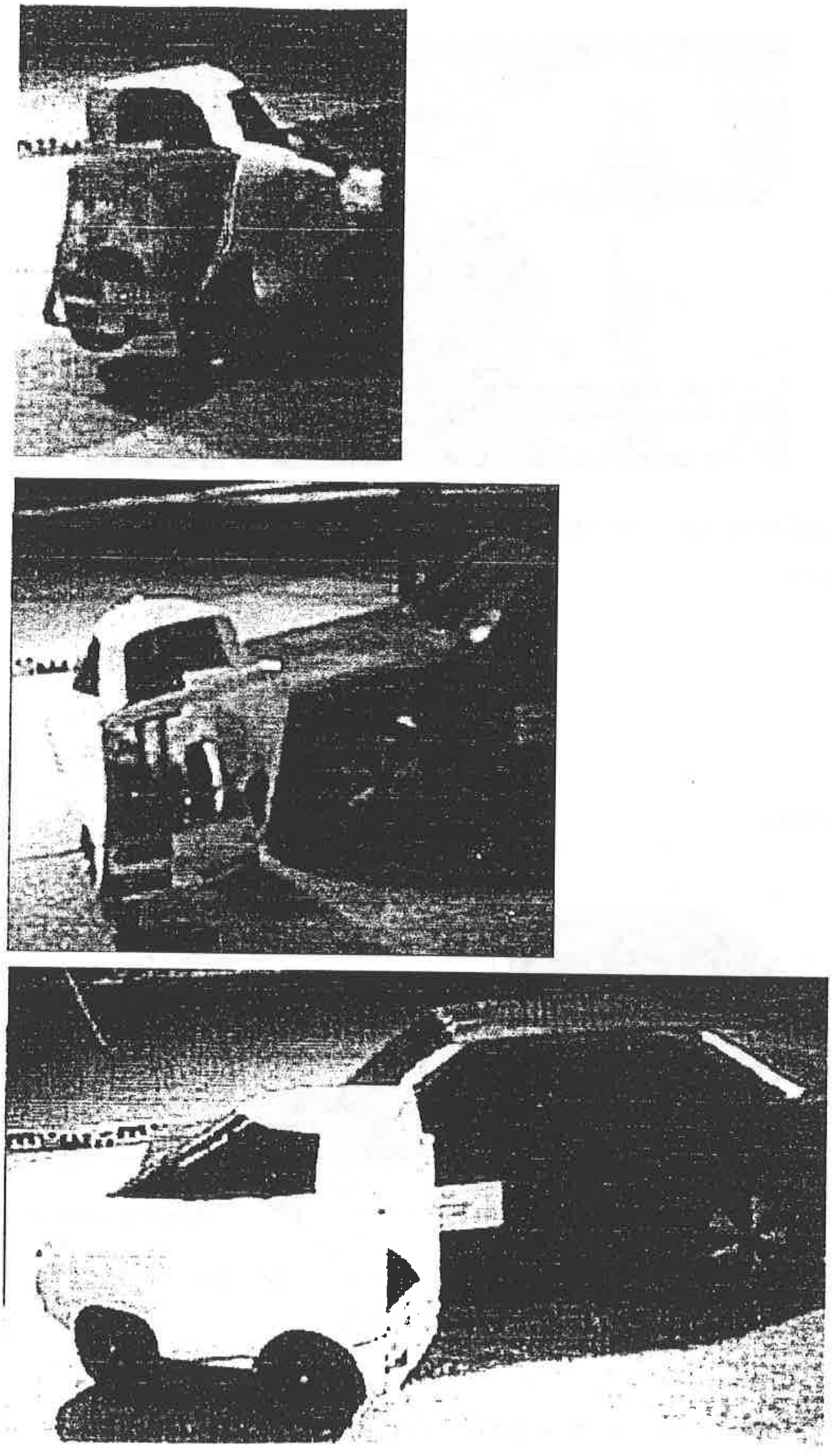


Figure 10: Dynamic frontal impact, 30 degrees, soft fairing

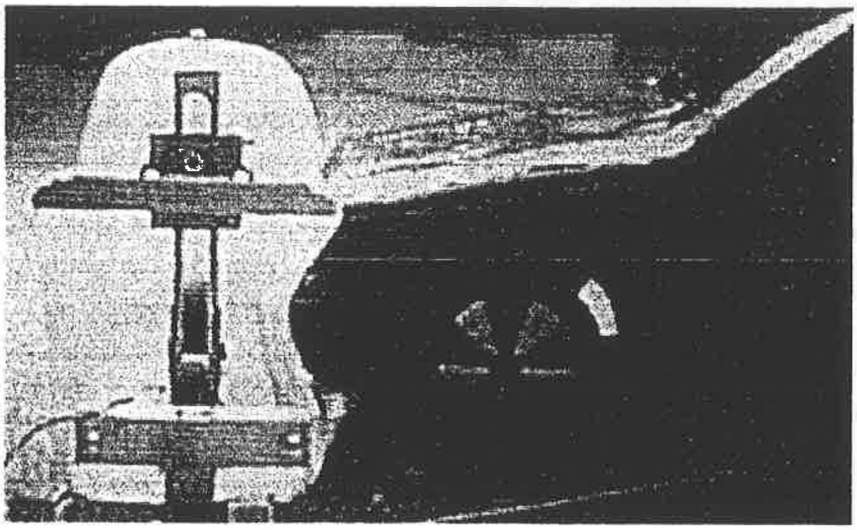


Figure 11: Maximum intrusion during dynamic frontal impact, soft fairing without safety panel

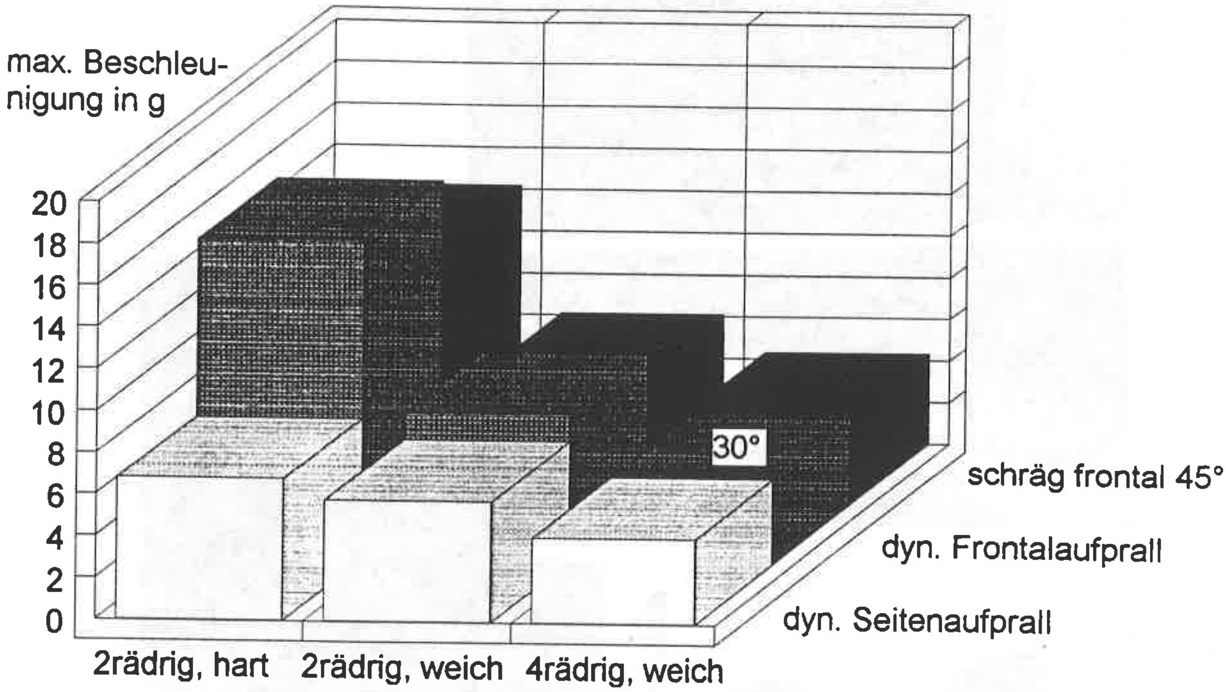


Figure 12: Maximum accelerations measured during the crash tests

3. Directly around the drivers body there should be a stiff safety panel or an overroll bar.

4. The velomobil surface should have low friction.

5. The velomobil front should be deformable, the side panels should be stiff.

5. Further aspects

Are those tests with model vehicles relevant for real world accidents? After all we know up to now, we believe they are. At least shortly before the tests were completed some kind of a validation happened: During the side wind experiments with the DESIRA-2 (2) an unexperienced rider reacted falsely to the crosswind attack and produced collission type one. The vehicle movement was exactly as described (again filmed by a High-8 camera). Nobody was hurt. Both vehicles were slightly damaged. Half an hour later the crosswind tests were continued.

What would happen, if all road vehicles including cars and trucks would have a rounded or elliptical structural shape? In every accident there would be a slight angle of attack so even at a high mass difference between the vehicles the lightweight one would have good chances to change the direction and to get out of the critical zone. The frontal impacts would loose there horrible scenario. Think of a 40% offset crash car to car. That wouldn't be a real crash. The same result came out of a big study made at the University of Tsukuba in Japan for self driving robots in a multi-robot environment (5).

Why don't do so and change car design? The whole underhood package and chassis design of modern cars is going the opposite dirction. Lateral assembled engines and transmissions (more space for the passengers) and longer wheelbases (better driving stability and comfort) are making things worse. Engines and transmissions are normally used over two or three vehicle generations and they are exchanged fluently through several carlines. Only if one designs a new car with a new engine-transmission combination (e.g. as Mercedes did with the A-Class and the SMART), he has a chance to introduce this new principle. So lets hope for the future and make use of the May-Bug-Principle.

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3. Results

All results were documented in test protocols with the film sequence and summarized in a table of results. Some typical results are discribed in this chapter.

3.1 Movements

The movements and kinematics of the vehicles were not dependend on vehicle speeds. There was a slight influence of the fairing stiffness and the number of wheels. The four wheeler (less degrees of freedom) was not worth than the two wheeler. So the May-Bug Principle works with all similar shaped light weight vehicles and all speeds that were tested.

Figure 4 shows the typical movement of collision type 1.

The collision type 2 is shown in *figure 5*.

In the special case of collision type 3 there is no advantage of the may bug principle. This is similar to the 100% rigid wall test for cars.

After collisions of type 1 and 2 there is the possibility of an secondary overroll (e.g. crash ends on the other lane of the road). We simulated this with a soft fairing (*Figure 6*) and a soft fairing with some reinforcements (overroll bars, *Figure 7*).

The movement after the dynamic side impact is depending on the region, where the velomobil is hit by the car. If the car hits not exactly in the center of gravity, the velomobile rotates as shown in *Figure 8 and 9*.

Figure 10 demonstrates that the may bug principle even works in the dynamic frontal impact with 30 degrees impact angle.

3.2 Deformations

In all front impact situations the velomobil front deforms so that it gets a rounded shape. This helps to change the moving direction and to reduce the accelarations. The space for the driver remained sufficient in every case. During the 90 degree side impact (car into velomobile) and the overroll test severe deformations of the soft fairing appeared (*Figure 11*). After introduction of a cross car safety panel (similar to an overroll bar) the deformations were reduced significantly. The four wheeler showed lower deformations in side impacts caused by the stiff chassis parts.

3.3 Accelerations

The measured accelarations were allways lower than the critical ones for humans. The highest appeared in the dynamic impacts (both vehicles accelerated; *Figure 12*). On the other hand this shows that without a good safety belt system You will get hurt by contact with parts of the velomobil.

4. Design Guidelines

Some specifications for safe velomobiles can be concluded out of the test results:

1. Velomobils should have a safety belt system or something with a similar effect.
2. The structural shape of the vehicle front should be round or elliptical.

"Smallish Recumbents"

Werner Stiffel

Aims of construction

Compact measurements of recumbents are useful for the transport in trains, buses, cars and planes but also to store recumbents in cellars, flats and garages. That`s the reason why I`m sure, foldable recumbents will come up.

I looked for a way to shorten non - foldable recumbents. A very effective way to reach this aim is to use wheels of 400 mm outside diameter and tires of 340 or 305 mm inside diameters.

(Some people still measure both in the oldfashioned way and call them "16 inches"- wheels)

In the following text these wheels are called "small wheels) I kept to the rim size 305 mm because I had some of them in store.With this size of tires you can build a short wheelbase recumbent (SWB) for an adult who is 1,75 m tall, an the recumbent is shorter than an upright racer.

Some aspects of the design of recumbents with small wheels

1. "steering - feeling"

Many people know: the smaller the front wheel the more nervous the steering.To find a good compromise in the handling I built the test recumbent "K 11". It has a kind of rear swinging arm which can be fixed by a kind of stays (instead of a spring) in a more or less steep manner. By this the rear part of the bike can be lifted and so the steering angle can be changed. At the front fork rear dropouts are mounted, sothat the rake can be changed too.

With a steering angle of 70° and a rake of 80 mm the bike "falls a bit into curves" at very low speed, but up to 60 km/h it feels very stable and safe.

2. drive train, transmission

A small wheel brings a very low gear range.(Gear range means the distance the bike covers at one turn of the crank) The rear range with the normal transmission of 52 : 13 is 5,0 m.

With a chain wheel with 68 teeth)[1] and a sprocket of 11 teeth you reach already 7,7 m. You have a lot of design possibilities with an intermediate drivetrain. With sprockets of 20 and 28 teeth on the intermediate shaft and 52 : 11 transmission you have satisfying 8,3m. I like very much the Sachs 3 x 7 combined hub and chain gear.With 52/11 You ha ve 7,9m in the 3. gear of the hub.

3. Comfort, suspension

Of course a small wheel falls deeper in a pothole than a bigger one.On the other hand a well suspended small wheel provides more comfort than an unsuspended big one. Small wheels make it easier to design suspensions with long travel. Additionally the position of the center of rotation of the rear swinging arm is better w ith a small wheel.

4. Weight

The shorter frame , swinging arm,and chain makes the bike about one kg lighter. Tire and rim are about 100 g light than with 406 mm. wheels.

5. Design of frame, stiffness

The builder of upright racers know, that the length of the frame has a very high influence on the stiffness. C. Smolik [2] says, the stiffness against torsion increases at the exponent 2,5 with decrease of the frame length. So small wheels make the frame much stiffer. My "dolphin 5" has a main tube of 60 mm Ø but because of the Z -shape of the frame it is less stiff than the K 12 with a 50 mm main tube. The upper main tubes of the K12G are 10 x1, the down tube 15 x 1. The front beam looks a bit like the"Eiffel tower" but is less stiff than the 50 mm monotube beam of the "K 12"

6. Rolling resistance

I have not taken anymeasurements myself, and some of the manufacturers do not offer any exact figures referring to this topic. (I suppose partly they have no figures) Ian Sims has published in the internet a diagram about his own measurements of the rolling resistance of tires with 500 and 400 mm Æ. The best was the Tioga Competiton, but the second was the Schwalbe Cityjet 54 x 305. This really "fat tire" had for example a lower resistance than the 28 mm broad Conti Grand Prix at the same pressure. I presuppose these measurements are comparable to eachother, but cannot be compared to other measurements because of the varying mea surement conditions..

7. Use of small recumbents

For long travels the space for lugg age ist a bit small. For weekend rides or commuting and riding in cities these bikes are very suitable.

8. Stiffness of rims

As I already found at 406 wheels a decreasing diameter brings a very high amount of stiffness. On a 3 week journey in Spain with a LWB with 80% of the weight (including tent, sleeping bag and so on) on the rear wheel I had not any problem with spokes or the simple rims (no box type rim)

9. Seat position

Small wheels allow a deep position of the seat (About 500 mm), important for persons with short legs

10. Trikes

Trikes with one steered front wheel (I prefer this design because of the better braking behaviour when running at high speed downhill) are more than 10 cm shorter with a small front wheel

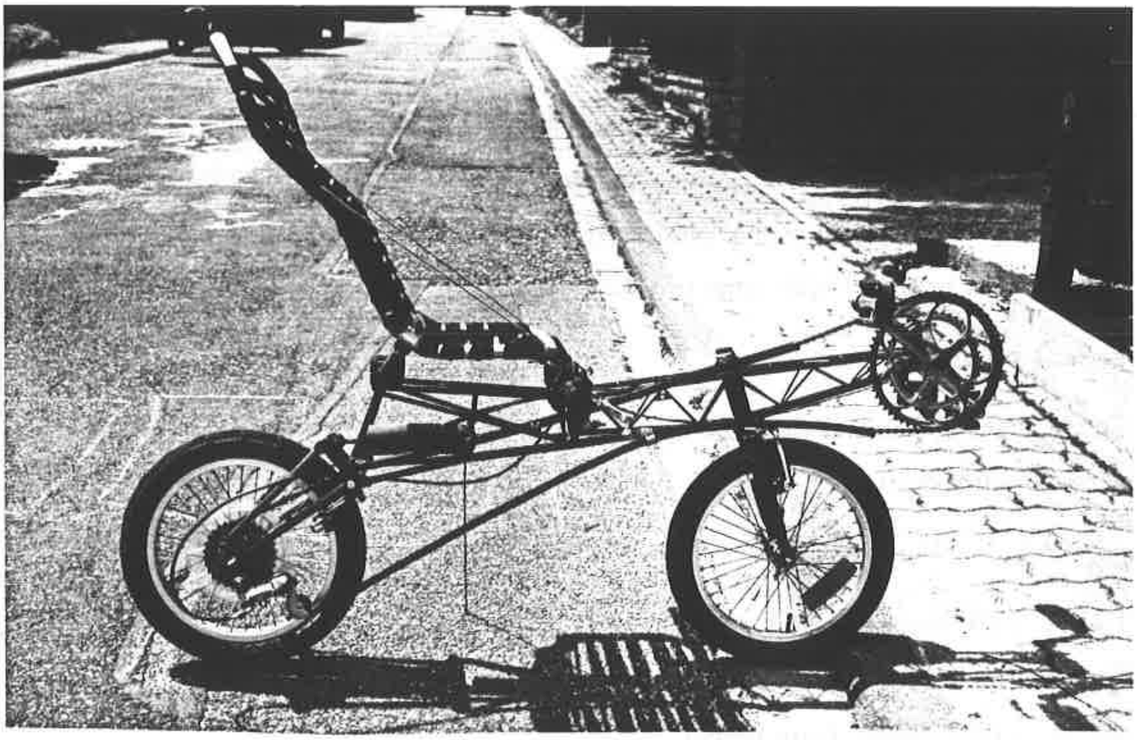
11. Further remarks

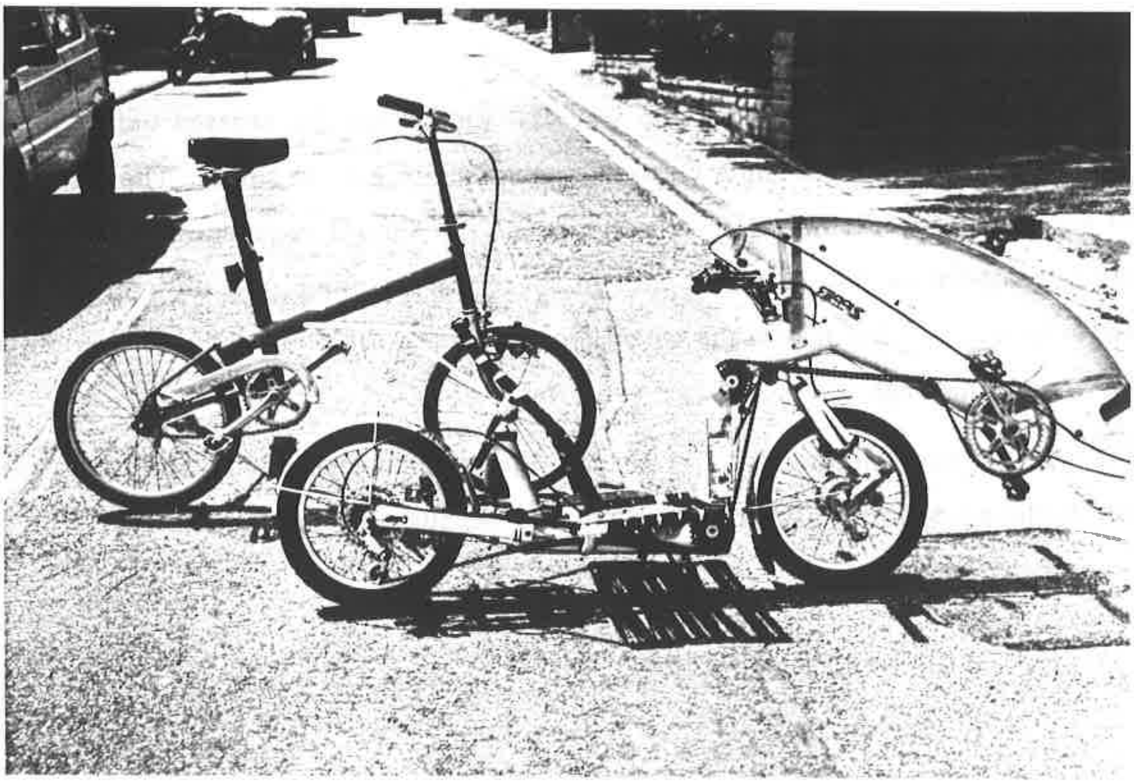
In my small wheels (including 406 wheels) the spokes are crossed only one or two times otherwise the angle between spoke an rim gets to small. The distance of spokes next to the hole for the valve in the rim should increase in direction to the hub otherwise you have not enough space for the pump. All my rear wheels are symmetrical, that makes the wheel more stable so the rear swing - arm must be unsymmetrical.

Wear of tire and rim are a bit higher and on long and steep downhillrides the rims get hotter, e specially when riding slowly, because of the smaller area which gives away heat.

Basicly such small wheels do not need 36 spokes. But rims with this number of holes allow the use of drumbrakes and the Sachs 3 x 7 combined hub and chain gear.

The following pictures show details of recumbent bicycles constructed with small wheels:





12. Advantages and drawbacks of wheels with 400 mm Ø

total length is extremely reduced	higher tire wear
low weight or/and	without suspension less comfort
stiffer frame, stiffer swinging arm	higher rim wear
more travel at suspension possible	for satisfying gear range , special devices necessary

[1] Chainwheels up to 68 teeth are available in Europe by TA, France

[2] Fahrradrahmenbau, Christian Smolik, Editor Moby Dick. 1994

LINE-GO
A Linear Driven HPV Design Family

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Summary

I present my view of how **the linear drive train adapts to the human motor.** comprising: • Linearly and near-linearly moving pedals • A linear chainless highly efficient drive train • Continuous step-less gear-ratios. The LINE-GO family of bikes was developed with the user in focus. To prevent bike theft and to facilitate using means of collective transportation together with bikes, the designs include examples of: • Foldable frames • A Self-supporting foldable canopy. Including • Seat developments • A minimal slip differential • Suspension • Alternative steering wheel bearing and support • An all mechanical servo assisted minimal disk-brake system, the versatility of the project land with • Bike lay-outs and • Scooter lay-outs. • Recumbent trike lay-out with • Height-adjustable seats. To keep up the value of the folded bike: • Small diameter wheel phenomena were looked upon. • Producer, Retailer and User-friendliness, depend on • Reliability, potentially designed into, by a high degree of simplification. **A short chronological list of my bike project** couples the past to the present, as do some **ancient and modern linear drive configurations**

A couple of hardware prototypes will be presented with pictures and drawings and comments to the above, with outlines to further development to suite challenged athletes as well as ordinary athletes.

The linear drive train adapted to the human motor

The two different types of drives, LINEAR and CIRCULAR, are appointed names in regard of the way the feet move. The traditional circular drive with cranks, forces the foot to follow a circle, in a cadence set by the speed and gearing.

The linear drive-train principle is really simple. A rope unwinds with the pedal force from a line wheel, which transmit the torque over a freewheel clutch to the drive axle. When the pedal is retracted by will, the rope winds up back on the line wheel by a rubber band, in a winding direction opposite to the rope.

With a linear drive, it's possible to have a left and right foot cadence, as well as the preferred step length, independent of the speed.

With a linear drive, the entire working step length, is equally efficient, in opposition to the circular drive case, where efficiency is angular and co-ordination dependant.

With a linear drive, it is feasible to have a continuously and step-less change of the gear ratio during the working step, with a low gear ratio at the beginning, and a high gear ratio at the end.

The high angular momentum of the leg, as it reaches its stretched position, is a problem encountered on ordinary bikes, and possibly even more so, on linear driven bikes (1). This is usually come around on a circular drive, by either lowering the cadence or decreasing the distance from the seat to the crank (2).

Co-ordination of the force direction is a great efficiency factor (3). On a circular drive, this is left to the leg apparatus, developed by nature through walking and running, to adjust its force vector to the rotating trajectory of the crank.

On a linear drive, there is a need for either a dead stop, adjusted to the length of the leg, or a steep increase in gear ratio. The second opens up for a better use of the output from the motor, as the force direction remains and the momentum energy is put to use. I have found that a final Ggear ratio, at the end of the working step, of about 14 does that.

With a linear drive there are fewer constraints to the human motor.

The phantom of the linear drive

There is the possibility of extreme gear-ratios, efficiently put to use in a linear drive train. Why isn't the world full of them?

Gearing consists of three principles.

One being the diameter change on the line wheel, as the rope unwinds (4). This is a action close to the cam-roll or eccentric rolls, making the diameter change faster.

The other I would like to call the bow-line gear: A straight rope will give very high loads at its ends, when a force perpendicular to the rope acts on the middle (5).

The third gearing element is the ordinary built in ratio: The diameter of the wheel, divided by the diameter the rope acts on.

