Western Washington University SpeedBike Team

Viking Valkyrie
Design Report

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Team Captain
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Abstract:

The Western Washington University (WWU) SpeedBike Team was formed in October of 2006 to design and build a new Human Powered Vehicle. Design and fabrication were performed by WWU Engineering Technology students, with assistance from our sponsors. The vehicle is all-new and has not competed in any previous competitions.

The project began with a problem statement: Build a human powered vehicle that utilizes streamlining to achieve a minimum speed of sixty miles-per-hour. After researching similar vehicles, objectives were formulated as follows.

Objectives for the vehicle:

- Preserve ergonomic functionality in this unorthodox, one-off vehicle
- Provide outstanding mechanical quality, appreciated by serious cyclists
- Utilize an existing high-quality frame, readily available
- Optimize design for aerodynamic advantage

Objectives for the engineering process:

- Use advanced CAD/CAM techniques
- Focus on composite fabrication processes

In addition to meeting our objectives, the design, fabrication, and testing of our cycle was also governed by a list of constraints. A primary concern is safety in all aspects of the project. This included conscientious and safe fabrication practice, testing, and any transportation associated with the project. The rules and guidelines of the 2007 ASME HPVC West[7] served as a governing document on all aspects of preparation for the Challenge.

With the problem, objectives, and constraints clearly defined, more details regarding design were established. First-hand experience with human powered submarine design was utilized to define design criteria. For instance, minimizing size (single-rider) makes a vehicle easier to fabricate and transport. Shifting the center of mass forward (ahead of the drag center) and downward increases stability. Use of existing components is always advisable over custom-made parts, which should be

fabricated only when absolutely necessary. Finally, it is advisable to develop fabrication techniques with small parts before attempting large constructions.

Time and human resources were precious commodities for our team, as most students have busy schedules and receive no financial compensation. Though funding was very limited, time was used to solicit sponsorship and grants, although money could not buy more time.

Description:

Successful speed-oriented land vehicles have appeared in many formats over the last century; the most recent record holders share some common themes.

> "All speed and performance records in single-rider land, water, and air human-powered vehicles whose riders were in semirecumbent conventional bicycling positions, cranking circular chainwheels with only their legs." [3]

With these criteria in mind, the design was approached in a sequence of concept, refinement, and finally, CAD drawings. First, a concept of finished bike was conceived (see Fig.1). As the designs progressed, individual parts were more clearly defined with refinement drawing. Parts ready to be constructed were then modeled in CAD software and converted to fully dimensioned drawings prior to fabrication. Early in the project, we made the decision to utilize advanced CAD features to design the bike for optimum ergonomics, assembly quality, strength, and aerodynamic streamlining. Before design could progress, these were researched as described below.

Figure 1

Supporting Research:

Supporting references for advanced bicycle design are rare compared to other high performance vehicles such as race cars. This situation is not the result of a lack of bicycle use or competitive interest, but rather, of restrictive rules. The Union Cyclist International (UCI) is the governing body for almost all professional road racing. The UCI banned aerodynamic enclosures and recumbents from racing in 1914 and 1934, respectively[3]. These bans were aimed at preventing an unfair, engineered advantage in professional cycling. Unfortunately, their action stunted the development of higher efficiency designs until 1974 with the formation of the International Human Powered Vehicle Association and a renewed interest in human powered vehicles. Since then, the maximum land-vehicle speed achieved under human power has been raised to 81mph.[4]

Varna Diablo (the current record-holder) served as an archetype for the WWU SpeedBike, though the Viking Valkyrie is unique in shape. In the summer of 2006 our team tested a racing recumbent. The bicycle was an HPVeloteknic Streetmachine which felt considerably faster on flat ground than a standard road bike, even without additional aerodynamic streamlining. Unlike Varna Diablo and other similar recumbents, the HPVeloteknic used a rear wheel drive, forcing it to place the rider higher than what is possible with a front wheel drive recumbent. Lowering the rider of a bicycle is a proven method of reducing wind resistance because it reduces the vehicles frontal area[6]. Improved aerodynamics offset the biomechanical losses (about 4%) of supine recumbent compared to an upright racing cycle[3]. A German company, Toxy, made the front wheel drive model needed.

Though expensive and unavailable in the US, the Toxy ZR was ideal for a number of reasons: It is virtually identical to most custom front-wheel drive recumbents. Similar frames, such as the Baracuda, took years of tuning to develop[4]; our time frame was six months. Having a strong, safe, and reliable frame early in the project allowed for more test time and mechanical refinements. Finally, from a business standpoint, we could market a unique upgrade kit for the existing bicycle more effectively than attempting to compete with an established frame manufacturer.

The Toxy (see Fig.2), however runs on 20” wheels, and the trade-off between wheel diameter and lowering for aerodynamics was investigated prior to making a decision.

Figure 2

While smaller wheels do indeed exhibit greater losses due to rolling resistance, the conditions of use are very important in determining the magnitude of lessened efficiency. Pneumatic tires lose power by two primary mechanisms: deflection of the torodial tire shape under load, and deflections due to striking inconsistencies on the road. The loading-deflection type resistance is minimized by increasing inflation pressures; pressures above 120psi make such a marginal improvement that they do not warrant higher-pressure tubular tires (see Appendix 1.a).

