A Note on Rim Width, Tire Sensitivity, and Rim Depth in High Performance Bicycle Wheels.

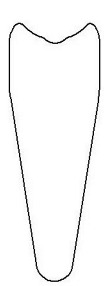
History:

In the late 1980's aerodynamic bicycle wheels were beginning to evolve past the revolutionary disc wheels first popularized during Francesco Moser's world hour record ride, and into something more applicable to real world racing. With the disc wheel holding the position of being theoretically ideal in terms of aerodynamic drag, the real push came to develop front wheels which were nearly as fast aerodynamically, while allowing the bike to be better handled in a cross wind, particularly in the front wheel application. This *cross-wind sensitivity* has come to occupy a place in the public perception of disc wheels, creating much fear and dread amongst many athletes, while going seemingly unnoticed by others. In fact, as a rear wheel, the full disc does contribute to side forces which may move the rider around on the road, but with the advent of modern high aspect ratio tubing for the bicycle frame, this contribution is now of a rather small percentage of the whole package, and seems to be less noticeable than ever.

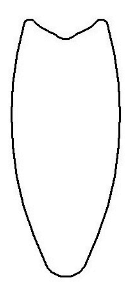
The early 1990's saw the advent of composite spoked wheels containing 3-5 spokes of airfoil cross section, which overall produced less drag than the 28-32 small round spokes and box section rims of traditional wheels in use at that time. These wheels were somewhat revolutionary in both thinking and appearance, and quickly gained acceptance by both manufacturers and athletes. However, the composite spoked wheels exhibited the properties of having disproportionately high side force in cross winds, or high cross-wind sensitivity, and also being subject to aeroelastic effects (aerodynamic induced vibrations) which were in some cases actually worse than with disc wheels, while at the same time, exhibiting aerodynamic properties which were very good, but not nearly as good as that of disc wheels. For many athletes the tradeoffs in handling were simply not worth the additional speed.

The next logical step was to remove the composite spokes and build tension spoked wheels having deep composite rims. This step was very progressive in that it changed the dynamic of the wheel from that of a harsh, vibration propagating compression spoke design, to a vibration attenuating tension spoke design. Wind tunnel studies soon showed that 90+% of the aerodynamic advantages found in composite spoked wheels were also seen in tension spoked deep section wheels, and that rim depth and not spoke count was the primary contributor to drag reduction. This was a major advancement in thought process, as the realization was that the rim depth and shape was the major factor in wheel performance, much moreso than simply the spokes themselves.

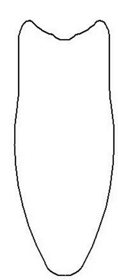
By 1996 companies were generally producing either composite spoked wheels or deep section tension spoked wheels having rims profiled in the shape of a 'V' or a 'U'. A patent co-owned by Zipp and Hed allowed for a 'toroidal rim section' which used the tire to form a leading edge of an oval cross-sectioned rim, and the early Hed CX utilized a variation of this profile, however rim depth and width of the design did not allow for optimization of the concept for tires wider than 17mm. At that time manufacturing difficulties and braking issues due to the curved brake track would lead to this product being replaced a few years later.



Original Concept 'V' Rim



Toroidal Rim



Hybri-Toroidal Rim

In 1998, Zipp introduced a rim of oval cross section utilizing parallel brake tracks and having maximum rim with *wider* than brake track width, similar to the toroidal rim, but without the curved brake tracks. This would be the discovery that would prove to blow the old theories out of the water. Previously, most all rims of a similar depth had nearly identical aerodynamics. Perhaps slight changes in sidewall curvature or rim width would allow for a rim to be slightly better than another, but all rims suffered from having very rigid triangular cross sections and were subject to being designed specifically around one tire width. Zipp quickly patented this concept and introduced it into the market later that year in both clincher and tubular 58mm deep rims.