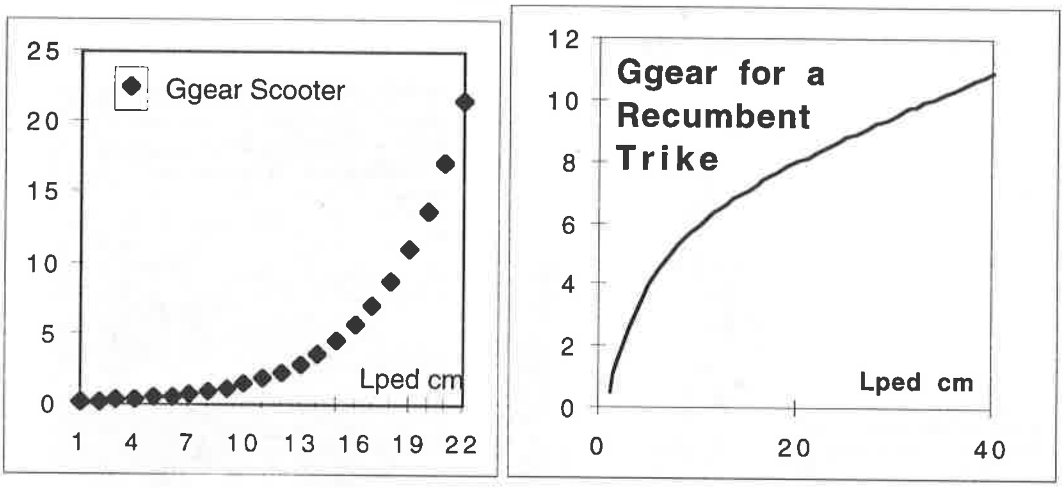
Together these three gearing element make up the total gear ratio by multiplying. I prefer to call it the generic gear ratio, Ggear. This is free from cog-inches.

It needs a generic gear ratio (Ggear), to be able to compare linear and circular drives. Ggear is the rolled out length of the wheel (Lroll) over the length the pedal has moved (Lped).

Hence,
$$\frac{\text{Lrolled}}{\text{Lped}} = \text{Ggear}. \qquad \text{equ 1}$$

Here the Lped is either along the curved line of a circular drive, or the travelled length of a linearly moving pedal. For comparison, the Ggear of a 21 geared bike with 26" wheels, range from 1.75 in the lowest gear to 7.5 in the highest gear.

On an ordinary upright bike with a linear drive, the automatic Ggear ranges available, easily become impressively high, with Ggear from 0.5 to 16.



Computed generic gear ratios, Ggear, with widely different characteristics.

A one-size-fits-all dream-design is closer with a linear drive without a dead stop.

With a linear drive, there is less support than with a circular drive, for a situation where the rider wants to make a jump standing on the pedals.

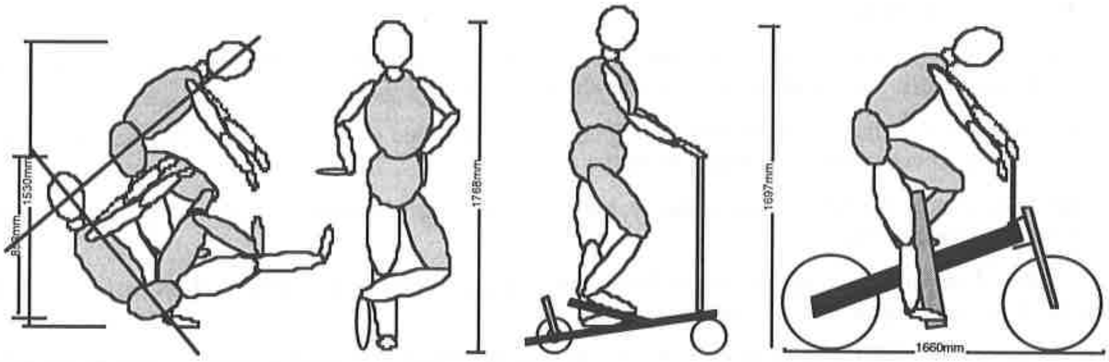
The linear drive was invented more than 100 years ago, and has a great history (5) (6). A design, comprising all three gearing principles, was granted a patent to B. Ljungström in 1897 (8). The story has it, it became the SVEA bike. There were built about 3000 of them. It was technically more complicated than other bikes, and maybe it priced itself out of the market. The project was sponsored by Alfred Nobel. The SVEA bike is today exposed at the Stockholm Technical Museum. It was of a third type, basically a linear drive train, but with pedals moving reciprocally along a circle line. This kind of drive train design, can be made for ordinary upright bikes and for a standing driver operated, scooter look-alike two wheeler design (7), as well as for a velomobile (9). I have no record of what became of them. I would like to see them work.

I have adopted different drive trains of my own invention, to different bike and trike designs, and I did not find any major restrictions to the linear drive philosophy. The research in the patent literature, was made afterwards. Where these to complicated or simply didn't last long enough.

Wear and fatigue are highly designable and will surely find several solutions. Modern materials may be the difference. For example are polymer fibre ropes better suited for linear drives than steel wires are.

Some weight is saved by replacing cranks, chains and sprocket wheels, with rope, rubber cord, delrin line wheels and rail bound, low weight pedals.

The effect of the posture

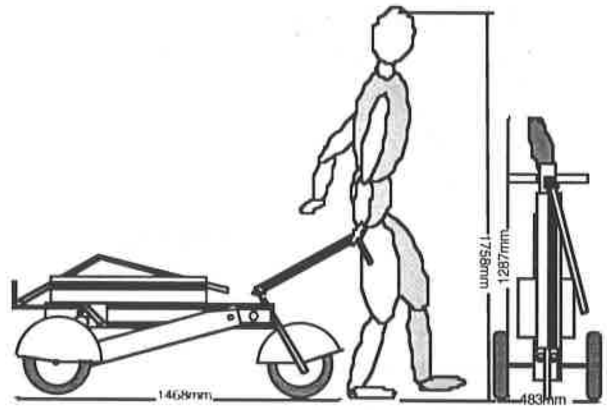


The body posture has a profound effect on the design of a bike. It affects the aerodynamic drag, the speed, the comfort, the balance of the vehicle, how injuries develop during an accident, the first impression starting social interaction with other people and road users. To satisfy the user, the variety of factors result in different designs for different user preferences.

When attempting to fit my linear drive train to different kinds of working postures, I end up with designs for : A traditional up-right linear-drive bike, a pedal driven scooter and recumbent two- or three- or four-wheelers of different heights, driven by the front or rear wheel(s). Some easier to use, and other easier to make. Not all presented here. Some designs may be driven either by foot or by hand.

I find it necessary to test in real life these designs, to feel the difference of the new designs in comparison to existing ones. Technical assessment can only be a first start.

The foldability difference



I have tried to find out what the user value of a bike that can be folded really is. To guarantee the accessibility of a bike, in my opinion, one has to bring it along. To do so, it has to be light, small and fast folding. It has to be very safe against "auto-folding". The luggage should best be left on the folded bike, to avoid the item multiplicity problem to the ordinarily limited number of hands. Awkward lifting postures are to be avoided, and rather rolling the whole thing should be quite easy, even up the stairs. Drive lube and dirt encapsulation needs designer attendance. The preferred method to fold, is in my opinion, to slide a tube into an other, and lock them with two bolts. A joint of this type is simple to make and its strength is easy to calculate.

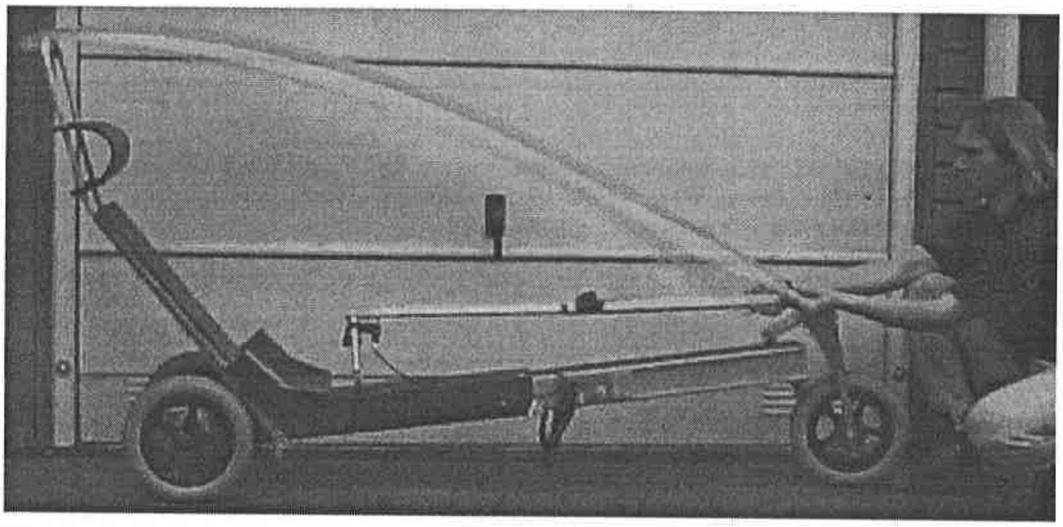
The Swedish MicroBike and the British Strida, both have toothed belt drives, and very fast ways of folding and unfolding. That makes them suitable for bringing them on a bus or a commuter train. They are both very unsuitable to lock outside a building, but rather handy to bring inside, hopefully out of reach for bike theft. They can both be stowed away or hung up inside a coat. I can see the limited applicability of this, but until some critical mass is acquired it'll probably work.

A come-rain-come-shine-canopy

Tailwinds are very rare for bikers, depending on the fact that the bike speed vector adds to all winds. Instead the most common wind direction to a biker, is an apparent head wind. Only a bent bikers will be meaningful to protect with a windshield, and it had better be foldable. Here bent could mean both forward over a triathlon tiller bar and recumbent. Friedrich Gauss (1777-1855) described a sphere in a fruitful way as two perpendicular bending radii in a constant relationship with each other, the Gaussian curvature K.

Hence, $$\frac{1}{R1} * \frac{1}{R2} = K. \qquad \text{equ 2}$$

This formula also describes the best approximation of the shape, that a double bent sheet of plastic elasticly will conform to when forced to bend. This means that a half sphere can be rolled together to a near cylindrical shape, and as long as the deformation is within the linearity limits of the material, it will spring back to its original shape whenever left to do so. The preferred shape will be the one a thermoplastic sheet was cooled into after heating. This could be either of the to shapes rolled in or rolled out, so to speak. This is the philosophy behind the folding canopy, which was cooled into the rolled in shape.



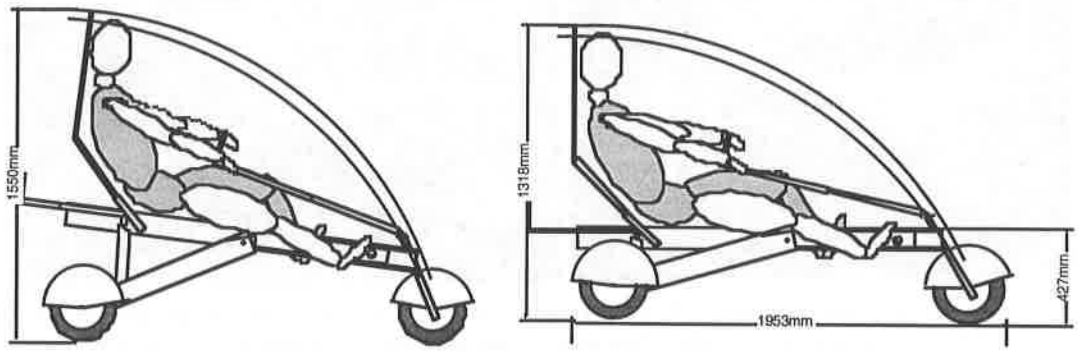
When stretched out in its rolled out shape, it stabilises itself and can work as a canopy. The surface treatment needed to have enough visibility when rained upon is yet to be applied.

Brakes

A braking apparatus has to be compact, especially when built into a weather protected part of a compact foldable trike, with the driving wheels mounted on a driven axle, as on go-carts. That makes up for the choice of a disc brake. Unamplified hand power, as transmitted through a braking wire, is far from enough to act directly onto a tiny disc of 90 mm diameter. I designed "self energised" brake pads, with the extra clamping force coming from the mechanical servo, consisting of one slightly moveable brake pad, with a parallelogram type of swing, caused by the rotating disc. The moveable brake pad is held by a pivoting pair of bolts, clamping the pads together. If contact between pads and disc is established before the pivoting bolts have come to a certain angle, here called A, the brake will come to a dead stop, due to the clamping forces do grow more rapidly than do the dragging forces braking the disc. Above a certain angle, called B the servo effect is almost negligible. With pads being of sole leather and the disc of aluminium, A is 10 ° and B is 30°. There has to be a strong spring to retract the sliding pad, and the wire and handle.

To avoid a pronounced fade of these tiny braking surfaces, they have to be ventilated and cooled by holes. They also have to be thermally isolated from heat sensitive parts like bonded surfaces and plastics.

Ups and downs, a magic spell



When sitting in a recumbent position, a low seat is, to some potential riders, uncomfortable coming in and out of, and by others regarded as unhealthy and unsafe in traffic interaction. Some people may even regard a low supine posture as a bodily language sign of social inferiority. To women in particular, legs above the seat is a non preferred posture. If it is possible to heighten the seat, it also may leave room for an ample storage underneath. I hope a feature like this may be regarded as a valuable option by different people with changing needs. Therefore I made different designs, that are possible to change, from a supine position in a head wind, to a high upright position for carrying goods.

Suspensions for comfort and hardware protection

Bumps in the road may cause overload on structural elements. Sitting down in a recumbent position gives the rider no way of avoiding the vertical accelerations of a bump. Sitting directly above a wheel axle is far worse than in between two axles, which reduces the centre of gravity movement to half the bump height.

A pair of blade springs has been tested with very good results, designed for giving a parallelogram type of action, sustaining three times the static load. They are fairly strait forward to calculate from a cantilever beam formula, but strain concentrations from combined loads are not simple to estimate or to come around. In polycarbonate, stress concentrations superimposed on the stress level at 90 % of a calculated rupture stress, repeatedly led to failure. Fibre composite materials are better suited for designing around a strain concentration problem. Composites need tooling and processing care to avoid resin rich areas with a low fibre content. A rubber cushion type of spring under the seat, in conjunction with the blade suspension, gave a remarkable feed back by the resonant phenomena of a wash board between the two suspension systems. I conclude that they are very similar in action and can be interchanged. For simplicity the rubber type of suspension is highly preferred.

Sitting is a noble art for noble parts

I have had a profound personal interest, from an acing back point of view, to try to understand, how a seat interacts with a human body. A major experiment, became moulding a fibreglass polyester sandwich seat, with an integral carbon fibre weave facing on one side and a polyethylene foam on the other, to the shape of my body as positioned in a selected armchair. I drew several conclusions from that experiment.

- First, a functional shape does indeed replace, the suspended action of the cushioned fillings of an armchair, with second to none comfort.
- Second, the vertical centreline of the mould, from below my shoulders to just above the seat, is indeed a straight line.
- Third, the 13 mm thick polyethylene foam, with a Shore A indention value of 25, which equals the value of all persons buts I have measured. It does indeed prevent a soar but when sitting hole days on a flat wooden chair.
- Fourth, the angle of comfort, between a flat, hard, horizontal seat and a flat, hard back support is very close to the small span of 120° to 130°.

Fifth, the spine and hip bone need support from a harder cushion filling than available in a cushioned seat, and the support is not to be transferred through the soft tissues of the waist. The polyethylene foam give enough support.

This all adds up to understand why sometimes a hard seat with an appropriate shape gives better relief to an acing back than does even a bed. The but tissue is best of when calandered no harder from the outside than from the inside.

Where does energy go in small wheels?

Small diameter wheels are prone to stumble over obstacles. On soft ground, like a lawn or a gravel faced pedestrian path, they dig steeper holes to come out of than larger wheels do. I think this is the main reason for big wheels. A folded bike with big wheels however is to bulky. Bike wheels have for long been preferably large, until sir Alec Moulton combined a small wheel diameter with a suspension. The Dunlop invention of the pneumatic tyre gave rise to a new type of rolling resistance that is to day fairly often misinterpreted, though the Michelin brothers did invent a good solution to one part of the problem with their radial carcass tyre.

A plea for good bicycle tyres have been heard before and is still to be emphasised for small diameters. One major problem is said to be the low priced import giving developers no margin between the cost for materials and ready available tyres on the market. I think there is a technical approach with patents and profits awaiting for a truly dedicated developer.

The rolling resistance when no power is transmitted, as measured by Ian Sims Australia, give to faint a difference between tyres, to make up for the sensation of power drain when going uphill, changing from a racing bicycle to a mountain bike or a small diameter wheel bike. Does size really matter this much? I think not, because the sensation is the same if only tyre pressure is lowered.

The missing link may be the power transmitted from the drivetrain through the pneumatic tyre to the ground. It has to be transformed into stresses in the tyre carcass, and in my opinion, these stresses tend to return the deformed cross-section to the toriodal shape. Meaning, the tyre cross-section flattened towards the ground, is deformed back to a round shape by the stressfields in a diagonal carcass, producing a redundant work-out equal to squeezing a tennis ball. This can be designed away in three ways.

- One being a radial orientation of the filaments together with circomferential filaments building up the carcass, whereby the tractional filaments are separated from the filaments deformed by the ground.

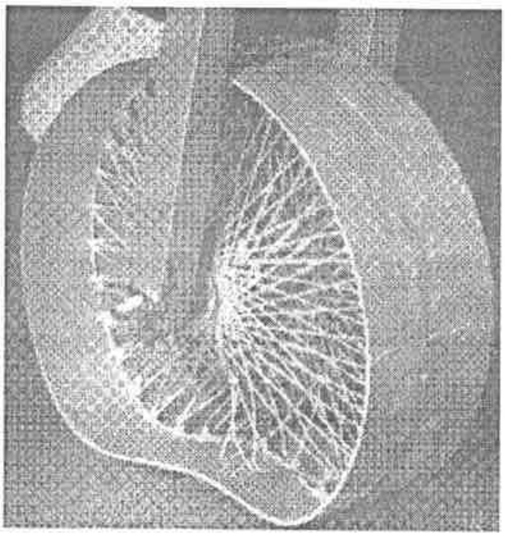
- The other, being a more wide shape of the tyre cross-section, seen on modern racing motor bikes, with a rim width to tyre height ratio slightly above one.

- Hence $$\frac{Wrim}{Htyre} \geq 1. \qquad \text{equ 3}$$

This could also be accomplished by simply putting an ordinary tyre on to a wider rim, which however is hard to find. This ratio has a value close to one for very thin racing push bike tyres and less than 0.4 for mountain bike tyres. I think proportion matters more than size uphill. I have not been able to test this hypothesis.

- Third, the rubber compound, inherited from the car tyre industry, where damping is favoured, could be switched to a blend with a greater bouncing factor, leaving more of the deformation energy to be elasticly recoverable.

A possible all composite wheel has been made, to show that it could be done. Soft spokes from Kevlar in Polyurethane matrix broke, after that they had been repeatedly bent at the rim.



The picture shows a prototype all composite filament wound wheel, when loaded across a cable in a softened state, by closing the hubs to each other. Climbing capability enhanced by the elastic deformability and an inherent suspension.

Friendliness to all users

- Users are manufacturers emphasising simplicity and reliability of parts and assemblies and a high through put on a production line and an expected high revenue on the investment.
- Users are also the transportation team of the gods and they have to give a high yield of sellable merchandise.
- Users are retailers, who don't want to keep voluminous goods in store, or spend to much time on a final assembly, or getting customers complaints for broken or bad parts. But a high price they want.
- The buyer and final user will settle for nothing less than the highest value and joy for their money. And that's final!
- Whether a design meets all these demands remains to be worked out. A small package with a ready-to-fold-out-and-go-bike, with a design added value of usable and easily maintained features and looks, may prove to be a major ingredient to a wider use of human powered vehicles.

Reliability in design with simplicity in mind

The drivetrain pulley can be a chain, a wire, a belt or a rope. The free-wheel clutch is needed for each line wheel. All bearings can be sealed. I have chosen a reciprocating way of action which need a rewind. The rewinding mechanism can be a clockwork spring, but I have chosen a rubber cord. The whole design would become simple to maintain, if standard elements are simple to change.

The framework is chosen to be in anodised aluminium for the prototypes, but the original design concept was in composite materials. An over-all low weight is contributed to by the choice of materials and greater cross-sections, whereby the stress levels are held down. This contributes to better security margins against mechanical failure, at the penalty of a slightly higher weight. The uncertainty of what the actual loads are in use, have been scrutinised by calculating backwards on existing bikes, which seem to converge to a safety margin for steel parts of only 1.25 over the ultimate load bearing capacity.

The steering system design for a foldable trike can be utilised having different approaches. Better than the steering wheel with a telescopic square tube and a universal joint, are the double pulley ropes, that seems to give a better feel. Direct steering certainly is preferable, but it is harder to combine with the foldability. I wanted however to test other solutions.

A steering wheel king pin made up by a couple of threaded nuts and a threaded bolt works fine when graphite grease lubricated. Almost as good as the traditional bike steer ball bearing unit. For trikes the threaded bolt and nut is quite adequate.

A possibly major draw-back from a life-time expectancy point of view, are the linearly moving pedals. The linear pedals are delicate components, heavily loaded and prone to wear and fatigue, and so is the rail they run in. The pedals have some similarity to in-line roller skates. After some 13 generations of trial and error in design, they now seem to work satisfactory, but they can be further improved.

A plurality of ball bearings are inevitable in a linear recumbent design, but they are readily available and reliable.

All plastic line wheels though have to be manufactured with close tolerances to press fit appropriately on to the bearings. They have all been laced from delrin and nylon for the prototypes.

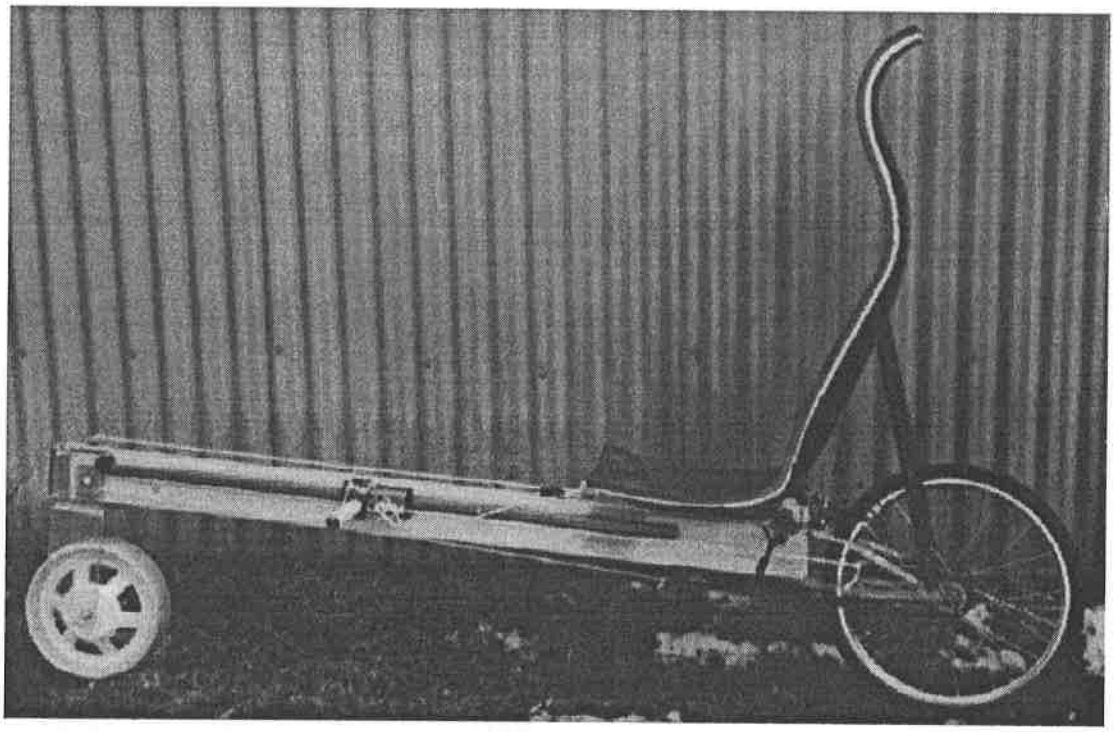
Joints between load carrying members in aluminium, have preferably been made with bolts and nuts to avoid the uncertainty a prototype welded joint. Some joints have been epoxy bonded, for example the box beam with the special profile for the pedal rail.

A short chronological list of my bike project

My interest in velomobiles started about 1983, as an intellectual hobby. I became interested, because a friend of mine was devoted to biking. He did not buy my suggestions for technical improvements, for example to spare the wrists by transferring the upper body weight to the tiller bar with the elbows.

In 1987 I grasped one universal part of the complex, the wheel. I designed and made a filament wound, all composite, no flat tyre, with adjustable hardness, and was granted a patent for the patent application (10).

In 1992 I went on with the drive train, by studying the human motor capacity, and how it was geared up on bikes, and I was hooked on the linear drive idea, as a technical challenge.

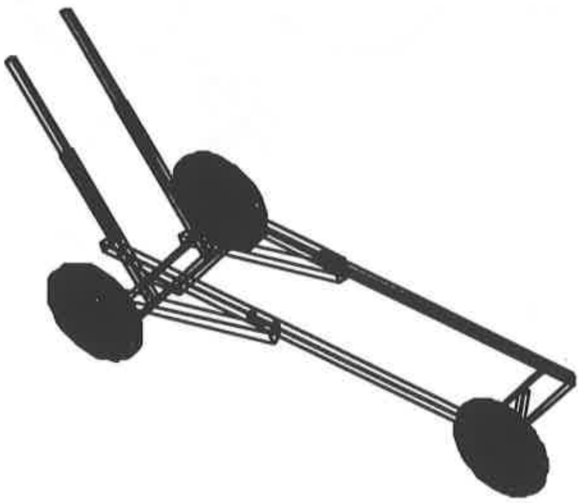


In 1993 I built my first recumbent, linear driven, all composite bike with the seat moulded to the shape of my back. With a constant Ggear of about 6. It became a test bench for so many technical solutions, that it did not also work as a bike. So I bought a foldable Micro Bike with a toothed belt from crank to wheel.

In 1994 I built my first linear drive, recumbent, all aluminium, box beam, foldable, delta trike with suspension, 206 mm barrow wheels and joy stick steer. It barley worked for test rounds. Pedal and rail wear was tested with different materials.

Since 1995 I have been busy improving things, trying to make the hardware as durable as bikes are. I have made computational modelling, tensile, bending and rupture testing on details and joints, establishing a feel for what will work, and taken the different prototypes on test rides commuting 7 km. I entered three contributions to the Danish Design Contest, one being a trike, with only some faint feed back.

