

Cristian Andreescu  
Adrian Clenci *Editors*

# Proceedings of the European Automotive Congress EAEC- ESFA 2015

 Springer

Proceedings of the European Automotive  
Congress EAEC-ESFA 2015

Cristian Andreescu · Adrian Clenci  
Editors

# Proceedings of the European Automotive Congress EAEC-ESFA 2015

 Springer

*Editors*

Cristian Andreescu  
University Politehnica of Bucharest  
Bucharest  
Romania

Adrian Clenci  
University of Pitești  
Pitești  
Romania

ISBN 978-3-319-27275-7

ISBN 978-3-319-27276-4 (eBook)

DOI 10.1007/978-3-319-27276-4

Library of Congress Control Number: 2015955888

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2016

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media  
([www.springer.com](http://www.springer.com))

# Foreword



The European Automotive Congress was thought to be a common scientific event of the traditional biannual European Automotive Engineers Cooperation (EAEC) Congress (this year at its 14th edition) and the Annual International Conference of the Society of Automotive Engineers of Romania (SIAR)—ESFA.

The Congress was organized by the SIAR and the Automotive Engineering Department of the University “Politehnica” of Bucharest in cooperation with EAEC under the patronage of Fédération Internationale des Sociétés d’Ingénieurs de Techniques d’Automobile (FISITA).

The motto of the Congress (*Academia, Industry and Government: together for automotive engineering development*) was an indication of the organizers belief that there is a need for meetings and discussions about the current and future challenges of the automotive world in order to find the best solutions. In other words, we are convinced that the challenges of the future can only be overcome if these tripartite discussions occur permanently.

The papers included in this volume are selected by the Scientific Committee among the almost 130 technical papers proposed to be presented at the Congress.

The authors of these articles are experts from research, industry, and universities coming from 14 countries among which nine from Europe. Their papers are covering the latest issues such as fuel economy and environment, automotive safety and comfort, automotive reliability and maintenance, new materials and technologies, traffic and road transport systems, advanced engineering methods and tools, advanced powertrains, and hybrid and electric drives.

Therefore, we hope these papers will generate fruitful discussions about an exciting topic: the automotive engineering in the light of the future challenges.

Prof. Cristian Andreescu  
EAEC-ESFA 2015 Congress Chairman

Assoc. Prof. Adrian Clenci  
SIAR President

# Scientific Committee

Prof. Cornel Stan, West Saxon University of Zwickau (President of the Scientific and Technical Committee)

Prof. Cristian Andreescu, University “Politehnica” of Bucharest, Romania

Prof. Gabriel Anghelache, University “Politehnica” of Bucharest, Romania

Dr. Rodica Baranescu, Former President, Society of Automotive Engineers, USA

Prof. Alexandru Boroiu, University of Pitesti, Romania

Prof. Nicolae Burnete, Technical University of Cluj-Napoca, Romania

Prof. Anghel Chiru, “Transilvania” University of Brasov, Romania

Assoc. Prof. Adrian Clenci, University of Pitesti, Romania

Prof. Grigore Danciu, University “Politehnica” of Bucharest, Romania

Prof. Vasile Dragu, University “Politehnica” of Bucharest, Romania

Prof. Cedimir Duboka, President, Yugoslav Society of Automotive Engineers (JUMV)

Prof. Victor Gheorghiu, Hamburg University of Applied Sciences, Germany

Assoc. Prof. Danut Grosu, Military Technical Academy, Romania

Brigadier Ret. Prof. Gunther Hohl, Austria

Prof. Daniel Iozsa, University “Politehnica” of Bucharest, Romania

Prof. Nicolae Ispas, “Transilvania” University of Brasov, Romania

Prof. Florian Ivan, University of Pitesti, Romania

Prof. Eden Mamut, University Ovidius of Constanta, Romania

Prof. Laurentiu Manea, University Ovidius of Constanta, Romania

Assoc. Prof. Danut Marinescu, University of Pitesti, Romania

Assoc. Prof. Marin Marinescu, Military Technical Academy, Romania

Prof. Viorel Mateescu, University “Politehnica” of Bucharest, Romania

Prof. Niculae Negurescu, University “Politehnica” of Bucharest, Romania

Prof. Mircea Oprean, University “Politehnica” of Bucharest, Romania

Dr. Pierre Podevin, Conservatoire National des Arts et Métiers de Paris, France

Assoc. Prof. Plamen Punov, Technical University of Sofia, Bulgaria

Prof. Edward Rakosi, Technical University “Gheorghe Asachi” of Iasi, Romania

Assoc. Prof. Adrian Sachelarie, Technical University “Gheorghe Asachi” of Iasi, Romania