Present day:

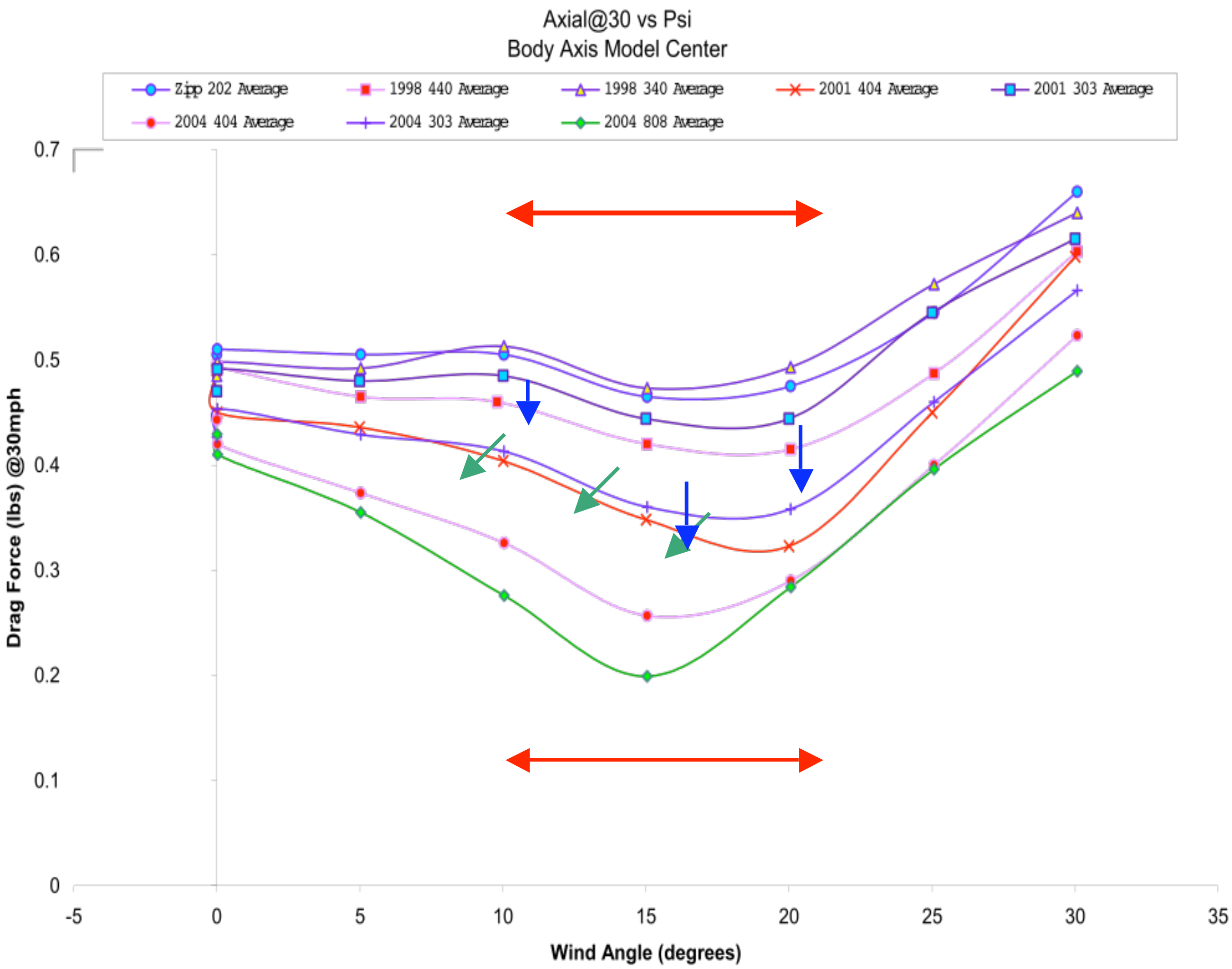
The Zipp patented rim shape has proven to be the most tunable rim shape ever developed. With standard shaped rims, the only design variations generally relate to rim width at the brake track and rim depth, with all other changes moving the rim from a roughly 'V' shape to more of a 'U' shape. With the Zipp concept, the maximum width of the rim can be tuned independent of brake track width, while the widest point of the rim may also be moved up or down within the rim cross section. By altering these parameters, the engineers at Zipp have been able to make 4 major alterations in the past 10 years to the rim shapes of the 404 and 303 lineup, finding improved aerodynamics and reduced cross-wind sensitivity each time. In addition, the Zipp has pushed this technology throughout its full wheel lineup, creating all new rim families like the 202, 808, 1080 and Sub-9 wheelsets.

