Aerodynamic Performance of VISION recumbents

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On October 29, 1999, I had the fortunate opportunity to gather some aerodynamic data on two VISION recumbent bicycles, the VR40EU and a VR65ET (Saber). Also tested, for comparison, was a Cannondale CAD3 upright road bike.

The testing took place in the Wright Brothers Wind Tunnel, located at the Massachusetts Institute of Technology (MIT) in Cambridge, MA. The testing was performed with the gracious permission and assistance of Prof. Kim B. Blair, Ph.D., and Richard F. Perdichizzi, Senior Technical Instructor, both of MIT. (Thanks again, guys!)

Test Apparatus

The Wright Brothers Wind Tunnel at MIT is a subsonic recirculating design. It is basically an enormous tube, wrapped around on itself with two straight sections opposite each other. In one straight side is mounted an large fan, which pushes the air inside around and around. The testing section is opposite the fan, and has a cross-section of a roughly semi – circular shape and a diameter of approx. 3 meters. Constructed in 1937, the tunnel was capable of 400 mph winds at sea level pressure; our needs, however, were considerably less than that. In the floor of the testing section of the tunnel is a measuring device called the force balance. The force balance is a very sophisticated scale, capable of measuring the force on the test vehicle in many directions. Mounted on the force balance was a set of training rollers, with a bracket in the rear to capture the test vehicle at the rear dropouts. Testing was performed at a dynamic pressure equivalent to 10mph, 20mph and 30mph. For our testing, the data was taken visually from the external display readouts of the balance.

The Bikes

Testing was performed on three bicycles, a stock VR40EU, VR65ET, and a Cannondale Cad3 road bike.

VR40EU
The VR40EU tested was a stock 1999 model 40 with a 20" front wheel, underseat steering, and the seat back angle adjusted so that the seatstay was captured roughly in the middle of the seat adjustment range. The boom was set for an inseam length of 32"

VR65ET
The VR65ET tested was one of the first prototypes built, with a narrow prototype above-seat handlebar. It featured Shimano STI Ultegra componentry. The seat was mounted in the rear frame hole, with the rear seat adjustment again set so the seatstay was captured in the middle of the seat adjustment range. Boom length was again adjusted to an inseam length of 32".

Cannondale
The Cannondale Bicycle used was an aluminum frame Cad3 Road bike. It featured 32 spoke 700C wheels, a 20.5" main frame, a Kestral aero fork, and traditional drop style handlebars of 15.75 inch width. The bike was equipped with Shimano Ultegra STI componentry.

The rider

I used myself as the test dummy. I am of average build, 5'10" tall, 150 lbs., with a 32" inseam. For the test I wore a long sleeve mock T shirt, a set of winter spandex tights, Shimano road shoes with Speedplay Frog cleats, my regular single vision eyeglasses, no gloves, and a Bell bicycle helmet. Each bicycle was adjusted for my leg length before testing.

The Testing

Testing began with a measurement of the mounting apparatus' performance. Data was collected at 10mph, 20mph and 30mph. This data was used to correct the later bicycle measurements.

Bicycle testing started with the VR40EU, with no fairing. Data points were again taken at 10, 20 and 30mph, with the rider (me!) pedaling at approx. 90 RPM. This data proved to vary wildly, and since we were not using the computer to smooth the data, the pedaling numbers are only visual approximations of the measuring balance readings. After the pedaling measurement was complete at 30mph, the rider stopped pedaling so that "coasting" data could be taken, at 30, 20 and 10mph. Without the dynamic of pedaling interfering, the data readings were satisfactorily static. During the entire testing run, I kept both hands on the handlebars and made no attempt to improve my aerodynamics with body position.

The next test performed was on the VR40EU, but this time with the new Mueller fairing installed. The same test procedure was followed, with both pedaling and coasting data taken at 10, 20, and 30mph.

The testing of the VR65ET (Saber) proceeded in the same manner as the VR40EU, with two runs performed, faired and unfaired.

As a comparison, a traditional road bike was tested. The first run was done with myself as the rider, with my hands positioned on the top of the drop bars to simulate the most common road position as well as a mountain bike handlebar position. The second run was done pedaling with my hands "on the drops" and my upper body bent forward in a traditional tuck. Even though the bike was not equipped with tri-athlete handlebars, for the coasting part of the testing I attempted to simulate the extreme tri-athlete position, with my elbows resting on the top of the drop bars approx. 8" apart and my hands out front.

The Results

The data was recorded manually and was corrected for test apparatus drag. The summarized results are listed in table 1. Only the coasting data is listed in this summary, since the pedaling data had variation due to the pedaling motion. The wind tunnel's force balance output is measured in increments of 10mv, corresponding to a resolution of 0.48 Lbf. For this reason the data at 10mph has been omitted from this analysis, and it should be noted that the data at 20mph has a possible error in the 8 to 10 percent range. The full set of data, both raw voltage numbers and the corrected data, is listed in appendix A.