I attended the IHPVA events in Holland 1996 and Cologne 1997 and was further encouraged on my perception of the HPV idea.



One of my CAD sketched Trikes

Ancient and modern linear drive configurations

KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 29 MAI

PATENTSCHRIFT

— № 96534 —

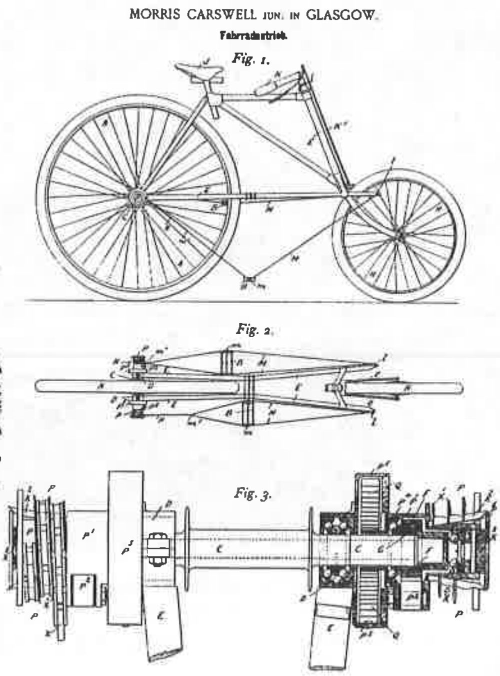
KLASSE 63: SATTLEREI, WAGENBAU UND FAHRRÄDER.

MORRIS CARSWELL JUN. IN GLASGOW.

Fahrradantrieb.

Patentirt im Deutschen Reiche vom 2. Februar 1897 ab.

Vorliegende Erfindung betrifft einen Fahrradantrieb derjenigen Art, bei welchem es dadurch, dafs jeder Fufstritt an einem unabhängig durch eine Feder zurückgezogenen und gleich- die Tritte B in ihrer tiefsten Lage stets noch genügend weit von dem Boden abstehen. Das Rad A erhält eine feste Achse C, die in Kugellagern oder anderen Lagern D am hinteren



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63

Tillhör bibliotekets samling, uppdelad i klasser.

PATENT

№ 8392.

BESKRIFNING

OFFENTLIGGJORD AF

KUNGL. PATENT- OCH REGISTRERINGSVERKET.

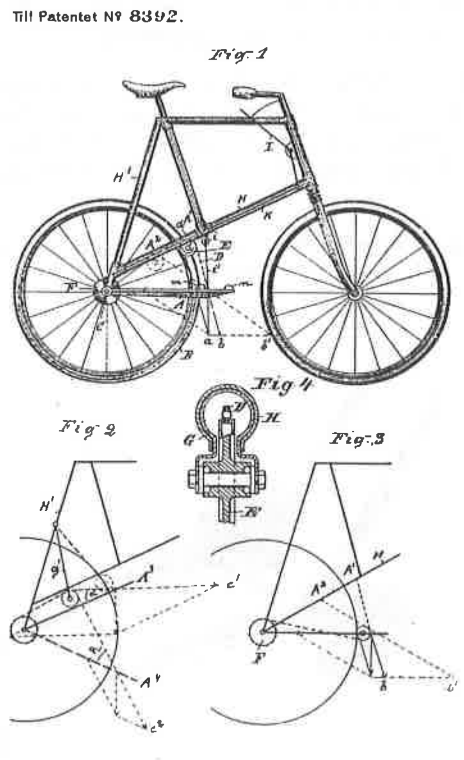
A. F. A:SON ROXENDORFF,

PARIS (FRANKRIKE).

Drifanordning med föränderlig kraftutvexling vid velocipeder och andra åkdon.

Patent i Sverige från den 11 september 1896.

Uppfinningen afser några till kraftutvex- skjutning kan åstadkommas på olika sätt, t. ex. medelst en häfstång I, som är förenad med



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Europäisches Patentamt
European Patent Office
Office européen des brevets

Veröffentlichungsnummer: **0 297 579 A2**

EUROPÄISCHE PATENTANMELDUNG

Anmeldenummer: 88110479.8

Int. Cl.4: **B62M 1/04**

Anmeldetag: 30.06.88

Priorität 02.07.87 DE 3721927

Veröffentlichungstag der Anmeldung: 04.01.89 Patentblatt 89/01

Benannte Vertragsstaaten: AT BE CH DE ES FR GB GR IT LI LU NL SE

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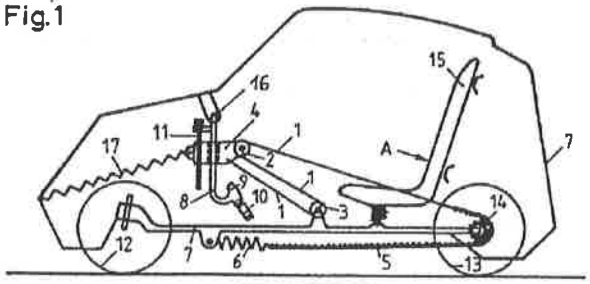
Antriebsvorrichtung für ein durch Muskelkraft angetriebenes Fahrzeug.

Bei einer Antriebsvorrichtung für ein durch Muskelkraft angetriebenes Fahrzeug mit wenigstens einem hin und her verschwenkbaren Trethebel, an dem ein Seil oder eine Kette befestigt ist, die über ein Antriebsrad geführt und unter Spannung gehalten ist, wird zur Erzielung eines großen Übersetzungsbereiches und einer leichten Umsetzung auch einer hohen Übersetzung eine flaschenzugartige Umlenkung des Seils bzw. der Kette zwischen einem Verstellteil (4), das längs des Trethebels (8) verschiebbar ist, und dem Fahrzeugrahmen bzw. einem Festpunkt (7) vorgesehen.

Fig.1



EP 0 297 579 A2

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(3) Bicycling Science, 2nd edition, page 63

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(5) Old German patent 96534 granted to Morris CARSWELL Glasgow Scotland 1897

(6) Old Swedish patent 8392 granted to A.F.A:son ROXENDORFF Sweden 1892

(7) French patent 738.319 granted to NOIZEUX and DUPIEUX Ltd Seine France 1932

(8) Swedish patent 10573 granted to B. LJUNGSTRÖM Stockholm, Sweden 1897.

(9) European patent application 0 297 579 A2 from Georg FELKEL Barkheim Germany 1988

(10)Swedish patent application 8801421-2 from Anders BRAGE Sollentuna Sweden 1988

Recumbent with encapsulated drive chain

Clemens Bucher

The acceptance of human powered vehicles is an important point to spreaden the velomobile idea. Bicycles - compared to cars - have a completely "open structure" i.e. almost each part or component is visible and accessible. This is desirable for the shifting lever for example, but not for parts like the drive chain. The drive chain gets splashed by water from the road and may dirty the rider´s clothes. This article shows an approach to encapsulate the drive chain in recumbent bicycles completely. The protection of the chain from environmental influences offers the advantage of almost no maintenance.

With properly designed recumbents, springing of the chain and a noisy chain can be easily avoided. Nevertheless, the chain maintenance is time consuming and dirty work. This is also the case when chain tubes are mounted.

Even with a regular and good chain maintenance, sand and dust cannot be prevented from getting inside the chain links. This leads to rubbing down of the bolts and to a reduction of the efficiency of the drive chain. This is one of the main reasons for the lengthening of the chain and cog wear.

A completely encapsulated drive offers a solution for these problems. However, the gearing should not be affected thereby. The bicycle should need little maintenance and the components should be made of stainless steel or similar materials. In addition, an encapsulated drive chain is more attractive than an open visible chain because of the clear design.

The first recumbent with that purpose was made of 1.5mm stainless steel sheet that was sawed out and welded. No component remained without changes in the design.

First of all, the space needed for the gearing makes it necessary to change the head tube geometry. The inside of the frame has to house a 26 teeth-chainwheel. This requires a special construction of the bottom bracket. The chainwheel is located in the centre of the bottom bracket, not at its side. Directly behind the chainwheel there are two tension pulleys. The upper one is fixed to the frame, the lower one can move forwards and backwards. This influences the length of the returning chain part inside the frame.

The cogs rotate at the rear part of the main frame, under the seat. An ordinary derailleur would take up too much space in this kind of construction. Therefore, a special horizontally mounted derailleur with only one derailleur wheel is set on the left hand side of the frame. It provides a certain distance between the cogs and the chain. The spring has to be exchanged against one that works in the other direction.

For taking up the rear part of the chain drive, a 20 teeth chainwheel is mounted on a hub body of a "Sachs 3x7" (a special hub with three internal gears and seven cogs). The hub must be completely disassembled. The hardened pawlrings inside the hub body were pressed out and a ringdisk - for the chainwheel - was welded on the body of the hub.

The rear part of the frame, guiding the rear wheel, is designed as a mono lever. The fulcrum of this part is running on the same (virtual) axis as the internal hub. The chain is running to the rear wheel where a freewheel of a BMX bicycle is mounted. Similar to the front chain, the rear chain is tensioned by a derailleur wheel. The rear hub is custom-made, the bearings are similar to those of the bottom bracket. The first recumbent of this type, made of stainless steel, was presented at Laupen/Switzerland and weighted 21 kg.

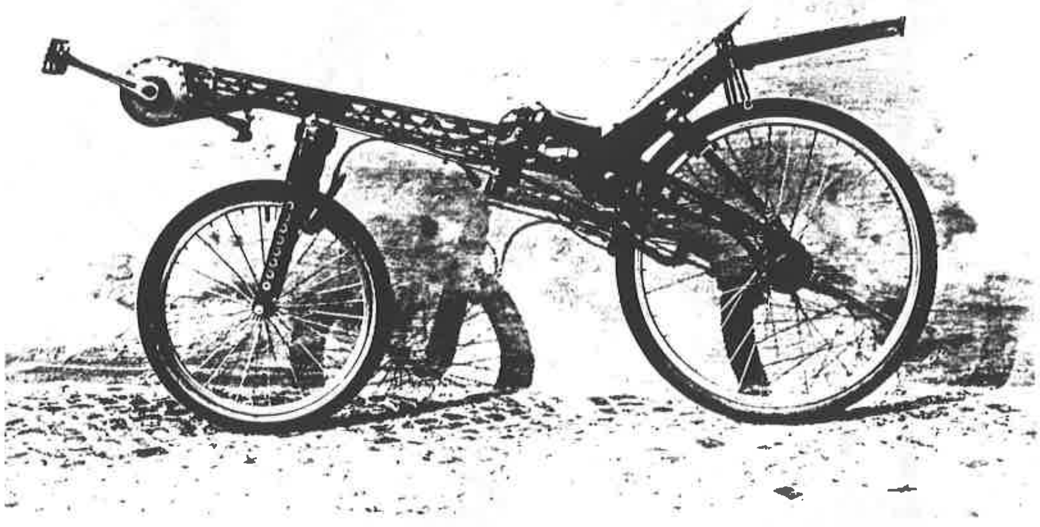


Fig. 1

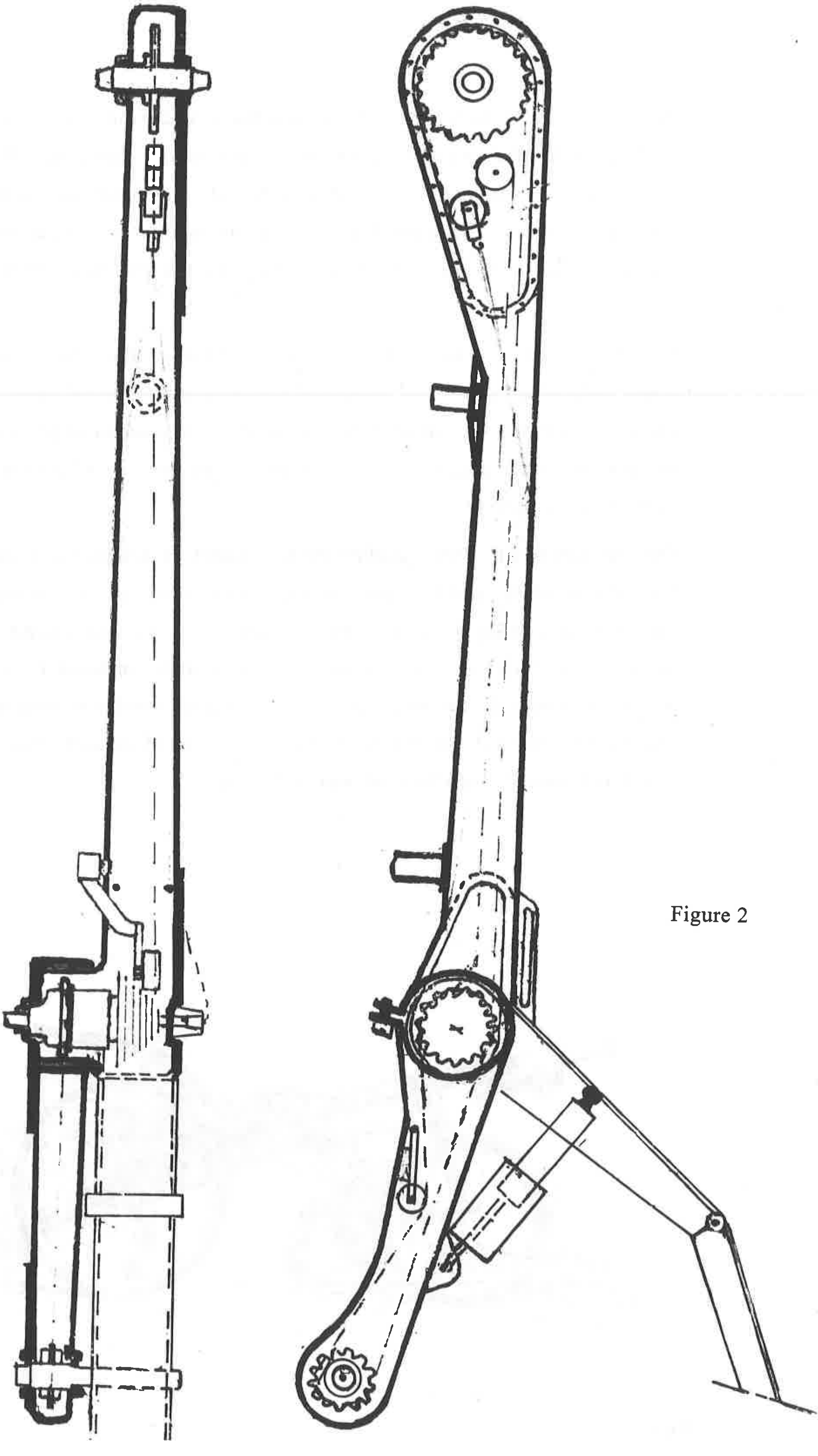


Figure 2

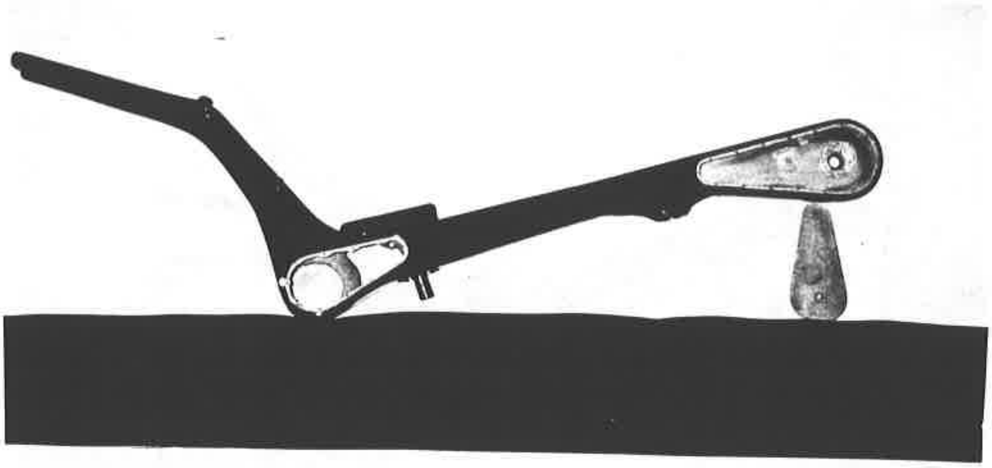


Fig. 3

The second model was the first attempt to build it out of carbon. It had not been finished, due to problems with the rear part of the frame.

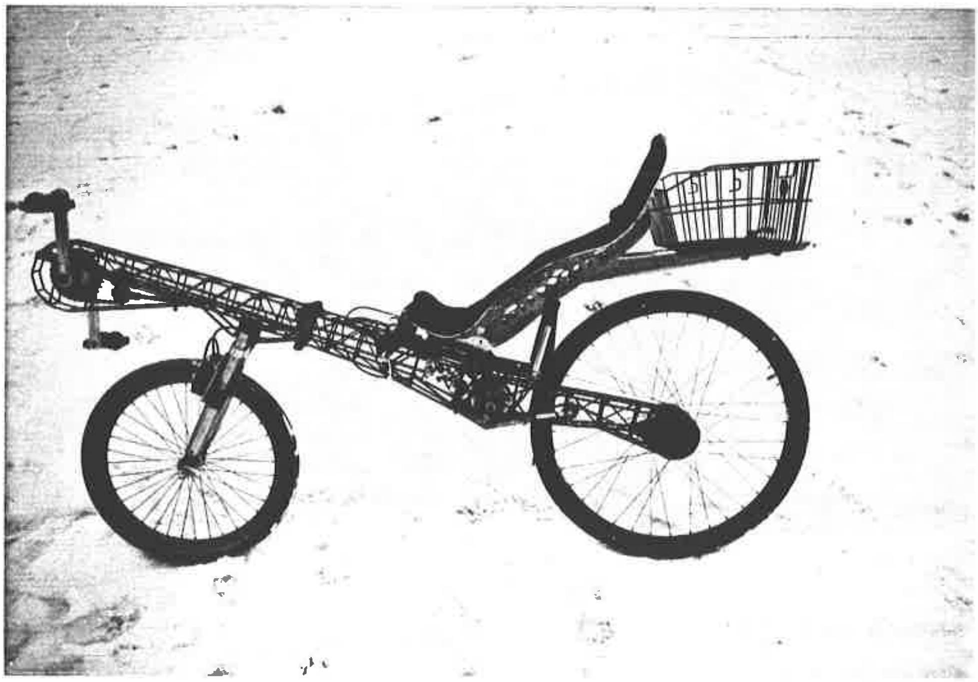


Fig. 4

The third construction is collapsible in the middle and looks like the "Eiffel-tower"

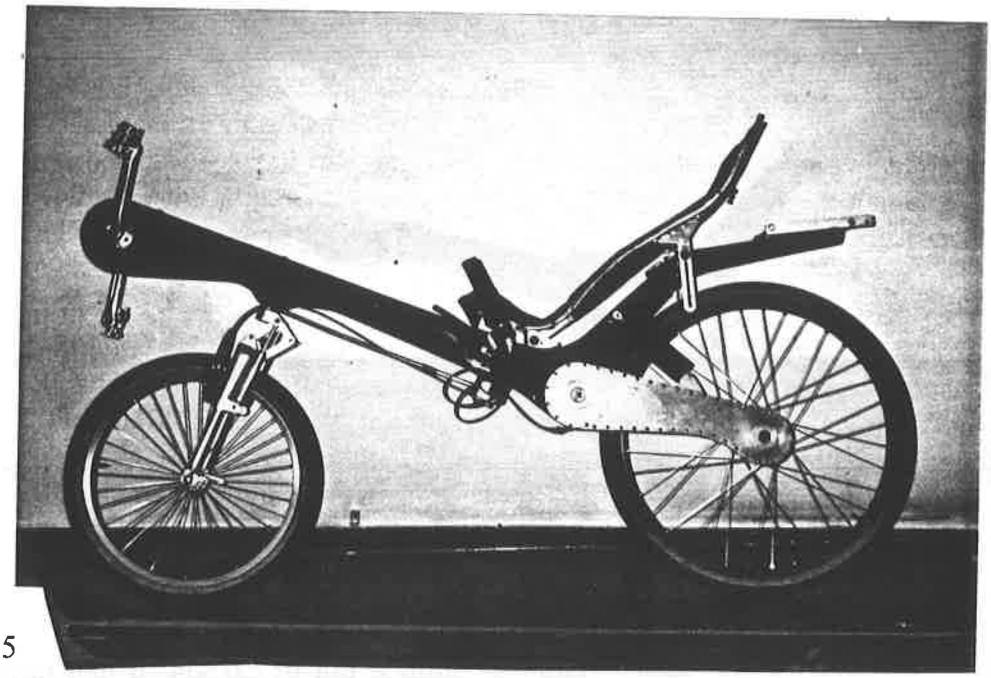


Fig. 5

The next one is the finished carbon-bike, with the rear part made of aluminium

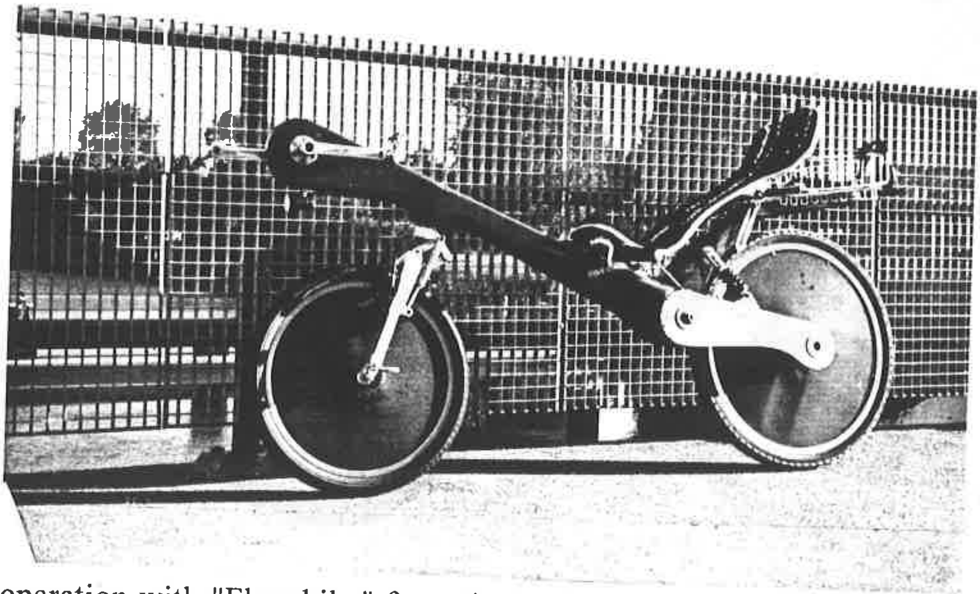


Fig. 6

In co-operation with "Flevobike" from the Netherlands, a new prototype was constructed. The head tube passes through the frame and makes a special bearing unnecessary. This construction allows upper seat steering. The frame is asymmetrically widened at the right hand side. Thus, the chain passes besides the head tube in the interior of the frame. The bearings of the rear part of the frame were improved.

Although constructing a recumbent with a completely encapsulated drive chain is complex, it showes the possibility of future bikes or velomobiles which demand less maintenance. This will hopefully lead to practical human powered vehicles for everyday and everyone.

Aluminium im Bau von Leichtfahrzeugen

von Thomas Senkel

Abstract: Velomobile design with aluminum

Aluminum is even for velomobiles an outstanding material. By its manifold manufacturing methods it has advantages for building prototypes and also for serial production. Though Aluminum is more expensive than steel, there are lower costs in processing, especially by extrusion, drawing, forging, casting and anodizing. Besides Aluminum is stable against corrosion and good for recycling.
By the example of **Senkels easy** comfortbike the advantages of a special extrusion profile are illustrated.

Zusammenfassung:

Aluminium ist gerade für Leichtfahrzeuge ein hervorragendes Material. Aufgrund vielfältiger Bearbeitungsmöglichkeiten hat es sowohl für den Prototypenbau als auch für die Serienproduktion seine Vorzüge. Zwar ist der Rohstoff Aluminium teurer als Stahl, was aber durch Kostenvorteile in der Verarbeitung, insbesondere beim Strangpressen, Tiefziehen, Schmieden, Gießen und Eloxieren wieder wettgemacht werden kann. Außerdem besitzt Aluminium eine gute Korrosionsbeständigkeit und Recyclingfähigkeit.
Am Beispiel des Komfortrades **Senkels easy** werden die Vorteile des speziellen stranggepreßten Rahmenprofils erläutert.

1 Konstruieren mit Aluminium

Wichtig für den Leichtbau ist eine aluminiumgerechte Konstruktion, die den Eigenschaften dieses Werkstoffs Rechnung trägt. Das entscheidende Kriterium ist meist nicht die Festigkeit, sondern die Steifigkeit, also die Nachgiebigkeit unter Belastung. Sie kann dadurch vergrößert werden, indem (bei gleichem Gewicht) der Profilquerschnitt erhöht und die Wandstärke verringert wird. Zu geringe Wandstärken sollten aber vermieden werden, da sonst die Verbindung der Bauteile schwierig wird und Beulen beim Gebrauch entstehen können.
Aluminium besitzt bei dynamischer Beanspruchung, wie sie bei allen Fahrzeugen gegeben ist, nur eine begrenzte Lebensdauer. Für die Festigkeitsberechnung sind daher auf jeden Fall die Werte für die Wechselfestigkeit und nicht die Zugfestigkeit anzusetzen. Für Fahrräder und Muskelkraft-Leichtfahrzeuge gibt es zwar keine Verpflichtung zu einer Sicherheitsprüfung. Um aber einer 30-jährigen Produkthaftungspflicht (In Deutschland BGB 823) zu genügen, wird empfohlen, sicherheitsrelevante Bauteile aus Aluminium mit bis zu 100 Millionen Lastspielen zu prüfen.