In 2001, Zipp first introduced the concept of *tire sensitivity* which was a technical term for the fact that a tire wider than the rim results in drastically reduced aerodynamic performance. Since most composite spoked wheels and deep section rims were designed around a specific tire, the shapes and widths of even the most highly tested components were dependent on the use of a particular tire width. Since the tire is the first part of the wheel to brake the air, the entire performance of the wheel is determined by tire choice in these traditional designs. However, the Zipp rim shape was proving in the wind tunnel to have tire sensitivity related not to the brake track width, but to the rims *aerodynamic width* which was the term given to the widest portion of the rim (previously referred to using the airfoil term 'thickness'). While popular 3 spoke and 60mm deep rims showed performance degradations on the order of 20% when using 22.5mm tires as opposed to 19mm tires, the Zipp 404 showed less than 5% shift in performance, which could be directly related to the increased frontal area of the tire itself.

Between 2003 and Present, the designers learned that not only could this bulge be used to allow for various tire widths, but could be used to shift the *aerodynamic sweet spot* of the wheel. Most deep section or composite spoke wheels show minimum drag at around 20 degrees of wind angle. However, more than 60% of real world wind conditions occur between 10 and 20 degrees of wind angle. By moving the aerodynamic width of the rim towards the spokes slightly, and increasing rim curvature, the engineers were able to shift the maximum performance zone of the wheels into the wind angles which riders will see most often.

Note how the aerodynamic width of the rims has been made wider and shifted further towards the spoke bed over time, this increased curvature helps with re-smoothing of the air coming off of the tire, minimizing *tire sensitivity*. Whereas with the older rim shapes, the maximum tire width was limited by rim width (commonly 19mm) with the new concept, the maximum tire width is generally accepted to be 105% of the aerodynamic width, meaning that with Zipp rims and wheels the rider is free to choose tires based on road conditions, weather conditions or personal preference, and not based on limitations imposed by the wheel itself. The graph below shows how the aerodynamics have improved with these changes.