Small tires will always have worse efficiency because a given load deflection will affect their roundness to a greater extent, but their real problem is with bumps on the road surface. Rolling over a bump causes the tire to deflect, opposing forward motion and converting forward momentum into lift on the entire vehicle. Three factors will lessen this type of rolling resistance: increasing the diameter, increasing the vehicle’s velocity, and finding a smoother road (see Appendix1.b). For high speed bikes on good pavement, however, the difference between a 20” and 27” wheel may be less than 1% overall power loss (see Fig.6.7, Appendix 1.c); so in conclusion, larger wheels are not necessary for this application.

The Toxy bicycle was built using standard, mid-level componentry and the highest performance 20” tires (20”x1”@110psi). Gearing was the next challenge, for even an aggressive 52:11 combination was inadequate after about 30 mph (due to the small tires). To maintain a good impedance match with the human engine, a gear ratio of 10:1 (cranks : wheel) is necessary, so a countershaft gear was implemented. Circular cranking was chosen for its prevalence among successful human powered vehicles, price, and availability. Questions regarding the value of non-circular chainwheels were addressed in existing research:

> Kautz and Hull (1991), using instrumented pedals, studied an elliptical chainwheel with the major axis oriented 90° to the crank arms. They found increased total energy expenditure during one crank revolution, resulting from increased downward forces applied to the upstroke pedal as the leg was accelerated against gravity. The resulting negative work necessitated additional positive work.
>
> Thus, in the mid 1990s, it is unusual to find any chainwheel shape in competitive or recreational cycling other than round. The subjective characteristics of alternative designs and their results in races seem to outweigh any advantages indicated by laboratory tests.[3]

Criteria for all design selections were based on the objectives weighed against the constraints. Though many designs were implemented according to expectation, there were some unforeseen challenges.

A problem arose with the stock crank position; it was too high for optimal streamlining at the nose of the bike. Furthermore, it was finicky to adjust for different team members, and we were anticipating 1-2 adjustments during the endurance relay at the 2007 HPVC[7]. Usually reducing variables is desirable, but here the opposite was the case, this was an opportunity for innovation. After a brief napkin-sketching phase, a solution was developed. Using the existing slider, a new assembly was be added to permit us to position our cranks along polar axes. Adjusting for different riders was now accomplished by an angular

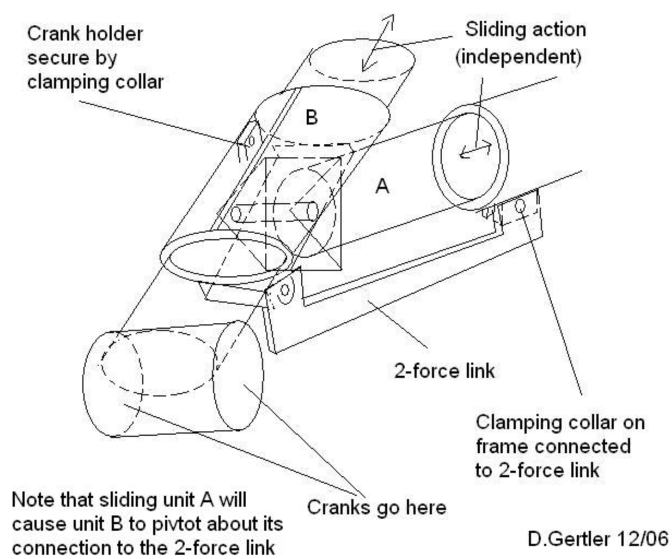


Figure 3

shift (see Fig.3). This is done by loosening the clamping collar bolt to slide shaft A while the 2-force link prevents any rotation of shaft A. The final design was modeled in CATIA, converted into NC code, and machined on a HAAS CNC mill to ensure quality tolerances. Other innovations were simple, for example, problems with a bobbing suspension were solved by immobilizing the rear swingarm and retrofitted its damper to reconcile steering wobbles.

Analysis:

Prior to any constructions, the designs inspired through research and experience were subjected to analysis. Criteria used to evaluate the application of analysis tools was directly linked to our original objectives and constraints. Analysis tools should help improve the safety, ergonomic functionality, quality, and efficiency of the design.

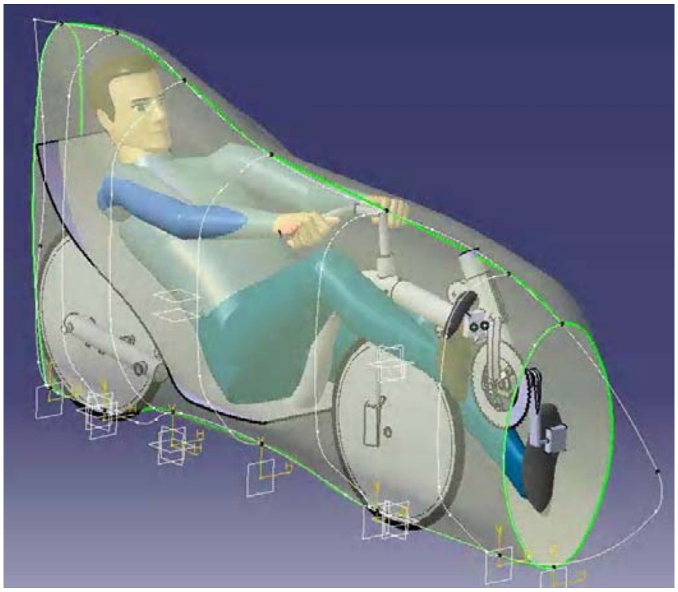


Figure 4

As mentioned previously, utilizing technology to its potential was a goal for our project, and advanced CAD features were marshaled accordingly. Though unavailable from the original manufacturer, an accurate assembly of the Toxy frame and associated componentry was assembled in Dassault CATIA. CATIA served

