Excellence in Design, Excellence in Materials, and Excellence in Manufacturing;
A Note on the history and development of the Zipp 202/84 and 220/95 hub systems.

There are currently as many hub designs and theories on design on the market today as there are manufacturers. However, the reasons for these designs are generally not clear to the consumer (and occasionally unclear to the manufacturers as well), so this Note is an attempt to better explain the design intent of the current Zipp hub lineup. We are often told that our hubsets must not be the finest on the market as they come pre-built into wheelsets, and do not have a cult following amongst those 'in the know.' One of the reasons the Zipp hub system does not have a rabid following (yet) is that the products are generally only available in prebuilt wheelsets, and are often not understood, plus we have not spent tens of thousands of dollars marketing them. Zipp is seen as a technology development company and a composites company, known for innovating the first ultra-light aerospace materials disc wheel, the first carbon fiber 3 spoke wheel, and more recently, for developing the world's most aerodynamic rim shapes, the multi-patented dimpled aerodynamic surface texture, and the means by which dimpled tooling can be produced. Because of this, the ability of the company to develop and manufacture aerospace quality machined aluminum components is often overlooked, or perhaps not even noticed by consumers of the media. Hopefully this design paper will dispel some of these myths about Zipp Speed Weaponry, and more clearly explain our position on design and manufacturing of these critical components.

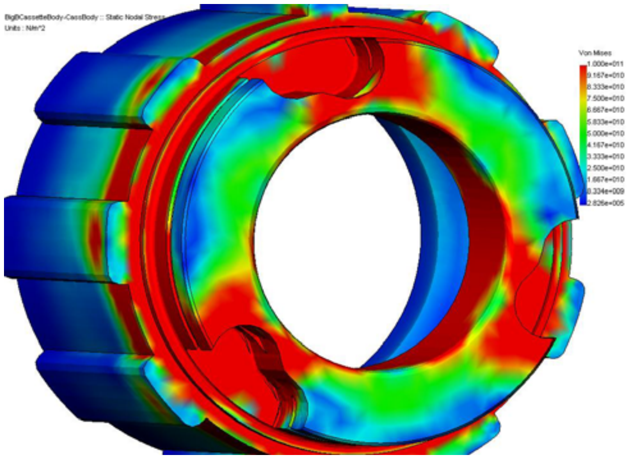
Excellence in Design and Materials

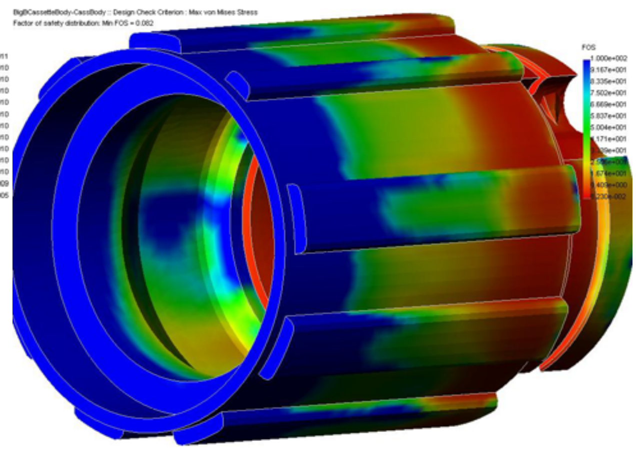
An excellent product must first begin with an excellent design, and the Zipp 202/84 and 220/95 hubsets have received some of the most advanced computer modeling and part testing ever used in the bicycle industry. The 4 years prior to Zipp bringing this technology in house, the company co-developed hubs with another firm, leading to some very advanced designs and concepts, but these designs quickly made their way into the other company's standard products, and therefore into our competitors products. Bringing this history and knowledge in house, and combining them with more than 30 years of machining and fixturing design expertise, allowed for Zipp to further push the design envelope, leading to the 202/84 product line. The entire product line was designed, developed, prototype manufactured, and tested in the virtual world, before a single part was ever placed in a lathe in the real world. Advanced 3D modeling allowed for the parts to be accurately run through every phase of manufacturing, and FEA testing was done to ensure every component met or exceeded design criteria while remaining as light as possible.

