



Proceedings of the 5th European Velomobile Seminar

–Towards Commercial Velomobiles –

Deutsches Straßenmuseum

Germersheim, 23.4.2004

Joachim Fuchs (Editor)



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About the Seminar:

Velomobiles are a muscle powered vehicles with an enclosed fairing that protect from wind, cold weather and rain. They are an ecologically desirable mean of transportation for everyday use. Compared with a normal bicycle, velomobiles provide a higher security standard and offer the advantages of a reduced aerodynamically drag.

The European Velomobile Seminar was initiated by Carl Georg Rasmussen in 1993. The main topics of the recent seminars were design, security, transport and power assisted velomobiles.

The subject of the 5th European Velomobile Seminar is: "Towards Commercial Velomobiles". The aim of this seminar is to denominate the factors that hinder further broadening of the velomobile idea. Guiding ideas for future designs should include technical as well as social aspects in order to get sophisticated, affordable and commercial available velomobiles in future.

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Preface



The sight of a velomobile in normal traffic still arouses feelings amusement and amazement to some members of the public. How do they stay up? How do they get in/out? Aren't they dangerous to themselves and other traffic participants? These are just some of the questions we, as velomobilists, often hear.

How can we vault over this situation and make the velomobile into a viable commercial vehicle of the future? The subject of our seminar today is "Towards Commercial Velomobiles" and, in this introduction, I'll just briefly touch on some of the things we'll be discussing.

In the first block we'll deal with some technical questions relevant to the development of velomobiles. Though cost-performance ratio is probably as important, we can be certain that sophisticated technical solutions are among the prime factors which focus customer interest. However, we would be unwise to ignore the public acceptance of the velomobile itself, as a means of transport. In another block of talks we'll be discussing historical developments. These too, should not be forgotten as they may well turn out to form the basis for further developments in velomobile construction.

I, for one and I'm sure you no less, am looking forward to hearing some exciting discussions on the development of the velomobile of tomorrow.

Joachim Fuchs, April 2004

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Who is who

German Eslava



Graduated in Mechanical Engineering and in Business Administration has worked in the computer field for many years. Since 1988 has been working on the bicycle business on consultancy for bike-design, international production of frames, parts and components.

Since 1994 has been intensively working on velomobiles. He is a mayor partner in the development and production of the Cab-Bike in Giessen, Germany.

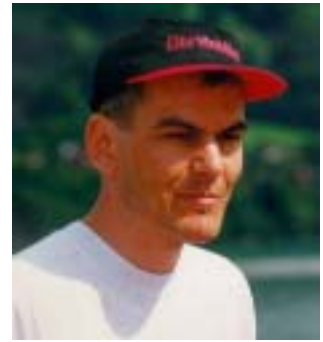
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Reinhold Schwemmer



After being a professional tennis player he got involve with velomobiles as a user since 1991. He drove all existing velomobiles and started making improvements on them right away. He has has been intensively working on his first Cab-Bike velomobile since 1993. He is a mayor partner in the development and production of the Cab-Bike in Giessen, Germany.

Andreas Fuchs



PhD in climate physics. Recumbent rider since the 80's, Leitra rider since 1991. Co-organizer of and speaker at earlier Velomobile Seminars. Assistant professor at Berne University of Applied Sciences. Conceptualisation and realisation of a working model of an urban quadracycle. Initiator of www.autork.com to develop and commercialize the chainless, electronic transmission for power assisted recumbent cycles and velomobiles (www.hta-be.bfh.ch/~fuchs/Transmission/).

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Stefan Gloger



Stefan Gloger, Design and daily use of Velomobiles since 1989, 1991 -1-995 PhD work'Velomobil Development", 42 Student thesis's regarding HPVs, 18 publications re-garding HPV's. Together with a student team 9 different -vehicles were designed and testet on the road. Since 1996 developement engineer at OPEL and member of the AKASOL (Solar technical group) Darmstadt.

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Carl Georg Rasmussen



built his first plywood velomobile in 1951. M.Sc. in engineering, Ph.D. in acoustics. R & D in industry. Pilot and member, of aircraft design group. Since 1979 designer and user of the LEITRA velomobile.

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Jürgen Eick



Diplomingenieur und (pensionierter) Professor für „Wärmetechnik und Energiewirtschaft“ an der Fachhochschule (University of Applied Sciences) Wiesbaden. Lebt ohne eigenes Auto und benutzt sein Velomobil (Typ Leitra) seit 1989 in Alltag und Urlaub.

Ingo Kollibay



Ingo Kollibay, 42, architect, lives in Hildesheim, Germany. Engaged in the network "Agenda 21". Busy in HPVs since 1983: many recumbents, mostly short wheelbase, trailers, trikes, disabled person's bikes, sociables and folding recumbents. No velomobile yet. Developed the "Brompton Recumbent Conversion kit" and the running scooter "Sauseschritt" with Junik (Juliane Neuss Spezialfahräder). Since 2002 one of the founders of Velo.Saliko (Velomobile Sauerwein, Lienhard, Kollibay) in Hannover, Germany, who totally redesigned the circular seven seater ConferenceBike and manufacture it.

Michael Grützner



Magister in History of Technology.

Bicycle collector since 1993. Committee member of "Historische Fahrräder e.V". Especially interested in company history of "Wanderer". Owner of a Mochet Velocar and a Velo-Velocar (recumbent)

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Gunter Kramp



Gunter Kramp

Student of mechanical engineering at the Technical University Darmstadt and environmentalist. The bicycle always was the most important means of transportation for me, a car-free lifestyle is therefore normality for me. Since 1990 I am mostly using Recumbents including an old selfmade long wheel-base "Chopper" and a HP Velotechnik Streetmachine. Since 1999 I am participating in the Läufer Project.

Student des Maschinenbaus an der TU Darmstadt und Umweltaktivist. Schon immer war das Fahrrad für mich das wichtigste Verkehrsmittel, autofrei Leben daher eine Selbstverständlichkeit. Seit 1990 fahre ich vor allem mit verschiedenen Liegerädern, darunter immer noch mein erstes Bastelwerk, ein "Einfälle statt Abfälle"-Langlieger und eine HP Velotechnik Streetmachine. Seit 1999 arbeite ich im Läufer Projekt mit.

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Joachim Fuchs



Built the single track velomobile Aeolos in 1995. 80000 km velomobile practice since that time. Support of the site www.velomobile.info.

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Frederik Van De Walle



I'm 25 and live happily with my girlfriend Anna, north of Stockholm, Sweden. Talk to me if you want to get to know 'me' ;-)

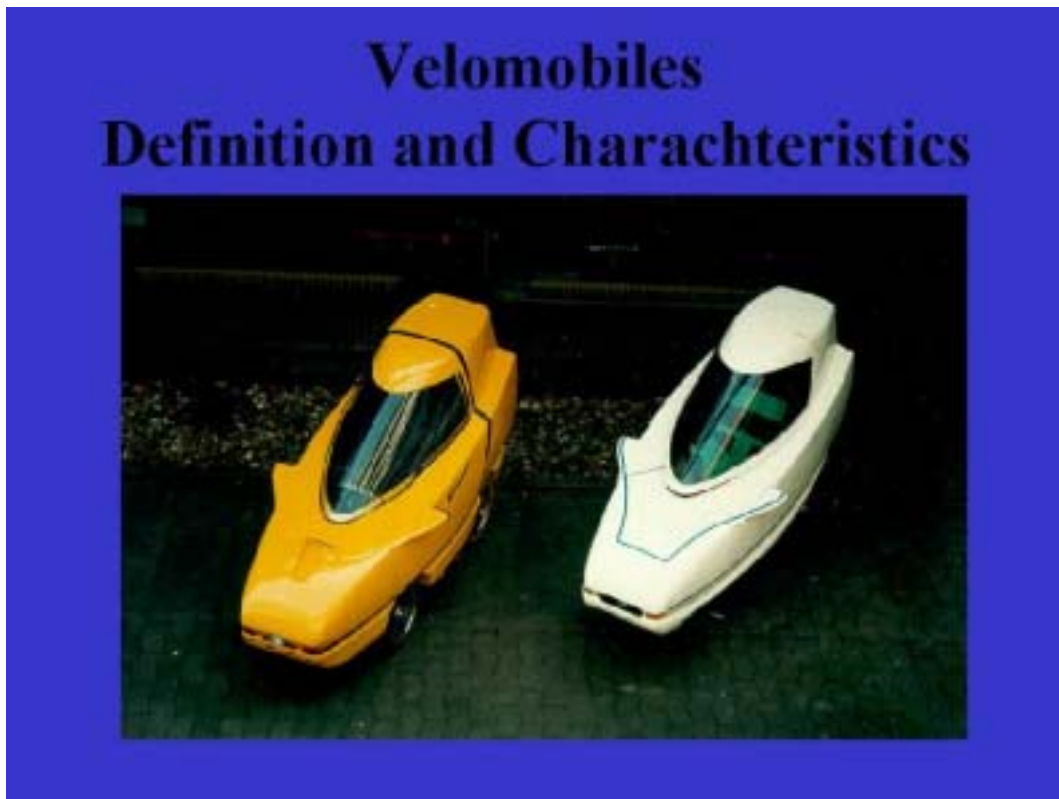
Academic career: last year [should have just finished by then] I studied Environmental Engineering and Sustainable Infrastructure at the Royal Institute of Technology (KTH) of Stockholm, most interesting experience. This study balanced my study of Aerospace technology at the VUB/KUL and Electromechanical Industrial Engineering at HoGent in my home country Belgium.

Experience related to velomobiles: Fortunate to know the HPV and velomobile scene quite well from the inside, mainly through racing but also from broader interest. Also a walking automobile and motorcycle catalogue, but not so for bicycles, too many of those ;-)

Did an ambitious velomobile project, WAW, which worked out fine for a first attempt. My colleague and friend Dries Callebaut further develops and sells it, among other cycling activities: see www.fietser.be .

Stefan Gloger, short presentation

1 Velomobiles- Definition and Characteristics



Velomobiles Definition and Characteristics

Definition

Velomobiles are human powered vehicles with the following

Additional or integrated Functions:

- weather protection
- big,protected luggage compartement
- superior passive safety

Additional Functions may be:

- protection from heat, vibrations, noise, etc.
- child transport
- etc.

Velomobiles

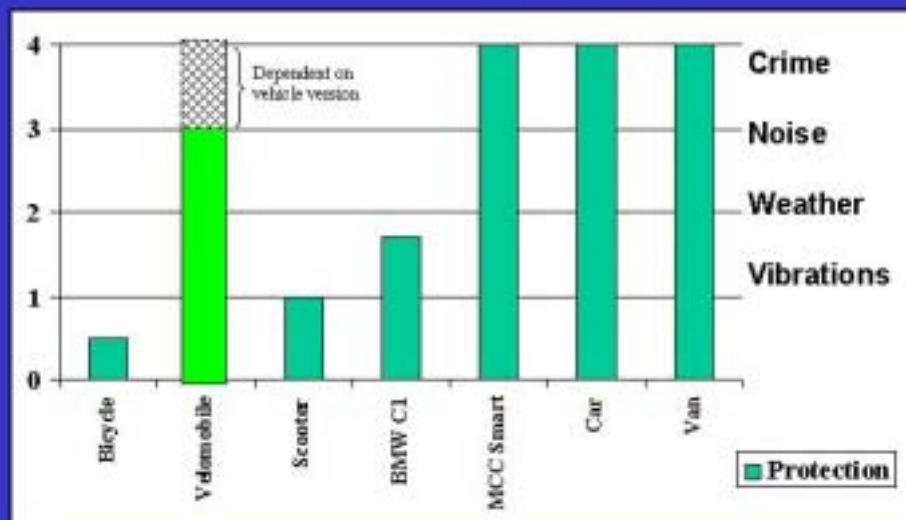
Definition and Characteristics

Characteristics

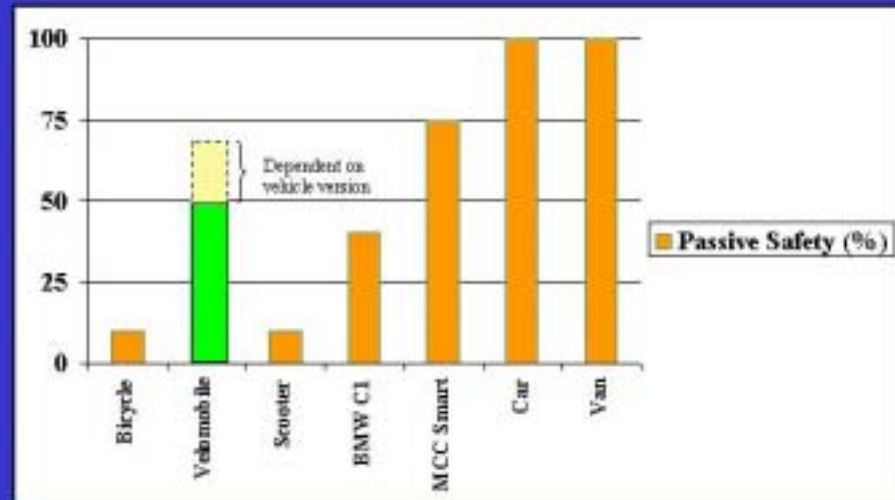
- Protection
- Passive safety
- Transport capacity
- Zero (low) emission and fuel consumption
- Low weight
- Good price performance relation