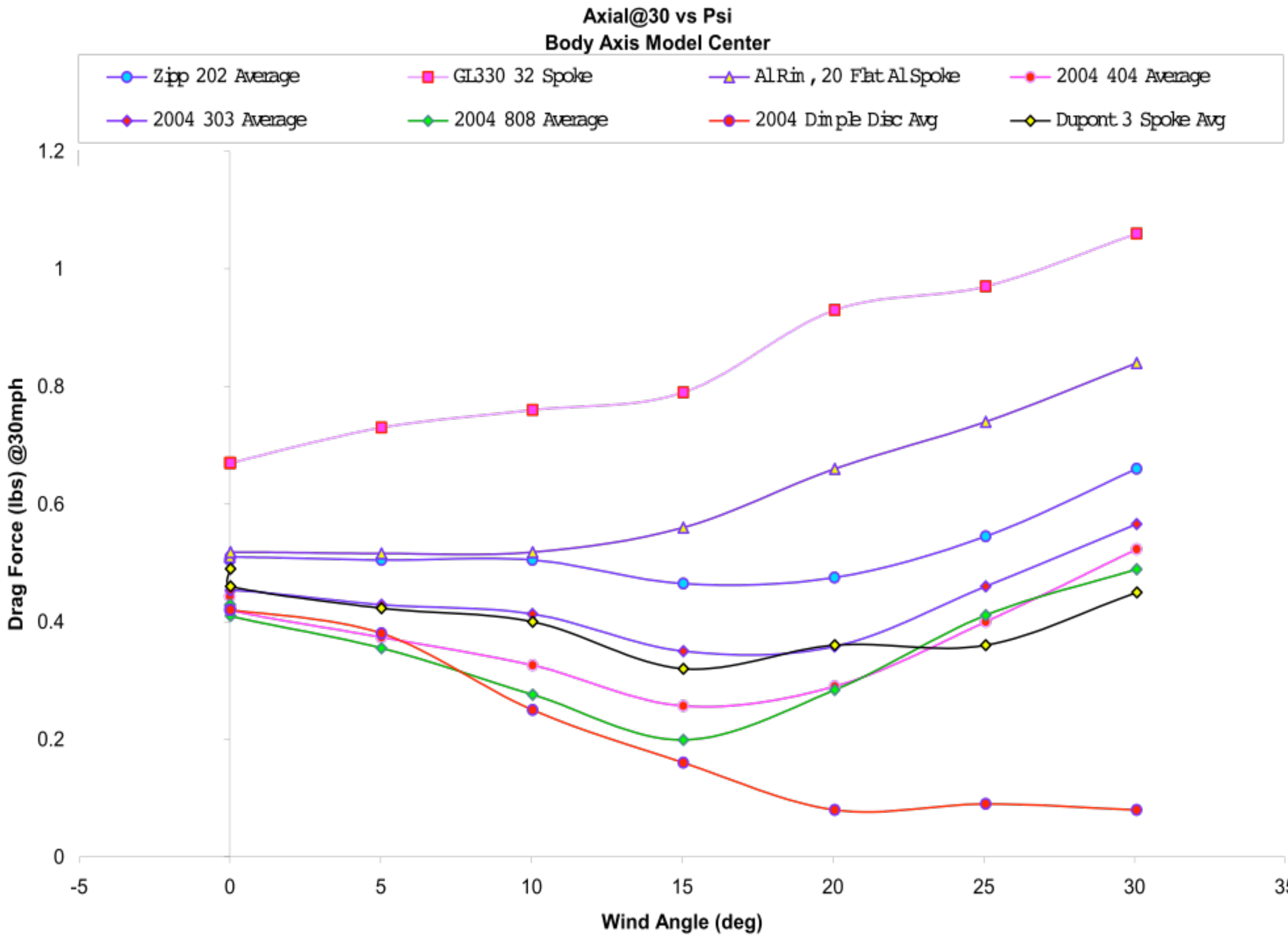
All wheels shown here were tested with the identical 21mm Vittoria Corsa CX tubular tire on the. Each line represents an average of a minimum of 3 runs in the wind tunnel.



The Red arrow indicates the wind conditions which occur most frequently in the real world. It is generally considered that the wind angles between 10 and 20 degrees account for 60% of real world conditions, and this zone is what we refer to as the 'sweet spot'. The **blue arrows** show the immediate improvement in drag when moving from the older 440 type rim having 'V' profile to the patented Zipp Bulge shaped rim having aerodynamic width of 21.35mm. The **green arrows** show how adjusting the position of the aerodynamic width of the rim allowed for the total drag to be reduced, while the point of total minimum drag was moved from 20 degrees to 15 degrees, essentially enlarging the aerodynamic sweet spot. The changes here represent over 4 years of research and more than 20 wind tunnel prototypes.