The last piece of the design puzzle was filled by corporate partner Alcoa; the Aluminum Corporation of America. Alcoa owns the patents and formulations for over 90% of the aluminum alloys on the market today, hence only true 7075 or 7050 comes from Alcoa, other companies can only sell 'near equivalent' materials based on reverse engineering of Alcoa formulations. It helps that Alcoa has a processing facility in Lafayette, Indiana only 2 hours away from the Speedway facility, so the Alcoa design team is on hand for specification of certain alloys for each particular component in the hubset.

With this tight design loop, the engineers can develop parts, computer model them in existing alloys and heat treats, and then quickly discuss the properties with Alcoa engineers to determine a direction to take on alloy type and heat treatment for each individual part. There are 3 Zipp proprietary alloys currently used in the Zipp 202/84 and 220/95 hubsets, which are unavailable to other companies and certainly not even able to be reverse engineered in overseas facilities.
With overall design and material decisions made, each component of the hubset undergoes intense design review processes using computer analysis to remove any unnecessary weight, while building in additional strength or toughness in critical locations.

The FEA models below show various load simulations on the Zipp cassette body design. This design highlights an initial problem with the early outsourced hubs. We saw cracking in the bottom of the pawl pocket in roughly 0.8% of the hubs sold within the first year of use. By bringing the design in house, utilizing information from Alcoa to move to a custom heat treated version of 7XXX alloy, and changing the engagement geometry of the drive mechanism, we achieved an 8gram weight reduction, and have not seen a single pawl pocket failure in 3 years with the new design.



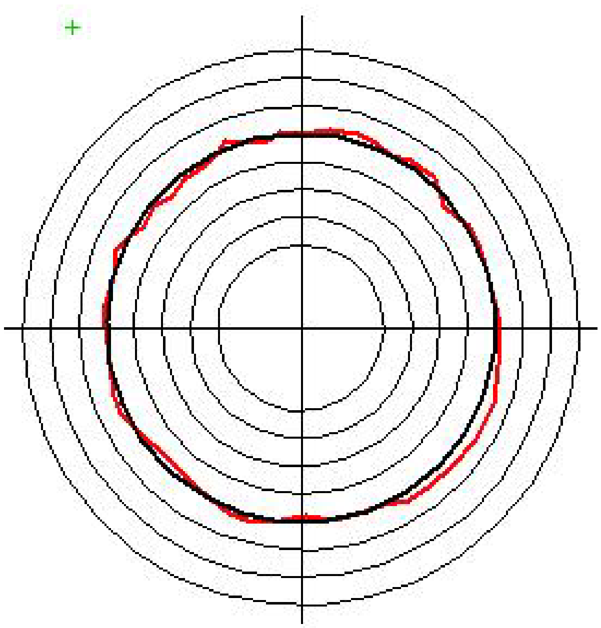


Moving the design and manufacture of these components in house allowed for a weight reduction of 10% while producing parts that were stronger and more fatigue resistant. Similar design changes were made in hubshells, axles and drive components ultimately taking hub weight from 262 grams for a rear hub to 202 grams for a rear hub, while driving warranty complaints from just under 1% to virtually 0%.

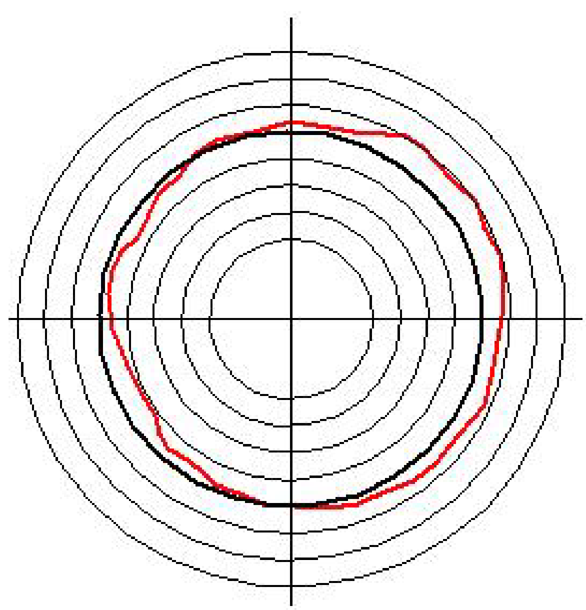
Bearing Design

One thing that has set the Zipp hub apart since the beginning has been the bearing design. Zipp is the only company in the world specifying Swiss made ball bearing cartridges, but these are not even standard Swiss made cartridges, they are highly specialized. Since most stock bearings of the size used in bicycle hubs come from the machine industry, they are invariably designed for higher rotational speeds and generally lower loading, and usually no shock loading. Working with a family owned Swiss bearing manufacturer, Zipp was able to define certain key criteria to bearing smoothness and long life, and develop the finest cartridge bearing every introduced into the cycling industry.