Table 1. Drag, measured in pounds force (Lbf)

		20 mph	30 mph
VR40EU		**4.4**	**10.6**
VR40EU w/fairing		**3.8**	**8.7**
VR65ET (Saber)		**3.0**	**7.0**
VR65ET w/fairing		**3.0**	**7.0**
Road Bike, Top of bar		**4.6**	**11.8**
Road Bike Aero Tuck		**3.2**	**7.0**

Table 2 takes the above data and normalizes it relative to the road bike data taken with the rider on the top of the bars. For example, a rider on a VR40EU enjoys a 4.7% reduction in drag at 20 mph compared to a mountain bike or a road rider on the drops. Put more simply, if these two riders were cruising side by side at 20 mph, the Vision recumbent rider would be putting out 4.7% less effort than the upright rider. If the two riders where putting out the same power, the VR40EU rider would enjoy a speed advantage of 0.3mph, or a cruising speed of 20.3mph. This is an approximation based on the assumption that the rolling resistance is small/or the same for the two bikes, the road is level, there is no wind, and the rider power input stays the same (See appendix B for a detailed description). Note that in all cases, <u>every</u> tested bike has an advantage over the road bike with rider on the top bar; ranging of a from a low of a 4.7% reduction in drag on the unfaired VR40EU to a high of 41.3% reduction on the VR65ET and the upright Aero tuck position.

Table 2. % reduction in Drag, Normalized to Road bike on t			
	20 mph		
	% reduction	increase in speed	%
VR40EU	4.3%	0.3	
VR40EU w/fairing	17.4%	1.3	
VR65ET (Saber)	34.8%	3.1	
VR65ET w/fairing	34.8%	3.1	
Road Bike, Top of bar	0.0%	0.0	
Road Bike Aero Tuck	30.4%	2.6	

Table 3 is the same as table 2 but now normalized for the unfaired VR40EU. Note that the new Mueller fairing reduced the drag of the VR40EU by 14.9% at 20mph, adding 1.1 mph to our rider's speed.

Table 3. % reduction in Drag, Normalized to VR40EU			
	20 mph		
	% reduction	increase in speed	%
VR40EU	0.0%	0.0	
VR40EU w/fairing	13.6%	1.0	
VR65ET (Saber)	31.8%	2.7	
VR65ET w/fairing	31.8%	2.7	
Road Bike, Top of bar	-4.5%	-0.3	
Road Bike Aero Tuck	27.3%	2.2	

The Mueller fairing did not decrease the drag for the VR65ET, however. My best guess at this point is that the decrease in drag coefficient due to the fairing was cancelled by the increase in frontal area the fairing presented. The current shape has been optimized for both weather protection and aerodynamic drag; further testing may result in a purely aerodynamic fairing shape that reduces drag without increasing frontal area. It should be noted that the Mueller fairing did not <u>hurt</u> the aerodynamic characteristics of the Saber – a VR65ET rider could still use the fairing for weather protection without hurting their drag numbers.

Another interesting result from our testing is that the VR65ET was the aerodynamic equal of the upright road bike in an aero-bar tuck. Admittedly, I am not the best upright tuck rider, and the tested bike did not have actual tri-athlete bars. On the other hand, the VR65ET tested has not had any work done on its aerodynamic characteristics yet (beyond its intrinsic reduction in frontal area due to the recumbent position). The French were right – a properly designed recumbent has an advantage over the traditional road bike – especially in 1933, before wind tunnel testing created the current time trial bikes. Note, however, that if the road rider comes out of the aero tuck the aerodynamic drag increases by 32.1% - and how many mortals can stay in the tuck for a whole day's riding? Add to that the vastly improved comfort enjoyed by the VR65ET's rider under <u>all</u> conditions, and I would guess that some time trial and tri-athlete riders are going to sit up and take notice!

Conclusions

1. VISION recumbent riders have a noticeable aerodynamic advantage over a road bike rider (when the rider is on the hoods or top bar) and, by extrapolation, a mountain bike
2. This is in addition to the advantage of comfort.

3. The new Mueller fairing reduces the drag on a VR40EU by 14.9% at 20 mph – equivalent to a 1.1mph increase in speed. This is in addition to the weather protection provided by the new fairing.

4. The VR65ET Saber is the aerodynamic equivalent of a upright road bike in a full tri-athlete aero position. The VR65ET rider has a 36.8% advantage over the upright rider when the rider comes out of the tuck position on to the hoods at 20mph.

5. The new Mueller fairing does not appear to reduce the drag of the VR65ET, but it doesn't hurt it, either. The fairing can still be used for rain and cold weather protection.

6. Since the Mueller fairing has a greater frontal area than the VR65ET, and the drag with the fairing installed was the same, there probably exists a smaller shape that can enhance the aerodynamics of the Saber.

7. Large wind tunnels, such as the one at MIT, run into resolution problems at the low airspeed and drag numbers presented by a bicycle. A contribution could be made by designing a wind tunnel optimized for low airspeeds and drag.

Further testing

This test is a great start, and confirms my suspicions based on past experience. This field is wide open – we will be conducting further testing on above bar vs. below bar, new fairing shapes and rear faring (perhaps shaped panniers). In the meantime, it is great to have real numbers to start from.

Appendix A – Measured Data

Raw voltage data from MIT wind tunnel testin			
conversion (lb/V)	21.13		
test jig	Voltage		
10 mph	0.02		
20 mph	0.07		
30 mph	0.17		
		coasting	pedaling, avg
VR40EU			
0 mph		0	0.045
10 mph		0.06	0.06
20 mph		0.28	0.295
30 mph		0.67	0.68
VR40EU w/faring			
0 mph		0	0.05
10 mph		0.07	0.085
20 mph		0.25	0.275
30 mph		0.58	0.575
Saber			
0 mph		0	0.045
10 mph		0.04	0.06
20 mph		0.21	0.32
30 mph		0.5	0.5
Saber w/fairing			