Dan Stancioiu, Ph.D., Lecturer, Liverpool John Moores University  
Prof. Ion Tabacu, University of Pitesti, Romania  
Prof. Stefan Tabacu, University of Pitesti, Romania  
Prof. Daniela Vasiliu, University “Politehnica” of Bucharest, Romania  
Prof. Nicolae Vasiliu, University “Politehnica” of Bucharest, Romania  
Dr. Ludwig G.E. Vollrath, FISITA Vice President, Europe



# Contents

<b>Investigation of a Mechanism Through a Transient Thermal Analysis and an Equivalent Steady-State Thermal Analysis. . . . .</b>	<b>1</b>
Alexandra-Raluca Moisescu, Stefan Sorohan and Gabriel Anghelache	
<b>Inter-cylinder Distribution of Di-Ethyl-Ether Injected into the Intake Manifold of a Diesel Engine Using CFD Simulation . . . . .</b>	<b>9</b>
Victor Iorga-Siman, Adrian Clenci, Rodica Niculescu and Alina Trică (Tuță)	
<b>Analysis of Complex Planetary Mechanisms Used in Nine Speed Automatic Transmissions of Cars . . . . .</b>	<b>21</b>
Neacsu Eugen, Banca Gheorghe and Oloeriu Florin	
<b>DUSTER ZERO—Electric Vehicle Research 4WD . . . . .</b>	<b>37</b>
Danut Gabriel Marinescu, Viorel Nicolae, Cristian Liviu Popescu, Liviu Calin and Nicusor Mierloiu	
<b>The Thermal Characterisation of a Disc Brake Rotor at Reduced Scale with Particular Reference to Pad Aspect Ratio . . . . .</b>	<b>51</b>
Varun S. Prabhu, Abdulwahab A. Alnaqi and Peter C. Brooks	
<b>Experimental Identification of the Automotive Magnetorheological Shock Absorbers. . . . .</b>	<b>61</b>
Nicolae Vasiliu, Anton Hadăr, Alexandru Dobre, Constantin Călinoiu and Cristian Andreescu	
<b>Application of Fuzzy Topsis and Ahp Method in Evaluating Vehicle Roadworthiness Performance. . . . .</b>	<b>69</b>
Jakimovska Kristina, Duboka Čedomir and Karastoyanov Dimitar	
<b>Concept Design of Twin-Sheet Thermoplastic Cellular Structures for Vehicle’s Bumper System . . . . .</b>	<b>81</b>
Stefan Tabacu, Claudiu Diaconescu and Alexandru Oltean	

<b>On the New Concept and Advantages of the Integrated Shock Absorber—Air Spring—“Isas”</b> . . . . .	93
Adrian Ioan Niculescu, Antony Jankowski, Mirosław Kowalski and Tudor Sireteanu	
<b>Forces Involved in Small Overlap Crash</b> . . . . .	105
Xavier Da Silva and Núria Parera	
<b>State of the Sm-Art Components Used on Autonomous Platforms for Sustainable Mobility</b> . . . . .	117
Valerian Croitorescu and Yassine Ruichek	
<b>Passenger Cars Exhaust Emissions Under Real Driving Conditions</b> . . . . .	127
Jerzy Merkisz and Jacek Pielecha	
<b>Studies Regarding the Influence of Exhaust Backpressure on the Performances of a Compression Ignited Engine</b> . . . . .	141
Nicolae Burnete, Dan Moldovanu, Doru-Laurean Baldean and Levente Kocsis	
<b>A Study of Waste Heat Recovery Impact on a Passenger Car Fuel Consumption in New European Driving Cycle</b> . . . . .	151
Plamen Punov, Nikolay Milkov, Quentin Danel and Christelle Perilhon	
<b>Modeling of Electric Vehicles for Driveability Control Applications</b> . . . . .	165
Ionut Alexandru Stoica, Marius Valentin Bataus and Ioan Mircea Oprean	
<b>Making of Safer Network Operating System Components</b> . . . . .	175
Arun S Nair and Jaideep Save	
<b>Statistical Decision in the Automotive Material Selection</b> . . . . .	189
Cristian Andreescu, Adrian Stere Paris, Cristian Dragomirescu and Constantin Târcolea	
<b>Effects Analysis of Zone 30 Based on Recognition, Age and Accident Experience</b> . . . . .	197
Ryosuke Ando, Yasuhide Mimura, Keiichi Higuchi and Marehiro Mukai	
<b>New Technology for Composite Materials Parts</b> . . . . .	209
Anghel Chiru and Lucian Eugen Rad	
<b>Tyre Dynamics: Model Validation and Parameter Identification</b> . . . . .	219
Andreas Hackl, Wolfgang Hirschberg, Cornelia Lex and Georg Rill	
<b>Smart Solutions for Vehicle Chassis</b> . . . . .	233
Mihai Florea, Valerian Croitorescu and Mircea Oprean	
<b>Study for an Electrified UTV Platform</b> . . . . .	245
Grigore Danciu	

**Measurement of Fuel Consumption for an Off-road Vehicle With Conventional and Hybrid Powertrain. . . . .** 259  
 Gabriel Anghelache, Alexandra-Raluca Moisescu and Ioan Mircea Oprean