Folgende Legierungen werden im Fahrzeugbau hauptsächlich eingesetzt:

Gattung	ISO	Zugfestigkeit N/mm²	0,2%Dehngrenze N/mm²	Bruchdehnung min.%	Wechselfestigkeit N/mm²	Aushärtbar	Schweißbar	weitere Eigenschaften
AlMg1	5005	165-205	ca. 130	6	50	nein	sehr gut	sehr korrosionsbest.
AlMg3	5754	180-230	80-150	14	90	nein	sehr gut	sehr korrosionsbest.
AlMg4,5Mn	5083	270-350	140-220	12	110	nein	sehr gut	sehr korrosionsbest.
AlMgSi0,5	6060	215-270	160-230	12	70	ja	sehr gut	gut umformbar
AlMgSi0,7	6005A	250-310	200-280	8	80	ja	sehr gut	gut umformbar
AlMgSi1	6082	310-370	260-350	10	80	ja	sehr gut	gut umformbar
AlMg1SiCu	6061	ca. 290	ca. 240	10	80	ja	sehr gut	gut umformbar
AlCuMg1	2017A	380-470	230-360	10	100	ja	mässig	sehr gut schmiedbar
AlCuMg2	2024	440-560	315-450	10	100	ja	mässig	gut schmiedbar
AlZn4,5Mg1	7020	350-420	290-370	10	90	ja	gut	hohe Festigkeit, gut schweißbar
AlZnMgCu0,5	7022	490-570	420-520	7	110	ja	mässig	hohe Festigkeit, gut schmiedbar
AlZnMgCu1,5	7075	530-670	460-630	7	110	ja	schlecht	sehr hohe Festigkeit, gut schmiedbar

Anmerkung: Wechselfestigkeit bei 10 Millionen Lastspielen   Quelle: Zusammengestellt nach [2]

2 Formen

2.1 Gießen

Durch Gießen lassen sich gerade in der Serienproduktion Teile mit aufwendiger Kontur herstellen, die sich durch Fräsen nur zeit- und materialintensiv fertigen lassen, wie z.B. Muffen, Anschlüsse für Federschwinge, etc.
Es wird nach Art der Form unterschieden zwischen Sandguß, Kokillenguß, Druckguß und Feinguß. Welches Verfahren gewählt wird, hängt von der geforderten Qualität, aber auch von Aufwand, Preis und Stückzahl der Gußteile ab.

Verfahren	Gußteilmasse	Wanddicke	Maßgenauigkeit	Lieferzeit	Seriengröße
Sandguß	<2000kg	>3mm	mittelmäßig	kurzfristig	Einzelfertigung
Kokillenguß	<200kg	>2,5mm	gut	mittelfristig	Serienfertigung
Druckguß	<60kg	>0.8mm	hoch	längerfristig	Großserien
Feinguß	<20kg	>0.8mm	hoch	mittelfristig	Serienfertigung

Gußlegierungen haben Silizium meist als Hauptlegierungselement mit einem Anteil von 2% bis 20%. Sie besitzen ein gutes Fließvermögen und geringe Warmrißneigung. Durch Veredelung mit Natrium oder Strontium wird ein feineres Gefüge erzeugt, wodurch Zähigkeit und Zugfestigkeit verbessert werden, Dehngrenze und Härte aber fast gleich bleiben.
Bei sicherheitsrelevanten Bauteilen spielt die richtige Auswahl der Legierung und der Nachbehandlung eine wichtige Rolle. Gerade bei dynamisch beanspruchten Teilen sollten Verunreinigungen von Eisen so gering wie möglich sein (unter 0,2%), da Eisen die Bruchdehnung vermindert. Poren stellen eine andere Ursache für verminderte Festigkeit dar. Um sie zu reduzieren, wird nach dem Gießen das Heiß-Isostatische-

Pressen (HIP) angewendet. Dabei wird bei hoher Temperatur das Gußstück erweicht und die Hohlstellen durch äußeren Druck zusammengepreßt.
Eine mechanische Nachbearbeitung der Gußteile ist in den meisten Fällen notwendig. Das beginnt beim Entgraten und Putzen, geht über Bohren, Planfräsen und Gewindebohren, bis hin zur Oberflächenbehandlung wie Polieren oder Eloxieren. [3]

2.2 Strangpressen

Durch Strangpressen lassen sich beliebig kompliziert geformte Rohre und Profile herstellen, mit einem konstanten Querschnitt über die gesamte Länge. Standardprofile, wie Rund- und Rechteckrohre, Winkel, U- und Z-Profile sind im Lagerprogramm diverser Hersteller leicht erhältlich, meist in der Legierung AlMgSi0,5. Andere Profile sind oft Sonderanfertigungen und nur für den Auftraggeber reserviert. Die Werkzeugkosten sind mit einigen Tausend DM noch relativ gering und selbst bei Kleinserienfertigung bald amortisiert.
Durch geschickte Konstruktion lassen sich durch Nuten, Verstrebungen, Vorsprünge, etc. verschiedene Funktionen in einem Bauteil integrieren und tragen so zur rationellen Fertigung bei. Die Vorteile des Strangpressens werden bei Fahrrädern bisher hauptsächlich bei Felgenprofilen genutzt. Viele weitere Anwendungen bei Leichtfahrzeugen sind denkbar, wie z.B. andere Rahmenprofile, Trittbretter, Einfassungen von Fenstern und Verkleidungen, etc.

2.3 Biegen

Grundsätzlich können Bleche und Profile in allen Legierungen gebogen werden. Der kleinstmögliche Biegeradius hängt von der Legierung, dem Zustand, Wandstärke und Querschnitt ab. Das Biegen von Rohren und Profilen erfolgt auf 3-Rollen-Profilbiegemaschinen. Beim Biegen ändert sich der Profilquerschnitt. Am Außenradius wird das Material gestreckt und die Wandung dünner, während am Innenradius die Wandstärke zunimmt und das zur Faltenbildung neigt. Auch die Breite kann sich verändern, allerdings verhält sich jedes Profil anders. Es gibt zahlreiche Kniffe und Hilfsmittel, um das Profil am Einknicken zu hindern, wie z.B. das Füllen mit Sand, Eis, Gliederketten, Kugeln oder die Anwendung von Hilfsrollen. Durch Biegen im weichen Zustand oder nach Erwärmung auf ca. 150-200°C lassen sich die zulässigen Biegeradien gegenüber dem Kaltbiegen halbieren.

2.4 Schmieden

Das Schmieden im Gesenk wird bei Fahrradkomponenten in großen Stückzahlen angewendet, z.B. bei Tretkurbeln, Bremsen, Pedalen, Vorbauten. Die Werkzeugkosten sind dabei recht hoch (einige Zehntausend DM). Das Aluminiumhalbzeug wird unter großem Druck in zwei Formhälften (Gesenk) umgeformt. Bei hohem Umformungsgrad sind zwei oder mehr Arbeitsgänge in verschiedenen Gesenken notwendig. Im Vergleich zu Gießen oder Fräsen werden die höchsten Festigkeiten erzielt, da das Gefüge beim Schmieden verfestigt wird und einen ungestörten Faserverlauf erhält.

2.5 Tiefziehen

Als Tiefziehen bezeichnet man die sphärische Umformung von Blechen. Es werden meist zwei Formhälften verwendet, zwischen denen das Blech unter Druck in Form gebracht wird. Auch beim Tiefziehen fallen hohe Werkzeugkosten an, die nur für größere Stückzahlen amortisiert werden können. Sehr schön lassen sich damit räumlich gekrümmte Formen erzeugen, z.B. bei Monocoque-Rahmen und Karosserien. Die einzelnen Teile müssen dann durch Nieten, Falzen oder Schweißen miteinander verbunden werden.

3 Zerspanen

Die leichte Zerspanbarkeit von Aluminium lernt man besonders bei handwerklicher Bearbeitung zu schätzen. Schnell sind mit einer groben Hobelfeile die Konturen eines Bauteils herausgearbeitet. Schleifen erfolgt dann, auch maschinell, immer nur mit Sandpapier. Schleifscheiben für Stahl sind nicht geeignet, da die Poren der Schleifscheibe mit Aluminium zusetzen.
Aluminium kann grundsätzlich beim Bohren, Drehen und Fräsen mit den üblichen Werkzeugen aus HSS oder Hartmetall zerspant werden; Schneidkeramik und Titan-haltige Beschichtungen sind ungeeignet. Es sind höhere Schnittgeschwindigkeiten als bei Stahl möglich (bis zu 1000m/min beim Drehen, 250m/min beim Bohren). Auch ist eine Kühlschmierung nicht unbedingt erforderlich, aber vorteilhaft für die Oberflächengüte und die Standzeit (Haltbarkeit) der Werkzeuge. Es gibt auch spezielle Bohrer und Fräser mit etwas anderen Schnittwinkeln, die besonders gut für Aluminium geeignet sind. Legierungen mit hohem Si-Anteil (vor allem Gußlegierungen) bringen einen höheren Werkzeugverschleiß mit sich. Den geringsten Verschleiß verursachen sog. Automatenlegierungen, die als spanbrechende Zusätze z.B. Blei oder Wismut enthalten.
Das CNC-Fräsen ist bei der Herstellung von Tretkurbeln, Bremsen, Vorbauten, etc. immer mehr in Mode gekommen und oft wird auch mit dem Begriff geworben, als handle es sich um ein Qualitätsmerkmal per se. Da zum Teil scharfe Kanten entstehen und der Faserverlauf gestört wird, sind CNC-Teile nicht unbedingt hochwertiger als geschmiedete Teile. Die Qualität hängt eher von der Konstruktion und vom Material ab. CNC-Fräsen stellt ein preisgünstiges Verfahren dar, um bei kleinen bis mittleren Stückzahlen zu komplex geformten Teilen zu kommen. Ohne großen Aufwand lassen sich CAD-Zeichnungen direkt in die Fertigung übernehmen.

4 Fügen

4.1 Schrauben

Für Schraubverbindungen eignen sich besonders gut rostfreie Schrauben aus Edelstahl A2. Die seewasserbeständige Legierung A4 ist etwas teurer und i.a. für Fahrzeuge nicht erforderlich. Sie ergeben zusammen mit dem Aluminium korrosionsbeständige Verbindungen, die keines weiteren Oberflächenschutzes bedürfen. Werden Gewinde direkt in Aluminium geschnitten, so sollte die Gewindelänge etwa das doppelte des Durchmessers betragen. Da das Aluminiumbauteil ein stärkeres Kriechverhalten hat als die Stahlschraube, kann die Spannung einer Schraubverbindung mit der Zeit nachlassen. Dem läßt sich durch größere Unterlegscheiben (Karosseriescheiben) vorbeugen, wodurch sich die Spannungen zwischen Bauteil und Schraube besser verteilen. Außerdem können selbstsichernde Muttern, Federringe oder Schraubenkleber das unbeabsichtigte Lösen einer Schraubverbindung verhindern.
Ein Problem bei oft gelösten und wieder angezogenen Schraubverbindungen kann der Abrieb von Aluminium sein. Wenn kleine Späne in das (Edelstahl-)Gewinde gelangen,

kann die Mutter so festfressen, daß sie nur noch abgesprengt werden kann. Deshalb solche Gewinde öfter reinigen und gut fetten.
Als Werkstoff für sehr leichte und feste Schrauben kommen AlZnMgCu-Legierungen in Frage, die aber korrosionsempfindlich sind. Sie sollten auf jeden Fall eloxiert sein und am besten vor dem Verschrauben in Wachs-Paraffin-Schmelze getaucht werden.

4.2 Kleben und Nieten

Eine Verbindung von Blechen und Profilen durch Kleben und Nieten ist insbesondere für die handwerkliche Bearbeitung gut geeignet, da auch ohne (teures) Schweißgerät gute Ergebnisse erzielt werden. Ein wesentlicher Vorteil gegenüber dem Schweißen ist, daß die volle Materialfestigkeit erhalten bleibt und sich auch hochfeste AlZnMgCu-Legierungen verbinden lassen, die nicht schweißbar sind. Daher werden diese Verbindungen nach wie vor auch im großen Maßstab, z.B. im Flugzeugbau, eingesetzt.
Klebeverbindungen von Aluminium können am einfachsten mit 2K-Epoxidklebern ausgeführt werden. Sorgfältiges Entfetten der Teile mit Aceton ist sehr wichtig, da die Haftung sonst stark reduziert ist. Durch Erwärmen (max. 150-200°C) kann die Aushärtezeit verkürzt und Festigkeit des Klebers nochmals erhöht werden.
Nietverbindungen können am einfachsten mit Popnieten ausgeführt werden. Es gibt auch Gewindeeinsätze, die in Bleche eingenietet werden können.
Gerade die Kombination von Kleben und Nieten bringt Vorteile für die Festigkeit der Verbindung: Klebverbindungen können gut Schubkräfte, aber kaum Schälkräfte aufnehmen, die wiederum gut von den Nieten verkraftet werden.
Die Verbindung durch Kleben und Nieten wird vorbildlich demonstriert in der Bauanleitung des „Flunder"-Anhängers. [5]

4.3 Schweißen

Beim Schweißen von Aluminium wird zumeist das WIG-Verfahren (Wolfram Inert Gas) mit Wechselstrom angewandt. Es ist sowohl für die handwerkliche als auch maschinelle Fertigung geeignet. Als Schutzgase kommen Argon, Helium oder Gemische in Frage. Der Schweißzusatz richtet sich nach den Legierungsbestandteilen der Grundmaterialien. Besonderes Augenmerk verdient die Vorbereitung der Bauteile: Sie werden zunächst entgratet und grob gereinigt (Rohre auch innen), dann entfettet und die Oxidschicht mit einer Edelstahldrahtbürste entfernt. Anwärmen auf ca. 150°C erleichtert den Schweißvorgang.
Die Festigkeit einer Schweißnaht ist geringer als die des Grundmaterials. Bei einigen Legierungen, wie z.B. AlZn4,5Mg1 (7020), härtet die Schweißnaht von allein fast bis auf die Grundfestigkeit wieder aus. Generell ist aber eine Wärmebehandlung nach dem Schweißen zu empfehlen, um dem Material innere Spannungen zu nehmen.

5 Nachbehandlung

5.1 Wärmebehandlung

Durch Wärmebehandlung nach genau definiertem Temperatur-Zeit-Ablauf werden bei den aushärtbaren Legierungen (Typ 6xxx und 7xxx) die höchstmöglichen Festigkeiten erzielt. Dabei werden mehrere Stadien durchlaufen. Das Lösungsglühen nimmt dem Material die inneren Spannungen, die insbesondere nach dem Schweißen vorhanden sind. Durch schnelles Abkühlen wird dieser Zustand quasi eingefroren. Die Temperatur von ca. 500°C (je nach Legierung) muß beim Lösungsglühen bis auf wenige Grad genau

eingehalten werden, und zwar am Bauteil gemessen. Es erfordert einen elektrischen Ofen mit sehr genauer Temperaturregelung und schließt ein handwerkliches Härten von Aluminium, wie es beim Stahl möglich ist, weitgehend aus.
Auslagern bezeichnet einfach nur das längere Liegenlassen der Werkstücke ohne Belastung bei Raumtemperatur, bzw. beim Warmauslagern mit ca. 160°C. Dabei stellt sich dann die endgültige Festigkeit ein.

Zustand	Bedeutung
F	Herstellungszustand (keine Grenzwertefür mech. Eigenschaften festgelegt)
O	Weichgeglüht
W	Lösungsgeglüht (instabiler Zustand)
T1	Abgeschreckt aus der Warmumformungstemperatur und kaltausgelagert
T2	Abgeschreckt aus der Warmumformungstemperatur, kaltumgeformt und kaltausgelagert
T3	Lösungsgeglüht, kaltumgeformt und kaltausgelagert
T4	Lösungsgeglügt und kaltausgelagert
T5	Abgeschreckt aus der Warmumformungstemperatur und warmausgelagert
T6	Lösungsgeglüht und warmausgelagert
T7	Lösungsgeglüht und überhärtet (warmausgelagert)
T8	Lösungsgeglüht, kaltumgeformt und warmausgelagert
T9	Lösungsgeglüht, warmausgelagert und kaltumgeformt

5.2 Eloxieren

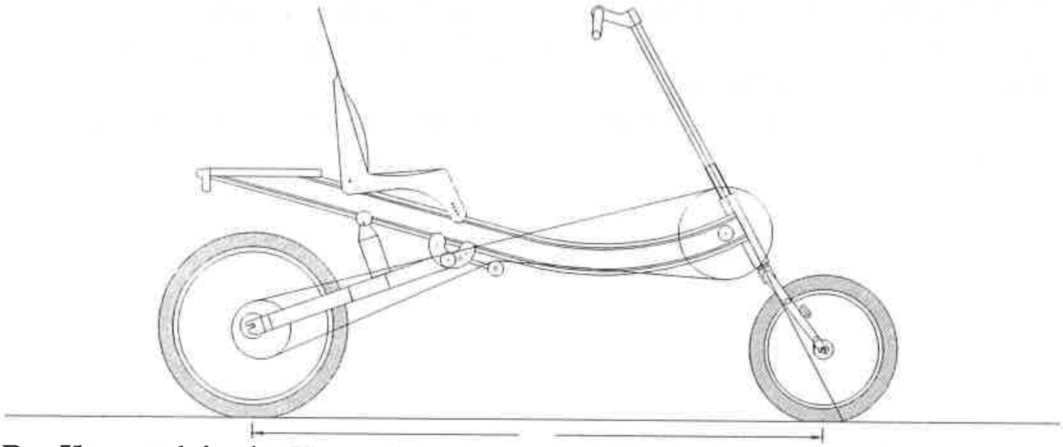
Eloxieren nennt man den gezielten Aufbau einer schützenden Aluminiumoxidschicht in einem elektrolytischen Verfahren. Es werden Schichtdicken bis zu 40µm erzielt, die auch eingefärbt werden können. Üblich sind Silber-, Gold-, Broncetöne und schwarz, aber auch Farben wie rot, violett, blau und grün sind möglich. Eloxalschichten sind gleichmäßig, relativ kratzfest und UV- und witterungsbeständig. Sie stellen die dauerhafteste Oberflächenbehandlung von Aluminium dar.

5.3 Pulverbeschichten

Um zu Oberflächen beliebiger Farbe zu kommen, findet das Pulverbeschichten immer stärkere Verbreitung. Es ist umweltfreundlicher als Lackieren, da keine Lösungsmittel verwendet werden. Eine abschließende Schicht mit Klarpulver ergibt entweder eine matte oder glänzende Oberfläche. Auch Metallicfarben oder andere Sonderbeschichtungen, wie z.B. Hammerschlageffekt, Sprenkel oder Schlieren sind inzwischen möglich.

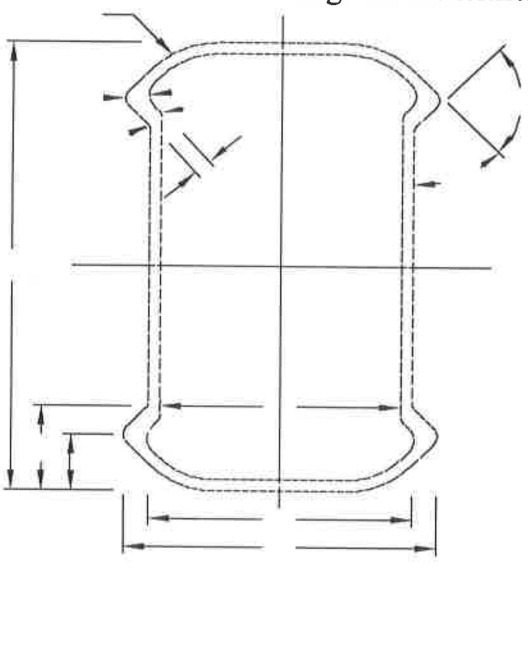
6 Beispiel: Senkels easy

Bei dem Komfortrad **Senkels easy** wurden einige der beschriebenen Fertigungsverfahren in beispielhafter Weise angewendet.



Das Kernstück ist der Hauptrahmen aus einem Strangpreßprofil, welches speziell für **Senkels easy** entworfen wurde, aber auch anderweitig Anwendung finden kann. Es handelt sich um ein Rechteckprofil mit 80x44mm, wobei an allen Kanten Vorsprünge vorhanden sind, an denen Klemmstücke ansetzen können. Die Kanten sind mit großen Radien versehen, um eine harmonische Optik zu erzielen. Gegenüber einem Profil mit Nuten ergeben sich mehrere Vorteile:

- Das geschlossene Profil hat optimale Torsionssteifigkeit bei geringem Gewicht.
- Es können sich keine Verschmutzungen ansammeln wie in Nuten.
- Die Klemmstücke müssen nicht am Ende eingefädelt werden, sondern können an jeder Stelle von außen angesetzt werden.
- Das Rohr kann gebogen werden.
- Das freie Volumen im Rohr ist größer und kann gut z.B. für Akkus genutzt werden.



Durch die Verwendung von einheitlichen Klemmstücken aus glasfaserverstärktem Polyamid können alle Baugruppen, wie Sitz, Schwinge, Federelement und Zubehör leicht angeklemmt und verschoben werden. Dadurch wird ein modularer Aufbau ermöglicht.

Die Einheit aus Steuerkopf und Tretlager ist ein Gußteil, das mit dem Rahmen verschraubt ist. Der Rahmenbau kommt somit ohne Schweißarbeiten aus. Lediglich die Schwinge aus Vierkantrohren wird geschweißt.

Der Sitz wird aus Aluprofilen und -blechen hergestellt. Die Eigenelastizität des Materials ergibt einen federnden Sitzkomfort. Alle Verbindungen am Sitz sind geschraubt oder genietet.

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Measurement and Simulation of the Vibrational Stress on Cyclists

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Abstract

The vibrational stress on cyclists riding on different bicycles and on different surfaces was measured. Most of the surfaces of West German cycle tracks impair the performace and sometimes even the health of the rider. Suspension systems, if properly designed, can significantly reduce vibrational stress.

The measurements also serve as an empirical data base for the evaluation of a mathematical model that calculates the vibrational stress on the rider dependent on the geometry, the construction and the components of the bicycle, and dependent on the specific road surface. The respective computer program is developed as a universal construction tool for bicycles with suspensions.

1 The Significance of Vibrational Stress on Cyclists

Vibrational stress on vehicle riders is not only a question of comfort. It can as well impair the riders capacity of perception and reaction, which is quite significant in road traffic, and in the worst case her or his health.

The minimization of vibrational stress plays an important role in automobile design and development. For bicycles the dicussion about vibrational stress and the development of suspension systems has begun only a few years ago, at first in order to improve the performance of MTBs. Suspensions on everyday bicycles are just beginning to establish themselves on the bicycle market.

2 Measurement of Vibrational Stress on Cyclists

2.1 Quantification of Vibrational Stress

In 1987 the bicycle research group started to develop a method of quantifying vibrational stress on bicycle riders and a respective measuring equipment in order to initiate a public discussion about cycle-track quality [1]. We use the same method for our current measurements. It is based on the international ISO standard 2631 and German VDI (Verein Deutscher Ingenieure = Society of German Engineers) standard 2057 [2, 3]. These standards are mainly used on tractors and other machines where the operational staff is exposed to vibrations.

According to the standards the acceleration is measured where the vibrations have an impact on the human body. The acceleration is then filtered according to the frequency response of vibrational sensitivity. The resulting effective value is called the K-value; it increases linear with the acceleration but differs with frequency. It is used to get exposure-time limits for health hazards or for impair of capability and/or comfort. The frequency response of (wo)man and the exposure-time limits are empirical results; the method is similar to the standardized measurement of loudness. The weighting functions are different dependent on the part of the body and on the direction of the vibrational impact. The hand-arm system is, independent of direction, most sensitive between 8 and 16 Hz. The maximum sensitivity for vibration in the direction of the spinal column of the body lies between 4 and 8 Hz. Both weighting functions for the hand-arm-system and the spinal column are shown in figure 1.

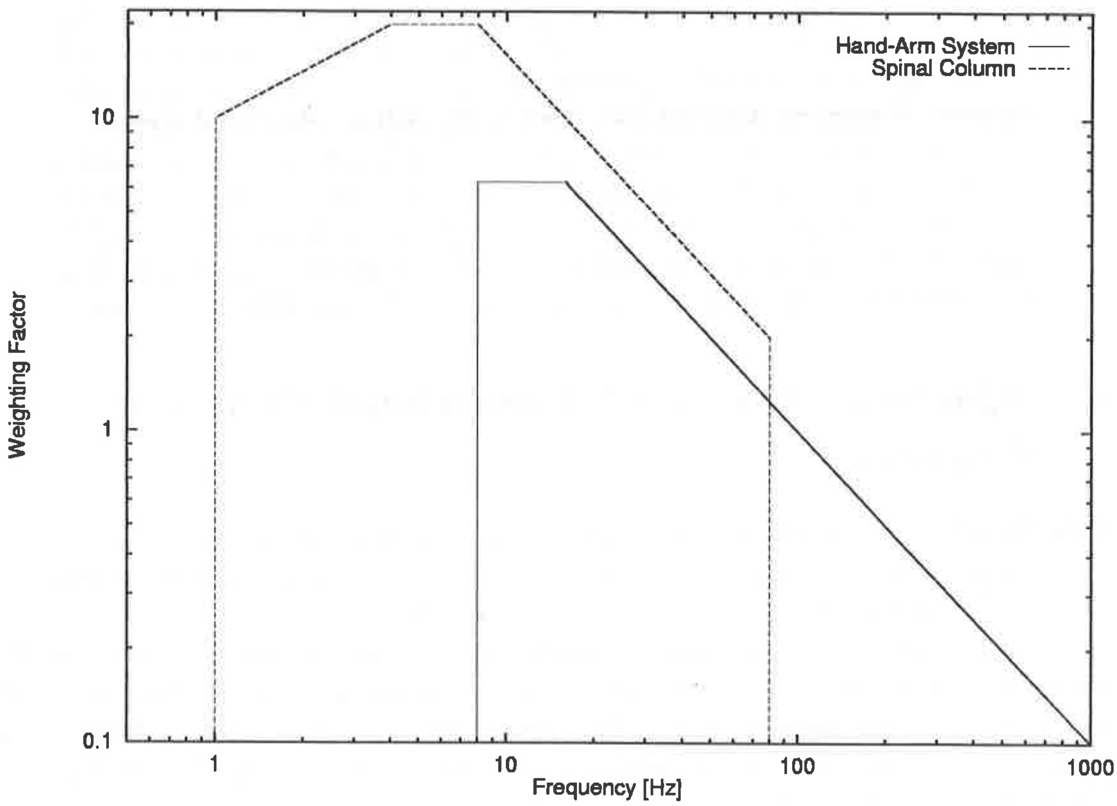

Figure 1: *Weighting Functions according to VDI 2057*

2.2 Measuring System

We measured the acceleration at the handlebar of the bicycle (in the direction of the forearm) and on top of the saddle (in the direction of the backbone). The signals of the sensors are amplified, digitized with 16 bit resolution and a sampling rate of 48 kHz, and stored on a digital tape recorder (DAT). It is possible to add spoken comments directly on the tape through a microphone. All components are put together into a rucksack and are carried by the rider during the measurement (see figure 2). This equipment allows recording times of several hours.

