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.'

Signed ……………………………………………..............

Date ……………………………………………..............

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Ευχαριστο μορο μου για ολοι την βοηθια σου. Χερομε καθε στιγμι που ειμαι μαζι σου, σα' γαπαο!

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 considering 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.

Contents

List of Figures

List of Tables

Nomenclature

AOA	wing angle of attack
c	wing chord
C_D	drag coefficient
C_DA	drag coefficient not normalised with a reference area (m2)
C_L	lift coefficient
C_LA	lift coefficient not normalised with a reference area (m2)
C_p	static pressure coefficient
C_S	side force coefficient
C_SA	side force coefficient not normalised with a reference area (m^2)
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

$\overline{P}$ 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

$\overline{U}, \overline{V}, \overline{W}$ 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_∞ 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

$\overline{X}$ 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

α angle of 2D LDA probe

β angle of 1D LDA probe

ε turbulent dissipation rate

ε percentage variation of coarse and fine variable for the calculation of the grid convergence index

Φ variable for which the error is required to be calculated

ϕ angle about a circumference of the wheel parallel to the ground measured from the central, upstream point

η non dimensionalised span measured from wing tip (0) to wing center (1)

η_i non-uniform weighting factor for correcting velocity bias

λ volumetric deformation

λ_{LDA} wavelength of laser beam

μ dynamic viscosity

μ_F fluid seeding is traveling in viscosity

μ_t turbulent viscosity

ν kinematic viscosity

θ angle around the central circumference of a wheel measured from the most upstream point

θ_{LDA} beam separation angle

ρ density of fluid

ρ_P seeding particle density

τ	shear stress acting on a volume of fluid
τ_o	time required to make slip velocity zero
ω	specific dissipation rate
ω_c	critical frequency for which slip can be tolerated
ζ	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