**Security in Connected Cars . . . . .** 267  
 Mushabbar Hussain

**The Development of New Evaluation Criteria for Supercharged Engines Based on Elasticity and Adaptability at Traction . . . . .** 277  
 Ivan Florian, Mihai Stelian Niculae and Dragoş Constantin Neacşu

**The Comparative Study of Engine Vehicles Functioning With Petrol and Liquefied Petroleum Gas. . . . .** 285  
 Ramona-Monica Stoica, Marian-Eduard Rădulescu, Irinel Dinu, George Ene, Daniel Neagu and Ion Copae

**Maintenance Costs Statistics for Urban Cars . . . . .** 297  
 Adrian Stere Paris, Cristian Andreescu, Cristian Dragomirescu and Constantin Târcolea

**Investigation of Third Body Phenomenon in Model Braking Using Infrared Camera. . . . .** 307  
 Zbigniew Skorupka and Antoni Jankowski

**Modelling and Simulation of the Dynamic Behaviour Automotive’s Suspension By AMESim . . . . .** 317  
 Alexandru Dobre, Anton Hadăr, Daniela Vasiliu, Nicolae Vasiliu and Cristian Andreescu

**Study Concerning the Loads Over Driver’s Heads in Cases of Cars Crashes with Involved Cars of the Same or Different Generation . . . . .** 325  
 Nicolae Ispas and Mircea Nastasoiu

**Use of GPS/INS Devices for Experimental Study of Vehicle Dynamics . . . . .** 337  
 Dinu Covaciu, Ion Preda, Dragoş-Sorin Dima and Anghel Chiru

**Study of the Dynamic Behavior of a Car Body for Mounting the Rear Axle. . . . .** 349  
 Ştefan-Ionescu Romeo, Petrache Gheorghe, Ionel Vieru, Viorel Nicolae and Pârlac Sebastian

**Simulation of the Air Conditioning Curtains with Turbulent Circular Jet Flows Inside the Cabin Vehicle Using ANSYS CFD. . . . .** 357  
 Vasile Caunii and Adrian Sachelarie

**The Influence of Exhaust Backpressure Upon the Turbocharger’s Boost Pressure . . . . .** 367  
 Levente-Botond Kocsis, Dan Moldovanu and Doru-Laurean Bâldean

<b>Investigating Maintenance Procedures for Engine Air Filters . . . . .</b>	<b>375</b>
Marius Toma	
<b>Fatigue Analysis for the Primary Shaft of a Mechanical Gearbox of a Car . . . . .</b>	<b>385</b>
Mario Trotea, Dumitru Neagoie, Loreta Simniceanu and Augustin Constantinescu	
<b>Optimizing Combustion in an Single Cylinder GDI SI Engine. . . . .</b>	<b>395</b>
Stelian Tarulescu, Radu Tarulescu and Cristian-Ioan Leahu	
<b>On The Possibility to Reduce Diesel Engines Emissions by Operating with Biodiesel B20 in PPC Mode . . . . .</b>	<b>405</b>
Alexandru Racovitza, Bogdan Radu, Mohanad Aldhaidhawi and Radu Chiriac	
<b>Public Transport—Feasible Solution for Sustainable Urban Mobility . . . . .</b>	<b>419</b>
Vasile Dragu, Eugen Roșca and Aura Ruscă	
<b>Uncertainty in the Study of Automotives Dynamics and Analysis and Reconstruction of Car Crashes . . . . .</b>	<b>431</b>
Ramona-Monica Stoica, Marian-Eduard Rădulescu, Irinel Dinu, George Ene, Daniel Neagu and Ion Copae	
<b>Assessment of Effective Elastic Properties of Honeycomb Cores by Modal Finite Element Analyses . . . . .</b>	<b>443</b>
Ștefan Sorohan, Dan Mihai Constantinescu, Marin Sandu and Adriana Georgeta Sandu	
<b>Model Preparation for Structural FEA on Main Components of an Internal Combustion Engine . . . . .</b>	<b>455</b>
Dan Mihai Dogariu, Cristian Tănăsie, Anghel Chiru, Cristian-Ioan Leahu and Vlad Ștefan Stancu	
<b>Dynamics of a Crank-Shaft Mechanism with Multiple Clearances by a Multibody Approach . . . . .</b>	<b>463</b>
Stănescu Nicolae–Doru	
<b>Research Applied to Exhaust Gas After-Treatment Systems in 1.6 L Zsg 416 Ford Engine . . . . .</b>	<b>475</b>
Lucian-Vasile Crișan-Lupa, Adela-Ioana Borzan, Dan Moldovanu and Levente-Botond Kocsis	
<b>Development of a Water Rankine System to Improve Diesel Engine Efficiency . . . . .</b>	<b>485</b>
Bogdan Radu, Alexandru Racovitza and Radu Chiriac	