Velomobiles

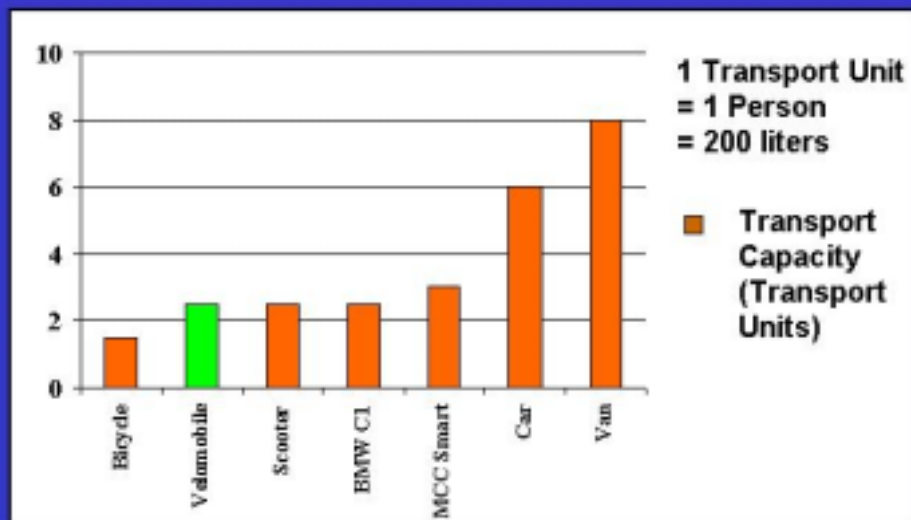
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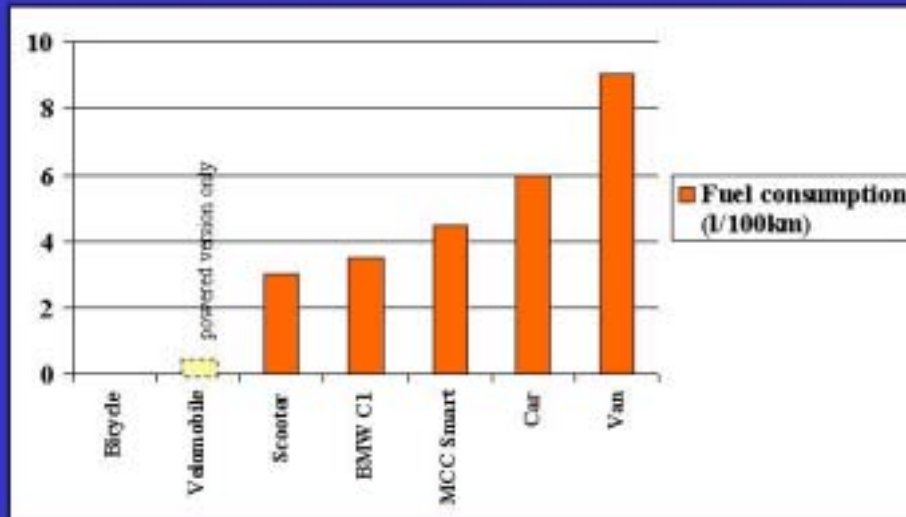
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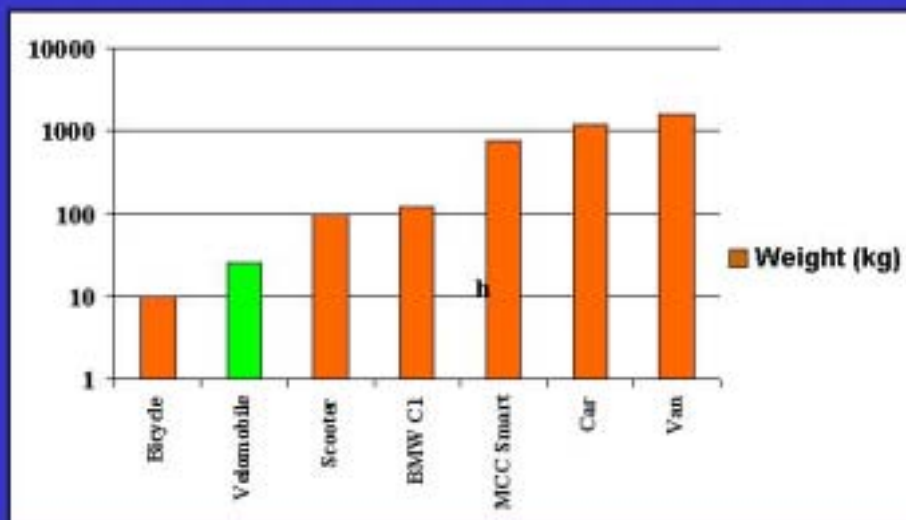
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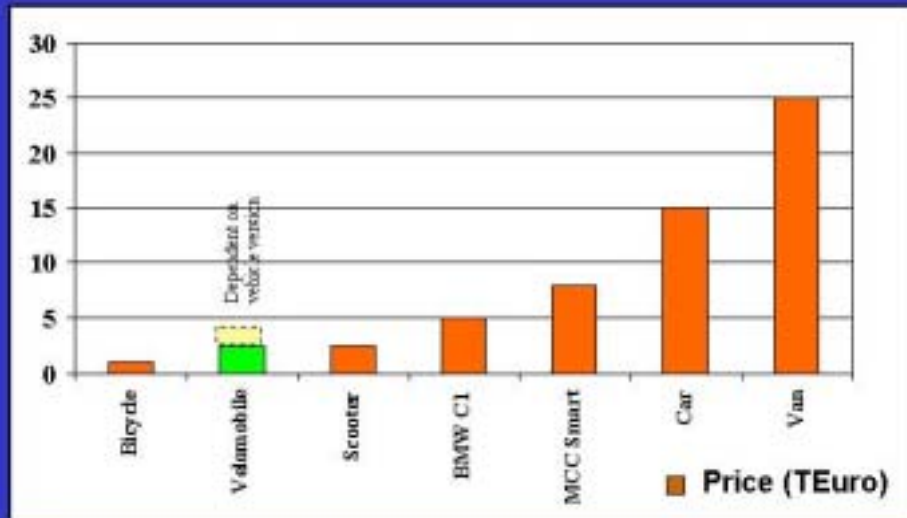
Velomobiles Definition and Characteristics



Velomobiles Definition and Characteristics



Velomobiles Definition and Characteristics



Velomobiles Definition and Characteristics



Velomobiles Definition and Characteristics



Velomobiles Definition and Characteristics

This product meets perfectly consumer image demands:

- creating a new way of transportation
- doubtless sporty and ecological friendly
- fun to drive
- **stylish** and multifunctional in daily use
- **good** price-performance relation
- drive Your first BRAND-product with 12 years
- develop technologies and vehicles for the CO2 challenge
- first time to market

Jürgen Eick, Carl Georg Rasmussen

2 Safety in spite of lightweight construction

1. Introduction

In his lecture at the 2nd European Velomobile Seminar in 1994, D. G. Wilson said that "...a breakthrough of HPV's....into the popular mass market is increasing likely. If the HPV that achieves this breakthrough has safety deficiencies that could have been easily remedied in the design stage, the cost in human suffering could be great. There could also be a backlash against the whole HPV movement". (7)

In the meantime, 10 years have passed and there has possibly been a breakthrough of recumbents into the market but the velomobile still has not achieved this. Wilson's statement is, however, also valid for velomobiles. They will only achieve mass usage in traffic if their designers fulfill high demands in their passive and active safety of construction.

Previous publications about the safety of velomobiles are almost exclusively theoretical, due to the (fortunately) small number of accidents involving velomobiles. It has hardly been possible to record statistics on the causes and results of accidents. However, at the 3rd Velomobile Seminar in 1998 (8), S. Gloger reported on model tests and discovered important findings about the way the accidents between velomobiles and automobiles happen. With these tests it was confirmed (at least in models) what he had assumed at the 1st Velomobile Seminar in 1993 (on the results of a survey conducted at the 1992 HPV Championships) (2): Safety is possible – even in the case of light construction. Safety for the velomobilist as well as for the other party involved in the crash.

At the 2nd International Velomobile Seminar in Laupen, T. Schmidt described important characteristics of passive and active safety of velomobiles (4), mostly in accordance with S. Gloger. According to these, it is of no benefit to use the same constructive means as those of the car in order to protect the driver from colliding with hard objects of other cars. It is far better to make use of its lightweight, smooth fairing that deforms itself which will delay the kinetic energy of the impact as much as possible. Thereby, it might be possible to avoid a highly critical negative acceleration of the body.

With this contribution, we would like to add an important empirical component to the knowledge of velomobile safety, which has previously been based mainly on theory or model tests. It is based on 32 accidents involving the velomobile Leitra, which were documented. The authors are aware that this number is too low for a statistical evaluation, coming up to strict scientific demands. Nevertheless, they believe that an analysis of the way these 32 accidents happened and of their results would give further direction to velomobile designers as to how velomobile accidents happen and its results.

2. Types and causes of accidents

By far the most common kind of accident involves no other party. Table 1 shows 18 out of 32 documented Leitra accidents are 'individual accidents'. The cause for these individual accidents were mostly one or more wheels going off the road and resulting in the velomobile overturning (table 2). However, steering movement whilst applying the brake can also cause the Leitra to overturn, even though the distance between the front wheels is comparatively wide at almost 1 metre. Picture 1

shows the damages that occurred to the Leitra when its driver tried to avoid a skateboarder on a cycle path. He lost the cycle path at about 30 km/h, overturned into a slope and landed on a river bed. He was uninjured.

In the case of some individual accidents, Leitras collided with fixed objects (table 3). Accident 2.3 happened to the designer of the Leitra himself, Carl Georg Rasmussen. During a long-distance trip (1000 km Paris-Brest-Paris), he tipped over when driving downhill along a narrow curve and slid into a concrete wall. The top of the fairing was dented. He merely received some small grazes and managed to continue his journey.

Table 4 shows that as many as 7 Leitras were hit by cars, four times from behind and three times from the side. Picture 2 displays a Leitra after it had been run into by a car on the lefthand side from behind. The driver of the car did not take notice of the Leitra and instead had paid too much attention to her two children sitting behind her. The left wheel, including suspension, was completely destroyed and the safety device against impact from the side of the chassis of the Leitra was bent (this cannot be seen on the picture).

Picture 3 shows a Danish Leitra which was rammed by a car from the side. Its driver did not receive any injuries either. One can easily see from the picture how the accident happened. The car bumper hit the safety device against impacts on the right side. The Leitra overturned to the left, which broke the leaf springs on the left front wheel. The safety device against impacts on the left side was bent when it hit the street.

In their research for this contribution the authors could only find one accident in which Leitra crashed into car. Accident 4.1 happened shortly after the author bought his first Leitra in 1989. He drove on a multipurpose lane when a car overtook him, drove on about 100 m and then stopped to let out a passenger. While he overtook, the driver started to drive into the lane. The Leitra crashed into the car at an angle of 45 degrees, tipped to the left, breaking the leaf springs of the left front wheel. After that, it slid along the asphalt for a few metres. The lockings between the fairing and frame remained closed which prevented him from touching the asphalt. He climbed out of the badly battered Leitra completely uninjured. The front of the fairing was dented (picture 4), the fixing mechanism between fairing and frame bent (picture 5) and the springs on the left side were broken (picture 6). The accident happened exactly according to Gloger (2;8) and Schmidt (4). The kinetic energy of the Leitra plus driver had been gradually reduced: Elastic/plastic deformation of the fairing and its fixing mechanism on the frame, muscular work of the legs against the strike, breaking of the springs and sliding on the asphalt.

The accidents mentioned under 5.1 and 5.2, table 6 are the only collisions between Leitra and cyclists known to the authors. Accident 5.1 involved the driver of a recumbent bicycle who chose a Leitra-fairing for his construction (picture 7). He drove on the righthand side of a forest lane. Driving into a blind bend, a cyclist rode towards him on the wrong side of the lane. A collision was inevitable. Eventually, the cyclist lay on the cover of the Leitra. The Leitra did not tip over and nobody was injured but the fairing was pretty ruined.

3. Types and frequency of damage and injuries

Table 7 shows a survey of injuries and damages, as well as their frequency in these 32 investigated accidents.

There was only one case of lasting physical complaint when a driver lost the lane and turned over sideways. For a few months he suffered from neck pain but its cause could not be traced through x-rays.

Mostly there were grazes which were caused by physical contact with components of the interior of the velomobile and not with the road.

As expected, the most common damage to property referred to the paint. There was often a deformation of the fairing and cracks in its main parts, the front and back of the fairing. In connection to that there were several bent fixing mechanisms of the front of the fairing.

Whilst the leaf springs on the front wheels broke occasionally due to high side impact, damage on the actual chassis surrounding the body of the driver like a basket, was rare. This is mainly due to the fact that the relative velocity between Leitra and collision partner (fixed object or car) was mostly so low that the kinetic energy could gradually be reduced by fairing, fixing-mechanism of the fairing, breaking of leaf springs, muscular work and friction between road and fairing. The deforming of the steel tube welded chassis did not even happen.

4. Active safety (crash-prevention)

The most important provisions enabling the prevention of velomobile accidents are:

- a. Good view of the traffic surrounding the velomobile
 - b. Striking appearance of the velomobile
 - c. Effective brake system
 - d. Defensive driving of the velomobilist
- a) The velomobilist needs as good a view as possible in all weathers. At relevant fairs and exhibitions, visitors are usually fascinated by large and aerodynamic fairings made from transparent polymers even though these are ineffective for the everyday use. In the sunshine it would soon be unbearable to sit in such a 'hothouse'. Windscreen wipers would leave scratchmarks on even the best of polymers, if it is at all possible to attach wipers to the fairing. Driving by night in the rain can easily become a bit of an adventure, especially when there is too much distance between the windscreen and the face of the driver. It clearly is better to install a flat disc of safety glass (at least in the front area) to which a windscreen wiper can easily be attached. The nearer the face to the disc, the smaller it can be.

The driver's side view should also be as good as possible. One could choose lightweight and flexible polymer sheets which should reach all around the driver's head which will enable him to see overtaking vehicles as early as possible. It is, of course, necessary to install a rearview mirror. It should be shaped and installed as to not create a 'blind spot'.

- b) A velomobile should be easily spotted by day or night and should have striking colours. The lighting system and indicator are of special importance. Unfortunately, the German authorities responsible for legalising the important equipment is very slow to act. An electric indicator does not meet the StVZO (traffic regulations) and indicating is still to be done by hand. It is, therefore, recommendable to use reflecting armbands.

The velomobile silhouette is lower than that of normal bicycles. When a velomobile approaches a crossroad with hedges, etc. and the view is hindered, others will often not see it early enough. This can be avoided by attaching a pennant, as it is common with childrens' bicycles.

Nowadays, velomobiles are still so rare that most car drivers are respectfully keeping a distance when overtaking. This will probably change once the velomobiles appear more in everyday traffic and belong to it the way normal bicycles do.

- c) At present, velomobiles are fitted with the same breaking system as normal bicycles which will probably also make sense for the future. Different types of bicycle brakes are highly developed and can be purchased at reasonable prices. Hydraulically or mechanically operated drum and disc brakes are particularly suitable for velomobiles as their wheels are mostly side-attached and their wheel diameter is comparatively small.
- d) Cyclists have an excellent view of each traffic situation because their eye level is much higher than that of car drivers. This applies particularly to inner-city traffic. This could give them an unjustified feeling of their own safety and induce them to take risky manoeuvres. The velomobile driver will not be exposed to such temptation. If his eye level is similar to that of a car driver he will have to drive accordingly, i.e. 'defensively'. This will have an effect on the whole velomobile design, esp. on the distance between the wheels – the higher the head, the higher the centre of gravity of driver and velomobile. We can, however, conclude that the pressure to drive 'defensively' contributes considerably to active safety.

5. Active safety (protection against crash)

If all the above measures to optimise active safety are taken and there still is an accident, it will show whether the velomobile is designed well in view of its passive safety.

It is only possible to minimize the negative acceleration forces (forces of inertia) on the driver's body through gradual reduction of kinetic energy if the relative speed between velomobile and collision partner is not too high. As seen with our collection of 32 accident reports, it hardly ever was. Even those accidents involving cars occurred at places where the cars did not drive very fast. Nevertheless, the injuries surely would have been much worse if riders of bicycles had been involved rather than velomobile drivers.