Figure 2: *Measuring Equipment "on the road"*

For evaluation the data are digitally read into a computer. The power spectra are calculated and weighted by the appropriate weighting functions (see figure 1) to get the K-values. A sketch of the measuring system is shown in figure 3.

2.3 Measurements

We carried out measurements on 18 different surfaces in Oldenburg. The selection contains aspahlt surfaces of very old and highway quality, different concrete stone, concrete slab, and brick stone pavements, some cobblestone pavements and also very old field stone pavements. They are examples for the most frequently used surfaces in everyday bicycle traffic.

Measurements were repeated with two riders (male, 98 kg, and female, 66 kg) on 7 different bicycles: a roadster bicycle, an unsuspended city-bicycle, two city-bike prototypes with simple suspension, a city-bike with an optimized suspension, and two recumbent bicycles, one with rear wheel suspension and one with full suspension.

The roadster bike is similar to the typical bicycles used in the Netherlands and is used most commonly in Oldenburg. The tire size and pressure are 37-622 mm at 300 kPa. The saddle has large springs and a soft foam cover.

The unsuspended city-bike (city 1) has tires sized 50-622 mm at 300 kPa and a "ladies"-frame with a large, single downtube, made from welded aluminum. This type of frame has become quite popular in the last years.

The prototype with simple suspension (city 2) is exactly the same bicycle as city 1, but with a hinge just in front of the bottom bracket and a spring-damper element (steel spring, hydraulic damper) mounted there, allowing front and rear part of the frame to move against each other.

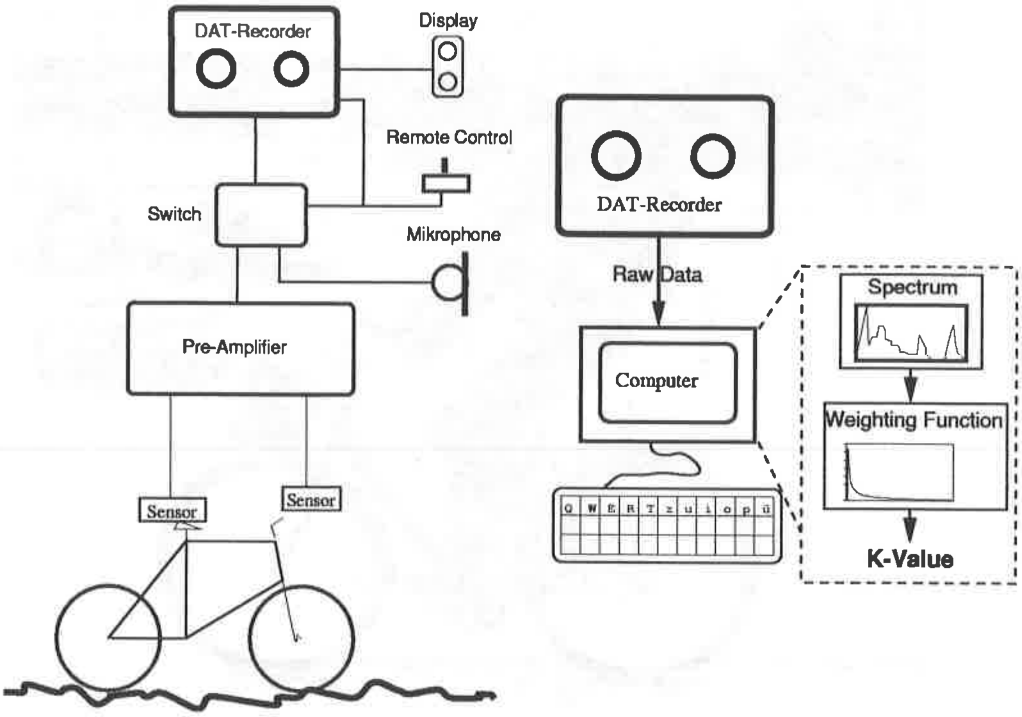

Figure 3: *Measuring Method*

The second prototype with simple suspension (city 3) has an MTB-like frame and tires sized 50-559 mm at 300 kPa. It is provided with a telescopic front fork and rear swingarm including the bottom bracket ("unified rear triangle") with an elastomer spring.

The city-bike with an advanced type of suspension is a "Radical" by Gerritsen & Meijers, Netherlands. It has 28-440 mm tires at 450 kPa, a leading link front suspension and a rear swingarm with identical elastomer springs and hydraulic dampers.

The recumbent bicycle with rear suspension (recumbent 1) has a "compact long wheelbase" configuration (the bottom bracket is above the front wheel and closely behind the steering tube) and above-seat steering. The tires are sized 32-406 mm at 500 kPa and the spring-damper element has a steel spring and a hydraulic damper.

The full-suspension recumbent (recumbent 2) has a "compact long wheelbase" too and under-seat steering. The tires are sized 44-406 mm at 400 kPa. The front suspension is a leading link with rubber spring elements, the rear swingarm has a large elastomer block spring with additional friction damping.

2.4 Results

Typical sets of data are shown in the appendix. The figures show the measured K-values of 12 out of the 18 road and cycle track surfaces. The rider was male and weighed 98 kg. The K-values of the female rider (66 kg) are generally a little higher.

The scale is logarithmic as is the human response. For each measurement the left column gives the intensity on the hand-arm-system, the right one that at the saddle.

For interpretation the exposure limits at different times of exposure per day are given as they are defined in the VDI standard. The labels at the lines mean:

G 1	at 1 min per day: health impaired
G 25	at 25 min per day: health impaired
G 60	at 60 min per day: health impaired
L 25	at 25 min per day: capacity of reaction impaired
L 60	at 60 min per day: capacity of reaction impaired
W 1	at 1 min per day: comfort impaired
W 25	at 25 min per day: comfort impaired
W 60	at 60 min per day: comfort impaired

If a column for a certain bicycle and a specific road surface exceeds the H 60 limit, then the health of the rider may be impaired if the total riding time of one day exceeds 60 minutes. If the exposure time is below 60 minutes per day, "only" the capacity of reaction is impaired.

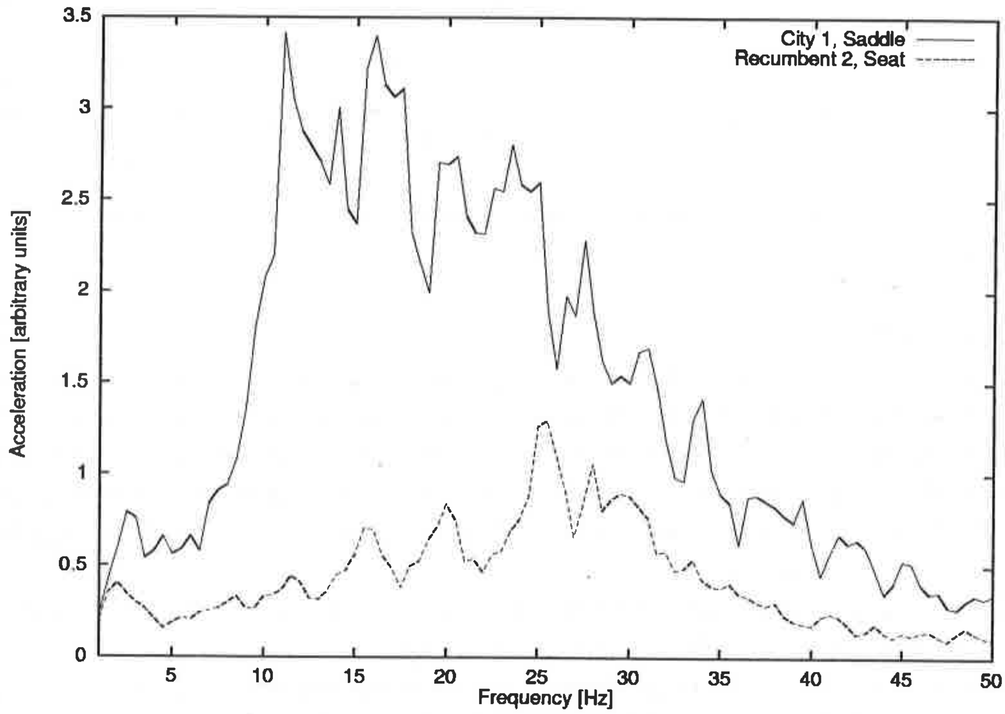

Figure 4: *Examples of Acceleration Spectra on Field Stone Pavement*

2.5 Interpretation

The K-values are generally lower compared to the measurements in 1987 [1], because this time we did not investigate any racing or touring bicycle with high tire pressure or extremely stiff frame. The actual measurements mainly serve as an empirical database for the evaluation of the mathematical model described below, which is meant as a tool to optimize bicycle suspensions for everyday use. For this reason only suspended bicycles were chosen for measurement and few city bikes without suspension as reference.

According to the standards, the measured vibrational stress on most roads and cycle tracks impairs the capacity of reaction of the rider, on rough surfaces even

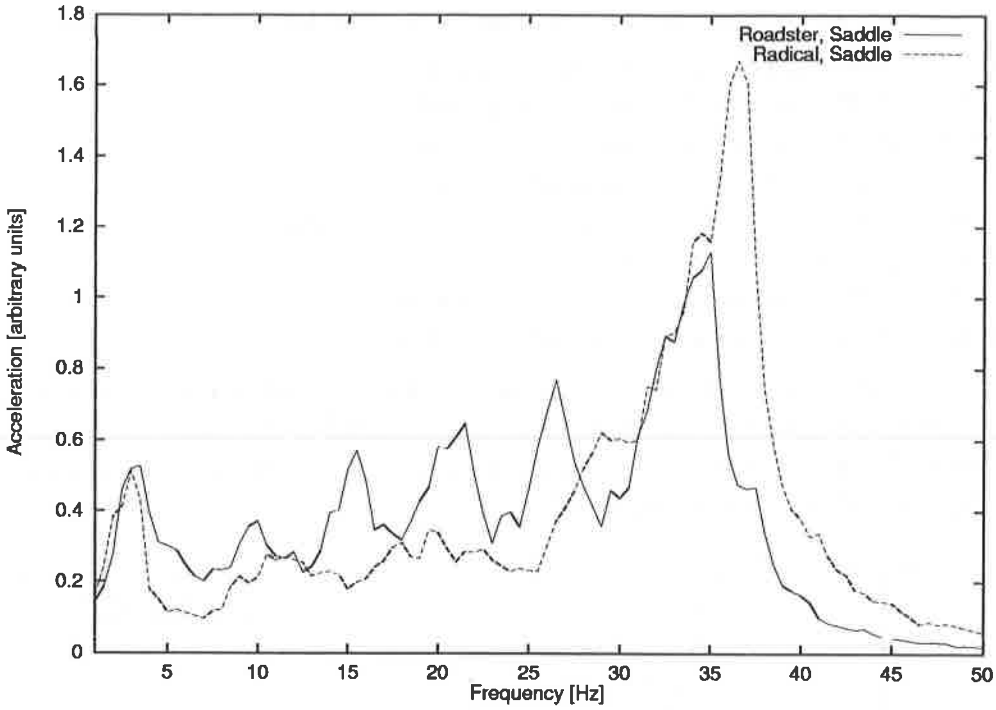

Figure 5: *Examples of Acceleration Spectra on Concrete Stone Pavement in a Figure-Y Pattern*

her/his health is impaired.

The data also show that bicycle suspensions can reduce the vibrational stress on the rider a great deal. The construction and the correct tuning according to the rider's weight play an important role for vibrational comfort. It can be seen that the simpler suspensions do not offer great advantages over unsuspended bicycles. The more advanced suspensions of the "Radical" and recumbent 2 can significantly reduce vibrational stress.

The examples of measured acceleration spectra in figures 4 and 5 show the vibrational behaviour in different frequency ranges.

The acceleration spectra in figure 4 show the significant reduction of the acceleration in a wide frequency range at the seat of recumbent 2 compared to the saddle of city 1. The data were measured on an old field stone pavement.

In figure 5 the acceleration at the saddle of the roadster is compared to that at the saddle of the "Radical". These data were measured on a concrete stone pavement in a figure-Y pattern. Both bicycles show a peak at the doubled pedalling frequency of about 2.7 Hz. At most frequencies the acceleration is lower on the "Radical", but between 35 and 40 Hz it shows a high peak which seems to be a wheel resonance (the rear wheel oscillates between the suspension spring and the tire "spring"). This effect of course is not present on the roadster bike without suspension. Obviously a specific wavelength of the pavement hit the wheel resonance frequency of the "Radical" and produced the resonance vibration.

3 Simulation of Vibrational Stress on Cyclists

We are developing a computer program as a construction tool for the optimization of the vibrational comfort of bicycles. With this tool the vibrational comfort of a planned bicycle can be predicted by simulation without the need of building a prototype, thus reducing the expense and costs of developing bicycle suspensions. Existing bicycle suspensions can also be optimized with a reduced number of trial-and-error-cycles.

This work is financially supported by Stiftung Industrie Forschung, Cologne (Foundation for Industrial Research).

3.1 The Mathematical Model for Bicycle Suspensions

The program is based upon a mathematical model of a suspended bicycle with rider. The bicycle-rider system is described as a mechanical system of rigid bodies linked together with rotational and linear joints, springs, and dampers (see figure 6). Geometrical nonlinearities are widely taken into account. The description of bicycle geometry is flexible enough to fit standard bicycles as well as a wide variety of recumbents. These characteristics enable the model to calculate the coordinates of the crucial parts of the system during everyday use as well as in extreme situations. Even the effects due to the forces in the power train are taken into consideration [4].

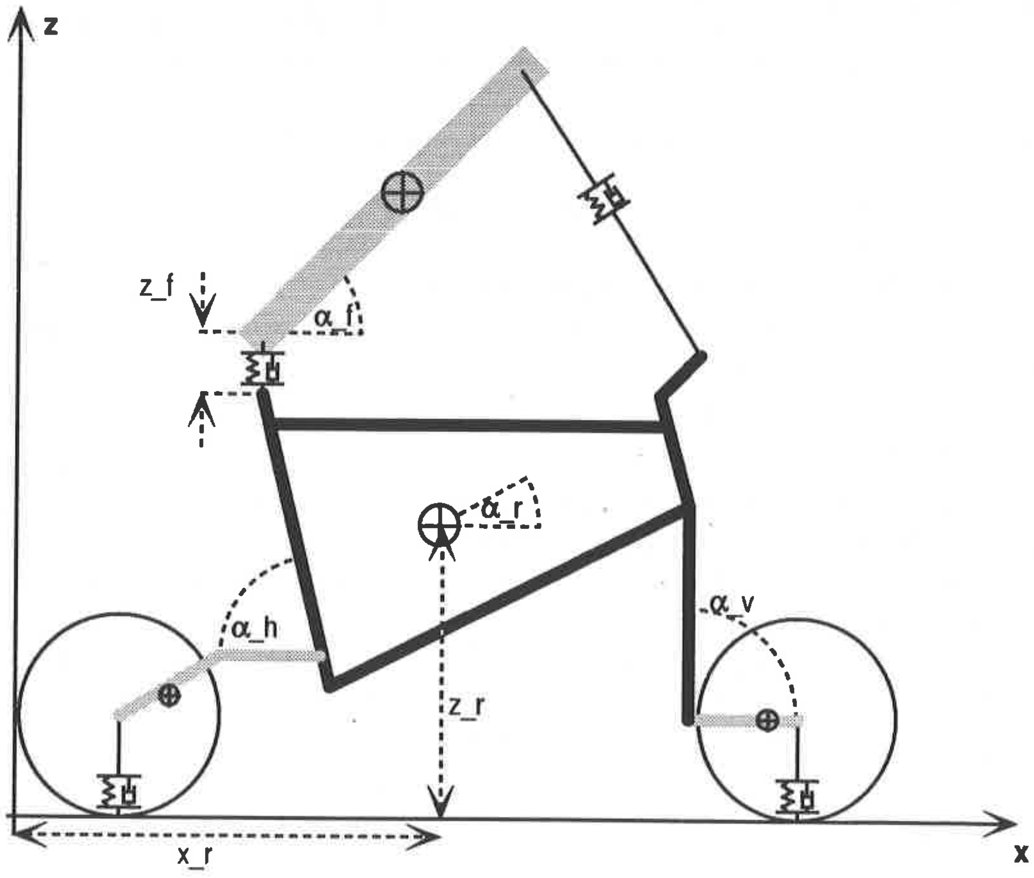

Figure 6: *Scheme of the Mathematical Model (⊕ = Center of Gravity)*

3.2 The Simulation Program

Given the equations of motion, the actual parameters of a bicycle and its rider and a logitudinal road profile, the program carries out a time series simulation of the movements occuring in the bicycle-rider system during movement. Figure 7 shows the structure of the program.

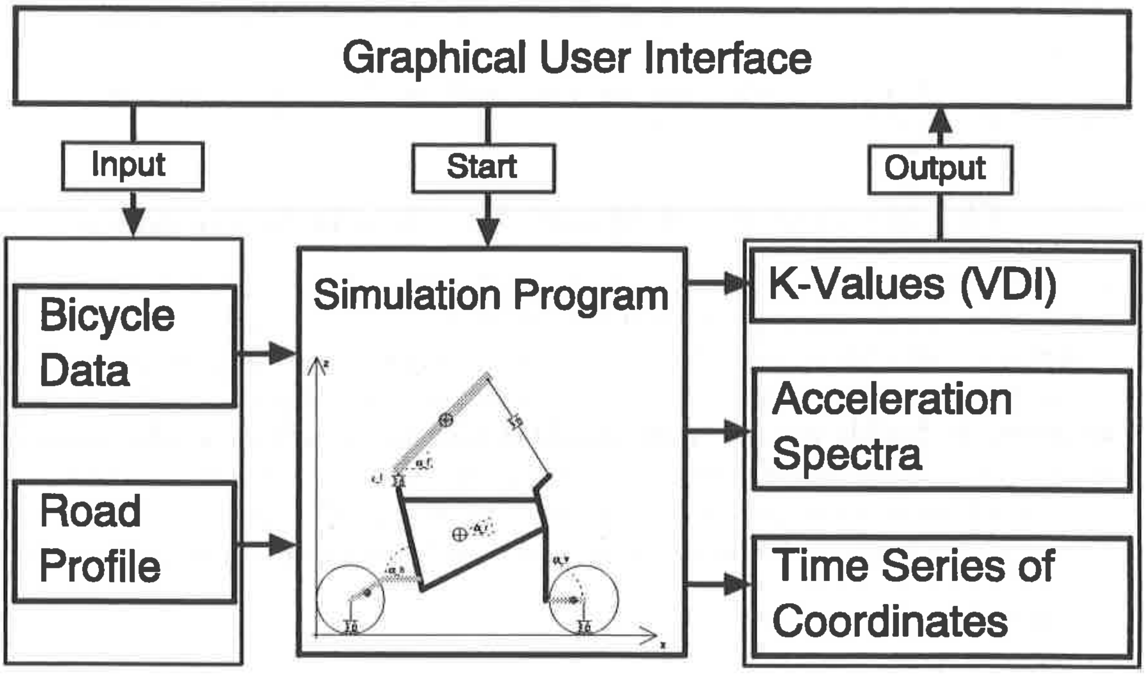

Figure 7: *Program Structure*

According to the actual standards (see above) the K-value as a measure for the vibrational stress is derived from the calculated accelerations at the saddle and the handlebars. Since all relevant coordinates of the bicycle-rider system are stored, the data allow for a lot of analysis of the simulated ride as ground contact, wheel load variation, and behaviour during braking.

3.2.1 Input Data

The following bicycle parameters are needed: geometry, masses, and moments of inertia of the bicycle parts; suspension parameters of the vibration damping elements (tires, saddle, springs, dampers). Especially the suspension parameters shall be given as libraries.

The road surface must also be specified by selecting one of the provided surface profile files that give a selection of the most common road and cycle-track surfaces. Additional surface profiles may also be defined or measured.

All input data can be put together into user-specific libraries.

3.2.2 Output Data

Output can be given in three different ways.

The K-values according to VDI 2057 allow for a comparison between the vibrational stress of different bicycles, suspension parameters, riders, and surfaces.

Frequency spectra of the acclerations are also available and can give insight in the vibrational behaviour in different frequency ranges. Figure 8 shows calculated acceleration spectra at the handlebar and the saddle for a bicycle with suspension and one without.

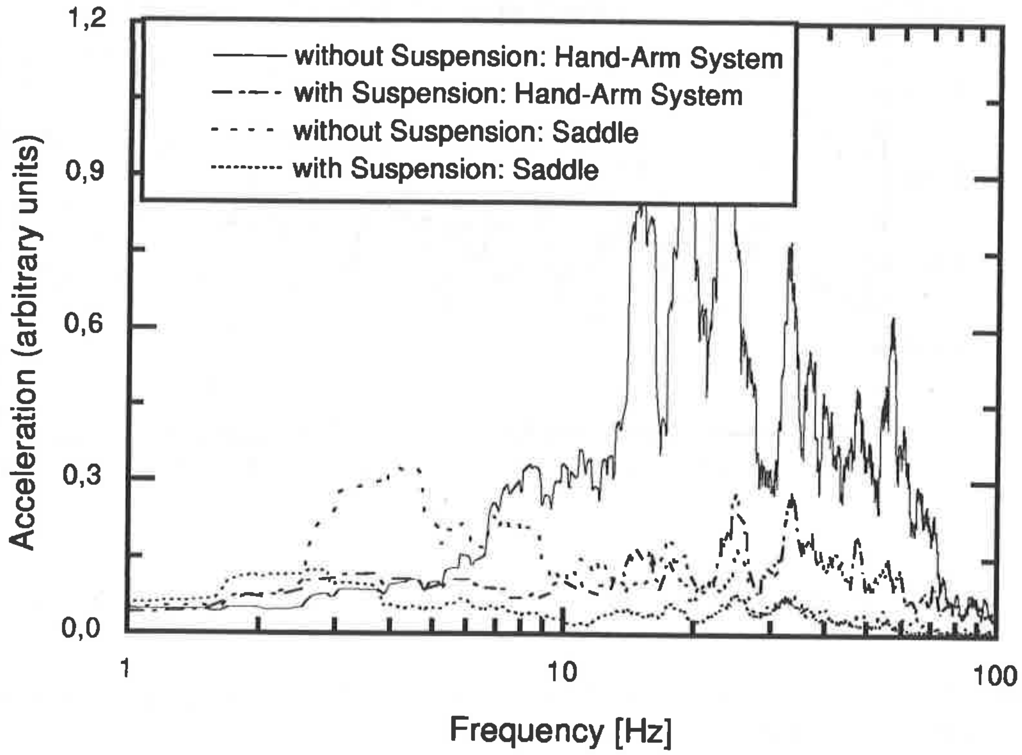

Figure 8: *Calculated Acceleration Spectra*

The complete time series of the coordinates can be plotted and interpreted, too. This allows for the evaluation of single events, e.g. potholes. Time series of some coordinates are shown in figure 9, calculated for the same bicycles as in the previous figure.

3.3 The graphical User Interface

A continuously graphical user interface ensures simple operation and control of the program and simulation process (see also figure 7). All input data can be given by input or file select dialogues, output data are presented in variable forms.