**Traffic Modeling Aspects Using Visum Software and Effects on the Traffic Optimization** . . . . . 495  
 Horea George Crişan and Nicolae Filip

**Performance Evaluation of Complex Intersections by Micro-simulation.** . . . . . 507  
 Sorin Ilie, Gabriela Mitran, Viorel Nicolae and Amalia Ana Dascăl

**Drag Phenomena Within a Torque Converter Driven Automotive Transmission—Laminar Flow Approach** . . . . . 517  
 Marin Marinescu, Octavian Alexa, Radu Vilau, Constantin-Ovidiu Ilie and Valentin Vinturis

**Analysis of Crashes at Intersections in Bucharest** . . . . . 529  
 Şerban Raicu, Dorinela Costescu and Ştefan Burciu

**The NVH Behaviour of a Powertrain Fixed on a Measurement Bench.** . . . . . 541  
 Andrei Daniel Calin, Nicolae Enescu, Radu Chiriac and Nicolae Orasanu

**Composite Materials Testing Method Steering Column Bracket Test** . . . . . 553  
 Lucian Eugen Rad, Anghel Chiru, Cristian Leahu and Dan Mihai Dogariu

**Calculation of the Steering Column Bracket Made of Composite Materials Reinforced with Continuous Fibers.** . . . . . 567  
 Lucian Rad, Anghel Chiru and Cristian Leahu

**A Method for 3D Geometry Scanning of a Combustion Chamber** . . . . . 577  
 Dan Mihai Dogariu, Ciprian Andrei, Bogdan Tiberiu Vieru, Radu Adrian Plămădeală and Anghel Chiru

**Researches to Improve the Reliability of Clutches with Dual-Mass Flywheel.** . . . . . 585  
 Valentin Nişulescu, Gheorghe Bancă, Marius Bâzgå and Alexndru Boroiu

**Theoretical and Practical Analysis of the in-Cylinder Tumble Motion** . . . . . 595  
 Dan Moldovanu and Adela Ioana Borzan

**Optimized Automotive Spark Ignition Engine.** . . . . . 605  
 Edward Rakosi, Sorinel Talif and Gheorghe Manolache

**Aspects Regarding the Evolution of the Depollution Norms and Test Cycles in Order to Determine Polluting Emissions** . . . . . 619  
 Gheorghe Bancă, Valentin Nişulescu and Gheorghe Frăţilă

<b>Measurement Equipment for Research of the Pressure Wave Compressors</b> . . . . .	633
Cristian-Ioan Leahu, Dan Mihai Dogariu, Anghel Chiru, George-Radu Toganel and Gabriel Mitroi	
<b>Friction Analysis of a Two Stroke Engine</b> . . . . .	641
Sebastian Radu, Horia Abăităneci, Adrian Tușinean, Gheorghe-Alexandru Radu and Marton Iakab-Peter	
<b>Independent Suspension—The Equivalence of Model and Vehicle Parameters</b> . . . . .	651
Ion Preda	
<b>Studies About Behavior of the Human Cervical—Head System During Frontal Crash Impact</b> . . . . .	665
Stefanita Ciunel and Bebe Tica	
<b>Considerations on the Vehicles Identification and Classification in Traffic by the Length Criterion</b> . . . . .	677
Nicolae Filip, Adrian Dohotari and Jacint Kovacs	
<b>Aspects Regarding Priority Settings in Unsignalized Intersections and the Influence on the Level of Service</b> . . . . .	687
Dumitru Ilie, Matei Lucian, Vîntorului Matei, Racilă Laurențiu and Oprica Theodor	
<b>Influence of Tyre Pressure and Weight Distribution on Axles on the Theoretical Speed Ratio in the Running Gear System of Four-Wheel Drive Tractors</b> . . . . .	695
Mircea Nastasoiu and Nicolae Ispas	
<b>The Development of a New Thermal Comfort Indexes</b> . . . . .	703
Catalin Adrian Neacsu and Mariana Ivanescu	
<b>The Correlation Between the Tests and the Calculation Method in the Case of an Engine Mount</b> . . . . .	715
Gîrbovan Daniel, Nicolae Viorel and Vieru Ionel	
<b>Dummy Kinematic Behaviour and Head Injuries Analysis in Frontal Collisions</b> . . . . .	723
Oana Victoria Oțăt, Ștefan Cristian Castravete and Victor Oțăt	
<b>Theoretical and Experimental Research on the Torque Variation of the Body Passing Through Landmarks</b> . . . . .	733
Dumitru Neagoe, Dumitru Bolcu, Loreta Simniceanu and Mario Trotea	
<b>The Simulation of the Vehicle Motion Based on Generalized Mathematical Model of Vehicle Motion</b> . . . . .	741
Loreta Simniceanu, Victor Otat, Trotea Mario and Mihaela Bogdan	