5.1 Fairing as primary injury protection

Based on the Leitra turning over, the most common occurrence during an accident, there have to be a number of demands one has to consider when designing the fairing:

- a. The fairing should remain closed after turning over.
 - b. The exterior surface of the fairing should be smooth and rounded.
 - c. The fairing should have sufficient elastic deformability.
 - d. The fairing should have sufficient plastic deformability.
 - e. The edges of cracks should not cause injury.
 - f. The danger of injury caused by protruding edges, levers and screws in the interior should be as small as possible.
-
- a) The accidents described above where the Leitra turned over seemed to have caused no serious injuries because the fairing did not open and thereby prevented the drivers from touching the road. The locking mechanism, however, must be easily opened so that the driver can climb out fast and without help.
 - b) If the velomobile hits an object at an acute angle and fairing is smooth and rounded, it will glide off easier, there is less danger of injury in both pedestrians and cyclists as sliding on the road is easier.
 - c) When turning over without crashing into any moving or immovable objects, the fairing should only be elastically deformed. Damage should be limited to fairing and varnish without any need for costly repair work.
 - d) Sufficient plastic deformability of the fairing (as well as the link between fairing and chassis) will help reducing the kinetic energy and thereby minimize the negative acceleration forces onto the body of the velomobilist.
 - e) There can be no doubt that the firmness of the material is important. However, it should not be the only criteria to be considered when choosing it. Carbon fibre, for instance, develops very sharp edges after cracking. Therefore, it should really only be used where there is little danger of the driver coming into contact with the fairing during a crash. The breakage of glass screens during an accident should also present no danger of injury (use safety glass!).
 - f) Protruding screws should be avoided or padded. Steering levers should be attached in a way that prevents injury when the driver collides with it. Chain and chain wheel should be covered. The velomobile should still be lightweight.

In the case of all different types of accidents, velomobilists in a velomobile that fulfill all these requirements are definitely better protected than normal cyclists. It seems that the basic principle to surround the driver with fairing, especially his head area, has proved itself. However, there has to be further development to improve the passive safety aspects of the velomobile and the design measures need to be checked frequently.

5.2. The Leitra frame as a secondary protection against injuries

If one accepts these 32 documented Leitra accidents as remotely representative, one establishes that these are almost all accidents where the kinetic energy before the accident is reduced through fairing + fairing attachment + muscles. Even if they are rare, those accidents with high speed or unfavourable hitting angle are particularly dangerous. The question is which constructive measures are useful in order to offer the velomobilist maximum safety also in these cases.

According to the accident reports, there are four cases where the wheels are extremely deformed, in eight cases the leaf springs (wheel suspensions) and respectively the steering system were damaged and the safety device against side impact were bent twice.

Picture 8 shows that the driver's back is comparatively well protected against car collisions. The Leitra has a frame with a carrier whose tubes stick out offering far-reaching protection. A collision from behind is additionally softened by the seat which is placed inside the chassis (frame) without the use of any screws so there can be a slight, horizontal, elastic deformation.

There are two ways in which the Leitra designer is dealing with possible side impact by cars. The driver's pelvis is primarily protected by two frame tubes at about the same height of car bumpers. There is a danger that the side impact pushes the seat away under the driver and the car bumper touches his body. In addition, therefore, the seat is shaped in such a way that it counteracts this. This principle has so far apparently been successful whenever a car has hit the Leitra from the side.

Whenever the carbon fibre leaf springs (which also serve as wheel suspensions) broke, it lead to dangerously sharp edges of cracks but they fortunately never reached to where the body of the driver moved, due to the comparatively high distance between the front wheels. This never knowingly caused any injuries.

6. Summary and conclusion

The aim of this contribution is to show the types and causes of accidents involving Leitras so far. It will be comparatively easy to translate this information for accidents of other types of velomobiles.

On the other hand, it is an attempt to establish if and how the concept of the Leitra has actually protected the driver. These findings will only partly be useable to different types of velomobiles, especially those where the fairing also has a carrying function and where frame and fairing cannot be dealt with separately. Further important differences that could require different safety solutions are for instance: The wheel base, the width of the vehicle, the way it adapts to body size and leg length, the order of steering levers, the problem of getting in and out as well as the decision whether the driver's head is in or outside the fairing. It will be largely depending on the creativity of the designers and producers to make sure that "SAFETY IN SPITE OF LIGHTWEIGHTNESS" will not only be a theory but also prove itself in everyday life.

References:

- (1) Rasmussen, C. G.: Fit for Survival-in a Velomobile.
In: Proceedings of the 1. European Seminar of Velomobile Design. Technical University of Denmark, 1993
- (2) Rohmert, W.; Gloger, S.: Passive Security of HPV.
In: Proceedings of the 1. European Seminar of Velomobile Design. Technical University of Denmark, 1993
- (3) Brunkalla, L. M.: Safety...Crashing...and related Debris.
In: Proceedings of the 2. European Seminar on Velomobiles. Laupen Castle, Switzerland, 1994
- (4) Schmidt, T.: What is HPV-Safety?
In: Proceedings of the 2. European Seminar on Velomobiles. Laupen Castle, Switzerland, 1994
- (5) Schmidt, T.: Subjective Speed as a Major Safety Factor.
In: Proceedings of the 2. European Seminar on Velomobiles. Laupen Castle, Switzerland, 1994
- (6) Walz, F.: Velounfälle aus der Sicht des Unfallforschers.
In: Proceedings of the 2. European Seminar on Velomobiles. Laupen Castle, Switzerland, 1994
- (7) Wilson, G. D.: What Safety Measures are needed for HPVs?
In: Proceedings of the 2. European Seminar on Velomobiles. Laupen Castle, Switzerland, 1994
- (8) Gloger, S.; John, H.: Investigation of the passive safety of Ultra Light Vehicles.
In: Proceedings of the 3. European Seminar of Velomobile Design. Roskilde Technical School, 1998

Appendix: Tables and pictures

1.	Accidents without other party involved ('individual accidents')	18
2.	Collision with fixed objects	3
3.	A car hits a Leitra	8
4.	A Leitra hits a car	1
5.	Collisions with cyclists	2

Tab. 1: Kinds of the 32 accidents documented

1.1	Sudden steering movement wit or without breaking	7
1.2	Severe breaking manoeuvre	3
1.3	One or more wheels going off the road	8

Tab. 2: Causes of accidents type 1. (individual accidents')

2.1	Inattentiveness and collision with a steel pillar	1
2.2	Evasive manoeuvre stopped by a hedge	1
2.3	Sliding into a concrete wall	1

Tab. 3: Causes of accidents type 2. (Collisions with fixed objects)

3.1	Car hits Leitra from behind	4
3.2	Car hits Leitra from the side	3
3.3	Car (in reverse gear) hits Leitra from the front	1

Tab. 4: Causes of accidents type 3. (A car hits a Leitra)

4.1.	A Leitra hits a car at an angle of 45 degrees	1
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Tab. 5: Causes of accidents type 4. (A Leitra hits ba car)

5.1	Head-on collision with a cyclist on a forest lane	2
5.2	Head-on collision with a cyclist on a cycle track	

Tab. 6: Causes of accidents type 5. (Collisions with cyclists)

Number	Cause of accident	Grazes	Contusions	Lasting physical complaints	Damages of the paint	Deformations and cracks in the front of the fairing	Deformations and cracks in the top of the fairing	Deformations and cracks in the back of the fairing	Fixing mechanism between fairing and frame bent	Deformations of wheels	Leaf springs broken	Steering mechanism damaged	Safety device against impacts from the side bent
1.1	Sudden steering movement with or without braking	2		1	9	5	1	2				1	
1.2	Severe braking manoeuvre												
1.3	One or more wheels going off the road	1	1		6	3	3	1	1		2	1	
2.1	Inattentiveness and collision with a steel pillar				1	1			1				
2.2	Evasive manoeuvre stopped by a hedge								1				
2.3	Sliding into a concrete wall	1			1		1						
3.1	Car hits Lettra from behind	1			4	1	1	1		1	1	1	1
3.2	Car hits Lettra from the side	1	1		3	2			1	3	2	3	1
3.3	Car (in reverse gear) hits Lettra from the front				1	1							
4.1	A Lettra hits a car at an angle of 45 degrees				1	1			1		1	1	
5.1	Head-on collision with a cyclist on a forest lane				1								
5.2	Head-on collision with a cyclist on a cycle track										2		
	Sum total of injuries and damages	6	2		27	14	6	4	5	4	6	7	2

Tab. 7: Kinds and frequency of injuries and damages



Pict. 1: Leitra after overturn and landing in a river bed



Pict. 2: Leitra after hit by a car from behind



Pict. 3: Leitra after hit by a car from the side



Pict. 4: Front part of Leitra after accident 4.1



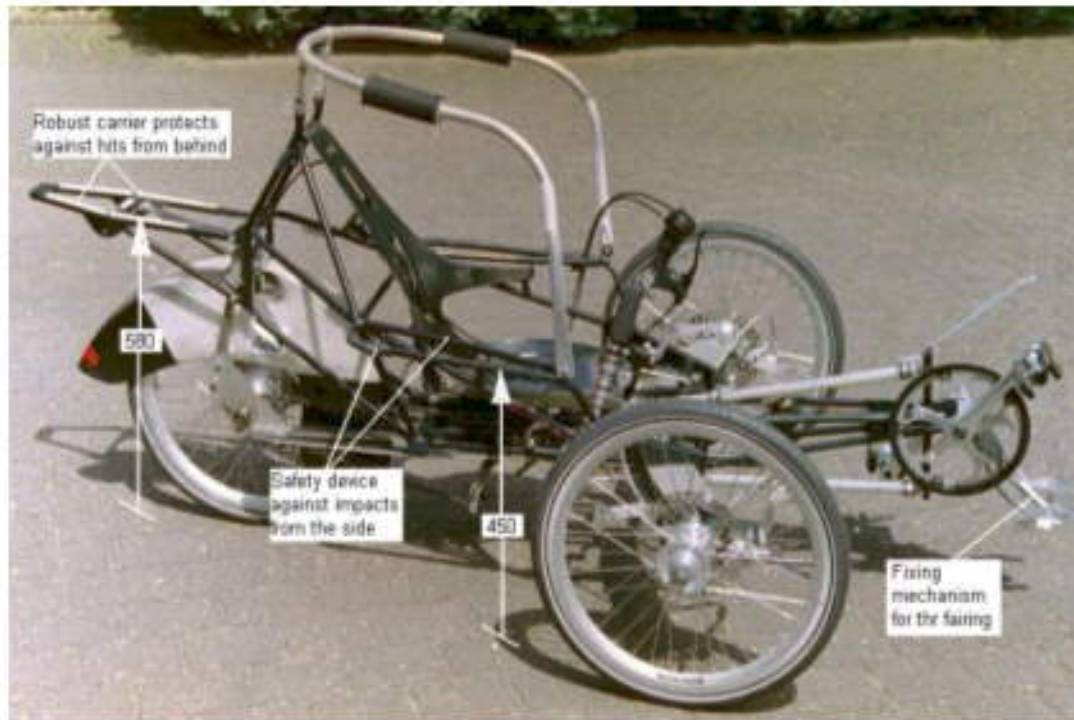
Pict. 5: Bent fixing mechanism between fairing and frame after accident 4.1



Pict. 6: Broken leaf springs after accident 4.1



Pict. 7: Leitra-fairing on a self-built recumbant (O. Heldmann)



Pict. 8: Chassis of the Leitra (A.Schröder)

German Eslava, Reinhold Schwemmer

3 Cab-Bike Velomobile based on a Modular Concept

This paper covers the usage of the Modularity concept on velomobiles. It expands the general thoughts of different issues important for the commercial expansion of velomobiles based on compatibility, standardization of some components up to some ideas on a platform concept for velomobiles and on electric power assistance.

From Modules to Platform to Multi-Purpose Motor Vehicles

“Modularity” in motor vehicles means normally manufacturing vehicles out of different modules. The automobile industry divides for this matter the vehicle in different modules e.g. the engine, the gearbox, the axles, etc. It means the vehicle gets divided in groups of modules. When using a module in different vehicles it gives the opportunity to the manufacturer to have a large scale production of this specific module. In this way the production cost of the module can become much lower due to the large scale manufacturing. The R&D cost of a new vehicle is much lower since some of the modules have been already developed. In other words the modularity is a system to reduce cost using large scale production and less R&D.

“Platforms” are more or less modules. Large part of a vehicle as it is the chassis with suspension, steering and brakes are considered to be a module. Some platforms include even the dash board, the seats. In some cases only the outer shell is different. That is why some of the cars from brands Volkswagen, Skoda and Seat are more or less the same. In any case the platform means a large reduction on production and R&D cost as well as on the acceleration of developing a new car model.

Automobiles used to be manufactured for a specific purpose of the users. But with the time a lot of different adjust abilities have been introduced to the automobile e.g. partly or full foldable rear seats, etc. In the mean time and because of marketing reasons, automobiles have been design for a lot of different usages e.g. four-wheel drives, sports, vans, etc. In the most recent pass some automobiles have been built to be used for more than one usage. At the present the new definition called “Cross-over” has been introduced e.g. for automobiles used to drive fast and comfortable on the highway but at the same time usable for off-road applications with four-wheel drive. Also some automobiles can be converted at the push of a button from a top-less cabriolet to a hard-top. All this type of adaptability is part of the “multi-purpose” concept.

All above stages could be considered to be part of the Modular Concept.

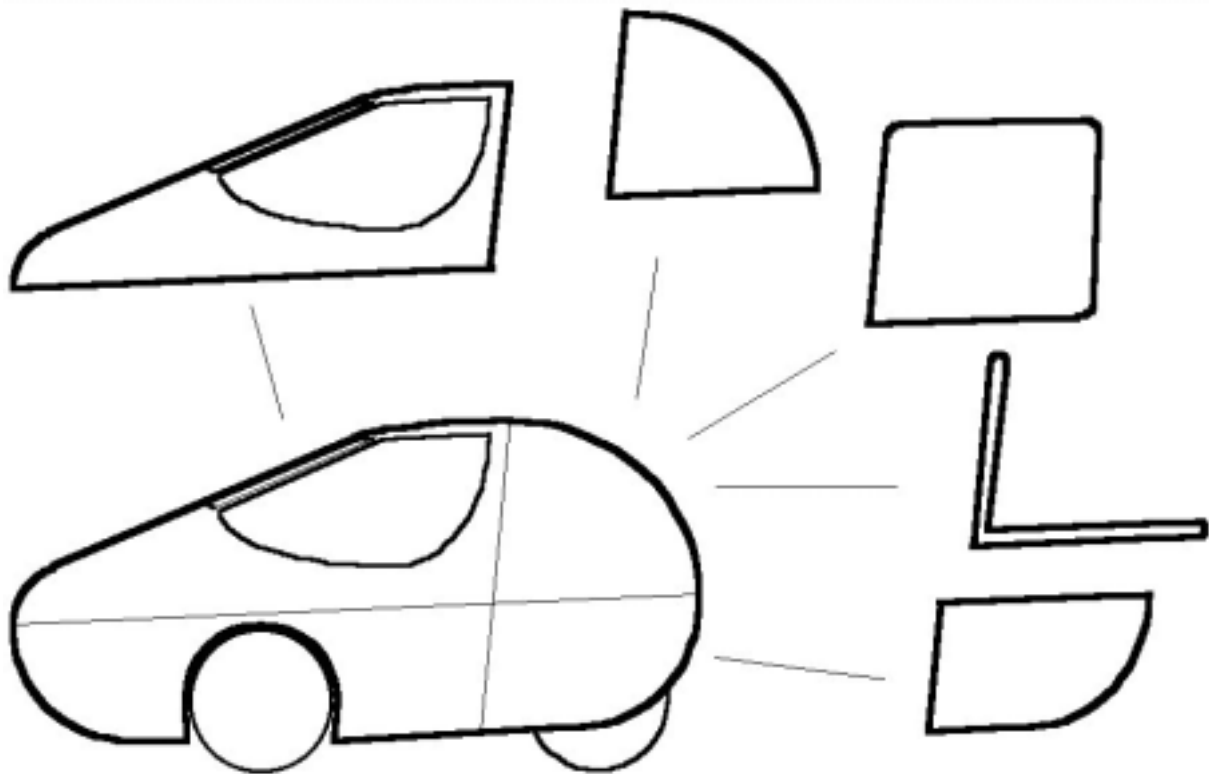
The Modular Concept on Velomobile

The Modular Concept can not be normally applied to the manufacturing of velomobiles. The reason for it been that velomobiles are made just in single production and in very little quantities.