References

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[2] ISO 2631. Guide for The Evaluation of Human Exposure to Whole-Body Vibration; 1985

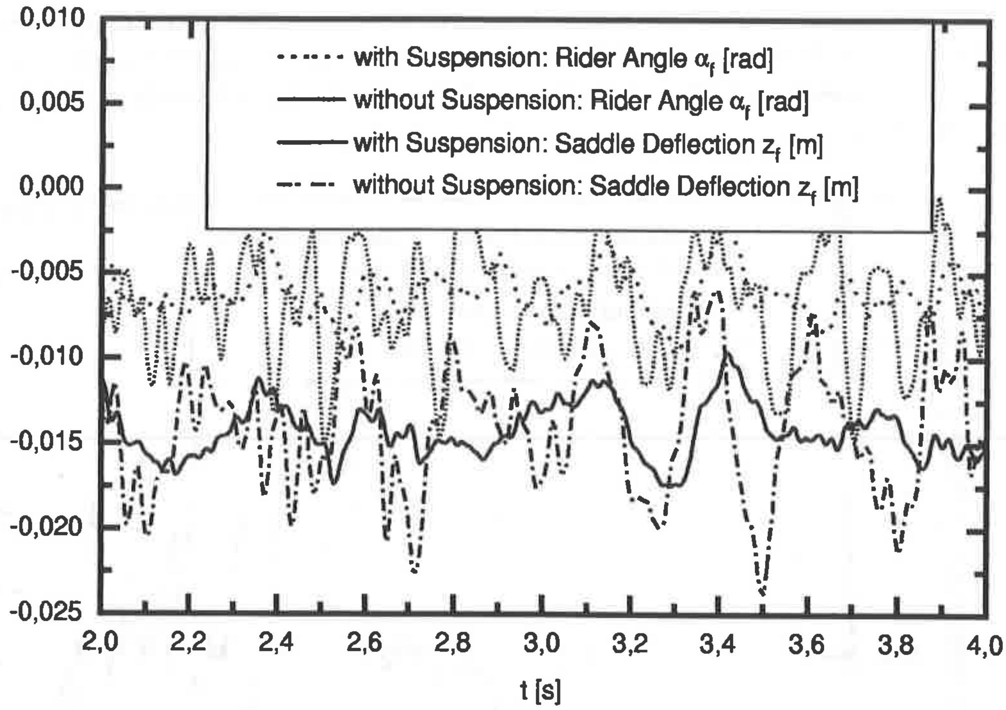


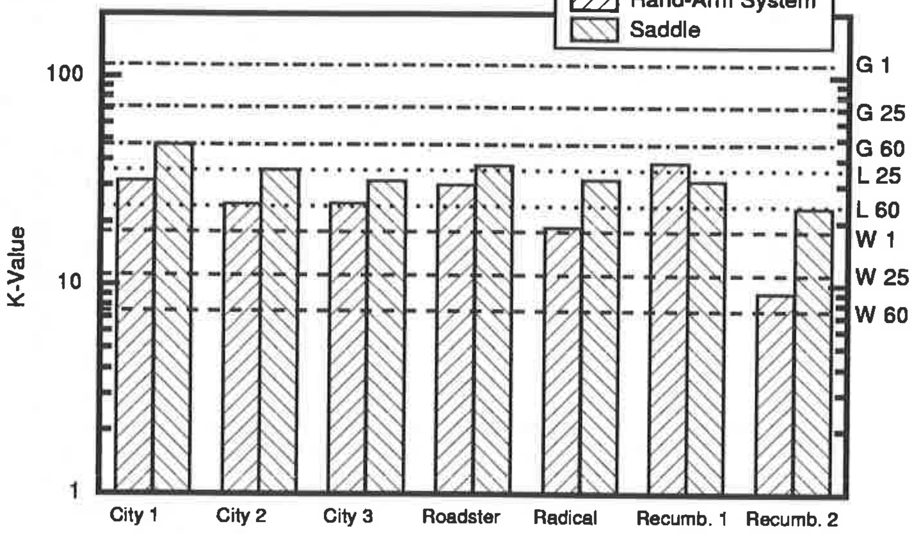
Figure 9: *Time Series of Selected Coordinates (Counted from the Initial Position)*

[3] VDI-Richtlinie 2057. Einwirkungen mechanischer Schwingungen auf den Menschen; VDI-Verlag, Düsseldorf, 1987

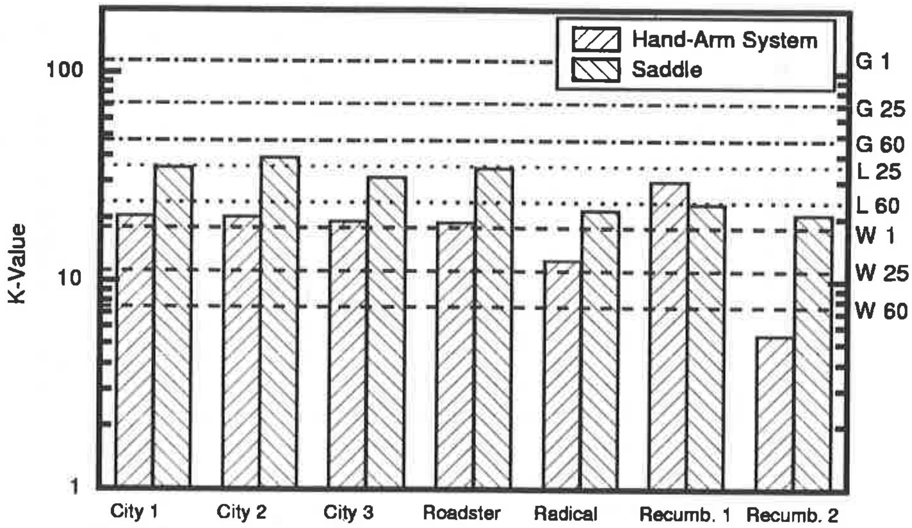
[4] Wächter, M.: Modellierung der Bewegungsgrössen bei Fahrrädern mit gefederten Laufrädern; Diploma Thesis, Oldenburg 1994

Appendix: Vibrational Stress Measurements

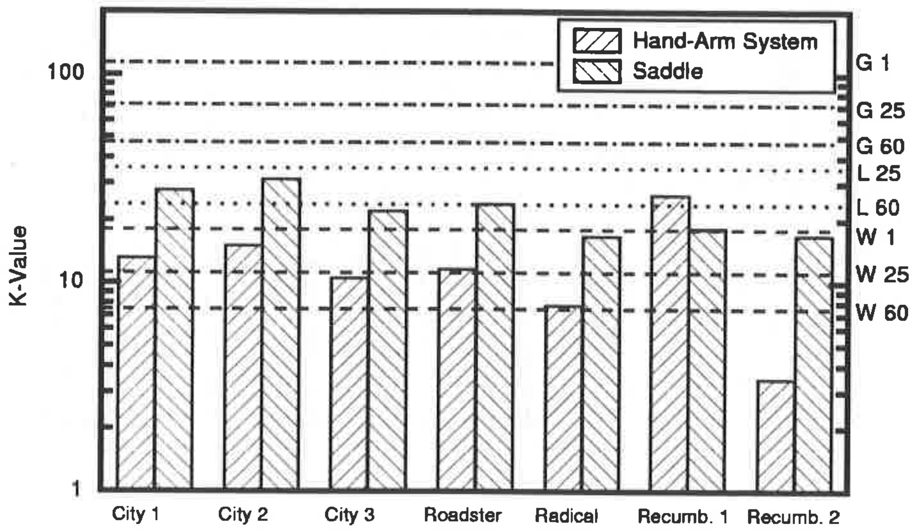
Concrete Stones, Figure-Y Pattern



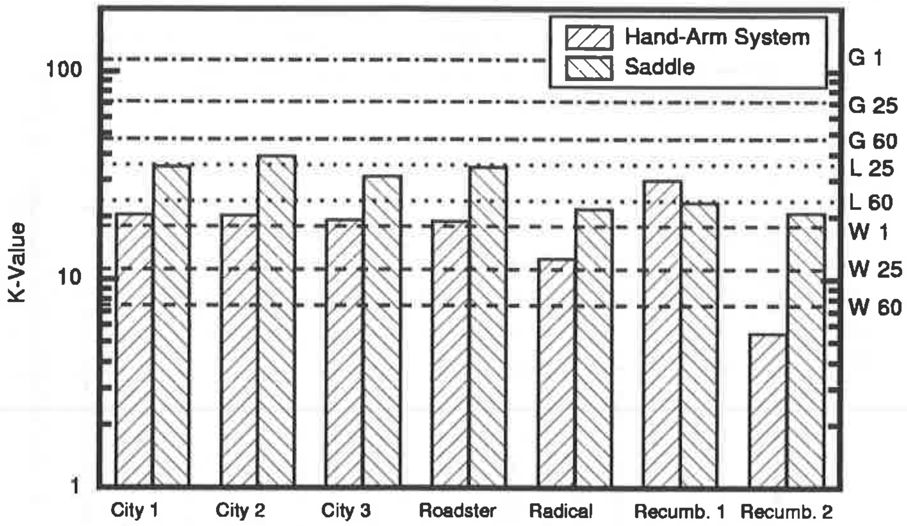
Concrete Stones



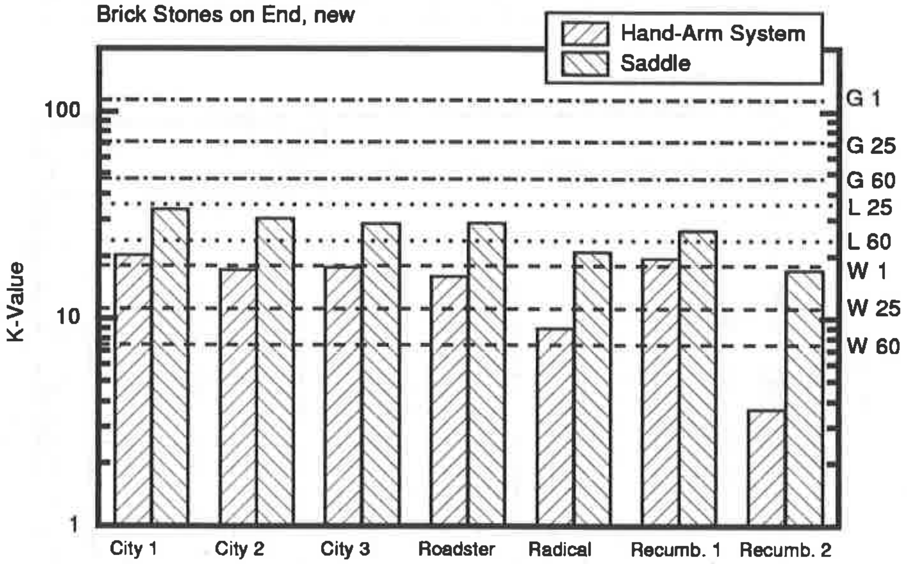
Concrete Stones, logintudinal Pavement



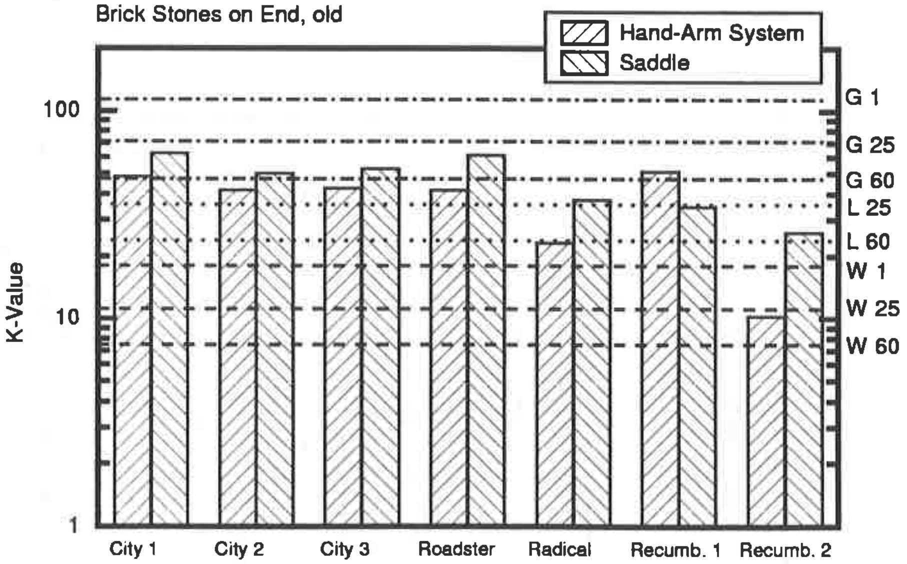
Brick Stones

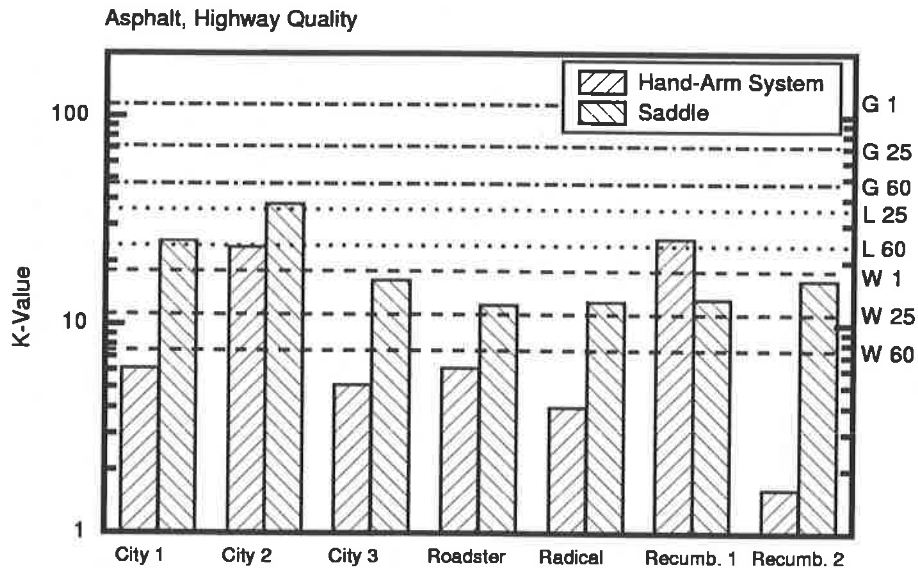


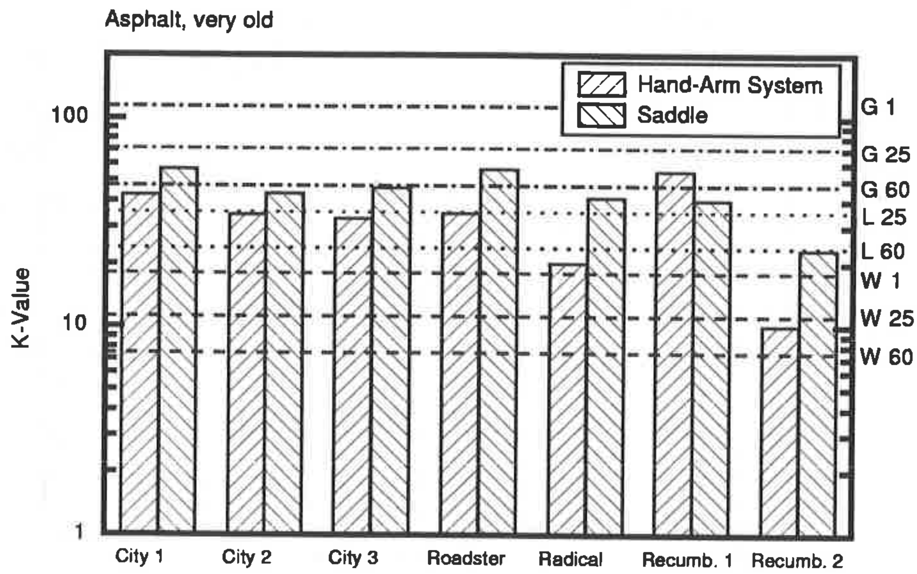
Brick Stones on End, new

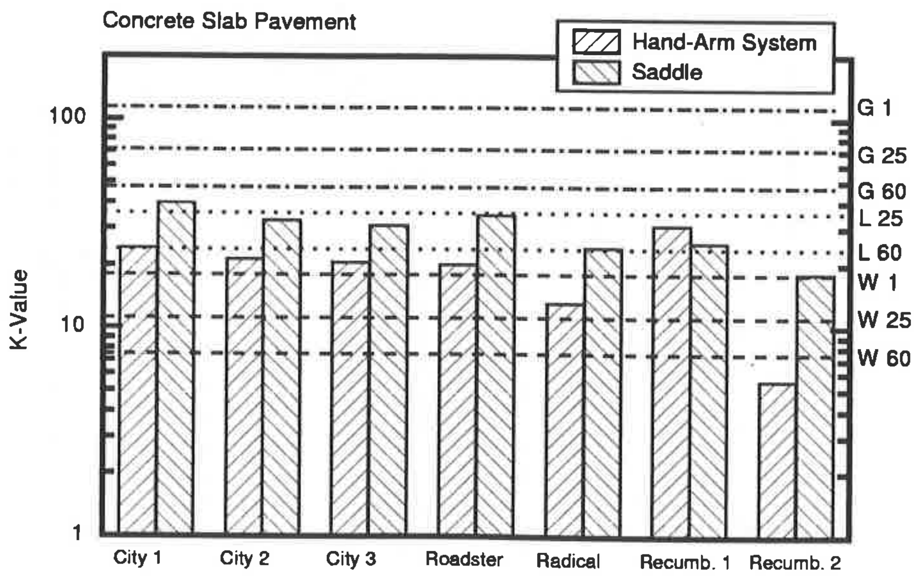


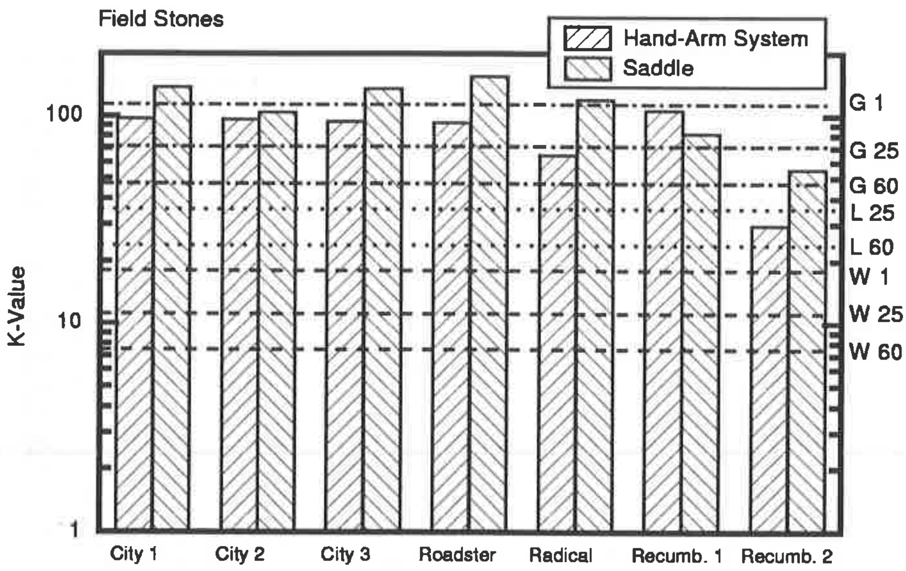
Brick Stones on End, old

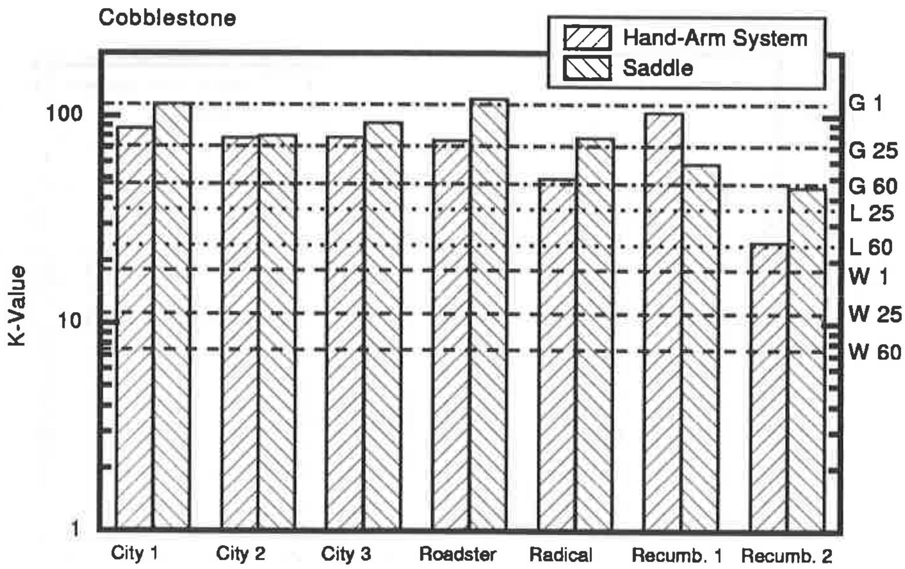


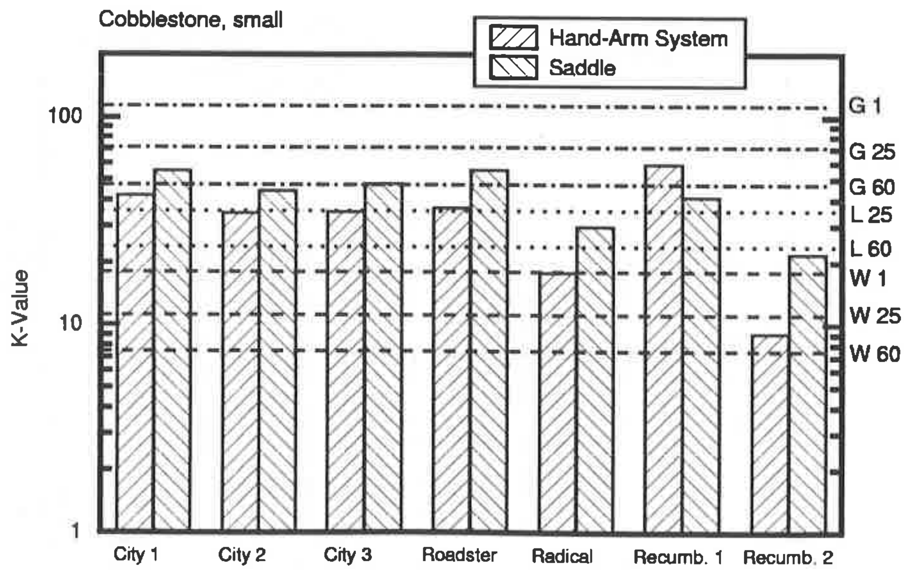

Asphalt, Highway Quality
Hand-Arm System
Saddle
K-Value
100
10
1
G 1
G 25
G 60
L 25
L 60
W 1
W 25
W 60
City 1
City 2
City 3
Roadster
Radical
Recumb. 1
Recumb. 2


Asphalt, very old
Hand-Arm System
Saddle
K-Value
100
10
1
G 1
G 25
G 60
L 25
L 60
W 1
W 25
W 60
City 1
City 2
City 3
Roadster
Radical
Recumb. 1
Recumb. 2


Concrete Slab Pavement
Hand-Arm System
Saddle
K-Value
100
10
1
G 1
G 25
G 60
L 25
L 60
W 1
W 25
W 60
City 1
City 2
City 3
Roadster
Radical
Recumb. 1
Recumb. 2


Field Stones
Hand-Arm System
Saddle
K-Value
100
10
1
G 1
G 25
G 60
L 25
L 60
W 1
W 25
W 60
City 1
City 2
City 3
Roadster
Radical
Recumb. 1
Recumb. 2


Cobblestone
Hand-Arm System
Saddle
K-Value
100
10
1
G 1
G 25
G 60
L 25
L 60
W 1
W 25
W 60
City 1
City 2
City 3
Roadster
Radical
Recumb. 1
Recumb. 2


Cobblestone, small
Hand-Arm System
Saddle
K-Value
100
10
1
G 1
G 25
G 60
L 25
L 60
W 1
W 25
W 60
City 1
City 2
City 3
Roadster
Radical
Recumb. 1
Recumb. 2

The Bicycle Research Group

Since 1982, a small research group in the faculty of physics has been working on the scientific and technological basics of the bicycle, or more precisely: of energy saving, in general human powered light weight vehicles.

The group is part of the department for energy and semiconductor research that deals - among other work - with the production and use of solar, wind and hydrogen power.

In the years since 1982, a wide range of bicycle related subjects were under investigation:

Mechanical energy consumption of transportation by human power is measured by various methods. The most important factors air drag and rolling resistance are measured directly by the coasting method. The overall energy consumption of human transportation can be simulated with a computer program; it also can be measured and stored with the help of a data logger during the ride.

Vibrational properties of bicyle tires are measured by a vibration testing equipment.

A prototype of a practical HPV for commuting has been developed for the use in future inner-city traffic with low speed limit. The group developed a bicycle trailer for do-it-yourself production and some improvements of the use of bicycles in the Third World.

Models and simulation of bicycle dynamics have been developed and used to examine the inherent stability of different bicycle types.

The group has published a commented bibliography of mostly German monographs about bicycles and bicycling. Beyond there is a data base of about 1600 articles about scientific and technical problems concerning bicycles and HPVs.

Measurements of vibrational stress on bicyle riders have been done since 1987. A newer method and results are presented at this seminar.

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Fiber Composites as Shock Absorbers

BY CARL GEORG RASMUSSEN

Abstract

Since the introduction of composite leaf springs as suspension elements for the front wheels of the LEITRA velomobile in 1983, the development has let to other configurations of composite springs for shock absorbers.

They are particularly attractive where low weight, long service life and no maintenance are important design parameters.

This paper presents the theory for the calculation of fiber composite springs and defines the limitations of the use of different types of springs. The analysis includes springs with unidirectional fiber structure as well as springs made of laminated glass/carbon fabric.

Comparisons of different leaf springs are based on laboratory experiments as well as practical tests, where the springs have been in service in a period of 5 - 10 years.

Introduction

Suspension for bicycles is no longer a luxory. During the last 10-15 years it has become more and more common on quality bikes. It is a simple consequence of higher demand for better comfort and safety.

At the same time people want to reduce the rolling resistance as much as possible, which means higher tire pressure and less elasticity of the wheels.

With the renaissance of the velomobile the need for shock absorbers of various kinds became even more obvious. It is necessary in order to reduce noise and vibrations and to obtain better road-holding qualities.

A good suspension also reduces peak loads on wheels and frame and, thereby extends the life time of essential structures.

Many different concepts are in use for bicycle suspension, e.g. elastomers, gascylinders, coil-springs with damping elements, leaf springs and even elastic spokes in the wheels.

The elastomers have a highly progressive characteristic, i.e. they become progressively harder under increasing load, while the leaf spring systems keep their elasticity rather constant over a wider range, but have a limited load carrying capacity.

Fiber-composite leaf springs are particularly attractive, when low weight, no need for maintenance and long service life in a tough environment are primary design parameters.