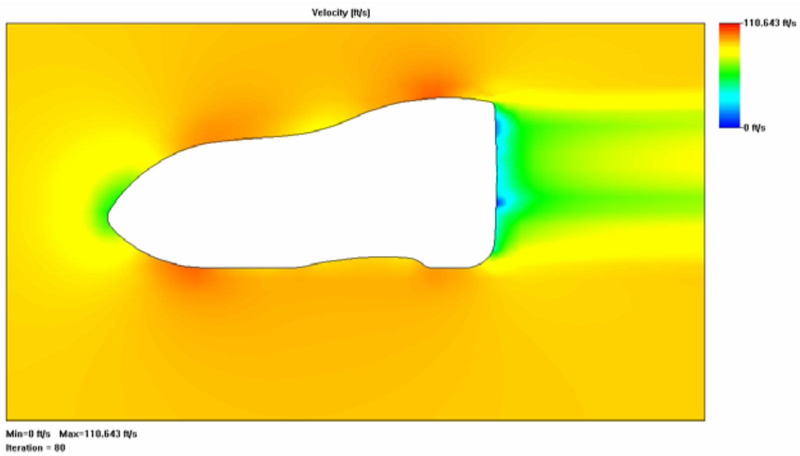


Figure 5

primarily as a medium to model assemblies and test their ergonomic capability using the Human Ergonomics module to insert a manikin into our design. Manikins for both genders and the entire size range of our team were alternated into the model to verify that we were maintaining optimum leg extension and appropriate reach. Once positioned, the manikin did more than verify existing dimensions.

Streamlined splines were sketched around the virtual pilot and the shape was lofted into a surface (see Fig.4). In that sense, our enclosure design is tailor-fitted to our bicycle and team members. Now, converted into Dassault SolidWorks, the enclosure underwent CFD testing to verify its streamlining would behave well at 60 mph (see Fig.5). Entirely accurate results were not expected from the CFD software: COSMOS FloWorks. Rather, the CFD testing would be more useful at comparing the relative aerodynamic efficiency of different designs and identifying specific problem area on a given surface. Multiple designs were tried, and successive generations of each design were updated in CATIA to improve streamlining (while maintaining ergonomic and other functional qualities) and retried in SolidWorks; the Valkyrie's final design went through 11 such generations.

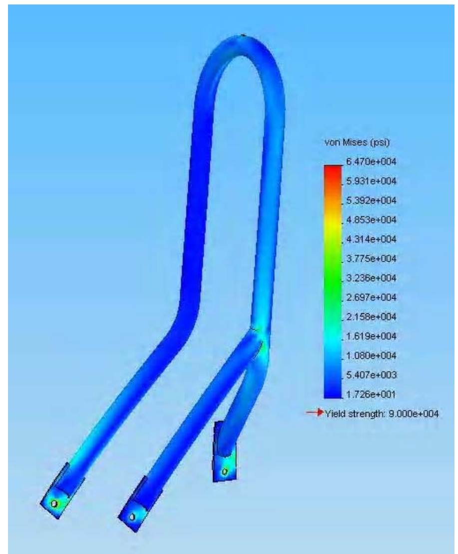


Figure 6

The third type of advanced computerized calculation employed on this project was FEA testing to ensure that our roll bar would protect the rider from a serious rollover impact of 500 lbf (see Fig.6). Interest in creating a composite roll bar began to wane as it became apparent that predicting the strength of a composite unit was not easy. Experimental testing would be required to verify an elastic modulus so the computer could run accurate FEA

Figure 7

calculations. Quality control in fabrication would be critical to ensure that the predicted strength matched the actual, deeming destructive testing necessary. Finally, the composite would be more likely to fail after repetitive impacts than resilient chromolybdnum tubing. Though the composite presented a fascinating research opportunity and potential weight savings, we didn't have the time or human resources to pursue it, and decided on steel tubing.

In addition to complex computer-assisted calculations, many calculations were carried out by hand. For example, our gear ratio of 52:11 or 4.73 would theoretically permit us to achieve 27.8 mph at 100 RPM (given the actual wheel diameter of 19.75"), the practical maximum on this bike. A ratio of 10:1 would be necessary to propel the bicycle at 60 mph, and a counter-shaft (see Fig.7) now multiplies the ratios of successive gear combinations. Multi-speed gearing was still necessary to accelerate the cycle, recalling the exaggerated rolling resistance of small wheels at low speeds (see Appendix 1. b).

Throughout the project, monetary expenditures were recorded. Along with estimates of donated consumables, cost estimates for the prototype and a ten vehicle per month production run have been compiled (see Appendix 2a), 2b).