Nevertheless we from our side have used the Modular Concept when designing our Cab-Bike. But we used it for the advantages offered to us when designing a new Cab-Bike velomobile model since it would mean to us to save on R&D.

What we have done is to design the Cab-Bike divided in modules in the same way the automobile industry develop their vehicles. But due to the non-industrial manufacturing of our velomobile the target of our development was different. We wanted to be able to create new velomobile models just by interchanging different modules. In this way we can develop a new Cab-Bike model with small investments and in a very short time.

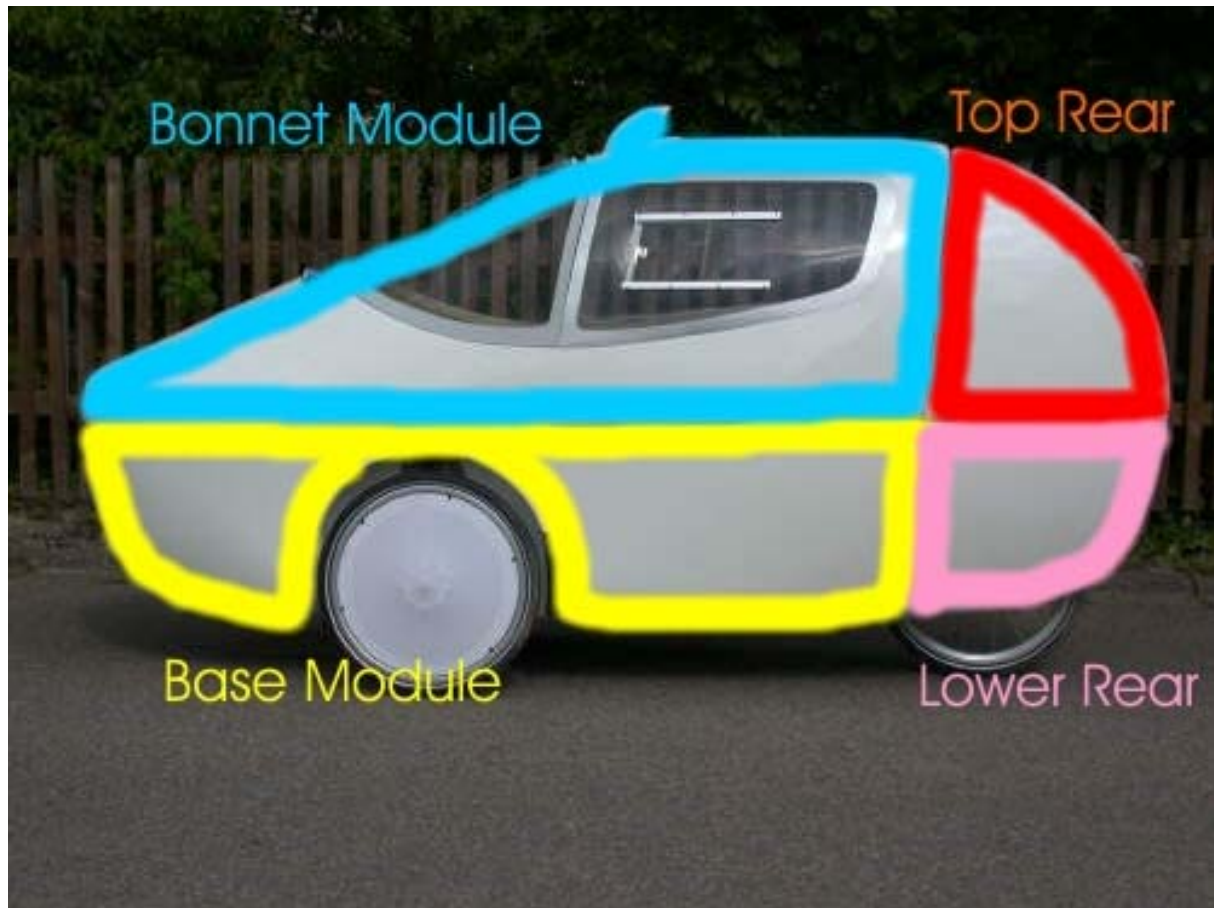
We developed the modules of the Cab-Bike in a way that the end user can change his/her Cab-Bike from one model to another in his/her house in a very short time.



Picture: Modular Concept

The Cab-Bike Modules

The basis of our work was to divide the Cab-Bike in different modules as follows:



Picture: Modules

* The „Base Module“: it is represented by the chassis. This module is designed as a compact monocoque which carries all technical components.

The „Base Module” is the chassis itself. It is made completely in fiber glass and some areas are reinforced with carbon fiber to allow the forwarding of different forces within the chassis.

The “Base Module” carries all the suspension, steering and driving elements and it remains unchanged when used on all different Cab-Bike models.

Although we had developed a different prototype in the first stage we redesign all our Cab-Bike later again. The reason for it been to take over all the measurements and the basic design for our Cab-Bike from the C-Alleweder model from the Co. Flevobike in Holland. This particularity was due to the vision of Mr. Johan Vrielink to archive some compatibility within different velomobiles. That is why all basic technical measurements and lots of parts of our Cab-Bike are very similar and compatible to the velomobiles Alleweder, C-Alleweder, Quest, Mango and Go-One. As what concerns “Compatibility” we shall see more details later on.

One of the most attractive features of the monocoque system is that the chain is completely covered. It means that not dirt from the chain comes into the vehicle. The inside of the Cab-

Bike is therefore cleaner. We considered this feature to be very important for velomobiles to be used on a wider scale.

* The second module is „the Bonnet“. This module is very important since it represent the main feature of our full fairing velomobile. European weather varies a lot from one region to another. In some areas like in most of Germany when it rains it is rather heavy, what does not happen normally in Holland. Also temperature drops constantly to minus 10°C and minus 15°C in winter. For all above reasons most of our development time is expend on further developing the Bonnet Modules.

We have the “Standard Bonnet” which is a fairing covering the cyclist completely. The most difficulty part on the development of this module is the ventilation. It is a fact that it is difficult to have good ventilation inside the Bonnet to avoid the windows to get fog up in particular when cycling uphill. That is why the windows of our Bonnet are either adjustable or removable. We also have developed an inner layer of PU to allow the redirection the ventilation to the windows which have the trend to get fog-up.

We have developed also the “Speedster Bonnet”. On this module the head of the rider is outside the fairing. On doing so the total frontal area of the velomobile is smaller permitting higher speeds. This type of construction is popular in Holland where the rain may be more often as in most European continental countries but is not heavy.

We have also developed the “Head-Protector-Module” which is a sub-module for Speedster Bonnet. This sub-module allows the Speedster Bonnet to be used when the weather becomes not friendly e.g. when it rains. Since the screen of the Top trends to fog-up under certain weather conditions we have improved it by using a non-fog screen composed of a twin anti-scratch material.

* The third module is „the Lower Rear“ part. This module represents the rear lower area of the Cab-Bike. Together with the top rear part it makes an additional luggage area on the Cab-Bike which can be covered in a simple way.

The Lower Rear part has been designed in a way that it can be substitute by another module later on depending on the request of the market. One example of it could be a particular aerodynamic tale.

* The fourth module is „the Top Rear“ part. This module represents the rear top rear area of the Cab-Bike. Together with the Lower Rear part it makes an additional luggage which is very usable for transporting non-heavy but bulky goods. The standard Top Rear has been designed to transport even a box of water bottles.

We are producing the top in two different modules at the moment. One of the modules is for the standard Cab-Bike while the other top rear module is for the Speedster Cab-Bike model. If requested another modules could follow.

Actual Cab-Bike Models

Based on the different modules we produce two different velomobile modules at the moment. Each of these models has got a different characteristic and usage.

The "Standard Cab-Bike" is designed as a full faring velomobile to be used all the year around independently of the weather situation, except when the snow is so high that riding is impossible or the icy roads do not give any holding to the tires.



Picture: Standard Cab-Bike

The "Speedster Cab-Bike" is designed to be ridden with the head of the cyclist outside the fairing. This model rides at a faster speed since the frontal area is smaller in relation to the one of the Standard Cab-Bike. Since some times the weather could become very unfriendly e.g. when it rains or is very cool, we have developed "Head Protector Bonnet". This submodule can be mounted and dismounted at any time on the road.



(Picture: Speedster Cab-Bike)



(Picture: Head Protector)

Exchangeability of Modules

The most important future when developing the different modules is the exchangeability. A good designed module allows the end-user to change from one model to another in very short time.

All Cab-Bike models used the same "Base Module". The other modules can then be put on according to the Cab-Bike model the end-user desire e.g. either the Standard or the Speedster Cab-Bike. Later different modules for making new Cab-Bike models could follow.

The end-user proceeds in the same way to transform his/her Cab-Bike in a different model in a matter of minutes. For instance the Cab-Bike becomes a Pickup Cab-Bike if the user takes away the Rear Top. And if we put the Speedster Rear Top instead of the Standard one than we have a very well ventilated Cab-Bike.

The Bonnet is mounted in a very simple way which allows the end-user to take it away in roughly one minute. In this case the Cab-Bike becomes a Cabriolet.

One sample was our trip to the races at the Cycle Vision in Holland in 2001 and 2002. We just cycle to Holland. There we change the modules to transform the Standard Cab-Bike to a Racing Cab-Bike.

We have also developed the Speedster Bonnet in a way that it can be used at different weather conditions. If it is very warm it can be used as it is. If it is cold but it is not raining it can be used with a small front window. And if it rains the Top sub-module can be built up.

At the same time we have design our modules for possible future uses. For instance the Standard Bonnet and Rear Top have been design in a way that one day amorphous solar sells can be mounted on them.

Compatibility

The modularity is for us only the basis for a successful development. But also very important to complete the modularity is the compatibility with another velomobiles.

As explained before we had developed a full-faired velomobile prototype, which was already compatible in many areas e.g. the steering with the Alleweder. The Alleweder was at that time the most popular velomobile in Holland and actually in the world. Mr. Johan Vrielink met Reinhold in Amsterdam to have a look at the prototype in 1966. Mr.Vrieling the owner of the Co. Flevobike with a look at the future development of velomobiles and to the possibility of making higher amount of parts at a lower price offers to Reinhold the opportunity of using the measurement of the chassis of the very new C-Alleweder as a basis for the Cab-Bike. The C-Alleweder was developed at Flevobike by Aller Jakobs and Ymte Sijbrandij, the today owners of Velomobile NL, the now producers of the Quest and the Mango.



Picture: Cab-Bike prototype

The suggestion of Mr. Vrielink meant for us to start the development almost from the scratch. We actually thought just for a little while and in view of the long term advantages as what concerns the Compatibility to the Dutch velomobiles we decided to start again. This decision meant for us a lot work and money, but as we can confirm today it was the correct one.

Due to above fact the Cab-Bike is today compatible in many areas to the most different velomobiles like Alleweder, C-Alleweder (renamed later Limit), Quest, Mango, Go-One and to the new Leiba and Versatile. It means a total of eight velomobile types have some wide compatibility.

The main advantages of the compatibility are logical ones. For instance if some one in cycling in Holland with a Cab-Bike and the front wheel or the suspension gets damaged in accident, than the user can get almost any spare parts very easily. This statement is valid in general for the brakes, brake components, steering, steering parts, suspension, suspension parts, sit, chain tensioner, rims, spokes, etc.

Standardizing

But compatibility is only the first step towards the success of velomobiles in the market place. A further step is the need of standardizing some parts of velomobiles. The first successful step has been archive during the yearly Velomobile Meetings we organize in Biebertal, Germany. These meetings for velomobile suppliers and end-users give all participants to exchange ideas and experiences. After some conversations with the different suppliers we

agree about a general guide for the wheel size for velomobiles. It was thought that the wheel size 20" and of tyres 20"x406x1.5 would be the most common for velomobiles. This small step seems no so important, but the implication on the expiation of velomobiles is fairly large. In fact not only the producer of tyres can have an orientation for what to produce, but also the price for tyres may get reduced. But more important is the fact that velomobile users can get tyres and inner-tubes at a lot of dealers.

Thoughts on Platforms for Velomobiles

The ideas of a platform are based on the development of the automobile industry with the target to save on R&D and time when developing a new car model. It all means saving time and money. In this case the chassis of a car is used in different automobiles. But not only the chassis but also the main technical parts attached to it e.g. the brakes, suspension, steering, engine, gearbox, seats and sometimes even the dashboard with its gauges. It comes to a point that certain models from Volkswagen (made in North Germany), Skoda (made in Czech Republic), Audi (made in South Germany), SEAT (made in Spain) are almost the same cars. But at the same time there are some car models based on a platform but which are completely different from each other and do target different markets. But at the same time they are lots of cars which are based on the same platform but are completely different from each other.

We do think that it would be possible to make a platform for velomobiles in which one company produces the chassis of a velomobile including some important parts e.g. the brake, suspension, steering. The other velomobile manufacturers can then produce the rest according to their own philosophy. If this idea is followed properly the price of velomobiles can be reduced substantially.

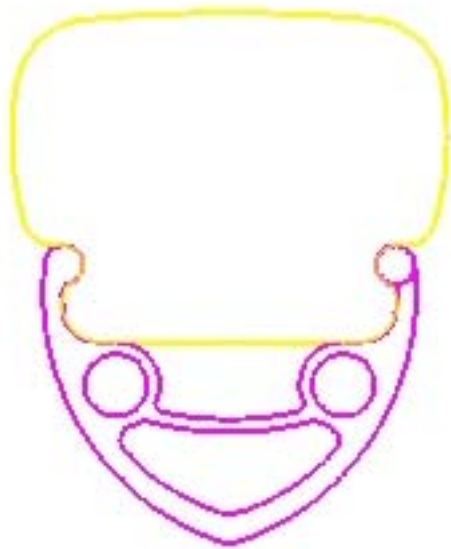
If we analyze following points we are not far from the point to start a velomobile platform. The standardization of tyres (406x20"x1.5") and brakes (Sturmey Archer or sizes of Sturmey Archer axis) together with the general sizes of front-wheel track (72mm to 76mm) together with the distance from front to rear wheel axis (around 1220mm) mean that the steering points according to Hoffmann calculations are roughly the same for all the velomobiles. This is a very big step for a platform.

