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The effects of simplifications on isolated wheel aerodynamics

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ABSTRACT

In order to study the aerodynamic forces and flow features of rotating wheels, compromises and simplifications are often made in wind tunnel testing, and more frequently so in numerical modelling. A CFD approach similar to that commonly used in industry was utilised to investigate common assumptions involving; the influence of geometric fidelity in wheel hub regions, ground representation, the modelling of the contact patch, and the effects of rotation on separation. It was found that the separation and wake characteristics were strongly influenced by the rotation of the wheel; the separation point changed by as much as 90% compared to a stationary wheel, and drag was close to 20% less – downforce was approximately 40% greater. In addition, the modelling of the contact patch, treated here as a small step to facilitate skew-free meshing necessary for a reliable converged result, was seen to cause up to a 52% difference in predicted lift characteristics, and an increase in the step of just 2 mm decreased the maximum wake thickness by close to 50% – considerable changes stemming from superficially-minor simplifications. Including indented wheel hubs proved to be more influential on the production of vortices and wake structures, causing the merging of previously-separate vortex structures. The results point to a need for very careful evaluation of the goals of any study when determining which simplifications can be made in both physical testing and numerical analysis.

1. Introduction

In studying the effects of flowfields around wheels, simplifications are often applied in order to reduce the complexity of the aerodynamics to a level which can be simulated in a reasonable timeframe using computational fluid dynamics (CFD). In motorsport applications, time-consuming but more realistic–transient analysis is rare due to tight deadlines. In the wind tunnel, the influence of stings, the ability or otherwise to rotate the wheel at all or at a suitable velocity, and the interaction with the ground plane all serve as critical points which can affect the usefulness of the results (Burgin et al. 1986, Lajos et al., 1986). On top of this, satisfactory correlation of wind tunnel and/or CFD results to track data is notoriously difficult and the focus of much time and effort (Cruickshank and Doig 2014).

Publicly-available aerodynamic investigations of an isolated wheel applicable to open wheel racing cars commenced with the three dimensional experimental study undertaken by Morelli (1969). Open-wheel vehicles are used in common types of racing all the way up to Formula 1, with the tyres almost always “slick”, in that they rarely feature a tread pattern. Category rules dictate that the wheels not be shrouded or enclosed, thus fully exposing them to the oncoming flow. The wheel wakes therefore have a very strong bearing on the aerodynamic performance of other vital components (Diasinos et al., 2014).

In Morelli’s study, the ground was represented by a stationary ground board which included a recess for the wheel to rotate within (i.e. the wheel was not in contact with the surface), which resulted in a cumulative downforce-this was later shown to be purely a product of the ground representation by Cogotti (1983), who demonstrated that an isolated wheel in contact with a true ground should produce lift. This was re-enforced by the experiments of Stapleford and Carr (1970), who concluded that the only way of making certain that the flow features reproduced during an experiment are representative of that of a wheel belonging to an open wheeler racing car is to have a rotating wheel in contact with a moving ground.

Fackrell and Harvey (1973, 1975) and Fackrell (1975) experimental investigations for three wheel widths and two wheel shoulder shapes would become the benchmark for later research undertaken on exposed wheels, although information about the sting geometry and other influential parameters was not detailed. Lift and drag were determined to be approximately 42% and 25% lower respectively than experienced by a stationary wheel in

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contact with a stationary ground. Between these two scenarios, the wheel rotation moved the forward stagnation point approximately 15° down towards the front contact patch at the ground. A peak pressure forward of the contact patch greater than two was obtained, due to the moving boundaries transmitting energy into the flow through the shear stresses created by the boundary layers that form over the two converging surfaces. This increase in pressure achieved at the wheel centre was expected to cause a jetting action at either side of the front contact patch to increase in strength and to encourage the formation of two stronger vortices from each side of the wheel. These features are shown schematically in Fig. 1 to orient the reader to the flowfields shown in later sections.

The first non-intrusive wake measurements of an isolated wheel were made by Knowles et al. (2002) using Laser Doppler Anemometry and a rotating wheel with a moving ground. Only four vortex structures could be found in the wake of the wheel, with two counter rotating vortices forming at the base of the wheel wake adjacent to the floor as previously measured by Bearman et al. (1998).