This graph represents the true beauty of the patented rim shapes employed in the Zipp rims. With traditional rims, the drag is essentially a function of only tire width and rim depth, but with the Zipp's aerodynamic width control, the rim curvatures can be altered in such a way as to fine tune rim performance. No other rim design on the planet can match the flexibility and tunability of this patented shape. You will notice that the bottom most line represents our latest weapon, the 808. With 2 years of planning, testing and developing the engineers were able to perfectly match the sweet spot of the rim to the 15 degree wind angle, and further reduce drag to levels previously seen only in disc wheels. Interestingly, this rim utilized the aforementioned 'toroidal' rim section, and with 81mm depth and patented ABLC (dimpled) skin, has pushed this weapon into a range of efficiency never before seen in any composite spoked or deep section wheel.

The chart below shows the same 808 and 404 graphs from above, compared with a disc, a 3 spoke and some other popular spoked wheels, and the results are quite dramatic. Note: all lines represent an average of at least 3 runs all using the identical Vittoria Corsa CX 21mm tubular tire. The scale appears compressed compared to the above graph because the 32 spoke wheel has such large drag values that the Y-axis registers up to 1.2lbs compared to 0.7 lbs on the above graph.

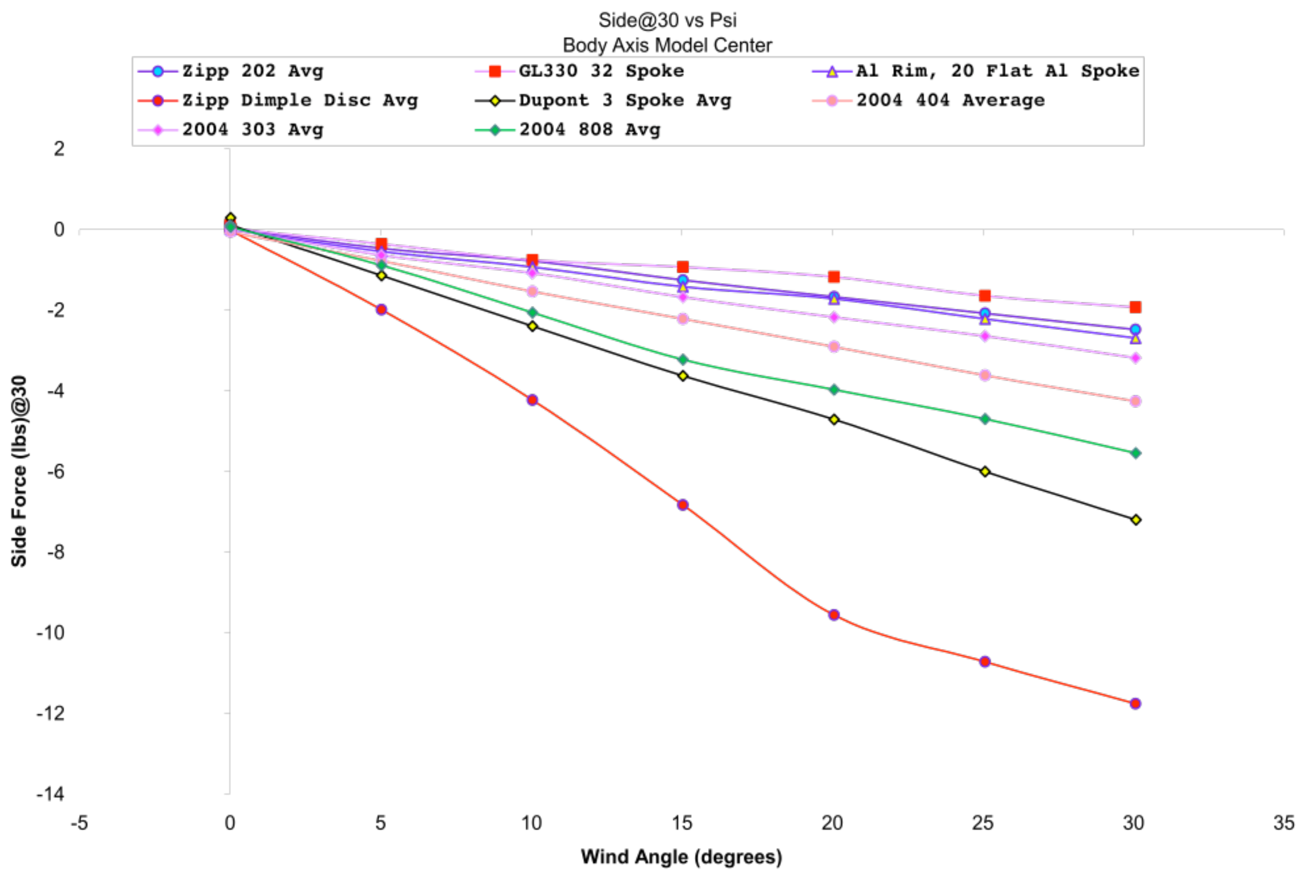


Cross Wind Sensitivity of the Wheels

Since the goal here is to minimize both drag and side force, the engineers complete the design loop here by looking at the side force on the wheel during these same tests. This will determine just how much influence the wind will have on the wheel. At the higher wind angles, the airflow is completely separated, and the wheels with the largest side are with generally have the lower drag and higher side force. The disc wheel has the largest possible side area, and therefore the highest side force and lowest drag. Previously, 3 and 4 spoke composite wheels offered low drag at moderate side force improvements, but only using the Zipp toroidal and patented bulge rim cross sectional shapes have deep section wheels truly challenged or bettered the composite spoked wheels for low drag honors while offering significantly reduced side force at the same time.