**Research Regarding Night-Time Pedestrian Visibility . . . . . 749**  
Bogdan Tolea, Daniel Trusca and Csaba Antonya

**Research Regarding the Effects of Emergency Vehicle Braking upon  
Its Occupants . . . . . 757**  
Alexandru-Ionut Radu, Daniel-Dragos Trusca, Bogdan-Adrian Tolea  
and Corneliu Cofaru

**Effect of Water Injection at Inlet of Turbocharger on Compressor  
Performances . . . . . 765**  
Podevin Pierre, Périlhon Christelle, Danlos Amélie, Punov Plamen,  
Nouri Hussain, Wagner Marc, Massouh Fawaz and Mansilla Raul

# Abbreviations

AEM	Advanced engineering methods and tools (CAD-CAM-CAE)
APT	Advanced power trains (engine and transmission)
ARM	Automotive reliability and maintenance
FEP	Fuel economy and pollution control
HEV	Hybrid and electric vehicles
MAT	New materials and technologies (lightweight solutions)
NVH	Noise vibration and harshness (NVH)
TTS	Traffic and road transport systems (including automated and cooperative driving and future sustainable mobility concepts)
VDS	Vehicle dynamics safety and comfort



# Investigation of a Mechanism Through a Transient Thermal Analysis and an Equivalent Steady-State Thermal Analysis

Alexandra-Raluca Moisescu, Stefan Sorohan and Gabriel Anghelache

**Abstract** The thermal analysis of a rotary engine mechanism requires taking into consideration the transfer of heat from the combustion gas to the engine parts, which include rotating parts and fixed parts, as well as the transfer of heat to the environment. During an engine mechanism rotation, the conditions of convective heat transfer are variable, and the surfaces of fixed parts exposed to combustion gas are continuously changing. In this case, the transient thermal analysis using the finite elements method is very complex because of the permanent modification of surfaces covered with combustion gas, as a consequence of mechanism rotation. Therefore, in the current paper, an equivalent model for steady-state thermal analysis is developed, so that the same results are obtained as in the long transient thermal analysis, but with significantly smaller requirements of time and computational resources. The transient thermal analysis performed for a large number of rotations, which provides the stationary thermal conditions of mechanism parts, is compared with the equivalent steady-state thermal analysis performed using the equivalent film coefficients and the equivalent convection temperatures. The distributions of fixed part temperature and heat flux obtained from the steady-state thermal analysis are compared to those obtained from the transient thermal analysis, and very good similarities are ascertained. In conclusion, the equivalent steady-state thermal analysis provides similar results, compared with the transient thermal analysis, but with significantly lower computational effort.

**Keywords** Finite elements · Thermal analysis · Heat transfer · Film coefficient · Temperature

---

A.-R. Moisescu (✉) · S. Sorohan · G. Anghelache  
University Politehnica of Bucharest, Splaiul Independentei 313, 060042 Bucharest, Romania  
e-mail: raluca.moisescu@upb.ro

© Springer International Publishing Switzerland 2016  
C. Andreescu and A. Clenci (eds.), *Proceedings of the European Automotive Congress EAEC-ESFA 2015*, DOI 10.1007/978-3-319-27276-4\_1

## Introduction

The development of a rotary engine involves simulation, performed using the finite element method, of mechanism behaviour under thermal and mechanical loads during engine cycles. The simulation provides the temperature distribution of engine parts, so that thermal expansion can be investigated in conjunction with mechanical loads applied on engine mechanism parts.

The thermal analysis requires taking into consideration the transfer of heat from the combustion gas to the engine parts, which include rotating parts and fixed parts, as well as the transfer of heat to the environment (Heywood 1988). Both the rotating and the fixed parts are exposed to combustion gas over an interval of the mechanism rotation. Throughout this interval, the conditions of convective heat transfer are variable, and the surfaces of fixed parts exposed to combustion gas are continuously changing. In this case, the transient thermal analysis using the finite elements method (Kurowski 2004) is very complex because of the permanent modification of surfaces covered with combustion gas, as a consequence of mechanism rotation. Furthermore, the transient thermal analysis needs a large number of engine cycles to be performed, in view of obtaining quasi-constant temperatures for each point of the mechanism (Reddy and Gartling 2010).

Therefore, an equivalent model for steady-state thermal analysis has to be developed, so that the same results are obtained as in the transient thermal analysis, but with significantly smaller requirements of time and computational resources. The temperature distribution from this steady-state thermal analysis must correspond to the results from the transient thermal analysis, which provides the stationary thermal conditions of mechanism parts.

## Mechanism Model for Transient Thermal Analysis

The hypothetical mechanism, shown in Fig. 1, consists of a cylindrical rotor inside a fixed part. The 300 mm diameter rotor has a pocket on 90° of its circumference. The fixed part has been modelled as a cylindrical ring with 300 mm inner diameter and 330 mm outer diameter. Both rotor and fixed part are made of aluminium, with the following properties: density 2700 kg/m<sup>3</sup>, thermal conductivity 200 W/(m K), specific heat capacity 800 (W s)/(kg K). The rotor angular speed corresponds to rated engine speed 60 min<sup>-1</sup>, and each mechanism rotation corresponds to an entire engine cycle.