Testing:

Two types of testing were used on this project: developmental testing and performance testing. The objective of developmental testing is to optimize fabrication procedures and verify the function of individual components. Methods of developmental testing include visual and manual inspection of fabricated parts, mechanical testing of assemblies and physical verification of ergonomic fit. The counter shaft (see Fig.7) received mechanical testing to verify operation. It exhibited two problems related to its design and fabrication: the design relied on a 4-hole pattern alone to locate the chainwheels and ensure concentricity. Loss of tolerance accuracy due to manual machining error stack-up caused a wobble which was visually apparent upon mechanical testing. Drag caused by a compression of the inner bearings due to an excessive interference fit also plagued this unit. A redesigned replacement was machined on a

MAZAK turning center. It solved the drag and wobble problems and permitted for a greater ratio multiplication (2.4x vs. 1.7x).

Another case study of developmental testing was the construction of composite wheel discs (carbon/epoxy). Experimental evidence suggests that replacing or covering spokes leads to large gains in efficiency (see Appendix 1.c). This component of the project was a challenge and a good learning experience. Different mold materials were experimented with such as: body filler coated polyurethane foam, epoxy coated particle board, and fiberglass/polyester. Molds were spun against a disc sander on a slanted datum – creating the cone shape of the wheel profile (see Fig.8).

Figure 8

Three molds and 7 disc wheel parts were produced; four of the discs have been trimmed and mounted to the spoked wheels. Different thicknesses of carbon fiber matrix were experimented with in addition to lay-up techniques. Mold damage occurred from part release (foam mold) and vacuum force (particle board mold). Our experience with these materials, processes, and problems on a number of smaller parts allowed us to apply the lessons learned to the construction of a large and complex enclosure. In any case, inferior (but functional) parts such as the first few wheel discs and aforementioned countershaft serve as valuable spares in the event of damage to the current units.

Sometimes creative alternatives must be found when a proven design becomes inconvenient. Poor clearance between the rider's heel and the bike's derailleur pushed us to adopt an internally geared hub. Test evidence confirms that internally geared hubs have poorer efficiencies (~3%) than derailleur systems (see Appendix 1.b), however, the small, 11-tooth derailleur sprocket we were using was a culprit for losses itself:

> Sprockets with at least 15 teeth give a measurable efficiency gain, the 12-tooth sprocket gave the worst derailleur efficiencies. The big (44-tooth) chainwheel and the small (12-tooth) sprocket were well aligned, yet the efficiency was 92%...The efficiency gain between a 12-tooth and a 16-tooth sprocket was about 2%.[5]

Switching to a geared hub with a 16-tooth sprocket would only incur a 1% loss of overall efficiency compared to the derailleur system, an acceptable loss.

The objective of performance testing is to road-test the vehicle to confirm its function as a system. Informal performance tests have been performed since the bicycle was first assembled in October of 2006 (see right). As more custom components are added and more team members participating in testing, road-tests have taken on a more formal precedent. Modifications and new riders complicate testing, as evidenced in an example of a more recent test (see Appendix 3.). It took two subsequent test sessions to remedy the problem of fitting our smallest rider. Testing was used to confirm analysis, for example, the maximum speed predicted with 52:11 gearing was achieved empirically with a 1.1% error. The theoretical hypothesis was correct; gear ratio was responsible for limiting performance.

Figure 9

Performance testing also prepares riders to use the bicycle. Riding a recumbent is a different balancing exercise, and a low slung recumbent requires commitment. It is necessary to train all of the human pilots prior to installing the restrictive fairing so they have the confidence to operate a more complex machine. Even the world speed champion confesses that mental confidence is crucial:

"At high speeds like we experience at Battle Mountain, a fight-or-flight reflex kicks in," said Sam Wittingham, a record-holding HPV pilot. "You have to have absolute faith in you equipment and be 100 percent confident."[2] Hour-record holder Freddy Markham agrees that the human element outweighs technology: "The most aerodynamic shape is not always the fastest. The fastest is the one that gives the rider the confidence to start stomping on the pedals."[1]

Safety:

The enclosure or "shell" of the Viking Valkyrie serves as a safety feature as well as an aerodynamic structure. It is made out of carbon-fiber (22 oz. plain weave) / epoxy (Jeffco Type 1307) two piece unit. The thickness ranges from two to four layers of carbon weave, appropriately reinforced for mounting points and areas subject to high abrasion (where it will most likely slide). The transparent canopy is thermoformed 0.100” acrylic.

The frame material is 2” diameter mandrel bent and TIG welded 6061 aluminum. It has not been destructively modified in any way and is still covered by the original manufacturer’s warranty. The restraint belt is designed for an automobile. It is 2” in width and constructed to highway crash standards out of interlocking nylon.