To start with, standard bicycle bearings are usually tolerance at 50 millionths of an inch. This is done by blowing them up a graduated tube with air, and guarantees that all balls are within 50 millionths of an inch of each other in diameter, and any individual ball is round within 50 millionths of an inch. High precision balls utilized in most company's high end products up this spec to 25 millionths of an inch to ensure better roundness of the balls, and ensure smoother rolling. Zipp ball bearings are specified to 10 millionths of an inch tolerance, guaranteeing that they are at least 2.5 times better matched than most company's 'high precision' balls, and more than 5 times tighter than most 'precision' balls. The measurement reports below show two 'round' items, the first measuring 10 millionths round, the second 12 millionths round.



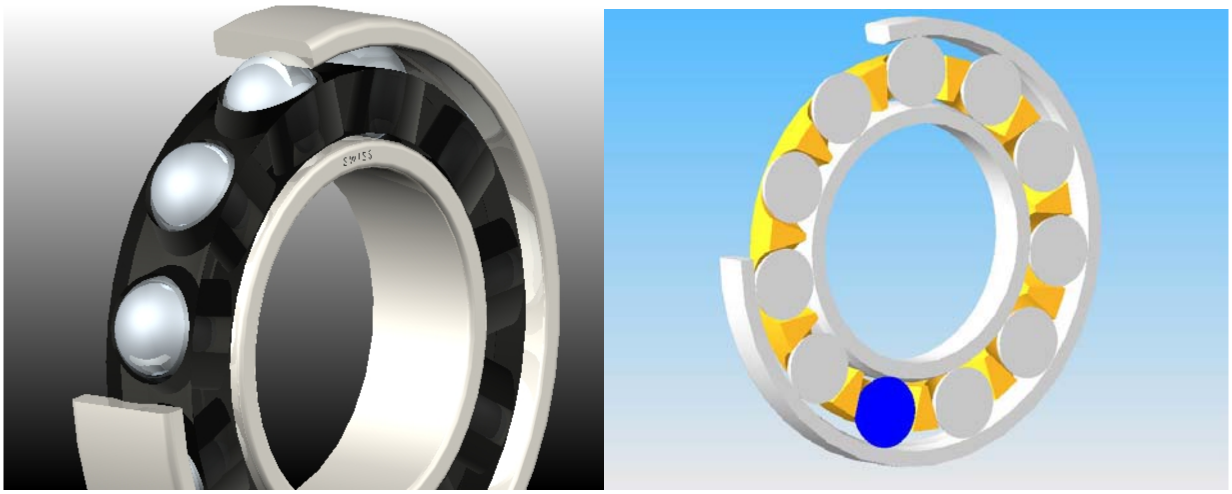
10 Millionths of an Inch Runout



20 Millionths of an Inch Runout

As you can see in the charts, neither item is truly round, but the 10 millionths ball is considerably better at the microscopic level than the 20 millionths round ball. This contributes to smoother rolling with less friction, and increased lifespan of the bearing.

Zipp bearings, then specified Teflon impregnated plastic ball retainers instead of brass. Most bearings utilize a brass waffle retainer within the cartridge to ensure the balls remain evenly spaced throughout the cartridge, this also keeps the balls from rolling against each other, but it does introduce a point of wear, heat buildup, and friction, as the ball is forever rolling against a metallic element. Zipp was the first company to spec a plastic retainer made from Teflon so that each ball is properly located in the cartridge, but the balls never have any sliding contact with any metal components. This retainer concept is now being copied throughout the industry by numerous companies, and was originated first in the 202/84 hubsets introduced in 2000, and is the only design to utilize Teflon instead of traditional plastics.   The end result of the plastic retainer is a 1 gram weight savings per cartridge, extended bearing life in the field, and smoother rolling with fewer frictional losses.