Heat is generated in the cavity corresponding to the rotor pocket (considered combustion chamber), on an angular interval between 0° and 90° of mechanism rotation, as shown in Fig. 2. Throughout the interval of combustion process, convective heat transfer of combustion gas (with film coefficient 300 W/(m<sup>2</sup> K) and temperature 800 °C) towards the fixed part is considered on the inner surface corresponding to the rotor pocket, and neglected on the rest of the fixed part inner surface. Throughout the remaining interval of mechanism rotation, heat transfer is

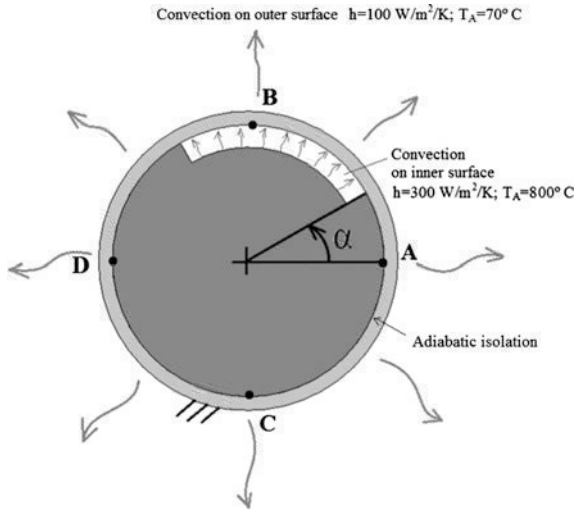


Fig. 1 Model for thermal analysis of a simplified rotary engine mechanism

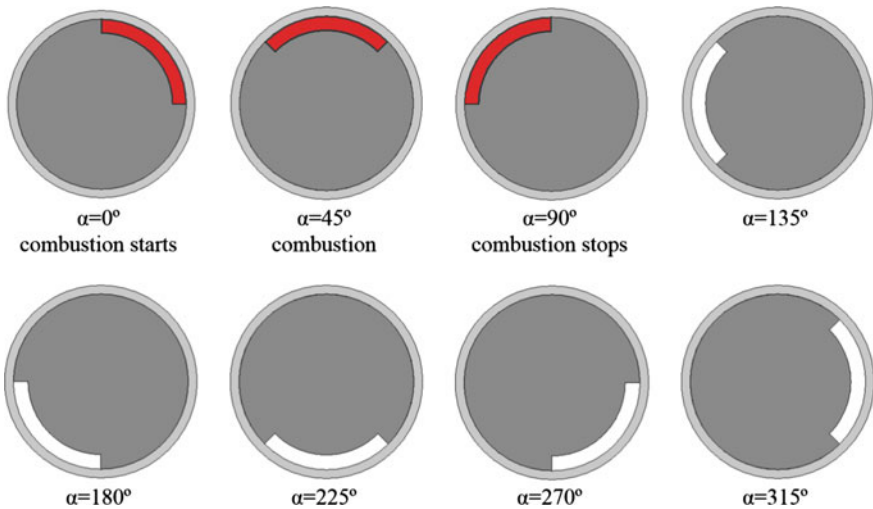
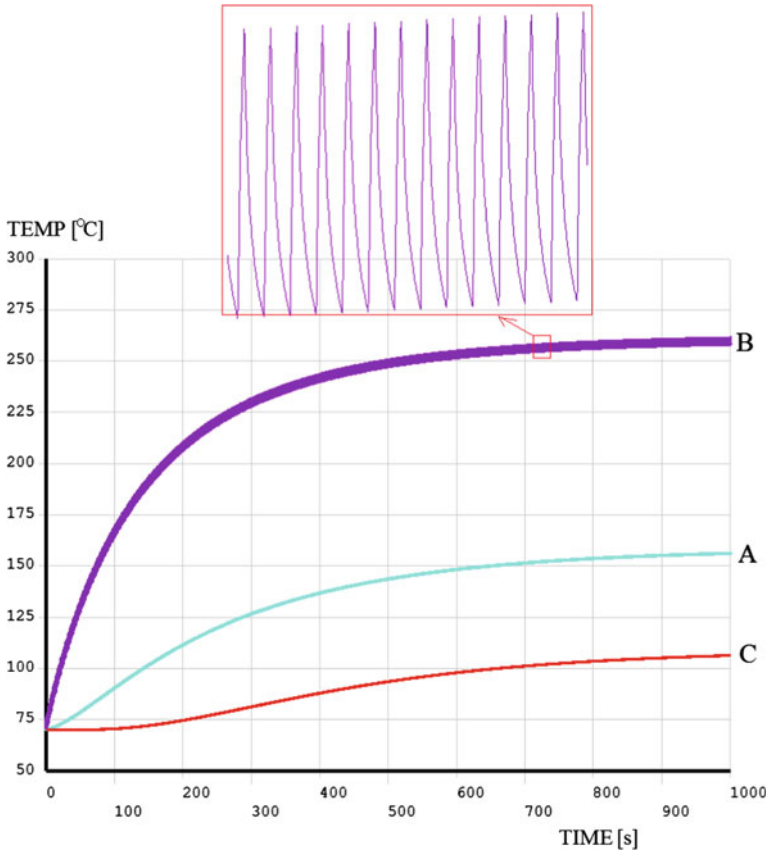