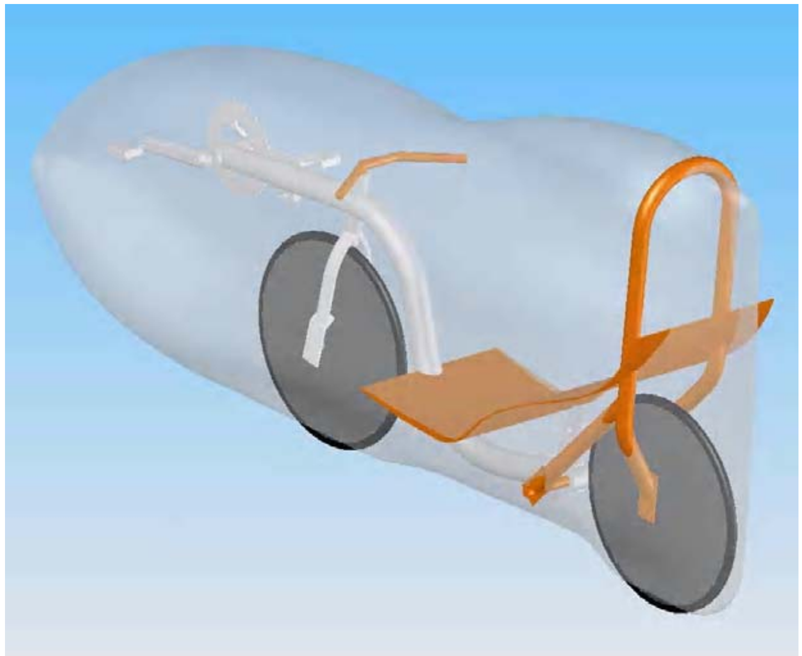


Figure 10

Besides the abrasion resistance to the skin material, a 4-6 layer carbon epoxy (same materials used on shell and wheel discs) seat extends to laterally across the shell. It is attached to the steel rollbar and firmly secured to the frame, acting as a stiffening rib in the event of a side impact. The rollbar provides ample side-protection for the head and is triangulated to resist deflection under any combination of side and roll-over impact. The lower mount bar for the fairing and rollover protection extends from side to side, acting as an internal frame slider as does the physically-restricted handlebar.

As mentioned previously, the rollbar survived a FEA test where 500 lbf was applied in a downward direction. The minimum factor of safety for the rollbar given these test conditions was still 1.4.

Field of view was a major contributor in the design process. CFD testing indicated that the canopy bump we choose was inferior to a constant sweep from the nose. Plastics processing limitations made it impossible to thermoform a canopy longer then 24”. Preserving a field of view to both sides, above the rider, and the ability to see an object on the ground 15 feet ahead contributed to our final design selection.

Additional safety features were incorporated on the Valkyrie. Careful attention was paid to the bottom of the fairing as we knew great lean angles were possible with the vehicle’s low center of mass. The lowest portions of the fairing have been shaped to accommodate a 40° lean angle before the ground is contacted. A pair of user controlled wheels, “landing gear,” is being implemented to permit single-handed operation with the complete enclosure and ease pilot training. Finally, it should be noted that the extension of the fairing and bike frame ahead of the rider combined with the vehicle’s low center of mass make it significantly safer in a frontal impact than an upright bicycle.

Appendix 1 a): Supporting Research

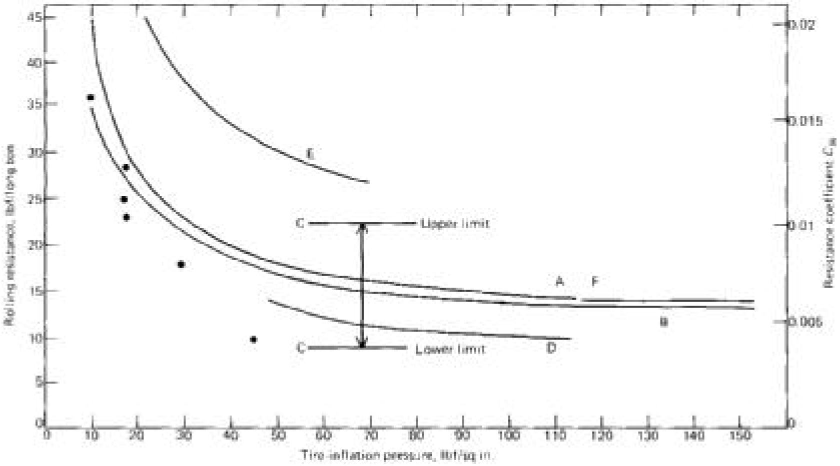


Figure 6.3
Effect of tire-inflation pressure on rolling resistance.

Curve	Wheel	Surface
A	auto	smooth, hard
B	auto	smooth, hard
C(limits)	bicycle, 28 in. X 1 1/2 in. (ave.)	road and track
D	bicycle, 27 in. X 1 1/4 in.	smooth, hard
E	bicycle, 16 in. X 1 3/8 in.	medium rough, hard
F	bicycle, 27 in. X 1 1/4 in.	medium rough, hard
• (points)	bicycle, 26 in. (assumed) X 1 1/4 in.	steel rollers

Data for curve A from reference 18 (bias-ply tires).
Data for curve B from reference 4 (bias-ply tires).
Data for curves D, E, and F from experimental data by Whitt (for low speeds).
Data for points • from reference 19 (see Table 6.2).

Figure 6.5
Effect of speed on automobile-tire rolling resistance. Each point is the mean of 6 measurements, and the standard deviation is indicated. Tire size, 5.50 x 16; load, 720 lbf. rolling resistance coefficient = $\frac{\text{rolling resistance}}{\text{load}}$
(a) Variation of rolling resistance with tire pressure and speed. Road surface, Tarmac.
(b) Variation of rolling resistance with road surface. Pressure, 30 lbf/sq in. From MIRA report (reference 16).