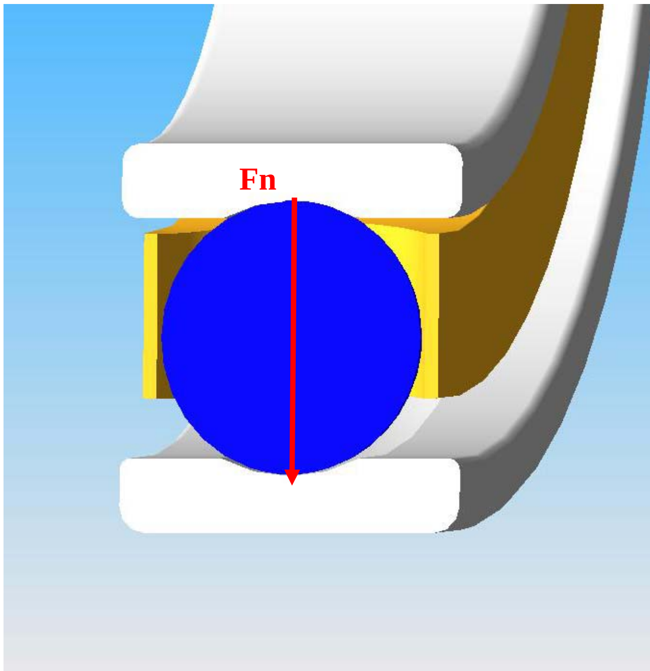


Zipp Cartridge Cutaway Views Showing Teflon Retainer

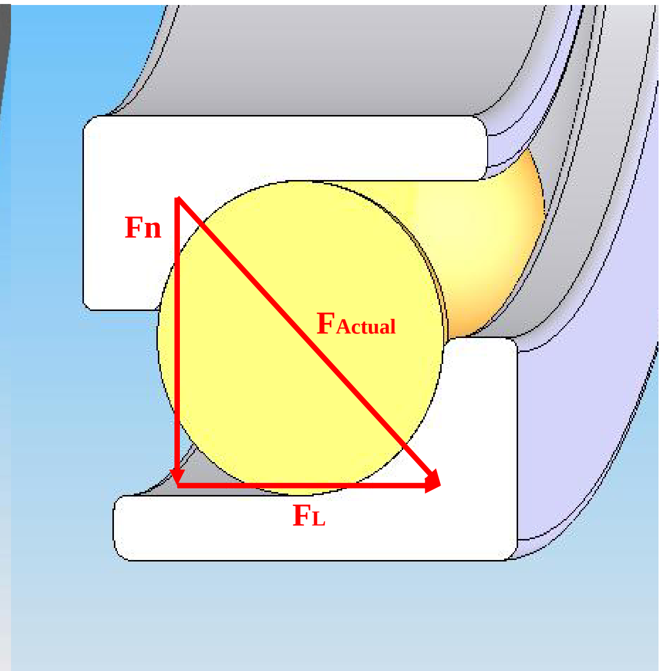
Radial Contact instead of Angular Contact

One area that we feel strongly about with our hub design, that is not shared by any other manufacturers in using radial contact bearings with ideal ball location. This means that we utilize deep groove cartridges, but confine their location to be optimal for friction and life, and do not allow them to be preloaded or adjusted by the consumer. Why are we so adamant about this design? And what does that mean for you, the consumer?

First, radial contact bearings much better handle the loads seen in a bicycle hub, and nearly ½ the manufacturers out there are using them. The radial ball loading better distributes the load fed into the hub, and can handle higher loading using lighter weight bearings that generally spin smoother than cup and cone type setups. Granted, that cup and cone bearings can be carefully adjusted to feel near perfect in your hands, but once the wheel is on the bike, the loading of the cup and cone bearing actually results in higher ball friction and reduced life.   The graphics below demonstrate:



Radial Ball Bearing



45 Degree Angular Contact (Cup and Cone) Bearing

The key to notice in the Radial vs the Cup and Cone design is that the force Fn is the Normal (vertical) force fed to the bearing through the weight of the rider. In the radial bearing design, Fn is the same force resisted by the ball, but in the angular contact situation, the normal force is only one component of the ball force, since the ball contact line runs 45 degrees to the force line, the ball must generate $\sqrt{2}$ times more force (and a lateral force component represented by FL). This means that Factual is 1.41 times greater than Fn, so the ball in the cup and cone scenario sees 41% higher load than the radial ball bearing. This higher ball load results in higher friction, decreased ball and race life, and increased wear of the internal components meaning that the hub will have to be adjusted more frequently.