Fig. 2 Combustion phase with respect to rotor position throughout mechanism rotation

neglected on the entire inner surface of the fixed part. Convective heat transfer (with film coefficient  $100 \text{ W}/(\text{m}^2 \text{ K})$  and temperature  $70 \text{ }^\circ\text{C}$ ) is considered constant on the outer surface of fixed part.

The transient thermal analysis is performed for 1000 rotations, in view of obtaining quasi-constant temperatures for each point of the mechanism after many



**Fig. 3** Evolutions of temperatures during transient thermal analysis

engine cycles. The evolutions of temperatures for points A, B, and C of the fixed part during this analysis are shown in Fig. 3. It can be noticed that point B has pulsating temperature variation, but all three points tend to stabilize to quasi-constant temperature values.

### **Equivalent Mechanism Model for Steady-State Thermal Analysis**

As the transient thermal analysis requires extended time and computing resources, an equivalent model is necessary for steady-state thermal analysis.

The heat flux of a point or an area element located on the fixed part inner surface is defined as an average considering its variation over an entire mechanism rotation:

$$q_m = h_m(T_0 - T_m) = \frac{\int_0^{360} q(\alpha) d\alpha}{360^\circ}, \quad (1)$$

where

- $q_m \left[ \frac{\text{W}}{\text{m}^2} \right]$  is the average heat flux of the point over an entire rotation,  
 $h_m \left[ \frac{\text{W}}{\text{m}^2 \text{K}} \right]$  is the equivalent film coefficient for the point over an entire rotation,  
 $T_m [\text{K}]$  is the equivalent convection temperature for the point over an entire rotation,  
 $T_0 [\text{K}]$  is the resulting quasi-constant temperature of the area element,  
 $q(\alpha) \left[ \frac{\text{W}}{\text{m}^2} \right]$  is the variation of heat flux of the point as a function of rotor angle over an entire rotation,  
 $\alpha [^\circ]$  is the rotor angle position.

The variation of heat flux of the abovementioned point as a function of rotor angle over an entire rotation is defined as:

$$q(\alpha) = h(\alpha)[T_0 - T(\alpha)], \quad (2)$$

where

- $h(\alpha) \left[ \frac{\text{W}}{\text{m}^2 \text{K}} \right]$  is the variation of film coefficient for the point as function of rotor angle over a rotation,  
 $T(\alpha) [\text{K}]$  is the variation of convection temperature for the point over an entire rotation.

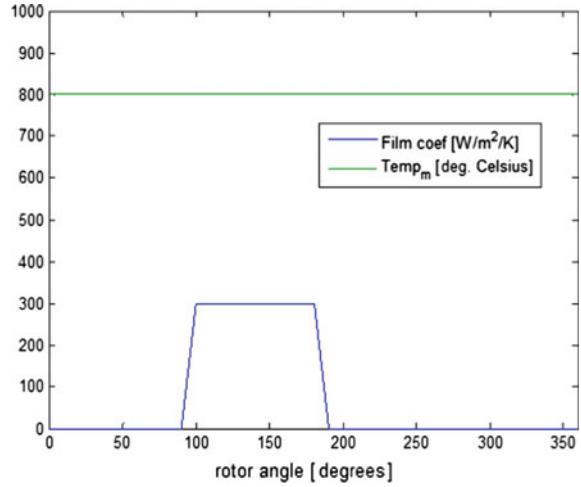
From (1) and (2), the following equation can be obtained:

$$T_0 360 h_m - 360 h_m T_m = T_0 \int_0^{360} h(\alpha) d\alpha - \int_0^{360} h(\alpha) T(\alpha) d\alpha. \quad (3)$$

Therefore the equivalent film coefficient for the mentioned point over an entire rotation is:

$$h_m = \frac{\int_0^{360} h(\alpha) d\alpha}{360}, \quad (4)$$

**Fig. 4** Variations of convection temperature and film coefficient for point B during a mechanism rotation



and the equivalent convection temperature for the same point over an entire rotation is:

$$T_m = \frac{\int_0^{360} h(\alpha)T(\alpha)d\alpha}{h_m 360}. \quad (5)$$

The Eqs. (4) and (5) allow that the transient thermal analysis, which tends to stationary thermal conditions, is replaced with an equivalent steady-state thermal analysis, which no longer requires  $\alpha(t)$  [°] the rotor angle as a variable.