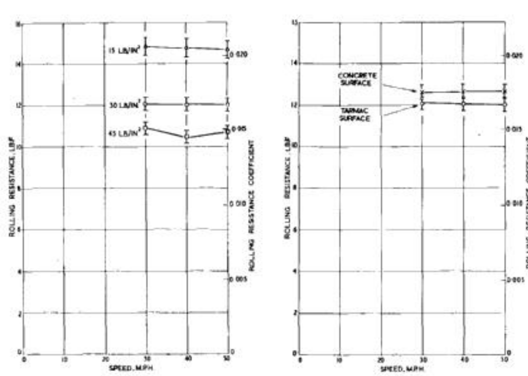
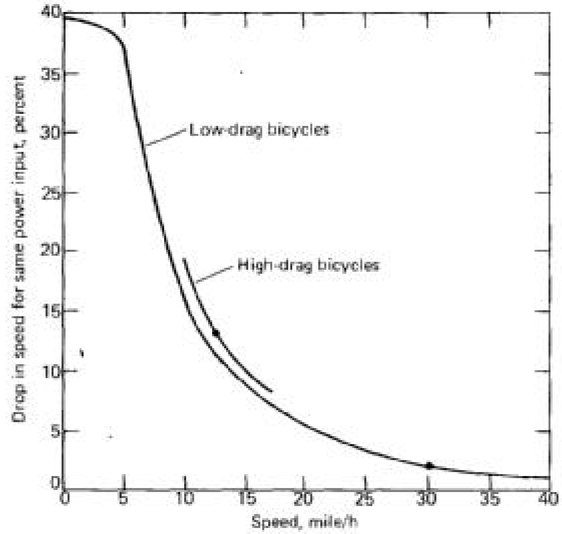


Table 6.4. Total rolling resistance calculated. (Load 170 lbf, curve D, Figure 6.3).

Speed, mile/h	Tire press. (1¼ in.), lbf/sq in.	Rolling resistance, hp	Rolling resistance, lbf/ton	Total power loss (includes air resistance), hp	Wheel diam., in.	Percentage speed reduction for given power due to small wheel
30	75	0.070	11.5	0.69	27	
30	17	0.140	23	0.767	27	
29.3	75	0.113	19	0.69	16	2.3
12.5	75	0.029	11.5	0.074	27	
12.5	17	0.058	23	0.103	27	
11.4	75	0.044	19	0.074	16	8.8
5-	75	0.0116	11.5	0.0140	27	
5	17	0.0233	23	0.0265	27	
3.6	75	0.0138	19	0.014	16	28
9.8	35	0.0337	17	0.053	16	

Appendix 1 b): Supporting Research

Figure 6.7
Slowing effect of 16-in.-diameter wheels compared with use of 27-in.-diameter wheels at same power level. Note: the 27-in. wheels are assumed to be running on a smooth road surface with a rolling resistance of 11.5 lbf/long ton weight, and the 150 lbm rider is crouching and has a frontal surface area of 3.65 sq ft. The drag coefficient is 0.9. The percentage drop in speed for a "slower" machine, that is, with a rolling resistance of 18 lbf/long ton and with a frontal area of 5.5 sq ft, is not very different. Point • is a single estimation for such conditions. In both cases the tire pressure is 75 lbf/sq in.



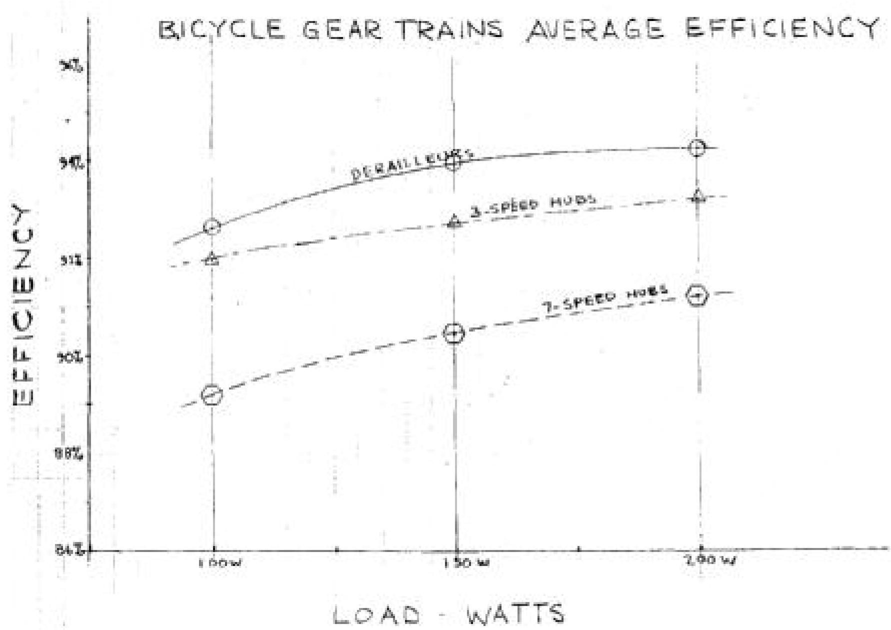


Fig. 14.35. Graph showing the results of the Kyle & Berto efficiency tests.

