

**UNIVERSITY OF NEW SOUTH WALES**

**The Aerodynamic Interaction of a Rotating Wheel  
and a Downforce Producing Wing in Ground Effect**

By

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**ORIGINALITY STATEMENT**

'I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at UNSW or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.'

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Date .....

## **Acknowledgements**

During the course of this research project, I have been fortunate enough to have received the assistance of many people that have been instrumental in the completion of this project. For this reason, these acknowledgements may seem long, but definitely necessary given that this is the only formal way that I can express my gratitude to all the people that have helped me along this journey.

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## **Abstract**

The performance and safety of current open wheeler race cars depend heavily on the effectiveness of the aerodynamic package. The front wing and front wheels make a significant contribution and therefore must be well understood. Previous investigations have focused on the aerodynamic characteristics of either an isolated downforce generating wing in ground effect or a rotating wheel in isolation. Investigations that have considered both bodies working in unison conflictingly claim that the addition of a wheel downstream of a wing can aid or hinder the performance of the wing, and the wheel's aerodynamic performance has not been reported. In order to obtain a more thorough understanding of the interaction of a wing and wheel, experimental results were used to conduct an extensive validation of a computational model, after an equally rigorous verification study had been conducted. A number of investigations were then conducted of a wing and wheel working in unison as well as each in isolation using the computational model.

The combined wing and wheel investigation demonstrated that three main interactions can occur, depending on the selection of wing span, angle of attack and height used, while the wheel width and track were found to be less sensitive parameters. The three interacting states differ in the path that the main and secondary wing vortices take around the wheel and the subsequent variation in the combined wake structure. In general, the wing in the presence of the wheel reduced the wing's ability to generate downforce by up to 45%. This is due to the high pressure regions generated forward of the wheel, which reduce the suction that can be achieved by the bottom surface. This was also found to alleviate the adverse pressure gradients experienced by the wing, and also reduce the drag by up to 70%. For this reason, the downforce loss phenomenon was observed to occur at a height 0.08c to 0.32c lower in comparison to the same wing in isolation, dependant on the wing span. Wheel lift and drag values were also observed to reduce in the presence of a wing by up to 65% and 38% respectively. The upwash and vortices generated by the wing were found to assist in reducing the separation from the contact patch and increasing the separation from the upper wheel tread; a phenomenon also observed during an isolated wheel investigation which was found to reduce the wheel's lift and drag. As a result, it was shown that the combined wing and wheel downforce and drag optima differed by up to 75% and 25% respectively to those which would be estimated if the two bodies were

investigated individually and the results summed. This highlights the importance of investigating these two bodies in unison.

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## **Nomenclature**

AOA	wing angle of attack
c	wing chord
$C_D$	drag coefficient
$C_{DA}$	drag coefficient not normalised with a reference area (m <sup>2</sup> )
$C_L$	lift coefficient
$C_{LA}$	lift coefficient not normalised with a reference area (m <sup>2</sup> )
$C_p$	static pressure coefficient
$C_S$	side force coefficient
$C_{SA}$	side force coefficient not normalised with a reference area (m <sup>2</sup> )
d	wheel diameter
$d_p$	diameter of seeding particles
$d_P$	seeding particle diameter
$f_c$	critical frequency for which particle follows oscillations in flow
$f_{coarse}$	result obtained with the coarse mesh that the grid convergence index will be calculated for
$F_D$	drag force experienced by a particle of seeding
$f_{Err}$	doppler frequency error
$f_{fine}$	result obtained with the fine mesh that the grid convergence index will be calculated in comparison to
$F_L$	lift force experienced by a particle of seeding
$F_S$	factor of safety for used for the calculation of the grid convergence index
h	height of wing measured from the point closest to the ground
$h_{grid}$	grid characteristic length
$h_{coarse}$	grid characteristic length of the coarse grid that the grid convergence index will be calculated for
$h_{fine}$	grid characteristic length of the fine grid that the grid convergence index will