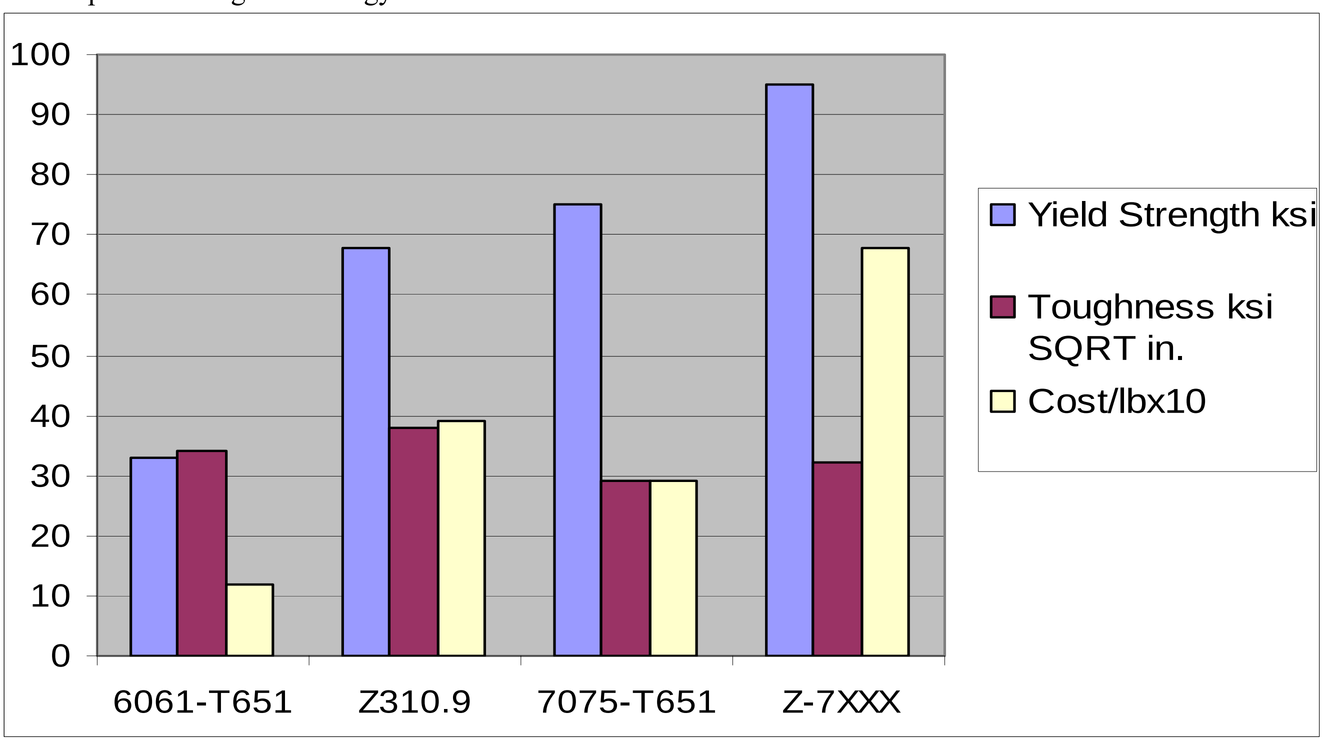
The reason for the cup and cone design is quite simple, it is much less expensive to machine and assemble since the components are adjusted for preload by the consumer. This means that the bearing race diameters can have nearly twice the tolerance, and there is little to no need to axial tolerances in the assembly as any slop can be accounted for in the adjustment of the cone. Contrarily, the radial ball situation, requires exact dimensional control of both bearing bore diameter, as well as axial length of both hubshell and center spacer, as well as requiring bearing planes to be exactly coplanar to each other. One design variant now becoming popular is to utilize radial cartridge bearings but to use an adjustable cone design, allowing for user adjustability for bearing preload, but this essentially negates the gains to be had in using radial cartridge bearings (other than the better seals). The precision necessary for a perfect radial cartridge hub is on the order of +/- 0.0002" in 3 axes, this is simply unachievable in Asian production, and is not even achievable in most types of CNC equipment, so it is very, very expensive to obtain. However, with proper machines and fixuturing, the Zipp hub is manufactured to these exacting tolerances and specifications, the only hub in the world to do so. The result is a hub that spins with as much as 1 watt efficiency improvement over competing designs! What's 1 watt mean? Well, that's roughly 2-3 seconds in a 40k time trial, and it was all achieved through design and process control measures.