We also have been working with other velomobile manufacturers (e.g. Flevobike, NL-velomobiles, Greenspeed) on our target of getting specific tires for velomobiles. Flevobike has been working on special rims and full-faired swing-arms. We have been also working with our friends on light systems, electronic controls, directional lights. Flevobike has been working on new material as used on their new Versatile velomobile. If we managed to put all this bit and pieces together we are sure that there is only a little step to be done to arrive to a velomobile platform.

R&D on Specific Parts for Velomobiles

If we continue thinking about the commercial expansion of velomobiles it is important to develop specific parts to be used on all velomobiles. One example is the talks we have been having among some velomobile manufacturers as what concerns specific tyres for velomobiles. The talks are based on the fact that we are using on our velomobiles tyres which have been developed for bicycles. But velomobiles which are recumbent tricycles (or could also have four wheels) do move on the road on a different way.

One example of it is the way velomobiles do cornering. Bicycles do bend on the side while cornering while velomobiles normally do not bend or at least the tyres of the velomobile remain more or less at 90° in relation to the road. That is why bicycle tyres do have a round shape (to be seen when a tyre is cut in radial way) while velomobile tyres should have a square profile similar as on car tyres. The need of a square shape is the fact that when cornering the centrifugal forces of the velomobile can be hold by the lateral forces of the square shape of the tyre against the road surface. The tyres with a round surface as we are using now are designed to control the lateral forces through the bending of the bicycle. That is why we and another manufactures are working together on the possibility of developing specific tyres with square shape.



Picture: PU-tyre

Another example of specific tyres is the reality that actual velomobile users need to be practical technical users. This fact is to be seen in the need of being able to change a tyre at a lot of conditions. This is in particular very unacceptable in cases when it rains; it is cold and may be it is dark. We have to make tires that do normally not have punctures at all e.g. as on PU-

tyres. Some suppliers have been working on this field as Mr. Ian Sims from the Co. Green-speed, Australia, will be speaking later in this seminar.

Just let me recall another field in which velomobiles need specific developments. One very important is the need of specific strong and wider lights if possible switchable for long and short distances. Also part of it is the energy source (dynamo or batteries). Another field is the very often needed directional lights, which for the moment has not been foreseen by any legal regulation. Another field is surely the central electronic control of all elements e.g. lights on/off, lights up/down, light sensor, directional lights, braking lights, cycle computer, hard-rate control, etc.

The Power Assisted System

Since we would like to make velomobile accessible to different type of users it is very important to think about the electrical power assistance (mechanical power assistance would lead us to the automobile). For lot of the actual velomobile users the power assistance is against their principals. But if we think on our desires of expanding velomobile usage it means to expand to people with less physical energy in their bodies. Basically the power assistance is need by less strong user on the physical acceleration of a velomobile. It means when accelerating the velomobile from a traffic light (when the light gets green). Or when there is a gradient e.g. climbing up a bridge or when a road goes up-hill.

In this paper we can not go further into the details of power assistance. But one of the problems of velomobiles with power assistance is the total weight including all its components. A HPV velomobile with some assistance to pass the main acceleration situations should be roughly less than 40 kg and it would be called a light-velomobile. While a velomobile with higher degree of support should normally not pass the 60 kg threshold. This latter velomobile would be called no-so-light vehicle. Passing the 60 kg limit would come to the need of more power assistance, larger batteries and higher and higher weight. The result would be an electric vehicle. One not so positive example of this development was the Swiss TWIKE which was though to be a HPV and finished being a not very successful electric car.

You can read more details on our story we have written for the monthly newspaper Bike Europe, Vol. 5, No.11 of November 2001.

Our Modular Solutions for Power Assistance

As what concerns our ideas on the electrical power assistance (an electrical motor helps the pedaling) they are also based on the Modular-Concept.

Within our modular thinking we are following two different paths. One is based on the traditional power assistance within the Cab-Bike. Another solution is what we called a detachable assistance consisting on having the power assistance outside the Cab-Bike.

Power Assistance within the Cab-Bike

Based on our modular system the standard Cab-Bike is used to put in the power assistance. The up-grade is made just adding just some components. But since the now valid European laws have some particularities some components need to be changed.

Just let me recall the basic request of the European law which is now valid for all European countries.

For specific details please do have a look at the “Directive 2002/24/EC of the European Parliament and of the Council of 18 March 2002”. As what power assistance without the need to be approved following requirements are needed:

- a maximum continuous power output of 0.25 kW
- the assistance has to be continuously reduced and finally cut at 25 km/h
- the assistance has to be cut as soon as the cyclist stops pedaling

Based on these requirements we put a special swing-arm on our Cab-Bike. This particular swing-arm carries the motor. On the shaft of the gearbox of the motor we built a double sprocket with a freewheel which at the same time works as mid-axis.

Additionally we mounted a special chain-wheel which has been developed by the company Lohmeyer in Germany. This latte company specializes on electric assistance for very light vehicles. The special chain-wheel incorporates a freewheel which allows to measure when the cyclist stops pedaling and in this way the power assistance can be cut off.

The only limit for our full Modular Concept of this type of power assistance is that a standard Cab-Bike can not be change to this type of power assistance in a very simple way. The main problem being that the position of the swing arm axis is slightly higher for the special swing arm.



Picture: Power Assistance

Detachable Power Assistance

Within our Modular-Concept we have now add another module to our concept of full compatibility. We just simply took out the motor and battery out of the Cab-Bike and put it in a detachable E-trailer module. This basic concept had been tried before on a velomobile by Mr. Rolf Blend in Germany. We just put the control of the assistance on the handlebar of the Cab-Bike. We also made the E-trailer detachable in just a couple of seconds just by putting a mechanical extracting devise on the trailer and a plug for separating the cable.

Additionally we will make an additional part to allow the connection of the E-trailer to a normal bicycle. In this way the owner of the E-trailer can use it also on his/her other HPV vehicles at home.

The fact that our Modularity Concept is completely fulfill in our E-trailer means that this module can be use at any other velomobile or trike which has a standard rear wheel. This is one of the advantages when concentrating on a Modular Concept. At the end a module has to be so well suitable to standard elements that it can be used on any velomobile or trike using some standard basic elements. In our case the E-trailer module can be used on almost any normal bicycle just using an adapter.



Picture: Detachable Power

Solar-Cells

Last but not least. When designing our Cab-Bike we already have explicitly foreseen areas for the installation of Solar-Cells as a new module. Unfortunately for all of us the industry is for the moment not investing in R&D of curved or bendable amorphous solar-cells. Nevertheless we all should keep optimistic since one day we may get political world leaders who care a bit about our small very fragile world and less about just "Killing for Oil".



Picture: Solar-Cells

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Joachim Fuchs, Andreas Fuchs

4 Noise in velomobiles

Introduction

In the past, many criteria for the construction of velomobiles were discussed. Among that were weight, comfort, design and many other themes. An additional, important point is that it can be noisy in velomobiles. The aim of this overview is to introduce the basics, rather than to give a precise physical description.

The task is not simply to reduce the noise level but also keep the sound agreeable and convenient. That's why physical and psychological effects have to be regarded separately. In one velomobile, the physical noise level can be really high, but it does not seem so. In another velomobile, it can be just the other way round. The feeling of noise can be rather different. A singing bird for example is more agreeable to listen to than a passing car. The industry has since some time discovered this subject and employ engineers who work on a good sound of a shutting door.

To give an approach of what is important to know about noise in velomobiles, here are some physical basics. Noise can be described as an oscillation of the density of air. Energy is transferred from the source to our ear. The range of the intensity our ear can detect is rather high. A convenient unit for noise measurements in the frequency range that is relevant for human beings is dB(A).

Due to the logarithmic scale of the decibel unit, noise levels in everyday situations are typically in the range of 0-100 dB(A). Noise levels can not simply be added. Two identical noise sources raise the noise level by 3 dB.

Some typical noise levels are shown in the following table:

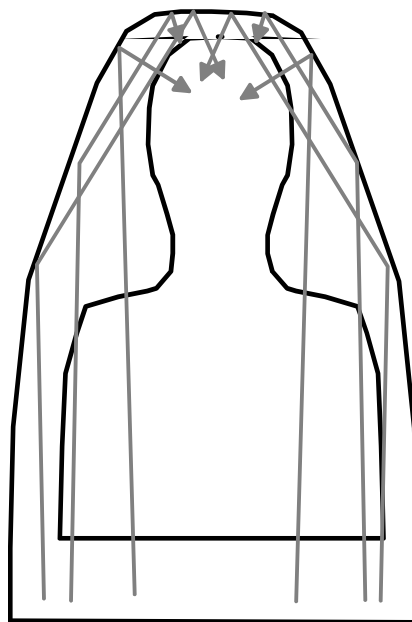
Noise emission source	noise level /dB(A)
typical background noise in houses	30...40 dB(A)
conversation	ca. 50 dB(A)
radio or TV	ca. 60 dB(A)
passing car	70...85 dB(A)

Back to the velomobile: What are potential sources of noise in a velomobile?

Generally, the source of the noise inside a velomobile is the rider. The energy of his pedalling motion is transformed manifold into heat. One very small fraction is transformed to oscillations we here as noise. Following the drive train from the foot of the rider, we can identify several noise sources that can be regarded as contributions to a total noise in a first approach. Such contributions can be the chain running over the cogs, bearings or tires rolling over the road. In addition, bumps from the road are transformed into oscillations inside the velomobile by various ways: the suspension swings, the fixing of the fairing and nevertheless the fairing itself.

It would be an interesting question to know which source dominates the noise level inside velomobiles. By microphone arrays, it is possible to detect noise emission sources. Nevertheless, these devices are too large for measurements inside velomobiles.

Several further effects make the subject more complicated. Transportation by conduction and reflection has to be taken into account. The head of velomobile riders for example is often within the focus of the fairing shell. This can locally enhance the noise level close to the ears of the velomobile rider (picture 1).



Picture 1: Sectional sketch of the upper part of a velomobile. The head of a velomobile rider is within the focus of a fairing shell.

Another design problem of velomobiles is the phenomenon of resonance. Fairing shells of a velomobile are often made out of glass fibre reinforced plastics. Like a tuning fork, this plate has a certain frequency range. If the fixing of the fairing is oscillating just in that frequency range, the fairing part can get in resonance, and the energy of the vibration fixing is transferred to the fairing part, which will start to vibrate intensively. Often, this swinging part result in a noise that can be described as rattling or bumping.

To avoid noise in velomobiles, the construction has to be properly engineered including each single part of the velomobile.

To give a practical example, a metal sheet can be brought in resonance by moving it at one end quickly. The noise emission strongly depends on the size of the sheet.

To avoid rattling of the fairing, the reduction of the plate size or fractioning the plate to several, individually fixed fairing parts could be a solution. This will result in a frequency shift towards higher frequencies and a reduction of the noise intensity.

Another way to change the properties of a fairing is to change the stiffness of the plate. According to the example discussed above, a stiffer plate as well as a softer plate (for example a foam plate) could solve the problem.

The following listing can be used as a starting point to reduce noise in a velomobile:

- Reduction of the size of hard shell segments that are individual fastened to the frame of the velomobile (see above).
- Variation of the stiffness of the fairing shell (fabric, foam or hard sandwich panels; see above).
- The fairing should be mounted with dampers. On rough road surfaces, strong forces act on the fairing and the fixing. The reason is the high inertia of the fairing caused by the air resistance of the fairing perpendicular to the driving direction.
- Soft suspension with long travel to avoid induction of fairing movements.
- Slick tires are less noisy compared to conventional bicycles tires. The partition of a car tire tread pattern is normally irregular in order to avoid "singing".
- If the velomobile construction is realised with the head outside the fairing, noise is almost no problem. There are different constructions to realise a foldable cover in order to maintain weather protection.

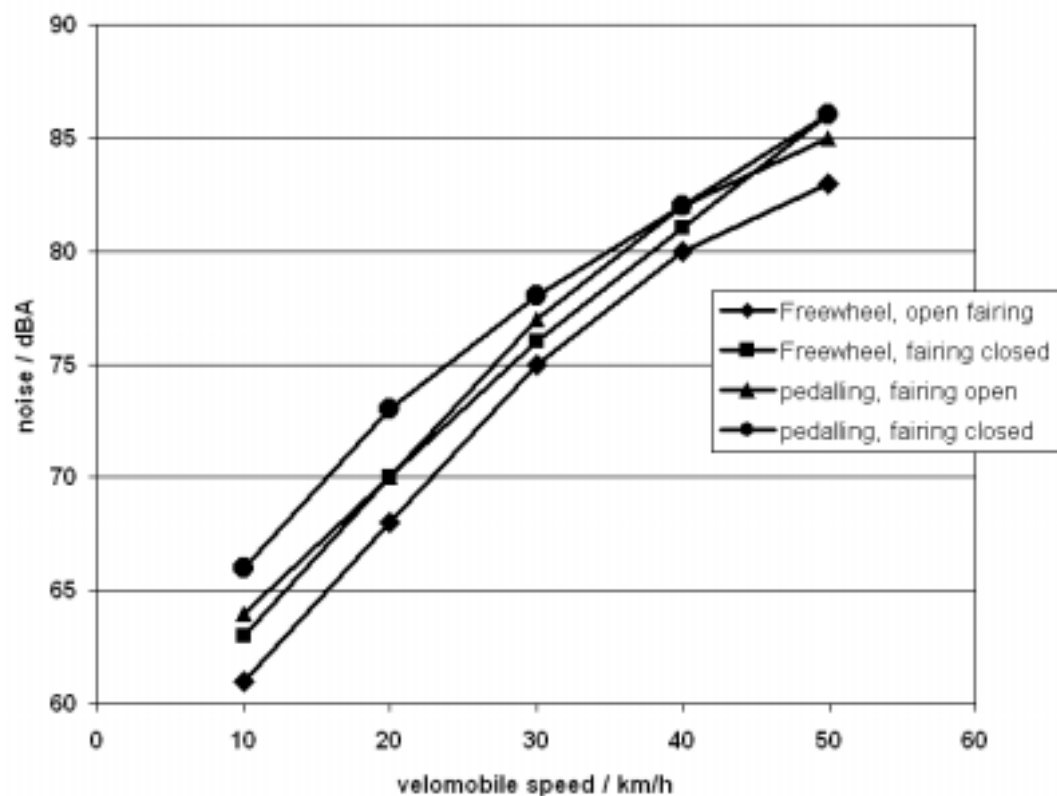
Noise level measurements

The following measurements were performed with a noise level meter Voltcraft 329. The “Aeolos” single track velomobile (picture 2) was designed by the author and has passed more than 80000 km since completion in 1995. The fairing shell is made out of glass fibre reinforced plastics. The vehicle is full suspended and the fairing is mounted with dampers.

Measurements of noise levels inside the fairing with respect to different conditions are shown in picture 3.