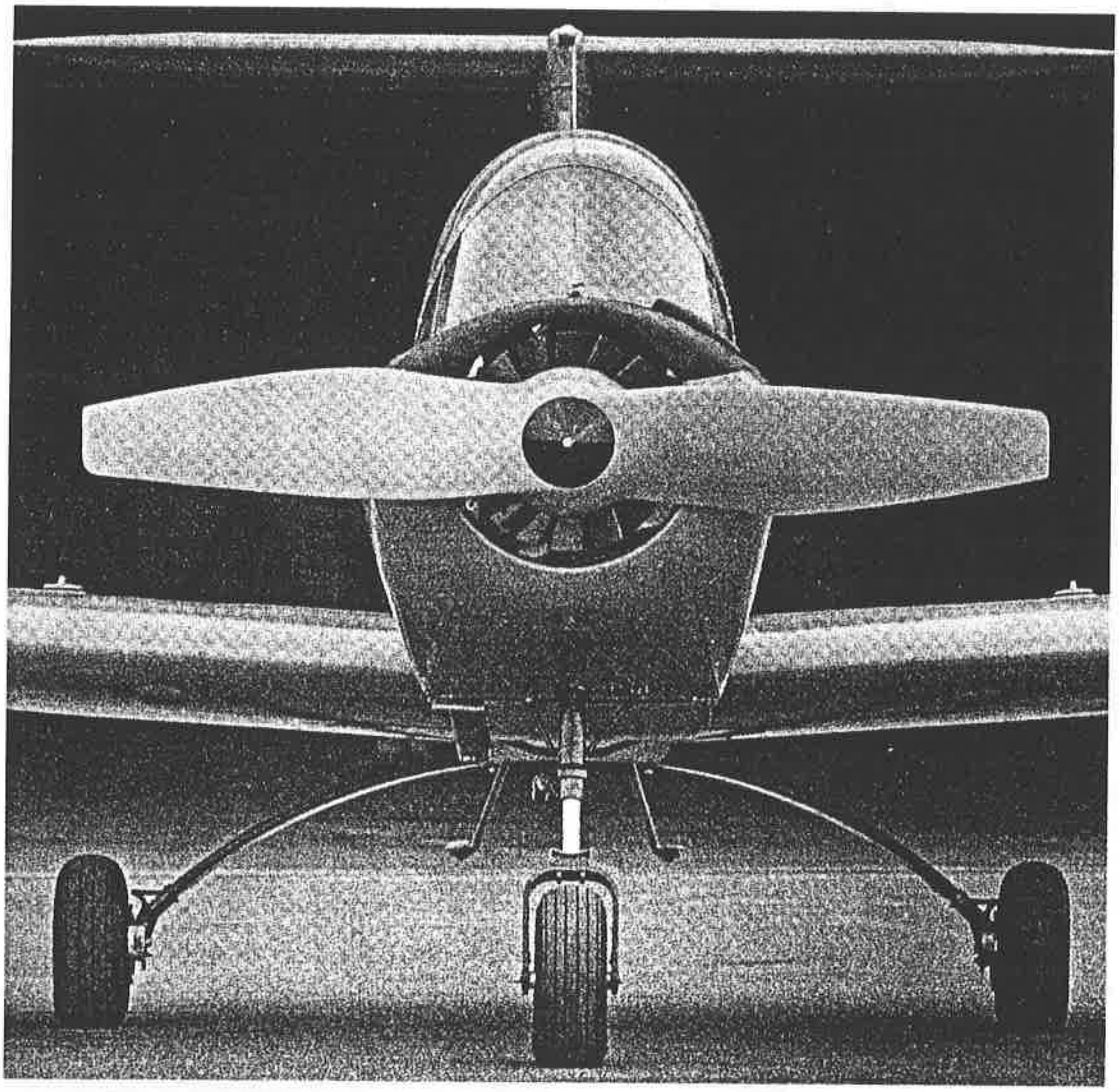

Fig. 1 The Polyt V landing gear made of glass fiber/epoxy

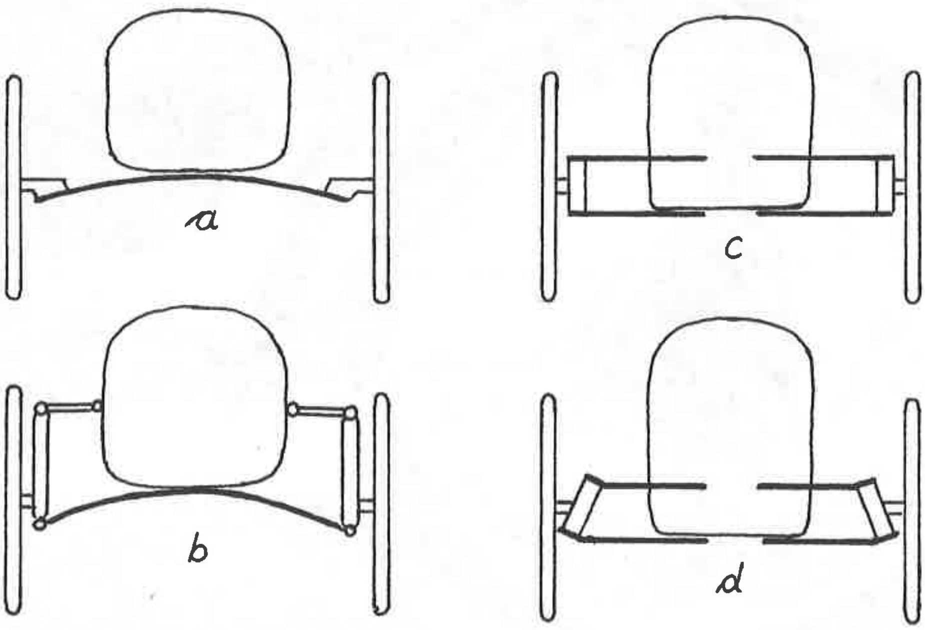

Fig. 2 Possible leaf spring suspensions for front wheels

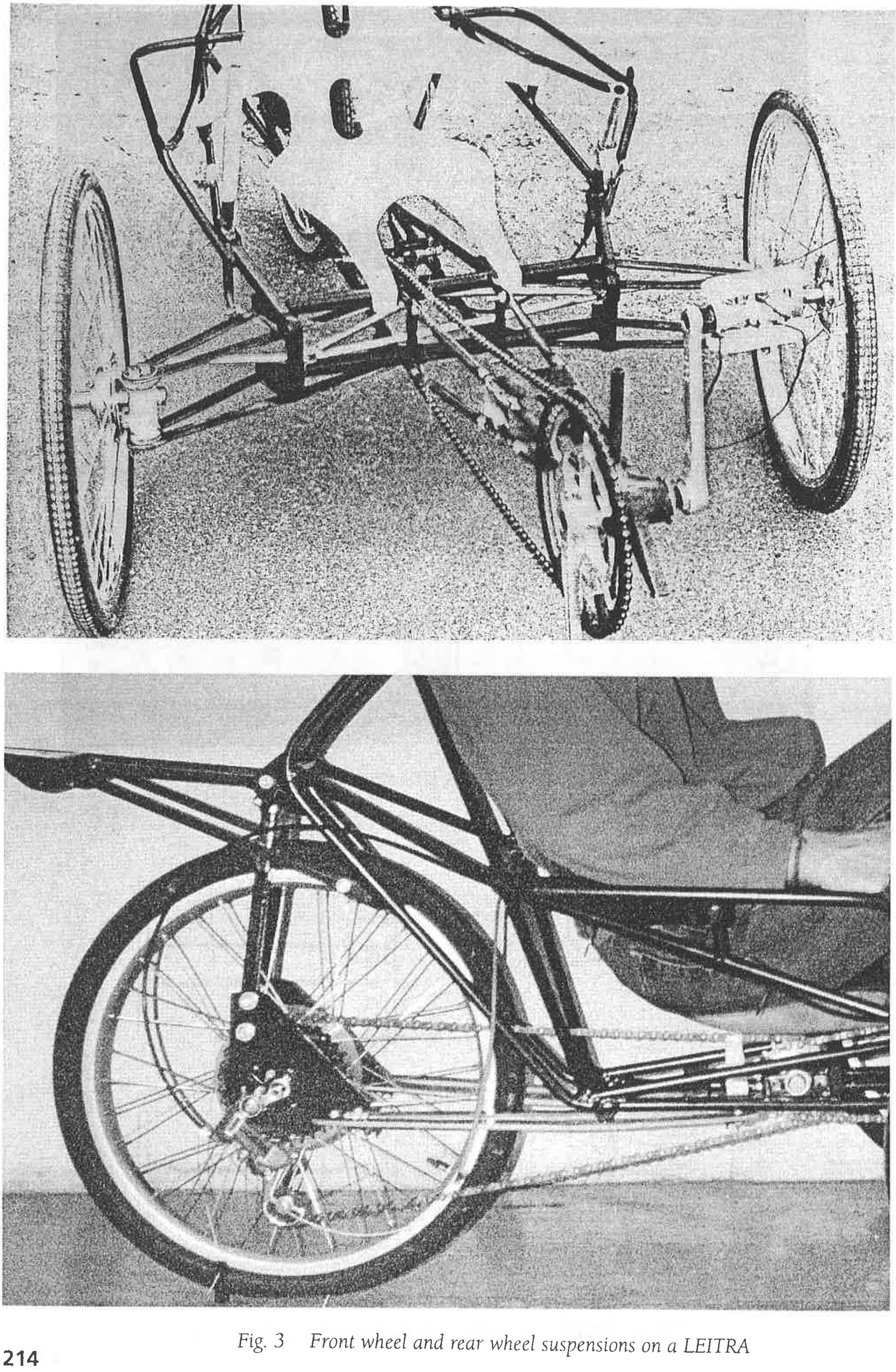

Fig. 3 Front wheel and rear wheel suspensions on a LEITRA

Spring configuration

When the front wheels of a velomobile has a gauge larger than the body or fairing, the suspension is visible. It means that it becomes subject to styling considerations.

You may draw a parallel to the landing gear of small aircrafts, which often gives the aircraft a characteristic look.

The Cessna company made a break through in good design of landing gears, when it introduced the nice and clean single leaf spring suspension.

The author designed a similar landing gear for a light aircraft, which is used for start of gliders. Therefore, it makes many take offs and landings.

Instead of steel we used glass fiber/epoxy, and the spring was made by winding a ring, which was then cut into three pieces.

The material has a suitable internal damping, the landing gear needs no maintenance and it has now been in service for many years.

Can the same solution be used for a velomobile ? Perhaps, but with the dimensions of a spring suitable for a velomobile the torque from braking will cause a considerable twisting of the spring.

Another possibility is to build in a torsional rigidity by using swing arms connected to the velomobile frame. This configuration was common on velomobiles in the thirties and forties. It costs additional weight and doesn't look particularly elegant, but it permits the same large displacement.

The author chose a cantilever configuration with four leaf springs attached to the frame. As we will see in the next section this limits the possible displacement to approximately 2 cm. It is enough to give some reduction of shocks and vibrations and doesn't cause a notable banking when cornering. This configuration has a very low weight, and it makes it easy to remove a front wheel with suspension as one unit. For front wheels with very strong brakes the configuration is modified as shown in Fig. 2 (d) in order to eliminate the effect on the steering from unbalanced braking. It is a little more expensive because it requires four different leaf springs instead of four egual.

The suspension for the rear wheel should meet the following specifications:

- absolutely stiff in the direction of the chain in order to avoid interference between suspension and chain tension.
- stiff against side forces on the rear wheel.
- softer than the front wheel suspension.
- can take a higher load than the front wheels.

For this purpose a configuration as shown in Fig. 3 was chosen.

The load is carried by two identical leaf springs, one on each side of the wheel. They also take up the side forces together with two small leaf springs on top of the wheel, which keep the fork in a vertical position.

Because the leaf springs are almost parallel to the chain over the full range of displacement there is no influence from the chain tension.

Calculation of leaf springs with unidirectional fiber structure

The suspension is subject to millions of small shocks and vibrations and we want it to have a long fatigue life. Let us, therefore, calculate the limits for displacement and load, which ensure a long life.

The leaf spring can be considered as a cantilever, fixed in one end and loaded by two concentrated forces P and R. K is the wheel load, and P and R are the forces acting on the cantilever by the frame.

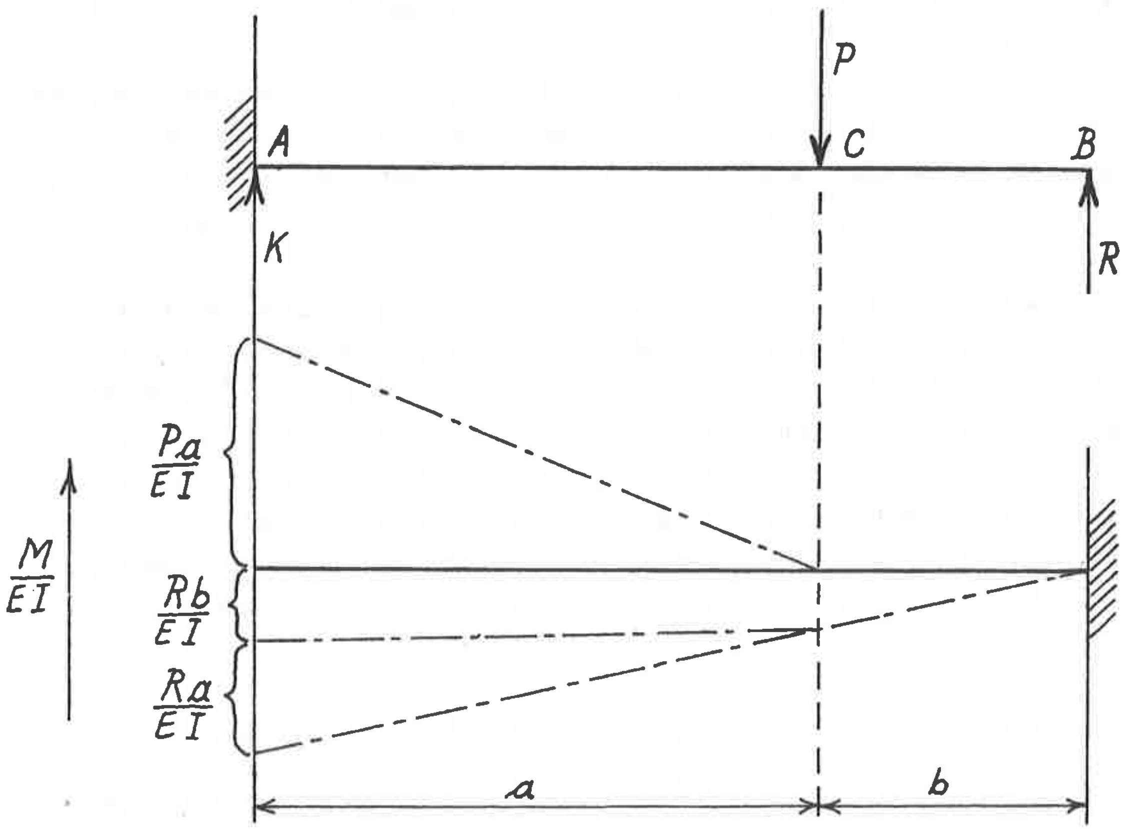

Fig. 4 A leaf spring simulated by a cantilever beam, and its conjugated beam.

The displacement in point C due to the force P is

$$u_C^P = \frac{1}{3}\frac{P.a^3}{EI}$$

and in the same way we get $$u_C^R = -\frac{R}{EI}\left(\frac{b.a^2}{2} + \frac{a^3}{3}\right)$$

$$u_B^P = \frac{P.a^2}{2EI}\left(\frac{2}{3}.a + b\right)$$

$$u_B^R = -\frac{R}{3EI}(a+b)^3$$

With the condition $$u_C^P + u_C^R = u_B^P + u_B^R$$

we get $$R = P\frac{a^2 b}{\frac{2}{3}(a+b)^3 - b.a^2 - \frac{2}{3}.a^3}$$

and $$K = P - R$$

We can now calculate the displacement in point C as a function of the wheel load K

$$u_C = \frac{K.a^3}{EI}\,\frac{4(a+b)^3 - 12a^2b - 4a^3 - 9b^2.a}{12(a+b)^3 - 36a^2b - 12.a^3}$$

If we put a = 2b and insert a+b=l we obtain

$$u_C = \frac{20}{567}\,\frac{Kl^3}{EI}$$

For a beam with rectangular cross section, width w and thickness t, we have the moment of inertia

$$I = \frac{1}{12}wt^3$$

and we get

$$\mu_C = \frac{240\, l^3\, K}{567\, E\, w\, t^3}$$

We have now found the stiffness of the leaf spring as a function of its dimensions and E-module.

The next problem is to find the limits for the load in order to make sure that fatigue will not occur in normal service.

Fatigue of composite materials has been described in the literature [1].

For epoxy the fatigue strain limit can be taken as 0.6 %.

For unidirectional composites, carbon-epoxy, the fatigue-life diagrams of several authors suggest a maximum strain of 0.5 %.

The strain is given by

$$\varepsilon = \frac{t M}{2 E I} = \frac{6 M}{E w t^2}$$

The bending moment M in the maximum stress points A and C is given by

$$M_A = \frac{8}{21} K l$$

$$M_C = \frac{6}{21} K l$$

The strain in point A, which is the point with maximum strain, is

$$\varepsilon_A = \frac{48\, K l}{21\, E w t^2}$$

With $\varepsilon_A = \varepsilon_{max} = 0.005$ we find the maximum load

$$K_{max} = 22 \cdot 10^{-4} \frac{E w t^2}{l}$$

and the maximum displacement

$$u_{max} = 93 \cdot 10^{-5} \frac{l^2}{t}$$

For a front wheel spring with l = 30 cm, w = 3 cm and T = 0.45 cm we get

$$u_{max} = 1.86 \text{ cm}$$

For glass and carbon fiber/epoxy (50%/50%) with unidirectional fiber structure we have

glass: $E = 4 \cdot 10^6$ N/cm^2 and $K_{max} = 177$ N

carbon $E = 12 \cdot 10^6$ N/cm^2 and $K_{max} = 530$ N

The suspension consists of two springs. Therefore, the maximum permitted loads on each wheel are 354 N and 1060 N, respectively.

From this we see, that a 100% glass fiber spring with the given dimensions will not be strong enough for long fatigue life, because the load 350 N may be reached at static load with maximum payload of 100 kg.

The spring constant for a full front wheel suspension, carbon fiber, one side, is then

$$\frac{1060 \text{ N}}{1.86 \text{ cm}} = 570 \text{ N/cm}$$

The rear wheel suspension has the spring dimensions: l = 40 cm, w = 4.6 cm and t = 0.45 cm, which gives

$$u_{max} = 3{,}3 \text{ cm}$$

and for glass $K_{max} = 205$ N

and carbon $K_{max} = 615$ N

A full rear wheel suspension (two springs) will carry the double load.

The spring constant of a full rear suspension, carbon fiber, is then

$$\frac{1230 \text{ N}}{3.3 \text{ cm}} = 373 \text{ N/cm}$$

Measurements of suspension characteristics

The simplest and most direct way to check the characteristic of a front wheel suspension is to vary the load on the front wheel and measure the displacement of the wheel relative to the frame. The characteristic will then be an average of the two leaf springs, and it also includes the effect of the mounting.

A batch of suspensions consisting of two leaf springs with unidirectional carbon fiber structure was measured. The characteristic is linear within the range of operation, and the spring constant varies from set to set between 430 and 550 N/cm, mainly due to small variations of the thickness.

The accuracy of measurement is not high enough to show a deviation of the actual E-module from the value used in the theoretical analysis.
The actual spring thickness may vary as much as 5 %, which results in a 15 % variation of the spring constant. It is also difficult to measure the effective length of the spring with an uncertainty less than 2-3 %.

One of the suspensions had been in use for 8 years and about 100.000 km, while others were relatively new. There was no significant difference in the characteristic of new and old carbon springs, which means that they have a very long life, provided they do not get overloaded.

The springs have been exposed to a tough environment, with water, ice, salt and sand and low temperatures during the winter seasons, without any sign of decomposition.

If a fiber composite spring is overloaded over a period of time, local breaking of fibers can result in cracks, which will grow until they finally result in a fatigue fracture. Glass fiber springs are more tough than carbon springs. Previous measurements on glass fiber suspensions showed,that the degradation can take place over an extended period. In spite of micro-cracks the leaf springs can still carry a load, but they lose in stiffness.

Cracks in carbon fiber springs grow faster and end with a sudden fracture.

Measurements on rear wheel suspensions show a slightly progressive characteristic. The springs were a mixture of 25 % glass fiber and 75 % carbon fiber. The non-linearity is caused by the special suspension configuration, where the leaf springs get an extra bend due to the motion of the rear wheel fork.

In order to increase the stiffness of the front wheel suspension in the horizontal direction and minimize the torsion due to a very high braking torque, e.g. when using hydraulic down-hill disc brakes, a different type of springs has been taken into use.
It is laminated, using glass fiber fabric for the outer plies and carbon fiber fabric in the central plane. The fibers are laid up in four directions in steps of 45 degrees, which gives a very stiff plate in the plane of the spring.

Perpendicular to the plate the stiffness can be controlled by the number of plies/thickness of the laminate. Experiments show, that a laminated leaf spring must be thicker and wider in order to obtain the same spring constant as for the springs with unidirectional fiber structure. The weight of a laminated spring is, therefore, almost double as high as the unidirectional, 180 g against 90-95 g.

The internal damping of carbon fiber composites is relatively low. Therefore, the

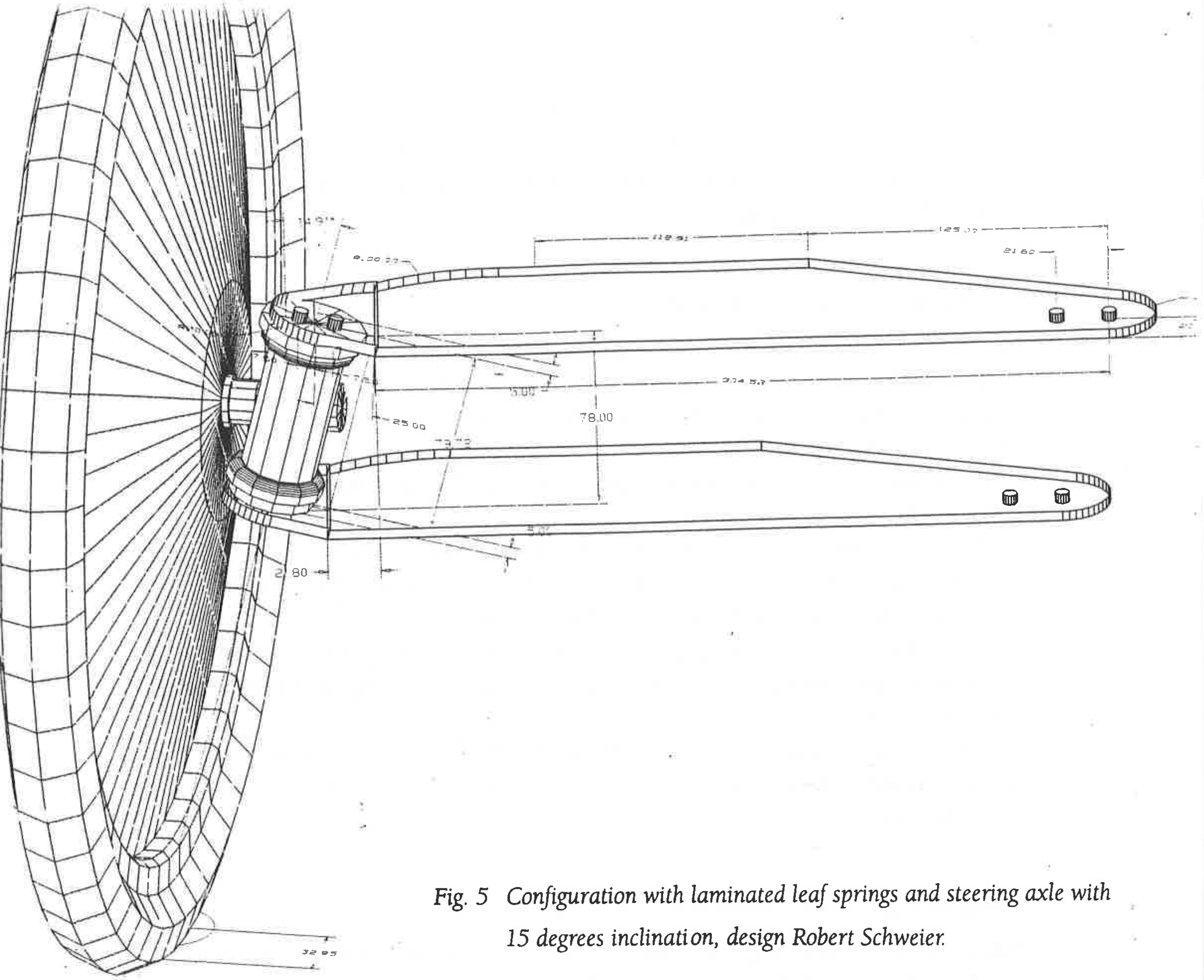

Fig. 5 Configuration with laminated leaf springs and steering axle with 15 degrees inclination, design Robert Schweier.

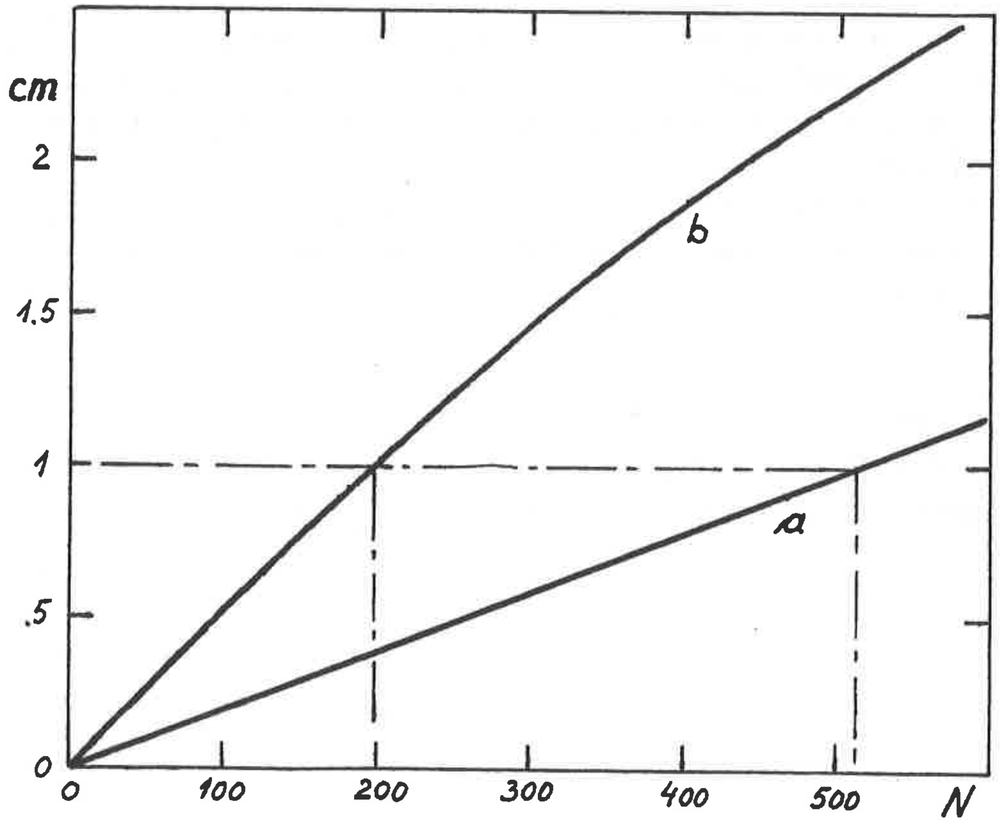

Fig. 6 Measured suspension characteristics. (a) Front wheel suspension, and (b) rear wheel suspension with two leaf springs, unidirectional fiber structure.

resonance frequencies should be outside the range of frequencies with high power input, e.g. the pedaling cadence.