Excellence in Manufacturing

The only real downside to the Zipp bearing philosophy, is that it creates many manufacturing and design challenges, as it is so very much harder (and more expensive) to manufacture than traditional designs. One way around this is that Zipp only utilized state of the art CNC equipment, and further relies on advanced fixturing and tooling techniques to help ensure that every hub is perfect when it leaves the shop floor. One way to do this is through use of highly advanced aerospace lathes and machines. Traditional CNC machining, still generally requires parts be manufactured in multiple steps or operations. Traditionally, a hubshell for example can have as many as 4 or even 5 operations, as the parts are first turned internally from one side, and then another operation to turn the other side, then the outside profile is turned in an additional operation, and finish operations such as drilling of spoke holes, or cutting of hub ears on straight pull hubs all constitute additional operations. The most critical of these operations is the turning of the hub internals and bearing bores. Traditionally, the inside of the hub is machined, then the part is removed and placed on another machine for the other side to be machined. This results in some inconsistency as any cutting fluid, dust or even skin oil, on the secondary fixture will cause the part to lose planarity or axiality to the initial bearing bore.

The Zipp methodology is to use a machine previously considered to expensive for use in the cycling industry, a double spindled machine with live tooling. This machine can pick the part off of the first spindle, with another spindle, and continue machining, ensuring that the part is never touched by a human hand until it is done. A machine like this costs 3-4 times more than traditional equipment, but runs to a higher accuracy, and with less operator intervention, so we reduce the number of man hours necessary per hub, and reduce scrap and out of tolerance parts. With less time spent moving parts, and re-fixturing them in other machines, our operators spend their time measuring and dimensionally checking 100% of all the parts to ensure that only perfect parts leave the shop floor. These manufacturing theories allow Zipp to maintain 100% of manufacturing of these parts in house, and in the USA, able to match the costs of our overseas competitors, while far exceeding their quality.

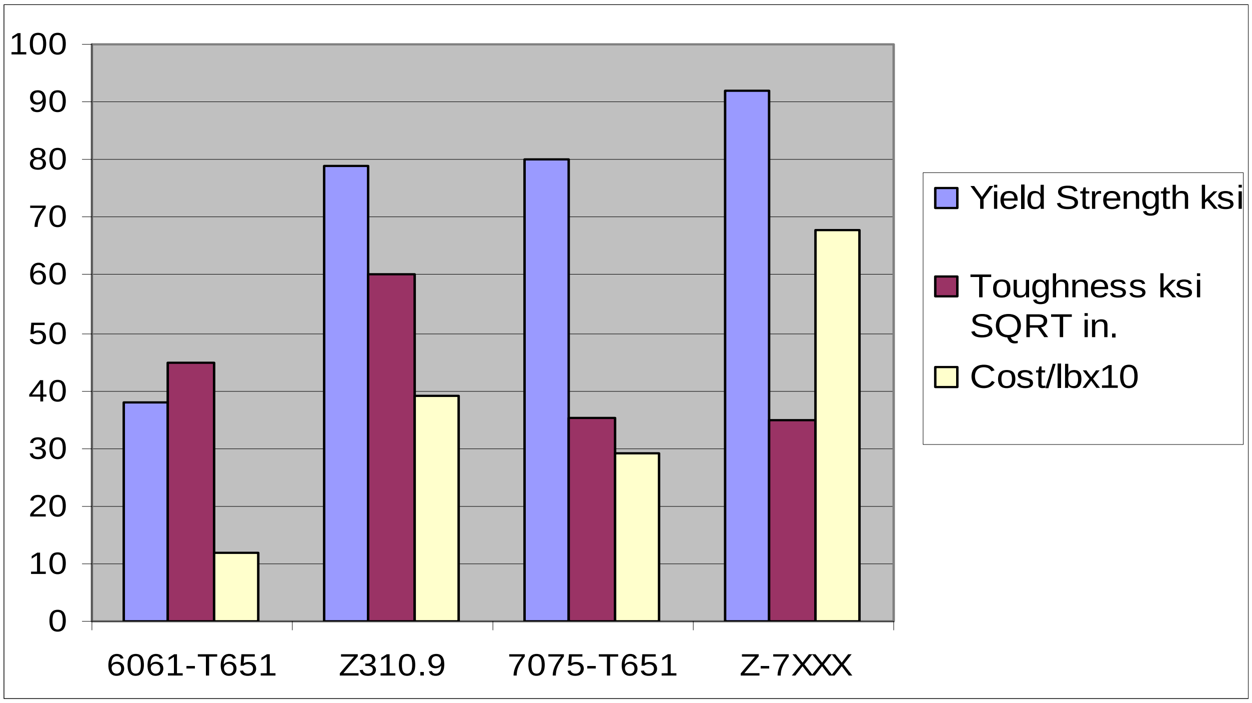
SHIFT Your Thinking
One benefit of American manufacturing and materials is the exposure we have to aerospace and defense critical technologies available nowhere else in the world. The new SHIFT technology seen in the 220/95 hubset is a perfect example of this. Many manufacturers use 6061, a very inexpensive alloy, but these designs require more aluminum mass in the part (more weight) and can be less efficient to produce on modern equipment due to its soft nature. The upside of 6061 is that is very tough, or resistant to cracking, so it will make hub flanges that can deform easily but generally will not crack. Through intense development with Alcoa Zipp has moved to a proprietary alloy called Z310.9 which is nearly twice the strength of 6061 while being slightly more crack resistant, and further increased the performance through a radical manufacturing process called SHIFT: Spoke Hole Impact Forming Technology.