The graph below shows the side force information for this same wind tunnel data. Interesting features to note are that the 808 offers substantial improvements in side force over the 3 spoke from zero to 30 degrees of wind angle, while offering significantly improved drag from 0 to 20 degrees of wind angle. Also the 404 offers roughly half the side force at all angles when compared to the 3 spoke, while offering improved drag from zero to 20 degrees of wind angle. Since the 20-30 degree wind angle condition is considered to make up only 15-20% of real world conditions, the use of these wheels on the front seems to only make sense in certain extreme conditions, and with larger riders. The problem for most athletes and coaches when making a decision regarding composite spoked wheels is that the wind conditions which make the most sense for these wheels aerodynamically, are exactly the conditions in which most athletes will not wish to ride them, except perhaps in the rear only. The disc wheel, however, is considered to offer a substantial enough savings in all conditions that riding it is beneficial in all wind conditions, with the wheel becoming even faster as conditions become more extreme.

In the sweet spot of wind conditions, a wheel such as the 808 or 404 can offer from 0.05-0.15 lbs of drag savings (3-7 watts of energy) while also offering a 2-3 lb reduction in side force, making one of these wheels the faster option for 90+% of real world conditions than any competing products. Also of note is that the 202 offers improved drag and side force when compared to the Aluminum rim with aluminum spokes. The large side area of these spokes generates the high side force, but seems to offer little drag reduction at the higher wind angles. In this case the aluminum rimmed wheels are also 500+ grams heavier, making the 202's the clear all around choice in all categories tested.



Conclusion:

The patented Toroidal and Hybrid Toroidal rim profiles pioneered in the current generation of Zipp rims and wheels offer unmatched aerodynamics across the widest possible range of wind conditions, while having the lowest possible cross wind sensitivity. These shapes are also not affected by tire width changes nearly to the effect that other 'V' and 'U' shaped rims are, allowing the athlete to choose the optimum tire for his/her event, and not have to compromise on a tire around which the wheel was originally designed, in some cases up to 15 years ago. Furthermore, the ABLC dimpled skin now utilized in all Zipp deep section rims further reduces pressure drag while improving handling in cross-winds. The combination of two patented rim shape technologies with a radical new patented ABLC (surface dimpling) technology have truly pushed Zipp rims and wheels to a new level of performance.