Appendix 1.c) Supporting Research

Table 10.4 THE AIR RESISTANCE OF SPINNING BICYCLE WHEELS

	Drag at 13.4 m/s (30 mph), N	10° yaw angle* N
27-in. wheels Du Pont/Specialized three-spoke composite wheel, 18-mm tire (waxed and polished)	1.1[a]	0.38[b]
27-in. wheels Du Pont/Specialized three-spoke composite wheel, unfinished surface	1.24[a]	
27-in. wheels Du Pont/Specialized composite wheel, 24-mm tire	1.64[a]	
Aerosports Kevlar lens disk, 8-mm tire	1.13[a]	0.25[b]
Campy lens disk, 18-mm tire	1.18[b]	
Trispoke, three-spoke composite, 18-mm tire	1.21[a]	1.13[b]
Aerosports carbon flat disk, 18-mm tire	1.21[a]	0.74[b]
Aerolite 16 aero-bladed spokes, aero rim, 18-mm tire	1.37[b]	
Wheelsmith 24 aero-bladed spokes, aero rim, 18-mm tire	1.44[b]	
Wheelsmith 28 aero-bladed spokes, aero rim, 18-mm tire	1.70[a]	
Wheelsmith 28 aero-Oval spokes, aero rim, 18-mm tire	1.72[a]	
USCF 18 round spokes, aero rim, 18-mm tire	2.02[c]	
Wheelsmith 36 round spokes, standard rim, 18-mm tire	2.53[b]	
26-in. wheels Aerosports carbon flat disk, 18-mm tire	1.07[c]	
Wheelsmith 32 round spokes, flat rim, 22-mm tire	2.04[a]	
24-in. wheels Huffy Special carbon flat disk, 18-mm tire	1.10[c]	
Aerosports 18 aero-bladed spokes, aero rim, 18-mm tire	1.25[c]	
USCF 16 aero-bladed spokes, aero rim, 18-mm tire	1.34[c]	
Wheelsmith 24-in., 28 round spokes, flat rim, 22-mm tire	1.78[a]	

Appendix 2a: Cost Report For Prototype					
Mold Fabrication					
Item	**Description**	Qty.	Item Total	Supplier	
Foam	FR-7112 Tooling Board 94"X46"x12", cut to size	2	$3,170.00	General Plastics	
Surface finish	Duratec polyester sandable primer	1	$65.02	RevChem Plastics	
Fasteners	Gorilla glue, wood screws		$45.00		
Total Mold w/tax			**$3,280.02**		
Composite Fabrication					
Part	Area	# of Layers	Qty.	Square Yards	Weight oz.
Wheel Disc	0.37	2	1	0.75	14.56
Seat	0.56	5	4	11.11	216.67
Enclosure	4.44	3	1	13.33	260.00
Item	**Description**	**Sold By [unit]**	**Unit Price**	**Unit Qty**	**Item Total**
Carbon fabric	GRAPHITE 19.5 OZ. 12K 2X2 TWILL 50"	sq. yd.	$48.60	25.2	$1,224.30
Epoxy Resin	SYSTEM THREE EPOXY RESIN	gal.	$65.70	2.6	$168.09
Epoxy Hardener	SYSTEM THREE #1 HARDENER	1/2 gal.	$50.63	2.6	$129.54
Bagging film	NYLON VACUUM BAGGING FILM 2 mil,54",	yd.	$2.74	30.2	$82.83
Bleeder/Breather	BREATHER FABRIC 4 oz. X 60 (YD)	yd.	$3.43	50.4	$172.81
Peel-ply	RELEASE PLY A 46" X YD,PEEL PLY	yd.	$7.95	25.2	$200.27
Mold Release	PVA PARTALL#10, 1 GAL	gal.	$34.10	0.8	$26.84
Mold Wax	PARTALL PASTE #2	24 oz.	$16.95	1.00	$16.95
Sealing tape	SEALANT TAPE AT200Y YELLOW 1/8" X 1/2"	25 ft.	$6.48	2.42	$15.67
Canopy	.100" Clear Acrylic Sheet 24x36"	5 sheets	$13.99	5	$69.95
Total Composite w/tax					**$2,284.27**
Bicycle Frame and Parts					
Item	**Description**	**Sold By [unit]**	**Unit Price**	**Unit Qty**	**Item Total**
Frame	Toxy ZR	frame/fork	$1,599.00	1	$1,599.00
Build Kit	All components, wheelset, drivetrain, brakes	kit	$507.18	1	$507.18
Upgrades	Spare parts,spd pedals, hub wheel, computer	kit	$234.45	1	$234.45
Misc. Hardware	Fasteners, adhesives, brackets, foam	kit	$35.82	1	$35.82
Seat Belt	Auto aftermarket replacement	kit	$36.85	1	$36.85
Total Bike w/tax					**$2,413.30**
Metal Stock					
Item	**Description**	**Sold By [unit]**	**Unit Price**	**Unit Qty**	**Item Total**
Aluminium	Bar Stock	lb	$3.99	25	$99.75
Steel	Chromoly Tube and plate	lb	$2.84	20	$56.80
Weld Rod	ARC welding sticks	25	$4.19	1	$4.19
Total Metal w/tax					**$169.70**
Grand Total Prototype					**$8,147.28**