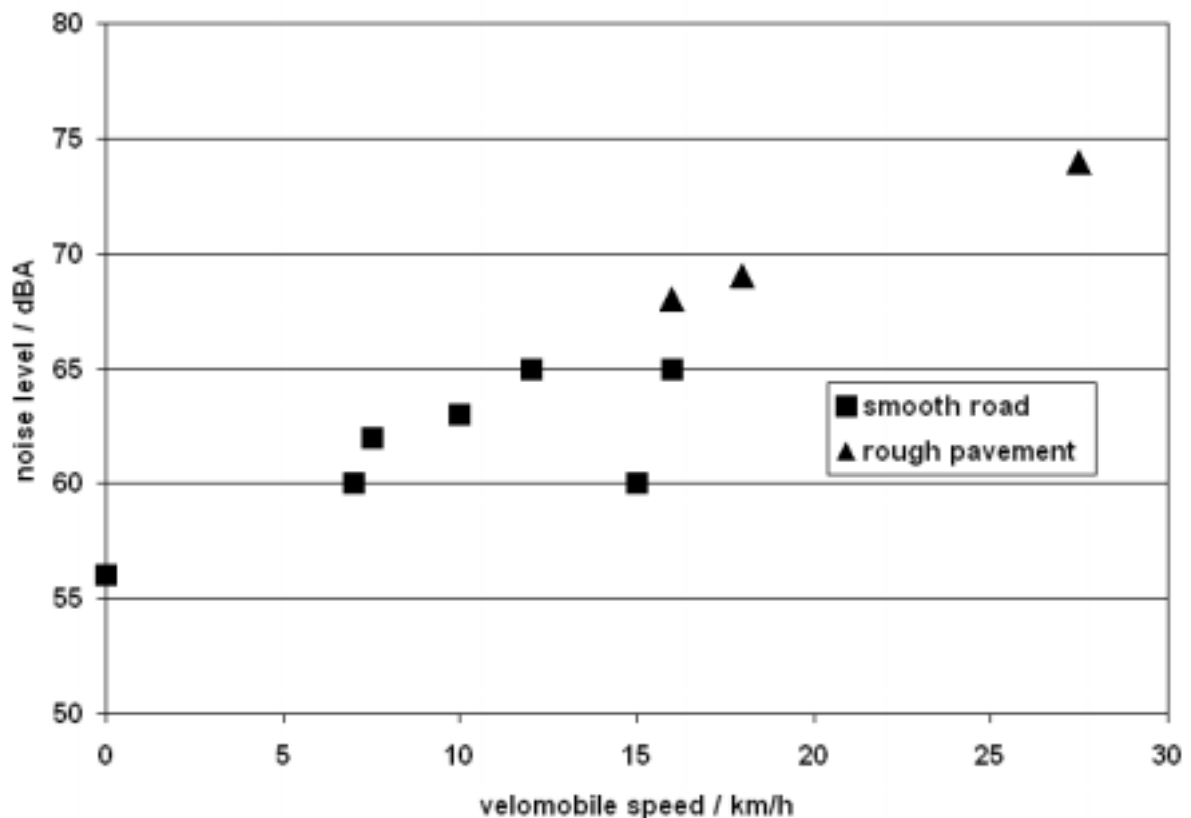
Picture 2: “Aeolos” single track velomobile



Picture 3: Noise level inside the “Aeolos” velomobile

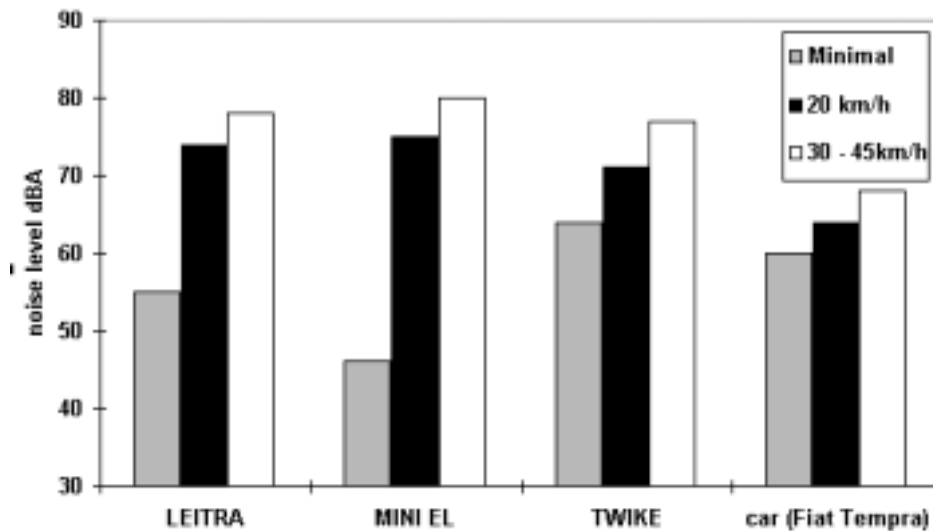
First of all, the graph in picture 3 shows that the noise level depends on the speed of the velomobile to a large extent. The rear part of the fairing can be pushed back to result in a higher ventilation and to get in and out. The measurements with the lowest noise level were gained without pedalling and the fairing pushed back (open fairing). In this case, the noise from sources inside the fairing (for example from the tires) is reflected at the fairing shell to a minor extend. As expected, pedalling with the closed fairing results in the highest noise levels.

In the next graph (picture 4), results from measurements by Andreas Fuchs are presented. A "Leitra" velomobile was used for these measurements. Although the speed range is less than in the previous example, the noise level inside the Leitra seems to be quite similar in comparison to the Aeolos velomobile. The data of both measurements can be a first approach to estimate the noise levels in velomobiles.



Picture 4: Noise level in a Leitra velomobile

Further measurements of Andreas Fuchs include a car, the Leitra velomobile, the Twike car and a Mini-EI electric car, also known as City-EI. The results in picture 5 show, that the noise level inside velomobiles is still relatively high compared to other vehicles.



Picture 5: Comparison of the noise level inside different vehicles

Conclusions:

- The subject 'noise in velomobiles' is rather complex. Slight changes in construction may result in large effects in noise levels. A detailed analysis is necessary to reduce the noise.
- It is important to avoid resonance effects, such as 'rattling' and 'bumping'.
- The noise of common velomobiles can be rather high compared to other means of transportation, like busses, cars and trains.
- In addition to the physical noise level, one has to take into account that there are also psychological effects regarding noise in velomobiles.
- The aim could be to reduce the noise level to 70 dB(A) or less in order to make it possible to hear radio or music (CD-player) in a velomobile.

Andreas Fuchs

5 Engineering of human powered vehicles using anthropometric data

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Abstract

For comfortable use, human powered vehicles need to be adjusted to the user very precisely. Designers therefore need to dimension the vehicles according to anthropometric data of the user group. Such data for example allows to define the range over which the bottom bracket or the seat and the handle bar should be adjustable.

In part A, this paper references some sources of anthropometric data and introduces how to apply such data.

Especially the design of the passenger compartement of pure or hybrid human powered vehicles is not straightforward due to the complex shape of the space needed by legs propelling rotatory pedals. The design process can be facilitated by using suitable tools such as manikin templates when at the drawing board or numerical models when operating a CAD-system. Manikins or numerical models allow to find the trajectories of knee, heel and tiptoe.

In part B of this paper a simple stick-leg model is presented that allows to calculate the trajectories of knee, heel and tiptoe using a spreadsheet. Unwanted interferences between the moving legs and parts of the passenger compartment or controls may be detected early in the design process.

For convenience, a version of such a spreadsheet is provided by the author.

Introduction

In the 80's, most hpv were custom made by the builder for himself or for friends. It is therefore not astonishing that these early vehicles did not fit much smaller or much taller people.

Today, more and more commercial hpv's and velomobiles are available. In order not to limit the number of potential users, these vehicles need to be adjustable to fit a wide spectrum of stature heights and body proportions.

The author of this paper is about 197 cm tall. Being that tall, it is quite common that testing of faired and even unfaired hpv's is impossible because the vehicles are designed for a limited range of users and because the range over which seat, pedals and control elements can be adjusted is much too small.

Aquiring of a hpv's often at least leads to rebuilding of the vehicle using a bottom bracket shell with longer arm, mounting longer stems to rise the handlebar, and to order the biggest seat if available at all.

In faired vehicles, it is very common that the noses of the vehicles are not wide enough to fit the authors shoe width (size 46).

As a keen Leitra rider, in the early 90's Andreas Fuchs was working for some time in the workshop of C.G. Rasmussen when CGR began to build the moulds for the big version of the Leitra fairing. Later, Fuchs aquired that new big fairing to replace the very old version of the Leitra fairing which has been lengthened to fit the author.



Fig 1. 197 cm tall Andreas Fuchs helping to build forms for the big Leitra fairing in the early nineties (Foto by Ian Feldman, <http://www.ihpva.org/people/ianf/bm92/Leitra/090.htm>)

On the other end of the stature-spectrum, for small women, it is often difficult to find hpv's that fit them. E.g. the seat of two wheelers are often too heigh above ground which makes safe starting and stopping almost impossible. The range over which bottom bracket or seat may be adjusted often is too small for people at the end of the size-spectrum.

Still, there are not that many commercial hpv's for children. Due to the steady growth of the market segment of recumbents it can be expected that more models for children will be produced. This requires careful reference to data bases with measures of kids and growth curves.

A. Application of anthropometric data to hpv's and velomobiles

General information about anthropometric data and available data bases

Tables of body measures can be found in books about ergonomics, human factors, or industrial manufacturing systems engineering. Also, there exist norms (DIN 33402, DIN EN 547 etc.). Very useful is Pheasant 1998.

Lots of information about how to apply these data bases can be found in the same references. We give a short summary (Sanders and McCormick 1993):

- Anthropometric data usually is compiled measuring some or many individuals from a certain specific group of persons: US military personnel, children from a certain age group, scandinavian females, Japanese males, etc. Therefore choose the data base that is most representative for the users of your vehicles.
- Body measures of a specific group of humans are distributed: Minimum, maximum and average values exist. Often, these distributions are approximated with normal distributions which are described by two parameters only: average, and standard deviation. The relative position of an individual with respect to a group of humans is given using "percentiles" (see below). The worksheet coming with this paper allows you to calculate the average and standard deviation from the percentile values and vice versa.
- There is no individual of which every anthropometric measure is x percentile, because some have short legs with respect to stature and others have long legs. Therefore summing up x percentile values of leg length and upper body lengths may not yield x percentile value of stature.
- Consider that stature increased during the last century at least of people growing up in industrialized countries. Therefore do not use data that is based on measurements that are too old, or at least round up tolerances!
- Anthropometric measures are related to body exteriors, because these measures can (easily) be made. Too few data is available regarding lengths between links. However this data would be important for the designers of human powered vehicles in which users do not take positions as static as in cars since they are pedalling. In this paper link lengths are calculated using factors and multiplying those with stature height.
- Anthropometric measures are different for static and dynamic body positions. This is due to the nature of some human body links: The shoulder for example is geometri-

cally not as well defined as a mechanical link and therefore centrifugal forces on the arm may lengthen “arm length”.

- Clothes, and, relevant for winter hpv rides, gloves, require to add tolerances to anthropometric measures! Gloves may increase hand dimensions up to about one to two centimeters in radius! Do not underestimate the tolerances that have to be added due to shoes. Thick clothes are not needed in order to ride faired velomobiles in winter. But on unfaired recumbents in winter clothes may add several centimeters in radius. The volumes in a faring of velomobiles that are used for racing for the head of the rider need to be so big that helmets can be worn. Vision to the side through windows or by mirrors needs to be possible.

Parameterisation of anthropometric data: Percentiles, normal distribution

Usually, anthropometric data is presented in form of tables including percentile values. Percentiles are the unit of an ordinal scale that references a certain body dimension or weight within a certain population. Percentiles tell you how many percent of the members of said population have a body dimension smaller than x mm. Usually, the length of a certain body dimension is given for the levels 5, 50 and 95 percentile. 50 percentile heights or lengths correspond to the average values.

The reason is that products manufactured according to modern industrialized standards are often designed to fit people within the range limited by the 5 percentile female and the 95 percentile male. All people bigger than the small females and smaller than the tall men therefore can use the product.

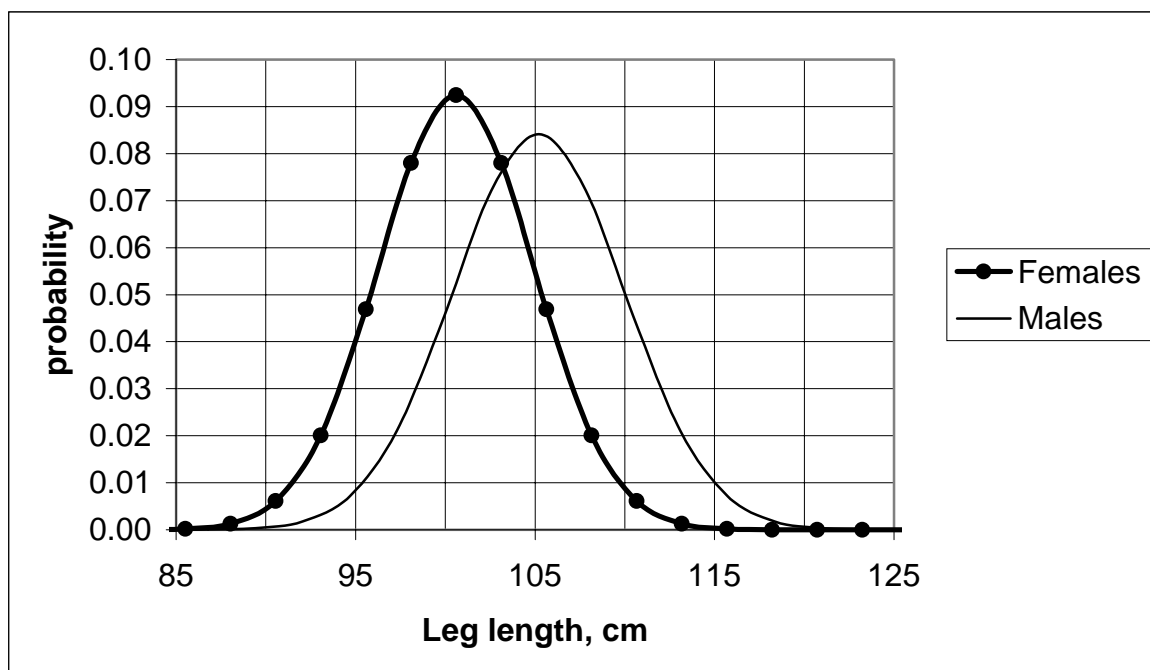


Fig. 2 Leg length of females and males according to the anthropometric tables below.

The graph shows common knowledge, that is that females usually are shorter than men and thus also, on average, have shorter legs.

