Developing Carbon Fibre Wheels for Peak Performance
(Title)

(Abstract)
Racing demands each gram of unneeded mass be removed. Blackstone Tek have recently introduced carbon fibre sports car wheels. The reduced mass equates to a benefit of 69 ms on a 400 m drag race. We review the state-of-the-art in carbon fibre wheel design and the test standards to ensure safety.


Brandon Heukelman
Engineering Manager
Blackstone Tek
Frank Kienhöfer
Visiting Associate Professor
The University of the Witwatersrand, Johannesburg

Before the turn of the century, the material to manufacture wheels shifted from steel to aluminium alloy. Blackstone Tek produced their first carbon fibre motorcycle wheel in 2002 and has since produced more than 30 000 carbon fibre wheels making it a dominant player if not the global market leader in the carbon fibre wheel market. The $2000 plus price tag and the difficulty to mass produce carbon fibre wheels make it unlikely that the material for mass-produced wheels will shift from aluminium alloy to carbon fibre. In spite of the low production numbers, Blackstone Tek have obtained OEM certification, being the first carbon fibre wheel manufacturer in the world to do so with Ducatti; and have recently expanded their motorcycle wheel range to include automotive wheels for the VUHL 05RR, Donkervoort GTO D8-40 (Fig. 1), Ariel Atom supercar and Vintech super-special Porches. Blackstone Tek carbon fibre wheels are lighter than their forged aluminium and magnesium counterparts and sell to a niche market of performance enthusiasts who are willing to pay to have the lightest wheels. In this paper, we quantify the performance benefit of reducing the unsprung mass and wheel's rotational inertia for motorcycles and sports cars, review the state-of-the-art in designing and manufacturing wheels using carbon fibre and detail the test standards to ensure safety and quality.

Quantifying the Carbon Fibre Wheel Performance
The lightest Blackstone Tek carbon fibre motorcycle wheels, intended for the racetrack only, have a mass of 1.7 kg for the front wheel and 2.3 kg for the rear wheel, which is 32% lighter than a competitor's carbon fibre wheel and 39% lighter than a forged aluminium wheel. Recently designed Blackstone Tek 19 x 9.00 and 20 x 9.00 carbon fibre wheels for the front and rear of sports cars are respectively 5 kg (55%) and 6 kg (57%) lighter than their forged aluminium and magnesium counterparts. In addition, the carbon fibre wheels are designed for a ~10% higher static wheel load rating.

An important consideration is how these weight savings translate to improved lap times on the racetrack. A comparison of Blackstone Tek carbon fibre and stock wheels on a ZX-10R superbike on Donington racetrack demonstrated a 1.6 s (1.5%) improvement in lap times.

The newly designed Blackstone Tek 19 x 9.00 and 20 x 9.00 carbon fibre wheels are yet to be tested on the track but the performance gain as a result of the weight saving was simulated using CarSim [1]. A rear-wheel drive racecar with a mid-mounted 300 kW engine and mass of 1461 kg was used for the comparison. Simulation has the advantage of being cheaper, and can normalise confounding variables associated with track testing like track temperature, driver variation between laps and gusts of wind. Using carbon fibre wheels reduces the total vehicle mass by 22 kg (1.5% reduction) but the effective mass is reduced by 29.3 kg (1.9% reduction). The effective mass elegantly includes the effect of the angular acceleration of the wheels by adding a term equal to the rotational inertia divided by the square of the rolling radius of the tyres. The simulated benefit of reducing the mass was surprising low; reducing the lap time by only 0.10 s (0.16%). Postprocessing showed the heavier vehicle catches up to the lighter vehicle during braking. This is physically correct if braking is initiated at the same point before a corner. The computer driver controller however needs to account for the improved braking deceleration of reducing the mass by braking later before a corner for the comparison of lap times to be representative of reality.

An easier analysis method was conducted by comparing the performance of the carbon fibre Blackstone Tek wheels on a 400 m drag race (thus eliminating the effect of the computer driver controller) (Fig. 2). The reduced mass resulted in a 69 ms (0.59%) improvement. These improvements in times (which appear to the uninitiated race enthusiast to be insignificant) are in line with studies conducted by Tyrrell Racing [2] and Sauber [3] which predict that a 1.9% reduction in mass would improve times by 0.45% and 0.36% respectively.

The Design, Thermal Analysis and Manufacturing

The design process of a carbon fibre wheel (Fig. 3) begins with a CAD model. The wheel is then analysed assuming a homogenous material to eliminate any stress concentration factors (SFCs) before modelling the full lay-up to ensure the wheel stiffness is in the desired range: a stiff wheel hops and feels too lively and a compliant wheel feels unresponsive. Once the stiffness is correct, the wheel strength is analysed and finally the model is exported using CAM (computer-aided manufacturing) for machining of the moulds.

An important consideration is thermal analysis of the wheel to ensure dissipation of the heat from braking, tyre hysteresis and bearing friction. Elevated temperatures can cause a reduction in stiffness and strength. Blackstone Tek collaborate with the University of the Witwatersrand, Johannesburg, to develop thermal models to predict the temperature of the wheel rim with experimental capabilities to conduct thermal imaging using a FLIR T640 camera and thermal liquid crystals (TLC), as well as flow visualisation using a Dantec PIV (particle image velocimetry) system (Fig. 4).