Performance and cost of Zipp Alloys vs. 6061

This chart shows that Z310.9 is nearly equivalent in strength to 7075 (more than double the strength of 6061) while being slightly tougher than 6061. The only penalty is Z310.9's cost at nearly triple that of 6061 and 33% higher than 7075. However, the key to a good hubshell is high strength and low weight, with excellent crack resistance, which is the number one mode of shell failure. This is why 99% of all companies will void your warranty for radial lacing of the hubshell, the 6061 hubshell can only be made so thick to accommodate the spoke head, and despite being tough, can begin to deform or crack at high spoke tensions.

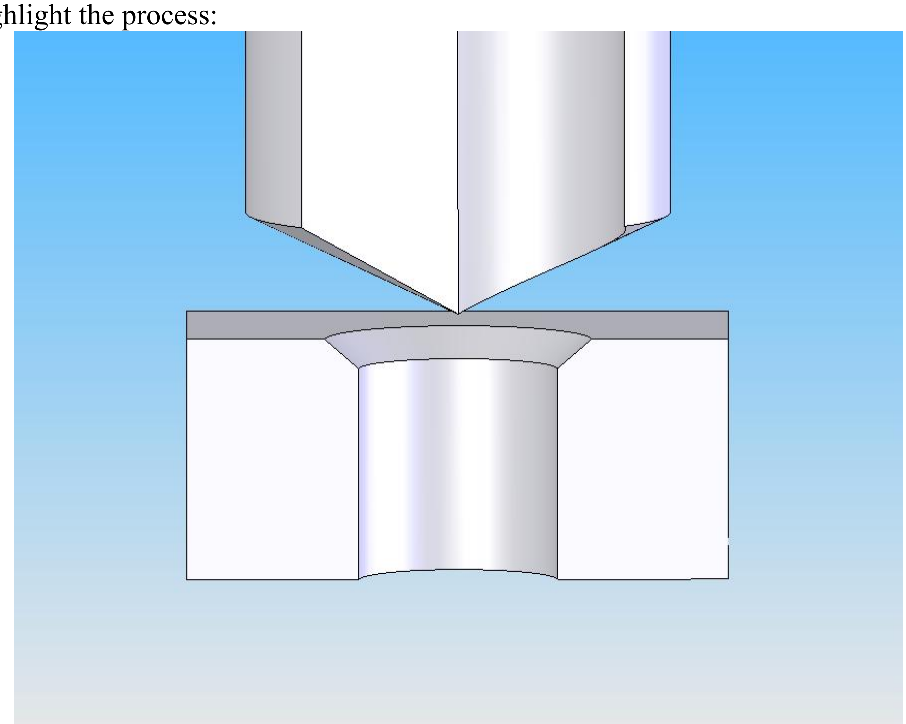
But here comes the high technology part of the exercise. The Zipp team developed an impact forming process to essentially forge each individual spoke hole to eliminate stress risers, develop favorable localized grain structure, and increase localized hardness all at the same time, and Z310.9 became the perfect alloy for the job.



