Aerodynamics and Cycling

This article comes from Jim Martin M.S:, an engineer, PhD candidate in exercise physiology at the University of Texas, and friend of mine. Jim has been a Masters Champion on the track, and has coached the EDS cycling team. He also has spent about as much time as anyone doing Wind tunnel testing for cycling, both at the GM and Texas A&M wind tunnels. This article was written for triathletes, but the information still applies to the straight cyclist.

It is very popular to use the term ‘aero’ to describe bicycles, wheels, helmets, and handlebars. However, do we really know exactly what ‘aero’ means, and what the consequences of aerodynamics are to you, which we measured drag in the wind tunnel of seven riders, then had them ride at three steady state velocities while we measured power with an SRM crank and wind conditions with an anamometer. The results indicate that our predicted power matched our measured power with a standard error of 5 watts, and demonstrate that this is a valid model for power during real world cycling.

Knowing the power required for a given riding velocity may be meaningless if you don’t know how much power you can produce. If you, as a Triathlete or Duathlete, are equally well trained at cycling and running, and have average running economy (1.6 kcal/kg/mile) and average cycling efficiency (19% gross cycling efficiency) your sustainable power output can be estimated from this simple equation: Power (watts) = 60 * Body weight (lb.) /10k run time (minutes). Based on this equation, Table 1 presents the estimated power output for 4 categories of triathletes/duathletes. Keep in mind that if you are estimating you power in a multi-sport event, you should use your ‘multi-sport run’ time, whereas if you are estimating your cycling time trial performance, use your ‘run only’ time. These estimated power outputs will be used to illustrate the effects of aerodynamics on a variety of riders.

TABLE 1. Estimated cycling power output for a 70 kg person based on 10k multi-sport running time

	Elite	Well Trained	Trained	Recreational
10k Time	35 min	40 min	48 min	60 min
POWER	264 watts	231 watts	192 watts	154 watts

Although much attention is focused on the aerodynamics of equipment, the most important aerodynamic consideration for a bike and rider combination is the rider. A typical 70 kg rider on a regular bike with standard wheels will have a drag of about 8 lb., a better position will reduce drag to about 7 lb., and an excellent position will yield a drag of 6 lb.. Based on these drag numbers, and the power outputs estimated above, equation 1 can be used to predict the effects of these positions on cycling performance on a flat course with no wind shown in Tables 2 and 2a. The differences in performance with no change on power are remarkable, ranging to about 6 minutes when changing from a typical to an excellent position.

TABLE 2: Predicted 40k time, flat course, calm conditions, 3 body positions, standard wheels.

Position	Drag @30mph	Elite	WellTrained	Trained	Recreational
Typical	8.0	62:49	65:51	70:16	76:01
Good	7.0	60:14	63:07	67:22	72:57
Excellent	6.0	57:23	60:10	64:07	69:47

TABLE 2a: Predicted time savings for a 40k based on 2 body positions compared with a typical position, flat course, calm conditions, standard wheels.

Position	Drag @30mph	Elite	WellTrained	Trained	Recreational
Typical	8.0	62:49	65:51	70:16	76:01
Good	7.0	2:35	2:44	2:54	3:04
Excellent	6.0	5:26	5:41	6:09	6:14

The key elements of a good aero position are:

1. Horizontal torso. Defined by having your chest, or better yet, your back parallel to the ground, this is absolutely the most important element, as it can result in large magnitude changes in aerodynamic drag. Unfortunately, it may be the most difficult to achieve, because as you approach this position, your thighs start to hit your torso. This interference imposes limits on your body's aerodynamic position, but is due to traditional bike geometry (i.e.; seat tube angles of 73 to 75 degrees). The way to overcome this limitation is to go to a more forward position, which will allow you to roll your whole body forward. Note of caution: a forward position seat post and long steeply-dropped stem may allow you to assume a good aero position, but will result in a bike that is not well balanced, and my be dangerous to ride. A much better approach is to buy a frame that is designed to be ridden in a forward position. These positions are uncomfortable in two ways. First and foremost, by rotating your hips forward to get your torso horizontal, you are rotating your weight right on to your soft and tender parts. Specifically, riding in this position may exacerbate the condition of prostatitis that is common among cyclists. Extra seat padding helps but does not eliminate the problem. A truly anatomical saddle that distributes your body weight over the whole seat might really help. Some riders try to alleviate this problem by tilting the nose of the saddle down, but this only results in a tendency to slide off the saddle and to strain your shoulder and arm muscles. Secondly, and to a much lesser degree, you tend to get a sore neck the first few times you ride, the discomfort lessens with time and can be minimised with stretching and massage. These draw backs are minimal because you don't have to ride the forward position daily to go fast on it. My experience with Team EDS, as well as my own bike is that you only need to ride it once a week (maybe less) to stay adapted to the position.

2. Narrowly spaced elbow pads. Narrow elbows are an essential detail of an aero position. However, the magnitude of improvement is much less than what is achieved by adopting a horizontal torso position. Research conducted by Boone Lennon has shown that subtle changes in elbow width and aero bar angle may have significant effects on drag. This research was performed on traditional geometry bikes, with the torso adopting the characteristic cupped shape, and probably illustrates the need to block air flow out of the torso area. More recent data on riders in a horizontal torso position shows much less effect from these variables. I do not believe these two findings are contradictory, rather, they indicate that once the torso is horizontal there is little you can do to improve or impair aerodynamic drag.

3. Knee Width can change aerodynamic drag by up to half a pound. Pedalling with your knees close to the top tube is an essential part of good aerodynamics.