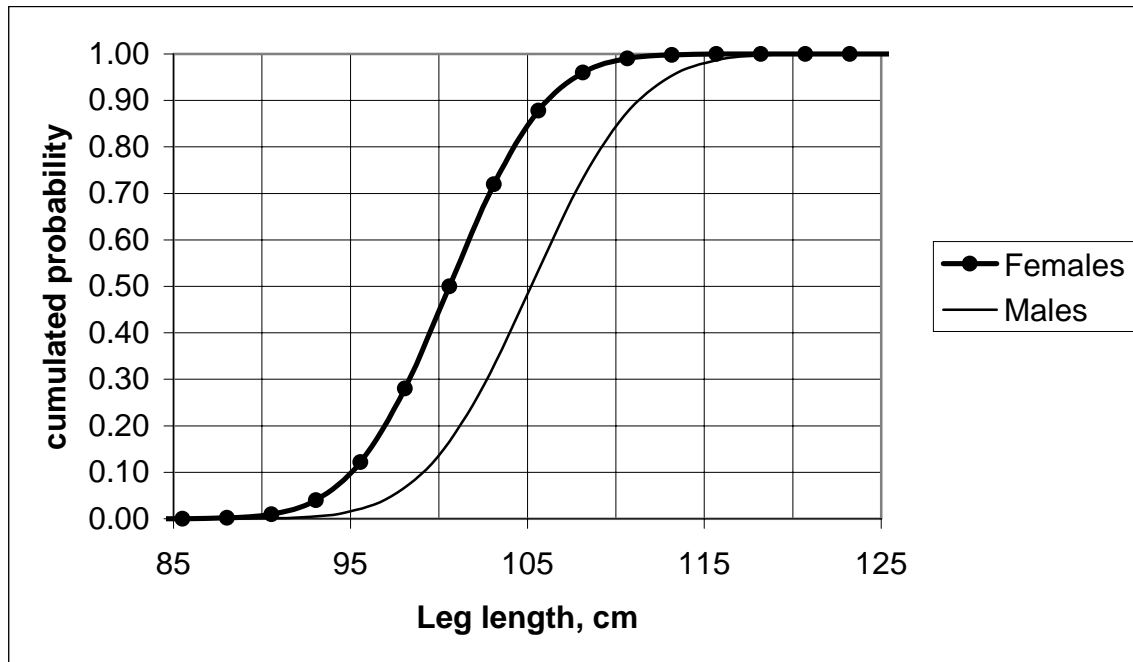


Fig. 3 The cumulated leg length distribution. The scale on the vertical axis gives you percentiles. Examples: The leg of the 5 percentile female is 93.5 cm, leg length of the 95 percentile male is 113 cm.

Tall guys like for example hpv'er Ymte Sybrandy or the author are even above 95 percentile in many scales of stature. Therefore, and in order to take the slow increase with time of the stature of the general population into account, you may consider designing for the range 5 percentile female, up to 98 or 99 percentile on a scale for e.g. scandinavians which are among the tallest Europeans.

Principles of the application of anthropometric data

This principles are cited from Sanders & McCormick 1993. Dependent of the parameter that is being dimensioned different principles apply.

a) Design for the extreme

Using this principle, a certain parameter is dimensioned such as to fit also the most extreme individuals (e.g. 99 percentile).

In human powered vehicles this principle applies e.g. to strenght of vehicle. Since no designer can exclude that very heavy persons sit into it the strenght of the seat supporting structures should be sufficient to bear the weight of heavy individuals.

On the other hand, brake pulling forces should be limited so that also weaker individuals are able to brake the vehicle with a reasonable braking deceleration.

Size of the vehicle may be limited to only fit individuals within a certain percentile-band. So designing for the extrem does not always apply to lengths and volumes.

b) Designing for the adjustable range

This principle is commonly applied in human powered vehicles in that the seats or the bottom brackets may be moved to fit a certain leg length. In cases in which the range of adjustment has to be limited e.g. for static reasons, 3 differently sized basic models of a vehicle may be built to fit all people e.g. between 2 and 98 percentile.

c) Designing for the average

Handles of control elements such as steering sticks may be designed for the average. The fit will neither be perfect for small and large individuals, but everyone may use that steering if the circumference is such that small women as well as tall men hands find sufficient grip.

B. Engineering of the leg space of hpv's and velomobiles

In the domain of faired human powered vehicles the proper design of the interior of the vehicle is crucial. For free movement, legs pushing and pulling rotatory pedals as commonly used in human powered or human power-hybrid vehicles need lots of space. For correct placement of controls (steering and braking controls) and passenger compartment interiors the envelope of this space should be known to the designer. Using trigonometry some key points of the envelope of the pedalling leg can be calculated.

When actually designing manikins are useful at the drawingboard or numerical models are useful in CAD¹-systems. One may make a cardboard template of the envelope of the moving limbs or define an envelope-curve in a 2D- or 3D-CAD².

Design processes are iterative: Sometimes, either the locations of the saddle/seat and/or the pedal axis need to be changed even quite late in the development-process. Accordingly, the envelope of the moving legs also changes its position: The template or the curve may be translated and/or rotated. Then interferences between the moving legs and controls or other parts are detected with ease.

¹ CAD: Computer Aided Design

The shape of the moving-leg-envelope

The distance of saddle/seat and pedal axis depends on leg length, knee and heel joint movement and the crank-radius. It needs to be defined early in the design process. Once the relative position of hip joint and crank axis and crank radius are defined, the shape of the space needed by the moving legs further depends on the ratio of the lengths of upper and lower leg limb and the position of the pedal axis under the sole of the foot.

Please note that some people do not pedal with equal placement of the left and right foot on the pedals. So the envelope of the left and right leg may look different. This has to be taken into account when choosing tolerances between the envelopes and controls or passenger compartment interiors.

The model to calculate the moving leg-envelope

A primitive stick-model is built to calculate the shape of the moving-leg-envelope (Fig. 4). It consists of upper leg limb stick, lower leg limb stick and heel-joint-pedal-axis stick. The crank arm is a stick also. The joints (hip, knee and ankle and pedal axis as well as bottom bracket axis) are pin joints in a direction perpendicular to the main plane of the leg bent in the knee and perpendicular to the plane of the moving crank arm (the leg plane and the pedal plane are parallel).

If the hip joint location, the bottom bracket location, the pedal arm angular position and either the knee or the heel angle are given, the positions of all sticks of the assembly are defined. To get the position of the knee cap and the heel, two short sticks are added. Their direction is chosen as the center line of knee and heel angle. The envelope of the toes is calculated by adding a stick of a certain length in the direction of the heel-joint-pedal-axis stick.

We choose to prescribe the heel angle instead of the knee angle. If the heel angle is given in dependence of the crank arm angular position, then the trajectories of all joints (pedal, heel, knee) and of the tiptoes, heel and knee cap are computable in dependence of the angular position of the crank arm.

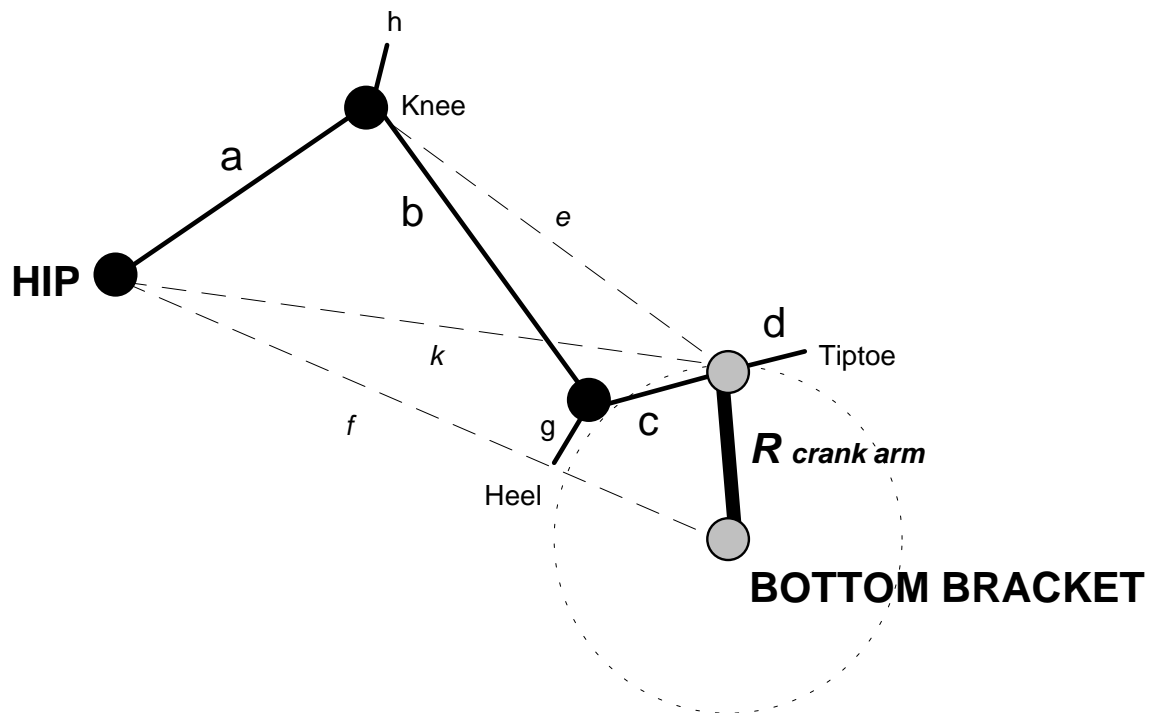


Fig. 4 The stick-model of leg and crank arm

Mathematically, the stick-parts (thin lines) of the leg are vectors (two dimensions):

a: upper leg limb

b: lower leg limb

c: heel-pedal-distance

d: pedal-tiptoe-distance

h marks the distance of the knee joint to the knee cap. Similarly, g defines the distance from the heel joint to the heel exterior.

The vectors e, f and k are used for the calculations only (broken lines).

The circles indicate joints with their axis perpendicular to the plane of the moving leg and the plane of the rotating pedals.

Fixed in space are the hip joint and the bottom bracket axle (vector f). The rotatory trajectory of the pedal axis is indicated with a dotted line; crank arm length is R (thick line).

The mathematical formulation

The crank arm angular position α is the main variable. The heel angle β is prescribed as a function of the bottom bracket axis angular position. Using vector geometry then the positions of all the limbs of the leg can be calculated.

The formulas were input into an Excel-spreadsheet. It allows to calculate the position of all the sticks of the leg-model as well as the trajectories of knee, heels and toes. Results are shown in Fig. 7a (stick model) and b (trajectories).

The distance from heel joint to pedal axis c was calculated from the stick-man foot length ($0.152 \cdot \text{body height}$) by multiplying with $0.72 \approx 21/29$ ($c \approx 0.11 \cdot \text{body height}$).

The radius h from the knee-joint to the knee-cap was calculated as (knee height sitting - knee height standing). Using factors in the way Drillis and Contini do, one can e.g. calculate $h = [\text{body height} \cdot (0.315 - 0.285)] = 0.03 \cdot \text{body height}$.

Heel radius g was calculated as the pythagoras of ankle height and the term $0.31 \approx 9/29$ times foot length according to Drillis and Contini (0.152). The result: $g = 0.047 \cdot \text{body height}$.

Crank arm lengths are somewhat dependent on body size. Typical crank arm lengths used in today's bicycles are listed in table 2.

Exterior body measures and approximated stick lengths

Most anthropometric data was collected for external body measures. For convenience, examples are listed below (Fig. 5a to 5c, Table 1).

Actually, when for example the knee-joint is bent, a sliding and rotating motion takes place inside the knee instead of a pure rotatory motion around a pin joint: the instantaneous center of rotation follows roughly a semicircular path. But to keep computer manikins and drafting manikins simple, point centers of rotation are chosen. The accuracy is sufficient for many design applications.

To actually calculate the trajectories of the leg-joints and kneecap, heel and tiptoe, one needs to know the length of the links. The primitive stick-model by Drillis and Contini (1966) allows to calculate link-lengths of adults from their body-length (Fig 6, Table 3).

The proportions of the links of humans younger than 20 years change dramatically with age and therefore the simple stick-model of Drillis and Contini is much too inappropriate. Data for children and youngsters may be taken e.g. from rough measurements on living examples.

Once the correct lengths of the links are input into the excel sheet, the trajectories are calculated with ease. Using plots as shown in Fig. 7a and Fig. 7b the designer may now define positions of controls and passenger compartment interiors.

One should not forget that the dimension from the hip joint to the back support of the seat and to the horizontal seat surface have to be taken into account.

Since the stick-model of Drillis and Contini is a crude approximation and since people may wear thick clothing, one should design with carefully chosen tolerances.

One should also consider that the 5% smallest women and the 5 % tallest men will not fit into the designed vehicle when the 5 percentile women and the 95 percentile man were chosen as the design limits. In this century from one generation to the next people became taller: It is therefore wise to choose the tolerance of the 95 percentile measures bigger than those of the 5 percentile measures.

The trajectories may be input in the form of ASCII-files into CAD-systems³.

As a final check before building any prototype, one may compare the dimensions of the interior of the vehicles passenger compartement with the exterior anthropometric dimensions listed in Table 1.

³ Not all CAD-software does import ASCII-files: A first CAD-system may have to be used to import ASCII, and to export to a second CAD-system in a format such as DXF or IGES etc. if the second is not able to read ASCII

Summary of how to apply the leg model

a) Standard application:

1. Calculate joint trajectories and add space for the distance of the joint to the exterior surfaces (eg. distance from knee-joint to knee-cap)
2. Design the vehicles using the trajectories of the exterior points (knee-cap, heel, tiptoes)
3. Before actually building a prototype, double check the chosen dimensions of the passenger compartment interior using anthropometric data such as that in Table 1 or in DIN norm 33402 or that given in Pheasant 1998.

b) Other applications:

- Study the influence of crank length onto the knee angles (By doing that we found that it is more appropriate to use a 160 mm crank for small women)
- By comparing the trajectories or stick-model plots of the lower and upper design limit (usually the 5 percentile women and the 95 percentile man) the needed range of adjustment of either seat or pedals is found easily.
- Take the trajectories from Fig. 7b and e.g. make cardboard-templates from them. By turning around an axis through the hip, the templates may be used for any difference in bottom-bracket to seat height.