Alloy properties compared to 6061 after SHIFT process

The Z310.9 alloy already appeared perfect for the design of the hubshell and flange, but after seeing the data on the SHIFT samples, the decision was made. Despite it's high cost, Z310.9 was chosen as it offers more than double the strength of 6061 at significantly higher toughness, resulting in lighter weight hubs which we actually recommend you radial lace.

The other beauty of the SHIFT process is that instead of removing material from the flange as in traditional processes, all the original material remains, and is simply forged into the surrounding flange geometry. The images below highlight the process:



Chamfering of hole edge removes material around edge to fit spoke head.

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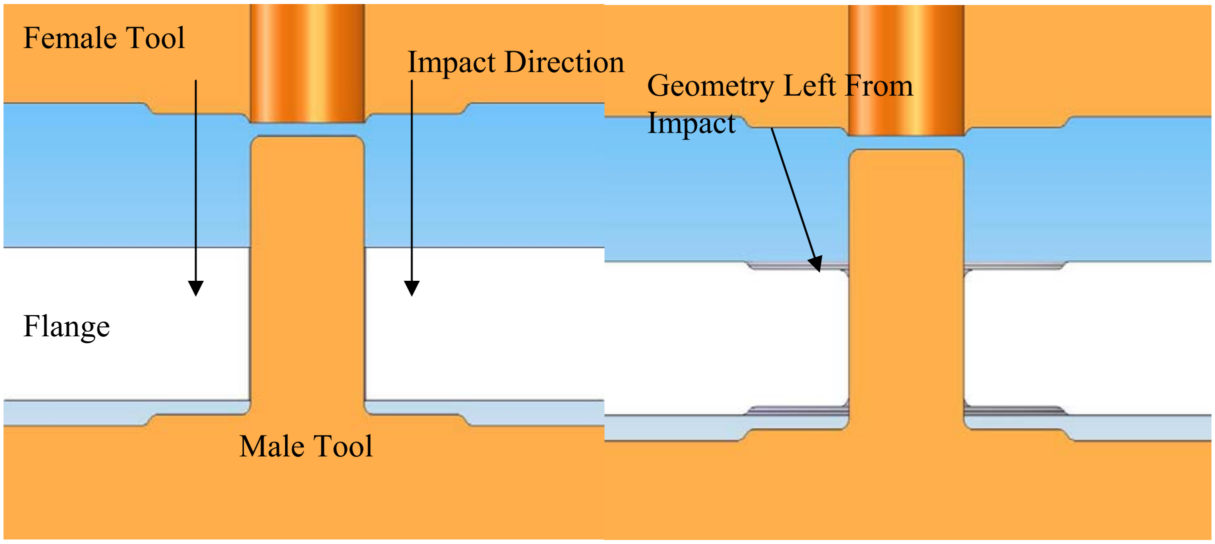

Flange Before Impact   Flange After Impact

The only downside of this shift technology is that the tooling is specific to each spoke count, and is very expensive. Currently 10, 28, and 32 hole front hubs are made, and 24, 28, and 32 hole rear hubs are made, which seems to fill most any need. The overall flange performance is so dramatically improved that radial lacing will not void the hub warranty, and is even acceptable in cyclocross wheelsets.

Conclusion
The combination of design, material engineering, and ultra high precision manufacturing technologies, have come together in the Zipp hubsets series, to create the world's lightest, strongest, and most trouble free hubsets. Zipp is proud to hand construct every single hubset under it's own roof, and carefully inspect each product before it leaves the building. These hubs are designed to spin smoother, last longer, and be lighter than any product previously available, and in all of these areas have succeeded dramatically. These hubs also represent numerous technological advancements made in their development, which have changed the product landscape as our competitors are forced to innovate or copy these designs. Ultimately, you, the consumer, benefit through superior materials, superior craftsmanship, and better efficiency on the bike, as technologies never before thought feasible outside of aerospace can be now be had at prices competitive with offerings available from our competitors. The Zipp hub range truly exemplifies the best of modern design capabilities, materials engineering, and manufacturing processes available anywhere in the world, and it all comes to you from a family run company in Speedway, Indiana.