Load and manoeuvring limitations

The front wheel suspension is more exposed to high peak loads than the rear wheel suspension, e.g. when running against an obstacle, in a situation of catastrophe breaking, in overturns and the like. Since the suspension is stiff in the horizontal plane it can not take up a major impact.

In a collision situation the leaf springs may break, while the frame normally will survive without damage.

The front wheel suspension on a LEITRA is designed for a payload of 100 kg, if not otherwise specified. In extreme manoeuvring situations, the load on a front wheel suspension may exceed the maximum load for long fatigue life.

This is the case if the total weight of a fully loaded velomobile lies on one wheel, e.g. when braking hard in a steep turn. One should, therefore, inspect the leaf springs for damages after such manoeuvres.

The rear wheel suspension may be exposed to high side forces,but it has never caused damage to the leaf springs, whereas the wheel itself may buckle or loosen/break a couple of spokes.

Conclusion

Fiber composite leaf springs with unidirectional fiber structure have been in use as shock absorbers on LEITRA velomobiles the last 15 years.

They can stand the tough conditions of a Scandinavian winter: snow, ice, water, salt and sand in combination with low temperatures, and they have a long fatigue life, if they are being operated within the limits of specification, i.e. provided they do not get overloaded.

For velomobiles with extremely strong brakes, e.g. down-hill disc brakes, it is necessary to use the laminated type of composite spring in order to take up the high braking torque.

REFERENCES

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Appendix

Poster Presentations

The *Nihola-Bike*

The ***Nihola-Bike*** is named after its inventor, **Niels Holme Larsen** , who is a 30 year old mechanical engineer living in Copenhagen.

The ***Nihola-Bike*** was conceived as mean of transportation of children and shopping bags. It will transport 2 children, several shopping bags and even a big case of beer. The way of steering, the shape of the loading space and the low weight is what makes this bike so different and outstanding.

The ***Nihola-Bike*** is patented based on a world-wide examination for novelty.

The *Nihola-Bike* features:

- Easy to ride due to low weight.
- Safe to ride due to steering and brake characteristics.
- Child placed in adjustable safety chair, that easily turns forwards or backwards.
- The child has a perfect view and a magnificent experience.
- Low turning radius and easy manoeuvrability.
- Fitted with only best quality components.
- Comes in many versions depending on transportation need.
- Easy conversion from one using purpose to an other.
- Equipped and coloured according to costumers specifications.

The *Nihola-Bike* technical specifications:

- Weight of basic structure (frame, complete steering mechanism, storage floor, pedals and steer) is 14 kilos.
- Front frame optimal solid and stable compared to weight and volume.
- Turning radius of only 5 meters.
- Total length: 1.785 mm.
- Maximum width: 910 mm.
- Volume of storage room: 170 litres.
- Front wheels: 20" with self adjusting drum breaks.
- Rear wheel: 26" with inside 7 shift Shimano gear and pedal break.
- Technical documentation, visualising and simulation of riding characteristics is done in Solid Edge and Auto Cad 14.

Contact:

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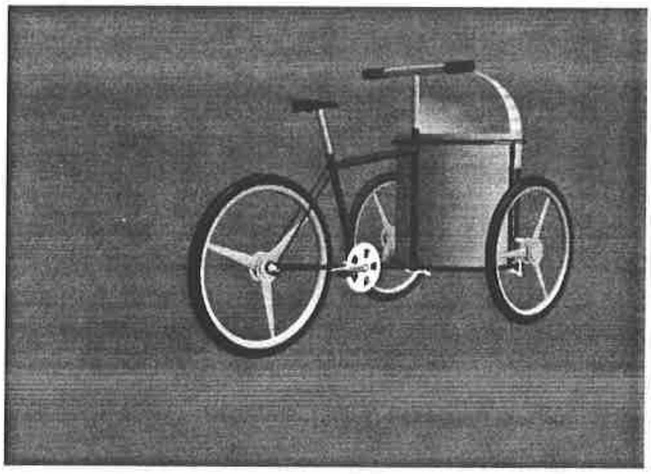
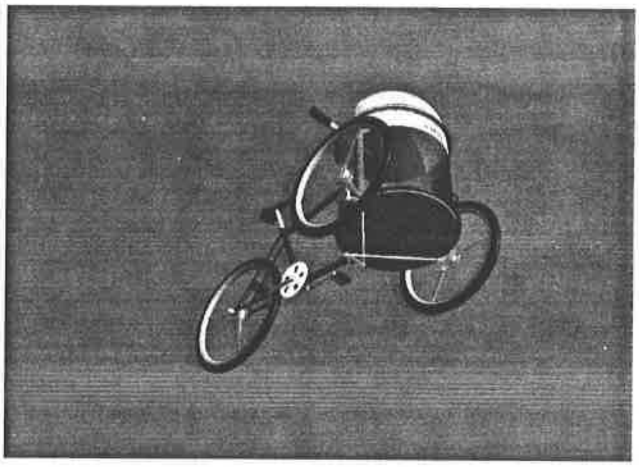




Nihola-Bike

Fortbewegung mit muskelkraftbetriebenen Fahrzeugen

Unsere heutige Gesellschaft ist durch Mobilität geprägt. Hierfür stehen eine Vielzahl von unterschiedlichen Transportmitteln zur Verfügung. Jedes ist für einen ganz bestimmten Einsatzzweck vorgesehen. Angefangen von den Flugzeugen, welche schnell große Entfernungen überbrücken sollen, geht die Kette weiter über Schiffe, Bahn, Bus bis hin zum Fahrrad und letzlich zum Fußmarsch. Jedes dieser Transportmittel deckt durch seine spezifischen Eigenschaften ein ganz klar definiertes Segment im verkehrslogistischen Gesamtkonzept ab.

Für wirtschaftlich genutzte Transportmittel wie z. B. Flugzeuge oder LKW bestimmt allein eine Kosten-Leistungsrechnung, welches Transportmittel eingesetzt wird. Diese Gesetze sind für privat genutzte Transportmittel z. T. außer Kraft. Hier wird das Auto häufig für Transportaufgaben mißbraucht, für die andere Fahrzeuge besser geeeignet sind. Nur die persönliche Bequemlichkeit und die z.T. sehr ungünstigen verkehrstechnischen Randbedingungen lassen viele auf das Auto zurückgreifen.

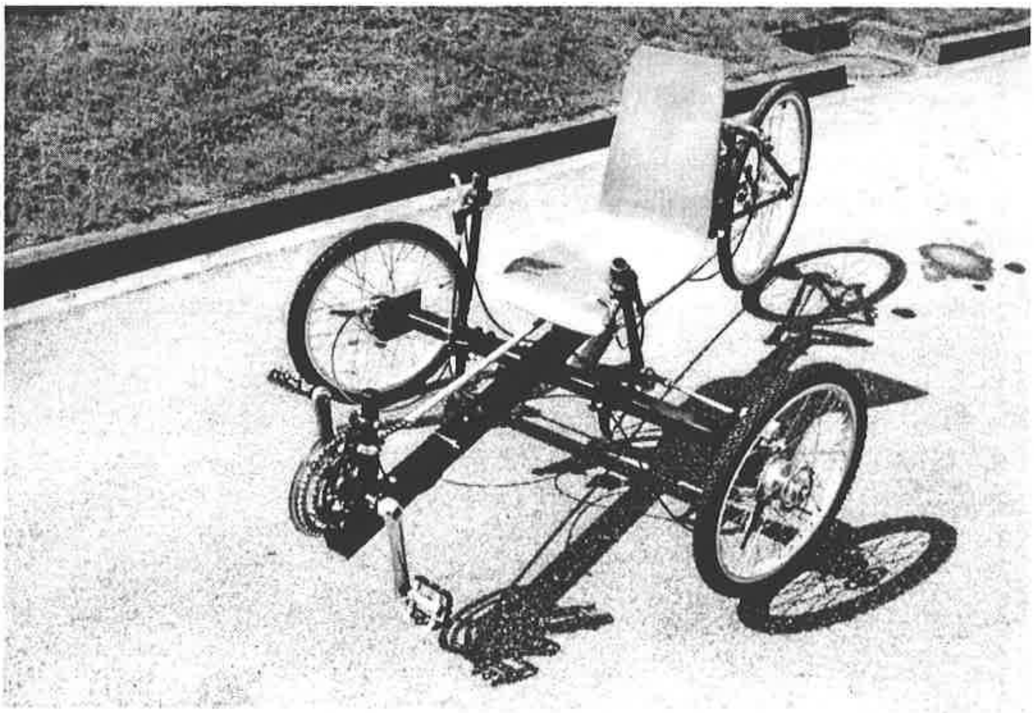
Wir haben es uns daher zum Ziel gesetzt einen Baustein im verkehrslogistischen Gesamtkonzept weiter zu entwickeln. Dieser soll kein anderes Vekehrsmittel ersetzen, sondern eine sinvolle Ergänzung zu den bisherigen Verkehrsträgern bieten. Die Zielgröße unserer Entwicklung ist daher ein witterungsunabhängiges, muskelkraftbetriebenes Fahrzeug für eine Person zu entwickeln, welches im städtischen Nahbereich bis 10 km eingesetzt wird und auch Lasten bis 50 kg transportieren kann. Angetrieben wird es nur von der menschlichen Muskelkraft.

Ansätze dieser Art hat es natürlich schon viele gegeben. Diese waren bisher jedoch recht unsystematisch und haben den wesentlichen Faktor „Mensch als Antriebsmaschine" nicht richtig berücksichtigt. Im Rahmen eines durch die FH Bielefeld geförderten Forschungsvorhaben ist daher im ersten Schritt ein sehr variables, dreirädriges HPV (Human powered vehicle) zunächst auf der Basis einer konventionellen Fahrradtechnik gebaut worden. Es verfügt über eine ungefederte gelenkte Vorderachse und über ein gefedertes Hinterrad, welches auch gleichzeitig zum Antrieb dient. Der oben definierte Einsatzzweck wird mit der ausgeführten Konstruktion am besten erfüllt.

Dieses rein als Versuchsfahrzeug konzipiertes HPV soll zum Testen verschiedener Komponenten im Antriebsstrang dienen, um die Leistungsfähigkeit des menschlichen Körpers besser zu nutzen. Berücksichtigt man, daß ein untrainierter Mensch etwa zwischen 90 W und 150 W Dauerleistung für den gewählten Aktionsradius abgeben kann, wird deutlich, daß hier jede Möglichkeit der Optimierung genutzt werden muß. In den nächsten Schtritten werden jetzt die Kenngrößen für Fahrzyclen im städtischen Verkehr bestimmt und dies mit der menschlichen Leistungsfähigkeit in Relation gesetzt. Dazu werden noch umfangreiche Ergometermessungen an verschiedenen Testpersonen zur Bestimmung der Leistungs-EKG gestartet. Erst mit diesen Daten macht es Sinn die einzelnen Komponenten im Antrieb zu optimieren. Dabei werden mechanische und auch elektrische Komponenten getestet.

Die Aufgabenstellung und die ersten Ergebnisse machen deutlich, daß es sich hier um ein weites interdisziplnäres Forschungsgebiet handelt, über das es in den nächsten Jahren noch viel Interessantes zu berichten geben wird.

<u>Das Versuchsfahrzeug hat folgende technische Daten:</u>
Gewicht: 32 kg
Länge: 215 cm
Breite: 115 cm
Übersetzung: 1:1 bis 1:4,36
Wendekreis: 7 m



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LISSY II

Technical Description of the Velomobil

Lissy II is a velomobil for two adults and up to four children. The seats are side by side.
On the left side for a stature of 165 up to 185 cm and
on the right side for a stature of 155 up to 175 cm.

Transport of goods
After turning down the right seat you can transport the following things.
Timber of approximate 3 m length, some bags of cement, a refrigerator,
a wasching-machine, two centner of potatoes,
approximate six crates of Mineral Water, Coce or Bear etc.

Technical Datas
The frame is welded of rectangel and square tubes.

Lenght	: 200 cm
Width	: 99 cm
Hight	: 130 cm, 55 cm with dismounted seats and only 40 cm without wheels.
Weight	: 48 kg (without cover)
Weight with Cover	: 60 kg (You can take off the cover)
Manoeuverable circle	: 3.2 m

The frame is without spring suspension. The seats have spring elements.
The steering works indirectly with rolls and cables and cardan.
Front wheel with 16" and two rear wheels with 20", all wheels are equipped with hydraulic disc brakes. The three-wheel-bike has two seperate drives,
each with 42 gears consisting of F&S 3x7 and moutain drive (pedalarm-shifting).
The bike goes up to nearly every mountain. You can tread on until a speed of 50 km/h (32 mph).

There is only one prototype until now, plans for construction are available from the builder from August 1998 onwards.

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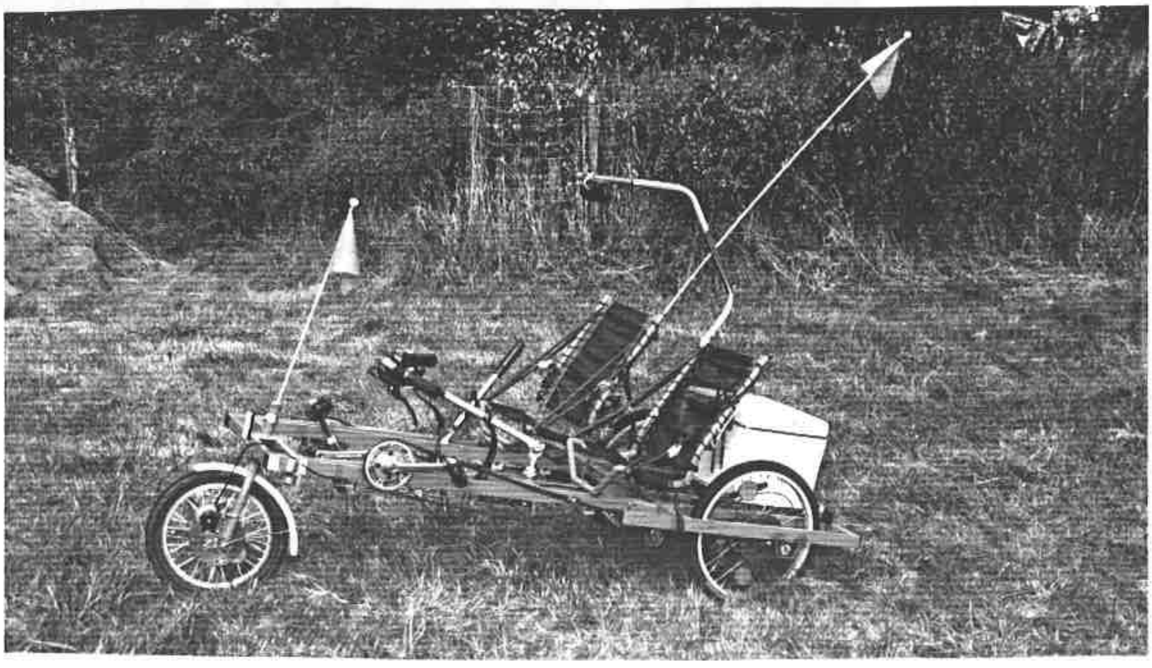
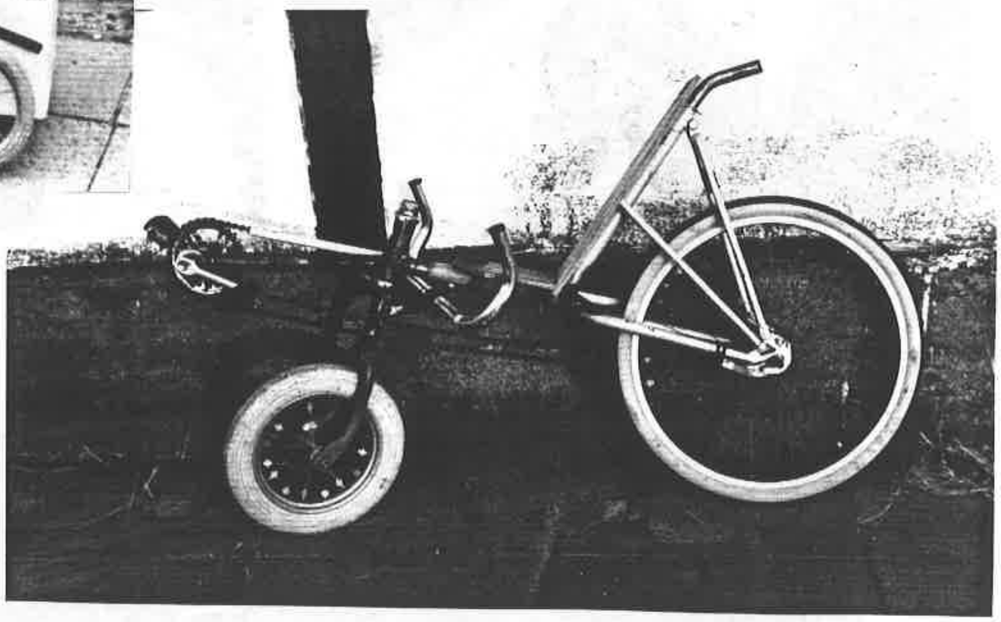


Recumbents for children

by Hans Jörgen Pedersen

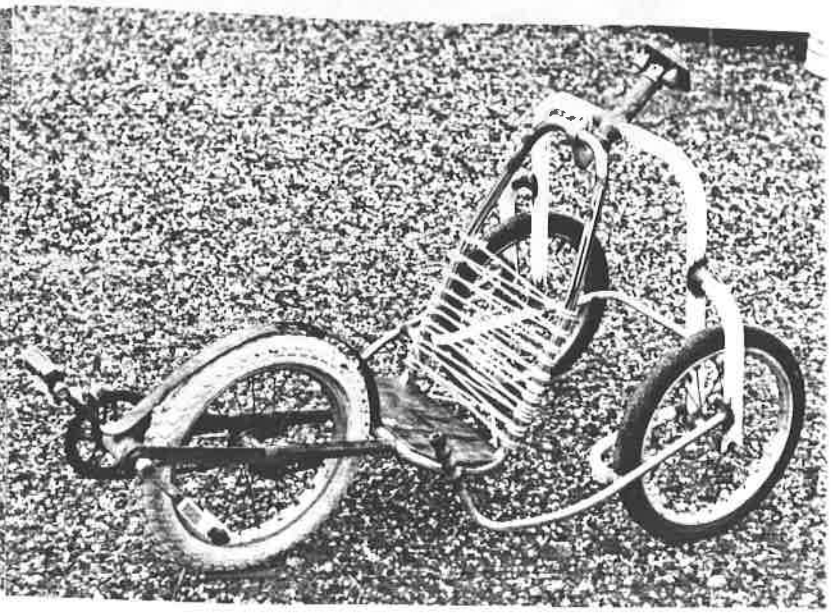
Children like to ride bikes, and when the adults ride the recumbents, the children want to do the same. Seven years ago I built the first bike for my eldest daughter. It was the first step to build special bikes for children. She was still in need of a three-wheeler, although she already had some. For me it could be fun to make one more -different from the others.

It is nice to have the luggage in front. and that's what the children also like, especially with the favourite dolls or tools. I got the idea from the Christiania bike, and I want to develop this type much more, also for children, who can't use pedals yet. It can even help them learning to walk pushing a bike around.
I make the bikes from old cycle parts, so they are cheap, and if you let the children help with the painting, it is a way to have a good time together.



When I built my first recumbent, my children beg for one also. The bike was very simple, a recycled children bike, where I could use the rear part of the frame and the pedals. The front fork was from a small bike with 8 inch wheels. The seat is made of two pieces of plywood and covered with camping foam mattress. The bike is easy to handle for children, who already are used to a two-wheeler.

My youngest girl was still not able to ride a two-wheeler, so I built a new three-wheeler on basis of the banana-bike concept. Again I used recycled components: two strong wheels for the rear axle, and a 16 inch rear wheel as front wheel. The child is sitting on the front fork with front drive. The steering axle has an inclination of about 30 degrees. The bike functions very well, and many people have been asking for similar bikes, so I am working on a model suited for massproduction.



Here are four different models of three-wheelers, but I am still not satisfied with look. The styling must be further developed.

Today my girls can ride two-wheelers, and I try to design some better and smarter for them. If I take the step to production, I can no longer use recycle parts. The frame should only have a few bends and as few weldings as possible.

About myself: I am a 45 years old carpenter and building designer. Supervisor in Kenya 1983-87. Member of HPV-Club Denmark since 1991. To make myself independent of a car, I built a velomobile and a long transport bike.

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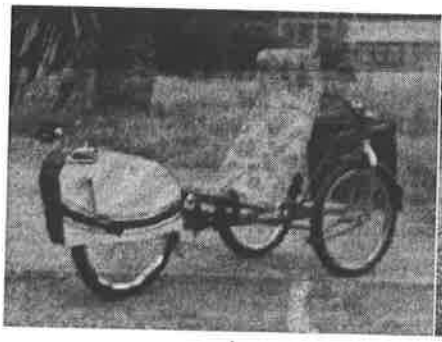
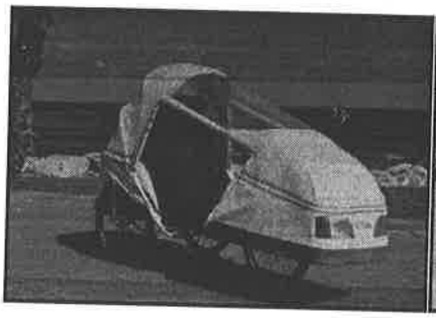
Last Updated - May 23th, 1998





This is the trike model "G.Thun" with one front drive and two rear steering all 20"wheeles.

- **Steering type - under seat by cables.**
- **Wheelbase - 1000 mm (~40").**
- **Trek width - 600 mm (~24")**
- **Seat height - 300 mm (~12")**
- **Recline angle - 65* adjustable.**
- **Weight - less than 22 kg (~48lb) empty, depends upon ordered materials and components.**
- **Weight distribution - 54% front and (23+23)% rear (rider 70 kg (~160lb) without luggage).**
- **Frame construction - folded; steel, CroMo, aluminum TIG welding according to order and manufacturer's possibility.**
- **Forks - different types (including suspended) as component according to order.**
- **Seat construction - frameless with pad and cover.**

All components: bottom bracket, crank set, freewheel/cassette/mid drive, chain, derailleurs, shifters, brakes, nub/rim/spokes/tires of 20" wheeles - according to orders.

- **Paint/color - depended upon manufacturer's possibility and order**
- **Gear Inch Range - 23-68(no need more)**
- **Rider height and adjustment - 160185 cm (5'3" – 6'1") sliding seat**
- **Model designed for daily commuting and long touring**

Length - 1600mm (~63"){with fairing 1950mm (~77")}

Width - 740mm (~29") {4-wheeled – 1240mm (~49")}

Height - 1015mm (~40") {with fairing –1250mm (~49")

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Pedicab Manufacturers

Disclaimer: The following list of commercially available pedicabs does not imply product endorsement by the authors, nor is the list believed to represent all vehicles suitable for pedicabbing. We provide the contact information merely as a starting point for individuals who may wish to begin exploring this topic in greater detail. Buyer be aware!

DELTA TRIKES

Main Street Pedicabs, Inc.

3003 Aparpahoe Street
Suite 226
Denver, Colorado 80205
USA
tel: +1-303-295-3822
fax: +1-303-604-2404
web: http://www.pedicab.com
email: pedicab@usa.net

Rideable Bicycle Replicas

2329 Eagle Avenue
Alameda, California 94501
USA
tel: +1-510-769-0980
fax: +1-510-521-7145
web: http://www.hiwheel.com

Tipke

18610 East 32nd Avenue
Greenacres, Washington 99016
USA
tel: +1-509-893-9473
fax +1-509-891-8382
web: http://www.tipke.com/
email: gregw@eznet.com

Worksman Trading Corporation

Worksman Cycles Industrial Park
94-15 100th Street Ozone Park
New York, New York 11416
USA
tel: +1-718-322-2000
Fax: +1-718-529-4803
web: http://www.worksman.com
Email: workcycle@aol.com

QUADRACYCLES

Brox

Emission Free Vehicles, Ltd.
PO Box 303, Douglas, IM99 2AZ
Isle of Man
Great Britain
Fax : +44 1624 628169
www.brox.com

Byke Kar, Inc.

100 Johnston Rd.,
Brome, Quebec, Canada
J0E 1K0
fax: +1-514-539-4377
web: http://www.ntic.qc.ca/~bykekar/
email: bykekar@endirect.qc.ca

Pickup

The Seat of the Pants Company Ltd.
PO Box 5
Cheshire
England M33 4AP
tel and fax: +44 16 976 5662
web: http://www.windcheetah.co.uk/seatofthepants/

Quadracycle

6715 East 500 South Street
Hamilton, Indiana 46742
USA
tel: 1-219-488-2983
web: http://www.bikeroute.com/Quadracycle.htm
email: quad@bright.net

Rhoades Car

Rhoades National Corporation
125 Rhoades Lane
Hendersonville, Tennessee 37075-8404
tel: +1-615-822-2737
fax: +1-615-822-4129
web: http://rhoadescar.com
email: info@rhoadescar.com

Surrey Cycles

Freetime Distributing Inc. (distributor)
414 First Street
Solvang, CA 93463
Phone: 1-805-688-0091
Fax: 1-805-686-4540
Web: http://www.bikeroute.com/FreeTimeSurreyCycles/
email:freetime58@hotmail.com
freetime@syv.com
cycleam@bikeroute.com

FRONT LOAD TRIKE

See **Worksman**

JINRICKSHAWS

Green Limousine Inc.

1330 G Street
San Diego, California 92101
USA
tel: +1-619-531-0996
fax: +1-619-531-0997
web: http://members.aol.com/greenlimo/greenlimousine.html
email: greenlimo@aol.com

RickShaw International

1972, Ste-Catherine East
Montreal, Qc. H2K 2H7
Canada
tel/fax: +1-514-273-7945
tel toll-free: 1-800-310-1001
web: http://www.dania.com/~vague/index.html
email:vague@dania.com

PASSENGER TRAILERS

See **Rideable Bicycle Replicas**