Abbreviations

Variables:

α crank angular position ($\alpha=0$ when horizontally and pointing in the direction of travel)
 β angle between lower leg limb and foot; $\beta(\alpha)$

Constants:

crank arm length R
upper leg limb a
lower leg limb b
'foot length' c
'toe length' d
radius of knee h
radius of heel g

Points, fixed in space:

hip joint A
bottom bracket axis X

Vectors:

f Position of bottom bracket
 k Actual position of pedal-axis

References

R. Drillis and R. Contini. Body Segment Parameters. Vocational Rehabilitation Administration, Grant No. R886, 1966

Stephen Pheasant. Bodyspace – Anthropometry, Ergonomics and the Design of Work. Taylor & Francis 1998. ISBN 0-7484-0326-4

John A. Roebuck, Jr. Anthropometric Methods: Designing to Fit the Human Body. Published by: Human Factors and Ergonomics Society, P.O. Box 1369, Santa Monica, CA 90406-1369, USA. Voice (310) 394-1811, Facsimile (310) 394-2410

Mark S. Sanders & Ernest J. McCormick. Human Factors in Engineering and Design. McGraw Hill 1993. ISBN 0-07-112826-3

Heinz Schmidtke. Ergonomie. Hanser 1993. ISBN 3-446-16440-5

Tables:

<i>Measurement</i>	Males			Females		
	<i>Percentiles</i>			<i>Percentiles</i>		
	5th [cm]	50th [cm]	95th [cm]	5th [cm]	50th [cm]	95th [cm]
<i>Side View Standing</i>						
1. Forward functional reach	61.5	67.1	72.4	55.9	61.0	66.0
2. Elbow height	102.1	110.5	119.1	94.5	102.1	109.5
3. Waist height	97.5	106.4	115.3	93.2	101.6	110.0
<i>Front View Standing</i>						
4. Knuckle height	70.1	76.5	83.1	67.1	72.9	79.0
5. Shoulder height	133.1	144.0	154.9	122.4	132.6	142.5
6. Eye height	159.5	170.9	182.6	142.0	152.4	163.1
7. Stature	164.1	175.5	186.9	151.9	162.6	173.0
8. Functional overhead reach	195.1	208.0	221.0	180.6	192.5	204.5
<i>Side View Seated</i>						
9. Thigh thickness	13.5	16.0	18.5	12.4	15.5	18.5
10. Eye height	73.9	80.0	86.1	69.1	74.9	81.0
11. Sitting height	85.6	91.4	97.5	80.0	86.1	91.9
12. Functional overhead reach	115.6	125.5	135.4	106.9	116.1	125.0
13. Elbow to functional reach	32.3	36.1	39.9	27.7	32.3	36.8
14. Knee height	49.5	55.1	60.5	46.0	50.5	55.1
15. Popliteal height	39.6	44.5	49.5	36.1	40.4	45.0
16. Buttock-popliteal length	44.5	50.0	55.6	43.9	49.0	54.1
17. Upper leg length	54.9	59.4	64.0	53.3	57.4	62.5
18. Leg length	97.3	105.2	113.0	91.9	100.6	107.7
<i>Rear View Seated</i>						
19. Shoulder breadth	36.6	39.9	43.4	33.0	36.1	39.1
20. Upper arm length	33.0	36.6	39.9	30.5	33.5	36.6
21. Shoulder height	54.6	59.9	65.5	51.1	56.4	62.0
22. Elbow height	19.6	24.4	29.5	18.5	23.6	28.4
23. Hip breadth	31.0	36.1	40.9	31.0	37.6	43.9
24. Body weight (kg)	58.4	83.2	108.0	43.5	66.4	89.3

Table 1 Anthropometric data of adult US citizens (Source: Internet, ErgoWeb).

Type of bicycle	Crank arm lenght
	[mm]
common	170
MTB ⁴	175
bikes for smaller women	165
bikes for children	100

Table 2 Typical lengths of crank arms.

⁴ mountain bike

		Males			Females		
		Percentiles			Percentiles		
		5th	50th	95th	5th	50th	95th
		[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
factor		1629	1733	1841	1510	1619	1725
stature	1.000	1629	1733	1841	1510	1619	1725
eye height	0.936	1525	1622	1723	1413	1515	1615
chin height	0.870	1417	1508	1602	1314	1409	1501
shoulder height	0.818	1333	1418	1506	1235	1324	1411
ellbow height	0.630	1026	1092	1160	951	1020	1087
wrist height	0.485	790	841	893	732	785	837
tiptoe height	0.377	614	653	694	569	610	650
foot breath	0.055	90	95	101	83	89	95
hip breath	0.191	311	331	352	288	309	329
chest breath	0.174	283	302	320	263	282	300
shoulder width	0.259	422	449	477	391	419	447
foot length	0.152	248	263	280	230	246	262
ankle height	0.039	64	68	72	59	63	67
knee height	0.285	464	494	525	430	461	492
hip height	0.530	863	918	976	800	858	914
chest height	0.720	1173	1248	1326	1087	1166	1242
sitting height	0.520	847	901	957	785	842	897
head length	0.130	212	225	239	196	210	224
half shoulder width	0.129	210	224	237	195	209	223
upper arm length	0.186	303	322	342	281	301	321
lower arm length	0.146	238	253	269	220	236	252
hand length	0.108	176	187	199	163	175	186

Table 3 Lengths of adult links using the factors by Drillis and Contini. Statures according to DIN norm 33402

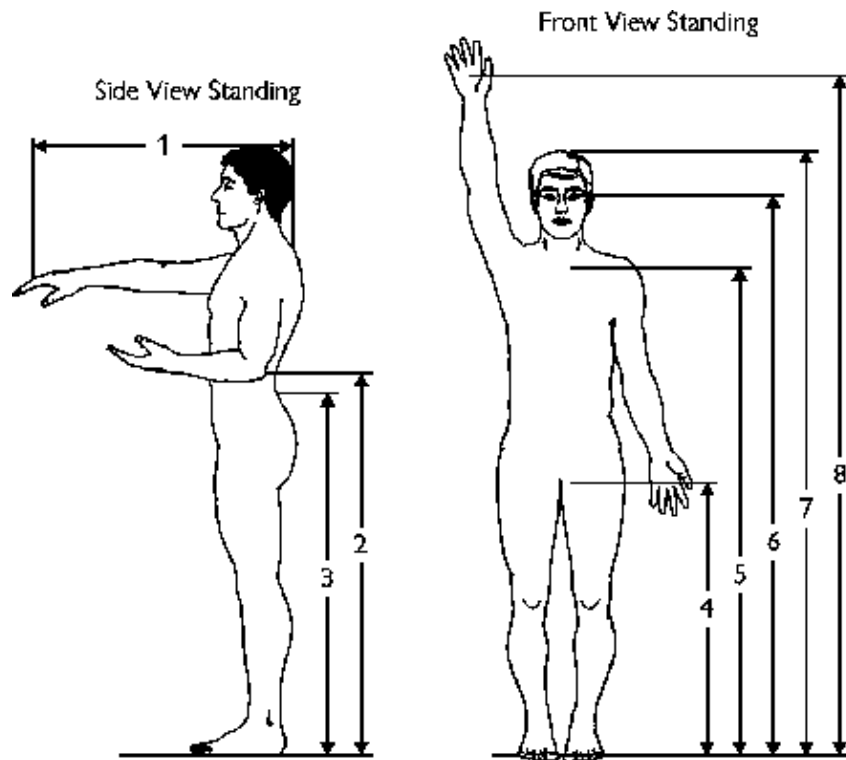


Fig. 5a Dimensions of the standing human as listed in Table 1

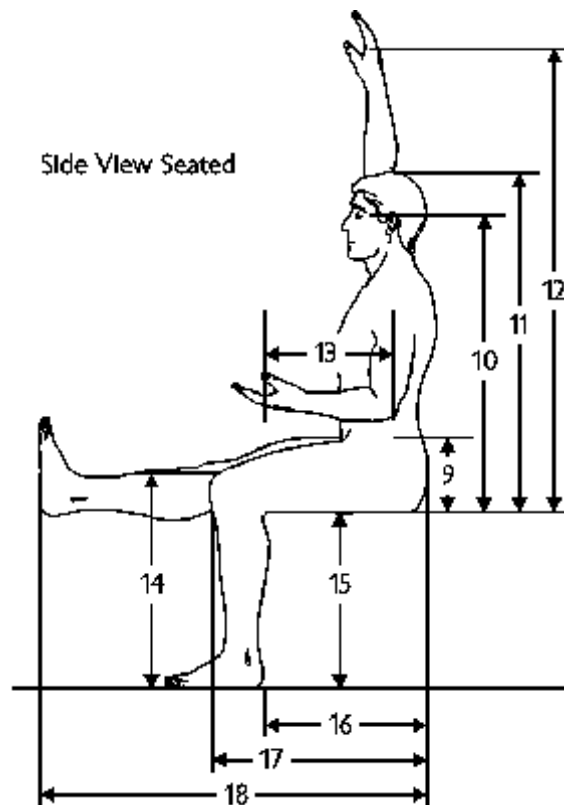
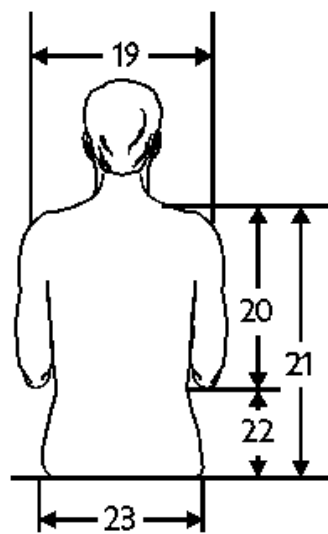


Fig. 5b Dimensions of the sitting human as listed in Table 1



Rear View Seated

Fig. 5c Dimensions of the sitting human as listed in Table 1

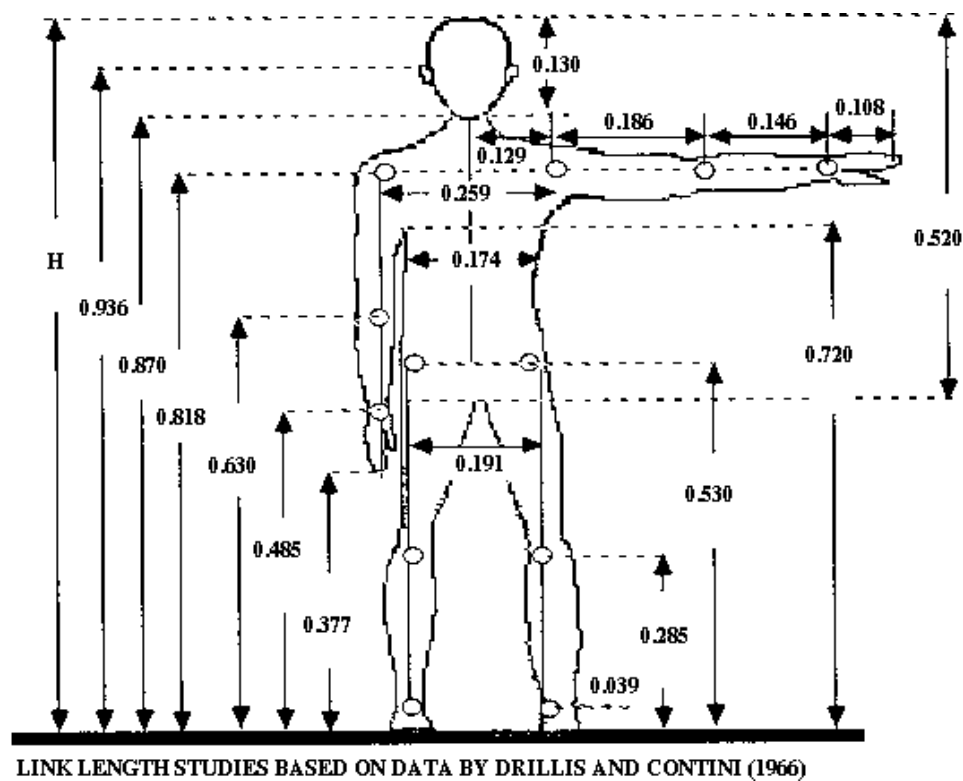


Fig. 6 Stick-model by Drillis and Contini, 1966

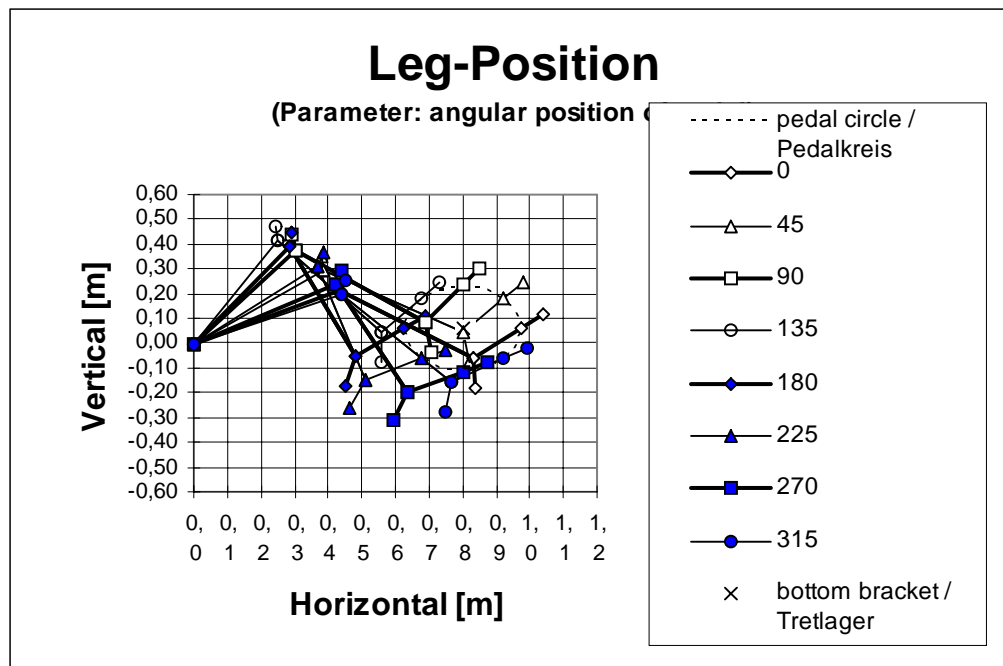


Fig. 7a Result of the calculations using the worksheet with the leg-stick-model. This picture shows the stick-legs in dependence of pedal angular position.

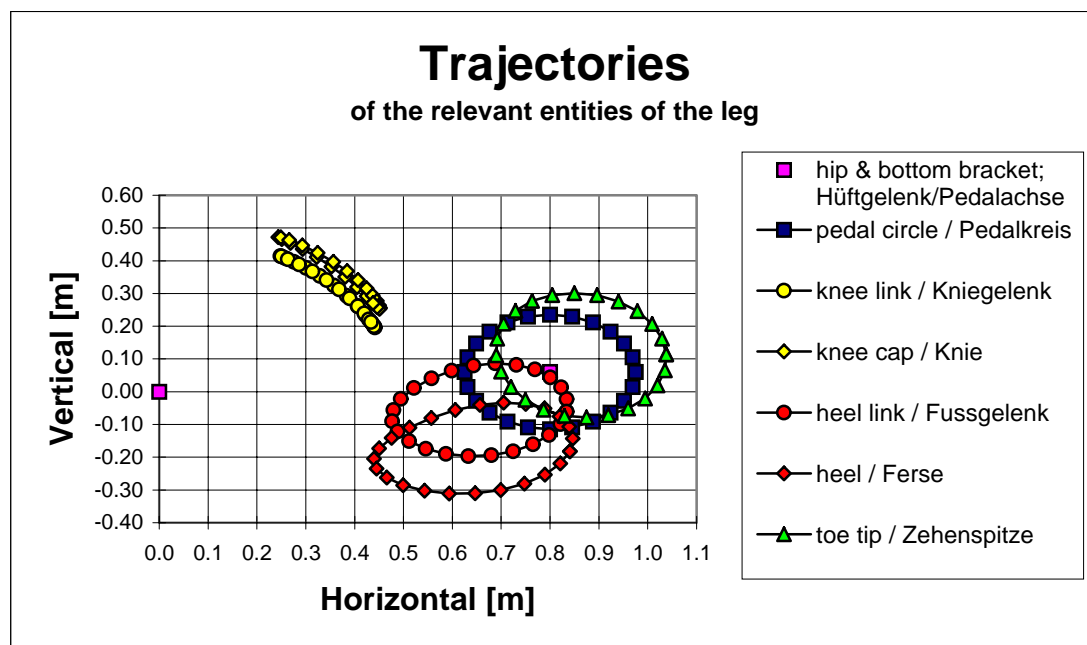


Fig. 7b Result of the calculations using the worksheet with the leg-stick-model. This picture shows the trajectories of important entities of the leg.

It is planned to add the remaining chapters in due course.

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