Blackstone Tek use aerospace FAR25 qualified materials as used by NASA and Formula 1 in the manufacture of wheels. The carbon fibre is imported from Germany and the temperature is controlled for the trip. It is stored at a constant -20˚C to maintain the integrity of the material. The carbon fibre is a combination of woven and unidirectional formats, and is impregnated with a resin matrix made from toughened epoxy. Each wheel is made from around 130 to 180 carbon components which are cut on Zund automated machines. Every step of the manufacturing process is recorded, and the entire history of each component is stored with its unique serial number, according to ISO 9001.

The Reliability, Durability and Safety

All Blackstone Tek wheels are tested to international standards to ensure reliability, durability and safety. These tests are conducted according to the German TÜV, American SAE, Japanese JWL and international ISO standards as required by the customer. The most important alternating torsion, cornering fatigue and impact tests are conducted in-house to ensure rapid research, development and turn around; so that when wheels are sent to be certified we can be confident of the result.

Blackstone Tek were instrumental in working together with TÜV in developing a new standard for composite wheels which includes a newly added thermal test.

The Carbon Fibre Advantage

Carbon fibre wheels manufactured by Blackstone Tek are several kilograms lighter than their aluminium and magnesium counterparts. The resulting saving on lap times on the racetrack are of the order of milliseconds, which may seem insignificant to the uninitiated, but are worth the price for the racing enthusiast. Stringent testing ensures that there is no compromise in the reliability, durability and safety of carbon fibre wheels.

References

[1] carsim. , [Online]. Available: http://www.carsim.com.

[2] B. Agathangelou and M. Gascoyne, "Aerodynamic design considerations of a Formula 1 racing car," *SAE,* vol. 980399, pp. 1-6, 1998.

[3] W. Toet, "Aerodynamics and aerodynamic research in Formula 1," *The Aeronautical Journal,* vol. 117, no. 1187, pp. 1-26, 2013.

(More information):

http://www.blackstonetek.com

Fig. 1: Donkervoort GTO D8-40 showcasing Blackstone Tek carbon fibre wheels

Fig. 2: Drag race simulation

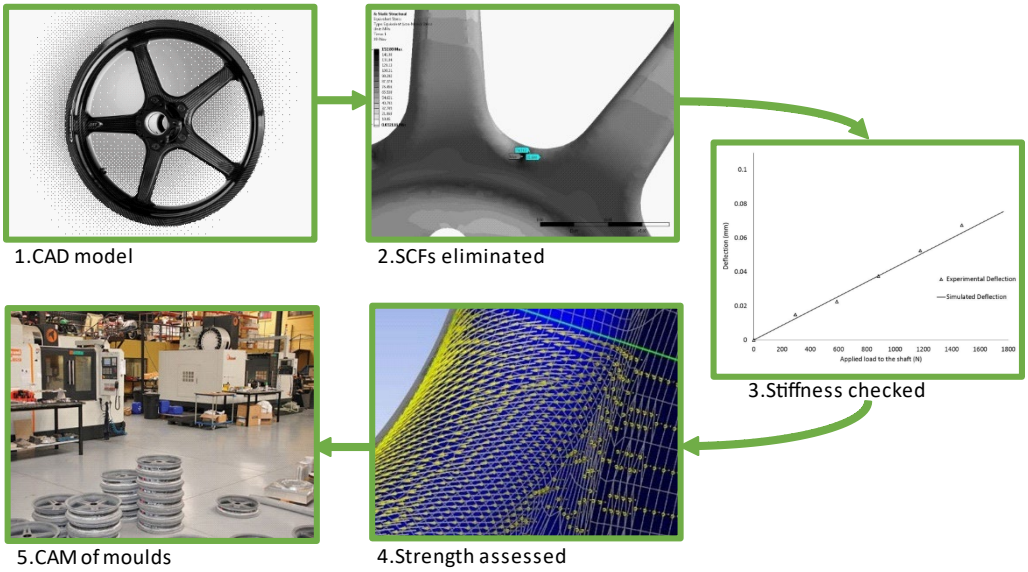

Fig. 3: The Carbon Fibre Wheel Design Process

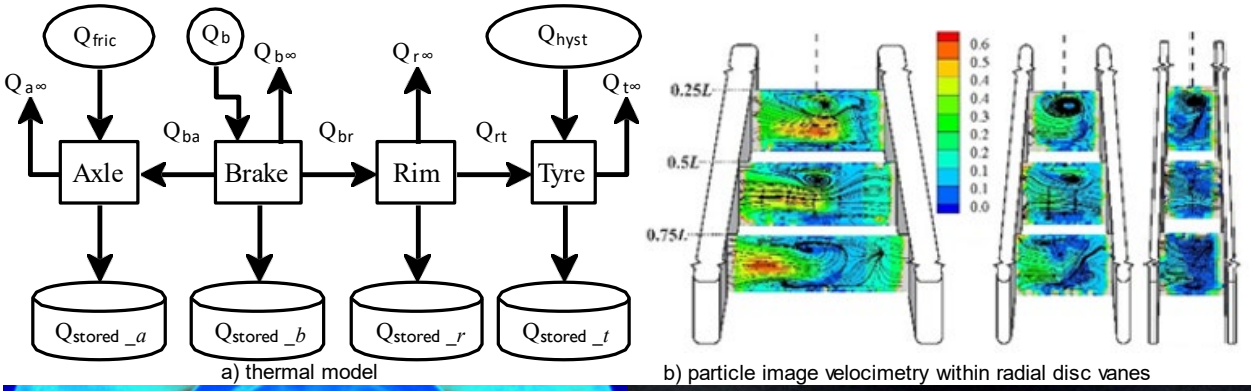

Fig. 4: Thermal models, PIV, thermal imaging and TLC