Pontifícia Universidade Católica
do Rio de Janeiro

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 Cientco 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
August 2011

Pontifícia Universidade Católica
do Rio de Janeiro

Luis Daniel Peralta Maldonado

Numerical study of the aerodynamics of a race car rear wing

Dissertation presented to the Postgraduate Program in Mechanical Engineering of the Departamento de Engenharia Mecânica do Centro Técnico Cientco da PUC–Rio, as partial fulfillment of the requirements for the degree of Mestre em Engenharia Mecânica. Approved by the following commission:

Prof. Sergio Leal Braga
Advisor
Pontifícia Universidade Católica do Rio de Janeiro

Prof. Luiz Eduardo Bittencourt Sampaio
Co–Advisor
Laboratory of Theoretical and Applied Mechanics
LMTA/PGMEC - UFF

Prof. Angela Ourivio Nieckele
Department of Mechanical Engineering — PUC - Rio

Prof. Marcos Sebastião de Paula Gomes
Department of Mechanical Engineering — PUC - Rio

Prof. José Eugenio Leal
Coordinator of the Centro Técnico Científico — PUC - Rio

Rio de Janeiro — August 16, 2011

Luis Daniel Peralta Maldonado

Graduated from Escuela Politécnica Nacional (Quito, Ecuador) in Mechanical Engineering in 2009.

Bibliographic data

L. Daniel Peralta

Numerical study of the aerodynamics of a race car rear wing / Luis Daniel Peralta Maldonado; advisor: Sergio Leal Braga; co–advisor:Luiz Eduardo Bittencourt Sampaio . — 2011.

87 f. : il. ; 30 cm

1. Dissertação (Mestrado em Engenharia Mecânica) - Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2011.

Inclui bibliografia

1. Engenharia Mecânica – Teses. 2. Dinâmica dos Fluidos Computacional. 3. Aerodinâmica. 4. Asa. Carro de Corrida. I. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Engenharia Mecânica. II. Título.

CDD: 621

To my grand mother and mother.

Acknowledgments

To my advisors Professors Sergio Braga and Luiz Sampaio for the support, advice, guidance and encouragement during all the stages of this project.

To the CAPES and the PUC–Rio, for the financial support, without which this work would not have been realized.

To Professor Angela Nieckele, for the advice and her support lending me to use the Department's cluster to run my simulations.

To Javier, for his help and friendship.

To my family to whom I am deeply grateful for their love, support and encouragement throughout my life and especially during these two years away from them. My most profound appreciation goes to my grand mother, my mother and my uncle Luis who thought me that by working hard I can get all the goals I have set in my life. There are no words in any language to express my gratitude for all that they have done for me. I hope someday to be able to reward them at least a part of all the love and joy they have given me.

Abstract

L. Daniel Peralta; ; . **Numerical study of the aerodynamics of a race car rear wing**. Rio de Janeiro, 2011. 87p. Dissertação de Mestrado — Departamento de Engenharia Mecânica, Pontifícia Universidade Católica do Rio de Janeiro.

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

L. Daniel Peralta; ; . **Estudo Aerodiâmico** . Rio de Janeiro, 2011. 87p. Dissertação de Mestrado — Departamento de Engenharia 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 avaliados 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. Conseqü entemente, embora as placas sejam reconhecidamente úteis na diminuição dos efeitos de ponta, ainda há um grande desperdício de energía na formação de vórtices.

Palavras–chave

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

Contents

List of Figures

List of Tables

Summary of notations

Roman

C_L	lift coefficient
L	lift
A	reference area
c	wing chord
s	wing span
U_∞	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 ω
F_2	second blending function in the model equation for ω
$CD_{k\omega}$	constant in the model equation for ω
S	invariant measure of the mean strain rate
a_1	constant in the model equation for k and ω
f_{v1}	closure coefficient in for the Spalart Allmaras model
f_{v2}	closure coefficient in for the Spalart Allmaras model
f_ω	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_τ shear velocity
W_{ij} vorticity tensor
$|d|$ distance between two adjacent nodes
f_x interpolation factor
k component of S_f

Greek

ρ density
ν kinematic viscosity
μ_t turbulent viscosity
ν_t kinematic eddy viscosity
ω specific dissipation rate
ε rate of dissipation of the turbulent kinetic energy
τ_ω wall shear stress
β^* constant in the model equation for k
σ_k constant in the model equation for k
γ constant in the model equation for ω
β constant in the model equation for ω
σ_ω constant in the model equation for ω
$\sigma_{\omega 2}$ constant in the model equation for ω
σ_{k1} constant in the model equation for ω
σ_{k2} constant in the model equation for ω
γ_1 constant in the model equation for ω and k
β_1 constant in the model equation for ω and k
β_2 constant in the model equation for ω and k
Ω magnitude of the vorticity
χ ratio between $\tilde{\nu}$ and ν