



**Luis Daniel Peralta Maldonado**

**Numerical study of the aerodynamics of a race  
car rear wing**

**Dissertação de Mestrado**

Dissertation presented to the Postgraduate Program in Mechanical Engineering of the Departamento de Engenharia Mecânica do Centro Técnico Científico da PUC-Rio, as partial fulfillment of the requirements for the degree of Mestre em Engenharia Mecânica.

Advisor : Prof. Sergio Leal Braga  
Co-Advisor: Prof. Luiz Eduardo Bittencourt Sampaio

Rio de Janeiro  
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To my grand mother and mother.

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## Abstract

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In order to gain deeper understanding of the flow physics around low aspect ratio wings, the current dissertation presents a numerical study of the flow around a race-car rear wing, in particular, the PUC-Rio Formula-University car. To diminish the time it takes to prepare a numerical simulation, we evaluate the performance and accuracy of a particular utility available in OpenFOAM, namely, snappyHexMesh, which generates hexahedral unstructured grids. The effect of using such a grid in numerical simulations employing two different turbulence models (Spalart Allmaras and  $k - \omega$  SST) for several angles of attack is investigated. The methodology of the study comprised six steps: 3D scanning of the real geometry, geometry modeling, grid generation, flow computation, solution validation, flow visualization and analysis. The grid qualities were assessed using a simple two-dimensional case, which showed good agreement with experimental data with an absolute difference ranging between 0.39% and 8%. While comparing them with numerical validated data the difference ranged between 0.5% and 3.6%. By visualizing the velocity and pressure fields, it was confirmed that the methodology used in the current study is capable of capture the various physical phenomena present in the flow around a rear wing, which is characterized by horseshoe vortices at the end plates, local recirculation zones, tip vortices and their interaction with the boundary layer at the suction surface. The simulations showed that the size of the tip and horseshoe vortices increases with the angle of attack, as well as their influence on the boundary-layer separation. Consequently, although the end plates are known to be useful in reduction of vortex, it was observed there is still a great waste of energy in their formation.

## Keywords

Computational Fluid Dynamics. Aerodynamics. Wing. Race Car.

## Resumo

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Mecânica, Pontifícia Universidade Católica do Rio de Janeiro.

A fim de obter uma compreensão mais profunda da física do escoamento em torno de asas de baixa relação de aspecto, a presente dissertação apresenta um estudo numérico do escoamento em torno da asa traseira de um carro de corrida, em particular, o carro de fórmula da PUC-Rio. Para diminuir o tempo que leva para preparar uma simulação numérica, avaliamos o desempenho e a precisão de um utilitário disponível no OpenFOAM chamado snappyHexMesh, o qual gera malhas não estruturadas usando em sua maioria elementos hexahédricos. O efeito do uso de tal malha nos resultados das simulações numéricas é investigado, empregando dois modelos de turbulência diferentes (Spalart Allmaras e  $k - \omega$  SST) para vários ângulos de ataque. A metodologia do estudo foi composta por seis etapas: a digitalização da geometria, a modelagem da geometria, a geração da malha, o cálculo do escoamento, a avaliação da solução, a visualização e análise do escoamento. As qualidades da malha foram avaliadas através de um caso bidimensional simples, que mostrou boa concordância com dados experimentais com uma diferença absoluta variando entre 0,39% e 8%. Em quanto que comparando-os com dados numéricos validados a diferença variou entre 0,5% e 3,6%. Visualizando os campos de velocidade e os campos de pressão, foi confirmado que a metodologia utilizada no estudo é capaz de capturar os diversos fenômenos físicos presentes no escoamento, o qual é caracterizado por vórtices de ferradura nas placas, zonas de recirculação locais, vórtices de ponta e sua interação com a camada limite na superfície de sucção. As simulações mostraram que o tamanho dos vórtices de ponta e dos vórtices de ferradura aumenta com o ângulo de ataque, bem como sua influência sobre a separação da camada limite. Conseqüentemente, embora as placas sejam reconhecidamente úteis na diminuição dos efeitos de ponta, ainda há um grande desperdício de energia na formação de vórtices.

## Palavras-chave

Dinâmica dos Fluidos Computacional. Aerodinâmica. Asa.  
Carro de Corrida.

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# Summary of notations

## Roman

$C_L$	lift coefficient
$L$	lift
$A$	reference area
$c$	wing chord
$s$	wing span
$U_\infty$	free-stream velocity
$D$	drag
$C_D$	drag coefficient
$Re$	Reynolds number
$C_p$	pressure coefficient
$u$	velocity vector
$p$	thermodynamic pressure
$(x, y, z)$	Cartesian coordinates
$t$	time
$u^*$	average of $u$
$u'$	fluctuating part of $u$
$u^*$	characteristic velocity scale
$l^*$	characteristic length scale
$k$	turbulent kinetic energy
$P_k$	rate of production of turbulent kinetic energy
$F_1$	blending function in the model equation for $\omega$
$F_2$	second blending function in the model equation for $\omega$
$CD_{k\omega}$	constant in the model equation for $\omega$
$S$	invariant measure of the mean strain rate
$a_1$	constant in the model equation for $k$ and $\omega$
$f_{v1}$	closure coefficient in for the Spalart Allmaras model
$f_{v2}$	closure coefficient in for the Spalart Allmaras model
$f_\omega$	closure coefficient in for the Spalart Allmaras model
$g$	closure coefficient in for the Spalart Allmaras model
$r$	closure coefficient in for the Spalart Allmaras model
$c_{\omega 2}$	closure coefficient in for the Spalart Allmaras model

$f_{t2}$	closure coefficient in for the Spalart Allmaras model
$c_{t3}$	closure coefficient in for the Spalart Allmaras model
$c_{t4}$	closure coefficient in for the Spalart Allmaras model
$V$	cell volume
$y^+$	non-dimensional coordinate
$S_f$	cell face area vector
$u_\tau$	shear velocity
$W_{ij}$	vorticity tensor
$ d $	distance between two adjacent nodes
$f_x$	interpolation factor
$k$	component of $S_f$

## Greek

$\rho$	density
$\nu$	kinematic viscosity
$\mu_t$	turbulent viscosity
$\nu_t$	kinematic eddy viscosity
$\omega$	specific dissipation rate
$\varepsilon$	rate of dissipation of the turbulent kinetic energy
$\tau_w$	wall shear stress
$\beta^*$	constant in the model equation for $k$
$\sigma_k$	constant in the model equation for $k$
$\gamma$	constant in the model equation for $\omega$
$\beta$	constant in the model equation for $\omega$
$\sigma_\omega$	constant in the model equation for $\omega$
$\sigma_{\omega 2}$	constant in the model equation for $\omega$
$\sigma_{k1}$	constant in the model equation for $\omega$
$\sigma_{k2}$	constant in the model equation for $\omega$
$\gamma_1$	constant in the model equation for $\omega$ and $k$
$\beta_1$	constant in the model equation for $\omega$ and $k$
$\beta_2$	constant in the model equation for $\omega$ and $k$
$\Omega$	magnitude of the vorticity
$\chi$	ratio between $\tilde{\nu}$ and $\nu$