Reynolds-Averaged Navier Stokes (RANS) computational models specifically of wheels emerged in the late 1990's: Axon et al. investigated an isolated wheel using a commercial CFD code (FLUENT). The wheel geometry utilised shared a common wheel width to diameter ratio as that used by Fackrell (1975) but was

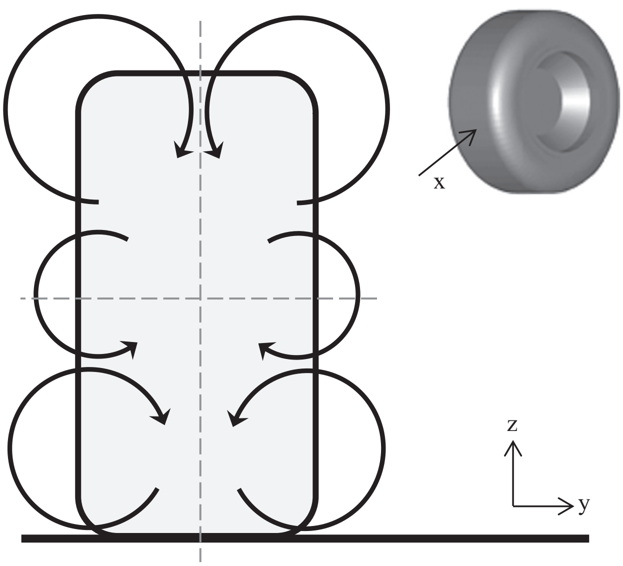

Fig. 1. Schematic of main vortices produced by a wheel, viewing on a plane normal to the freestream.

simplified such that the wheel hubs were removed and the wheel shoulder was replaced with a constant radius (as in Fig. 2c). The model indicated that the rotating wheel produced C_P values greater than 2 in the region forward of the contact patch and confirm the hypothesis that the jetting action forward of the wheel assists the formation of the vortical structures emanating from either side of the wheel (Fackrell and Harvey, 1973). Axon et al. (1998) also highlighted the difficulty associated with creating a mesh around the contact patch of the wheel. By meshing the acute junction between the ground and the wheel surfaces, a large number of skewed control volumes were introduced and so a small step around the perimeter of the contact patch was introduced. Unfortunately the effect that this common simplification might have on the flow structures was not investigated at the time.

McManus and Zhang (2006) conducted a transient computational analysis, using unsteady RANS, of an isolated wheel, although reported time-averaged results. While it is inarguable that flow around a wheel is inherently unsteady (Pirozzoli et al., 2012; Dassanayake et al., 2012), from an industrial point of view the computational power and runtimes involved remain largely impractical for anything other than steady RANS despite the potential for improved accuracy. Similarly, studies investigating flow around well-defined, high fidelity models featuring tyre treads, hub spokes, brake ducts, tyre camber and deformation, etc., lead to problems in reproducing the intricacies of the experiment with confidence in CFD, as many features are difficult to resolve in the model but strongly influence the wake (Saddington et al., 2007; Issakhanian et al., 2010; Axerio-Cilies and Iaccarino, 2012).

In this vein, the present study aims to investigate ways in which tunnel and numerical data sets can feature better correlation through modelling choices which should be considered from the start of a campaign featuring one approach or both. The results focus on the effects of how the wheel/ground contact patch is modelled, the importance of wheel rotation and defined separation points, and the role of the wheel hubs in influencing the force and wake characteristics.

2. Numerical method

All original results presented here for the asymmetric Fackrell A2 wheel-the dimensions of which are shown in Fig. 2. (along with variants tested for discussion in the subsequent sections)-were computed using ANSYS Fluent using the segregated pressure-based solver, second order upwinding for discretized terms, and a standard SIMPLEC algorithm for pressure–velocity coupling.

This study focused on steady-state RANS solutions, as this remains by far the most common approach in automotive and

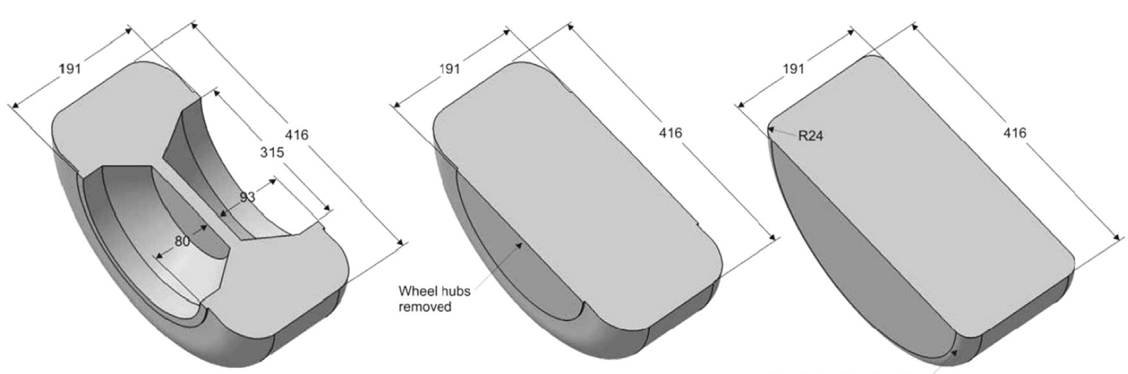

Fig. 2. Dimensions and characteristics of (a) the original A2 wheel, (b) the A2 wheel without hubs on the side and (c) the A2 wheel without hubs and a constant radius shoulder (W1 wheel).