Appendix 2b: Cost Report For 10 units per month					
Mold Fabrication					
Item	**Description**	Qty.	Item Total	Supplier	
Foam	FR-7112 Tooling Board 94"X46"x12", cut to size	2	$3,170.00	General Plastics	
Surface finish	Duratec polyester sandable primer	1	$65.02	RevChem Plastics	
Fasteners	Gorilla glue, wood screws		$45.00		
Total Mold w/tax			**$3,280.02**		
Composite Fabrication					
Part	Area	# of Layers	Qty.	Square Yards	Fabric Weight oz.
Wheel Disc	3.73	2	1	7.47	145.65
Seat	5.56	5	4	111.11	2166.67
Enclosure	44.44	3	1	133.33	2600.00
Item	**Description**	**Sold By [unit]**	**Unit Price**	**Unit Qty**	**Item Total**
Carbon fabric	GRAPHITE 19.5 OZ. 12K 2X2 TWILL 50"	sq. yd.	$48.60	251.9	$12,243.00
Epoxy Resin	SYSTEM THREE EPOXY RESIN	gal.	$65.70	25.6	$1,680.93
Epoxy Hardener	SYSTEM THREE #1 HARDENER	1/2 gal.	$50.63	25.6	$1,295.37
Bagging film	NYLON VACUUM BAGGING FILM 2 mil,54",	yd.	$2.74	302.3	$828.29
Bleeder/Breather	BREATHER FABRIC 4 oz. X 60 (YD)	yd.	$3.43	503.8	$1,728.13
Peel-ply	RELEASE PLY A 46" X YD,PEEL PLY	yd.	$7.95	251.9	$2,002.71
Mold Release	PVA PARTALL#10, 1 GAL	gal.	$34.10	7.9	$268.45
Mold Wax	PARTALL PASTE #2	24 oz.	$16.95	2.00	$33.90
Sealing tape	SEALANT TAPE AT200Y YELLOW 1/8" X 1/2"	25 ft.	$6.48	24.18	$156.71
Canopy	.100" Clear Acrylic Sheet 24x36"	5 sheets	$13.99	5	$69.95
Total Composite w/tax					**$22,013.26**
Bicycle Frame and Parts					
Item	**Description**	**Sold By [unit]**	**Unit Price**	**Unit Qty**	**Item Total**
Frame	Toxy ZR	frame/fork	$1,599.00	10	$15,990.00
Build Kit	All components, wheelset, drivetrain, brakes	kit	$507.18	10	$5,071.80
Upgrades	Spare parts,spd pedals, hub wheel, computer	kit	$234.45	0	$0.00
Misc. Hardware	Fasteners, adhesives, brackets, foam	kit	$35.82	10	$358.20
Seat Belt	Auto aftermarket replacement	kit	$36.85	10	$368.45
Total Bike w/tax					**$21,788.45**
Metal Stock					
Item	**Description**	**Sold By [unit]**	**Unit Price**	**Unit Qty**	**Item Total**
Aluminium	Bar Stock	lb	$3.99	150	$598.50
Steel	Chromoly Tube and plate	lb	$2.84	150	$426.00
Weld Rod	ARC welding sticks	25	$4.19	6	$25.14
Total Metal w/tax					**$1,110.56**
Grand Total / month					**$48,192.29**
Cost per bike					**$4,819.23**

Appendix 3: Sample Performance Test

SpeedBike Test #1

Dave Gertler

February 3, 2007, 11:00am-1:00pm
Location: Bellingham Airport, ~ 0.25 mile straight near-level
Conditions: ~ 45°F, overcast; Wind: Still

Bike Settings:

Max. Gear 52:11 (4.73)
Secondary Shaft: Stock pulley
Cross slider: rise position, fully inserted
Slider: fully inserted
Tire pressure: Front: ~110psi Rear: ~ 90psi
Handlebars: Stock wide bars, non-dampened
Aero: None
Seat: 2nd seat, Brackets: Front: forward, 3rd row; Rear: forward, 3rd row
Other: Suspension immobilized

Rider	**-**	**Max Speed (mph)**	
Jay Ostby	-	24.3	
Randy Holt	-	25.8	
Sarah Cornwell	-	7.7	(not pedaling)
Dave Gertler	-	28.1	
Tye Niskansen	-	24.9	
Gabe Murphy	-	25.0	(non-clipless)

Issues to Address:

1. Pedal position (Sarah was not able to reach pedals in shortest configuration)
2. Steering damper (needed for high speed stability & power delivery)
3. Seat position (better accommodate pedal adjustment range, rearrange padding)
4. Headrest (needs to be bigger, more supportive)
5. Shifter (not properly functioning, needs replacement)

Notes:

Chilly temperatures were mutually thought to hinder performance. Attempts to warm up and stretch were hasty, probably inadequate. Most riders complained of exhausted leg muscles after short ride durations and agreed that training on a recumbent exercise machine is necessary for better performance. It was also concluded that immobilizing the suspension was beneficial to pedaling response and not a comfort burden.

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