Is there a trade-off between position and power output? If done badly, maybe, but if done well, no. Recently, Heil et al., (MSSE, May 1995) have investigated this question, and the results tend to show that your cardiovascular stress for a given power is increased by decreasing the trunk to femur angle. Therefore, if you lower your elbow position, you may need to move the saddle forward to maintain your trunk to femur angle while getting a lower, more nearly horizontal torso position.

The effects of aerodynamic wheels can be substantial. They can lower the aerodynamic drag by about 0.4 lb. compared with standard wheels with round-wire spokes and require about half the power to rotate. For the following examples, I will use a Specialised 3 spoke front and a lenticular rear disc. Tables 3 and 3a show the predicted effects these wheel will have on 40k time trial performance.

Position	Drag @30mph	Elite	WellTrained	Trained	Recreational
Typical	7.6	61:40	64:38	68:54	74:39
Good	6.6	58:58	61:47	65:55	71:23
Excellent	5.6	55:57	58:39	62:35	67:47

TABLE 3a: Predicted time saved in a 40k by using aero wheels compared to standard wheels, flat course, calm conditions, 3 body positions.

Position	Drag @30mph	Elite	WellTrained	Trained	Recreational
Typical	7.6	1:09	1:13	1:22	1:22
Good	6.6	1:16	1:20	1:27	1:34
Excellent	5.6	1:26	1:31	1:32	2:00

The difference made by aero wheels is about a one to two minutes. When I was preparing this talk and I got to this part, I didn’t believe the model’s prediction. So I recruited a friend and went out to a fairly flat loop and rode at constant power with regular and aero wheels. The results were almost exactly what the model predicts. This study needs to be repeated with better control such as wind and road grade measurement, but it provides anecdotal evidence that the predicted effects of wheels are realistic.

Similarly, the effects of aerodynamic frames can be substantial. The best frames can reduce drag an additional 0.3 lb. compared with round frame tubes. The critical areas of a frame seem to be the leading edge (fork, head tube, handlebars) and the area between the rider's legs. The frames that perform the best tend to have air-foil shaped leading edges and seat tubes (or no seat tubes). The effects of an aero frame are estimated in Table 3.

TABLE 4: Predicted 40k time, flat course, calm conditions, 3 body positions, aero wheels, aero frame.

Position	Drag @30mph	Elite	WellTrained	Trained	Recreational
Typical	7.3	60:53	63:47	68:04	73:40
Good	6:3	58:05	60:51	64:55	70:21
Excellent	5.3	54:59	57:39	61:30	66:38

TABLE 4a: Predicted time saved in a 40k by using an aero frame compared to a standard frame, flat course, calm conditions, 3 body positions.

Position	Drag @30mph	Elite	WellTrained	Trained	Recreational
Typical	7.3	0:47	0:51	0:50	0:59
Good	6:3	0:53	0:56	1:00	1:02
Excellent	5.3	0:58	1:00	1:05	1:09

As you can see above, the effects of an aero frame result in saving about an additional minute.
The effects of light weight components seem to be a topic of interest for many triathletes/duathletes, however the effects of weight on cycling performance may not be as significant as one expects. To illustrate the effects of weight I have modelled a very tough out and back 40k with a constant grade of 3% which results in 600m or about 1970 feet of climbing/descending with aerodynamic bikes that weigh 22 lb. and 17 lb., and a slightly less aero bike/position that weighs 17 lb. The results are shown in tables 5 and 5a.

TABLE 5: Predicted 40k time, 3% grade out and back course, calm conditions, 2 body positions, aero wheels, 3 bikes.

Bike Wt.	Drag @30mph	Elite	WellTrained	Trained	Recreational
22 lb	6.3	65:04	69:38	76:55	87:24
17 lb	6:3	64:37	69:05	76:12	86:27
17	6.8	65:52	79:22	77:31	87:47

TABLE 5a: Predicted changes in 40k time due to weight and aerodynamics, 3% grade out and back course (600m or ~1970ft of climbing/descending), calm conditions, 2 body positions, aero wheels, 3 bikes.

	Elite	WellTrained	Trained	Recreational
Time saved w/5lb lighter bike	-0:27	-0:33	-0:43	-0:57
Time lost with 0.5 lb more drag, 17 lb bike	+0:48	+0:44	+0:36	+0:23
0.5 lb More drag, 23 lb bike	+1:15	+1:17	+1:19	+1:20

An extremely light bike on a very tough climbing course will only save you about 30 seconds to 1:00, but if this lighter bike compromises your aerodynamics even a little bit, you will be SLOWER by 23 to 48 seconds. Interestingly, lighter weight is more of a help to slower riders. Increasing drag by 0.5 lb. slows you down by about 1:15 on the same weight bike. IX. Till now, I've modelled everything in calm conditions, however, I personally have rarely ridden in calm conditions. Wind effects can be remarkable, largely because you spend a longer time in the head wind than you do in the tailwind, and consequently, the slower head wind portion has a greater effect on average velocity. Table demonstrates the effects of 5 and 10 mph winds on an out and back course, direct head wind one way, tail wind the other.

TABLE 6: Predicted 40k time, flat out and back course, windy conditions, good body position, aero wheels, aero frame.

Wind	Drag @30mph	Elite	WellTrained	Trained	Recreational
Calm	6.3	58:05	60:51	64:55	70:21
5 mph	6:3	58:45	61:39	65:52	71:31
10 mph	6.3	60:48	63:58	68:40	75:02

http://home.hia.no/~stephens/aero.htm