	be calculated in comparison to
$h_{LDA}$	constant dependant on confidence level of LDA measurements
$h_{ref}$	reference height for calculation of turbulence length scale
$I$	turbulence intensity
$k$	kinetic energy
$l$	turbulent length scale
$l_R$	ratio between aperture of a Guassian beam and the beam waist
$N$	number of samples
$p$	factor describing the order of convergence used for the calculation of the grid convergence index
$p'$	fluctuating pressure component
$\bar{P}$	mean pressure component
$r$	ratio of coarse to fine grid characteristic lengths for the calculation of the grid convergence index
$S$	wing span (measured from center to tip)
$s$	particle of seeding slip velocity
$T$	wheel track
$t_i$	transit time of the i'th particle crossing the measurement volume
$\vec{u}$	velocity magnitude
$u', v', w'$	fluctuating velocity component
$\bar{U}, \bar{V}, \bar{W}$	mean velocity component
$u, v, w$	velocities in the x,y,z directions respectively
$u_1, u_2, u_3$	velocity measured by the green blue and violet LDA channels respectively
$u_F$	fluid seeding is traveling in velocity
$u_i$	velocity of the i'th particle crossing the measurement volume
$u_\infty$	freestream velocities
$u_{rms}, v_{rms}, w_{rms}$	rms velocities in the x,y,z directions respectively
$u_t$	friction velocity
$v_F$	fluid seeding is traveling in velocity
$v_P$	particle of seeding velocity
$v_S$	particle of seeding slip velocity
$W$	wheel width
$\bar{X}$	mean value of variable that the error will be calculated for



$x, y, z$	orthogonal directions
$x_D$	beam waist
$x_{IFS}$	distance of inlet boundary from wheel center
$x_{OFS}$	distance of outlet boundary from wheel center
$y^+$	y plus value
$y_{FS}$	distance of side boundary from symmetry plane
$y_p$	distance from the boundary to the center of the adjacent control volume used to calculate the $y^+$ value
$z_D$	length of measurement volume
$z_{FS}$	distance of top boundary from ground

### Greek Symbols

$\alpha$	angle of 2D LDA probe
$\beta$	angle of 1D LDA probe
$\varepsilon$	turbulent dissipation rate
$\varepsilon$	percentage variation of coarse and fine variable for the calculation of the grid convergence index
$\Phi$	variable for which the error is required to be calculated
$\phi$	angle about a circumference of the wheel parallel to the ground measured from the central, upstream point
$\eta$	non dimensionalised span measured from wing tip (0) to wing center (1)
$\eta_i$	non-uniform weighting factor for correcting velocity bias
$\lambda$	volumetric deformation
$\lambda_{LDA}$	wavelength of laser beam
$\mu$	dynamic viscosity
$\mu_F$	fluid seeding is traveling in viscosity
$\mu_t$	turbulent viscosity
$\nu$	kinematic viscosity
$\theta$	angle around the central circumference of a wheel measured from the most upstream point
$\theta_{LDA}$	beam separation angle
$\rho$	density of fluid
$\rho_p$	seeding particle density

- $\tau$  shear stress acting on a volume of fluid
- $\tau_0$  time required to make slip velocity zero
- $\omega$  specific dissipation rate
- $\omega_c$  critical frequency for which slip can be tolerated
- $\zeta$  equation dependant on the variable that measurement error will be calculated for

## Glossary

- CCD Charged Couple Device
- DNS Direct Numerical Simulation
- F1 Formula One
- GCI Grid Convergence Index
- LDA Laser Doppler Anemometer
- LES Large Eddy Simulation
- PIV Particle Image Velocimetry
- RANS Reynolds Averaging Navier Stokes
- RNG Renormalization Group theory
- RSM Reynolds Stress Modeling
- SIMPLE Semi-Implicit Method for Pressure Linked Equations
- SIMPLEC SIMPLE Consistent
- SST Shear Stress Transport
- UNSW University of New South Wales