For example, during an entire mechanism rotation the point B undergoes variations of convection temperature and film coefficient as shown in Fig. 4.

The average values of the film coefficient and convection temperature for the point B situated on the fixed part at  $\alpha = 90^\circ$  (which has the longest exposure to combustion gas) are  $h_m = 75 \text{ W}/(\text{m}^2 \text{ K})$  and  $T_m = 800 \text{ }^\circ\text{C}$ . The area elements A and D situated on the fixed part at  $\alpha = 0^\circ$  and at  $\alpha = 180^\circ$  have practically no convective heat transfer, and therefore on the angular intervals  $[0^\circ; 90^\circ]$  and  $[90^\circ; 180^\circ]$  linear variations of the film coefficient and convection temperature are obtained.

## Comparison of Results from Transient and Steady-State Thermal Analysis

The transient thermal analysis performed for 1000 rotations is compared with the steady-state thermal analysis. The distribution of temperatures on the fixed part obtained from the steady-state thermal analysis is shown in Fig. 5 next to the distribution of temperatures obtained from the transient thermal analysis, and very

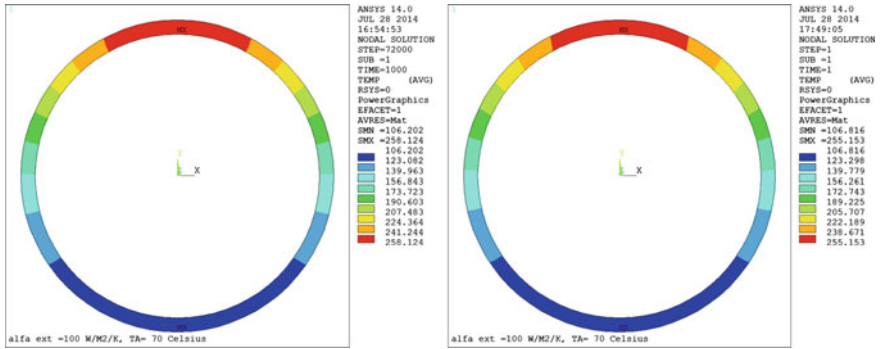


Fig. 5 Temperatures of fixed part obtained from the transient (left) and steady-state (right) thermal analysis

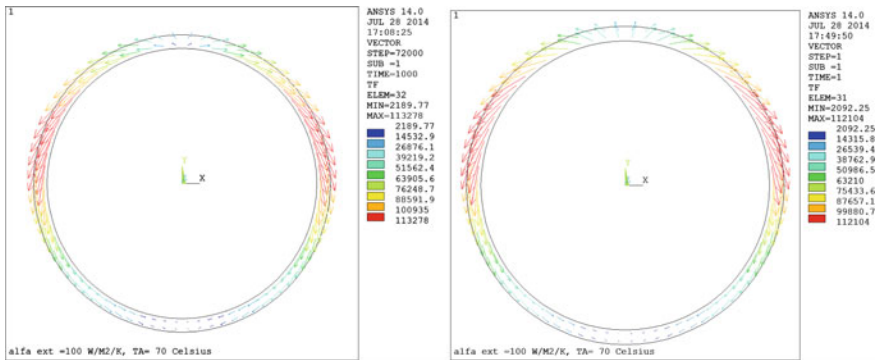


Fig. 6 Heat flux of the fixed part obtained from the transient (left) and steady-state (right) thermal analysis

good similarities are ascertained. Also, the results obtained from the two analyses for the heat flux of the fixed part are quite similar, as shown in Fig. 6.

## Conclusions

The transient thermal analysis takes into account the permanent modification of surfaces covered with combustion gas, as a consequence of mechanism rotation, but requires a large number of engine cycles to obtain quasi-constant temperatures for each point of the mechanism. The complexity of the transient thermal analysis makes it inappropriate for simulations of a realistic rotary engine mechanism, with many parts and complicated geometry.

The equivalent model for steady-state thermal analysis is developed based on the definition of heat flux as an average considering its variation over an entire mechanism rotation. This assumption allows expressing the equivalent film coefficient over an entire rotation and the equivalent convection temperature over an entire rotation. Thus, the transient thermal analysis, which tends to quasi-constant temperature distributions, can be replaced with an equivalent steady-state thermal analysis, which no longer requires the rotor angle as a variable.

The comparison of fixed part temperature and heat flux proves that the steady-state thermal analysis performed using the equivalent film coefficients and the equivalent convection temperatures provides very similar results, compared with the transient thermal analysis, but with significantly lower computational effort.

**Acknowledgments** The research presented in this paper has been performed within the scientific research project No 266059 funded under the European Union Programme FP7-TRANSPORT.

## References

- Heywood JB (1988) Internal combustion engine fundamentals. McGraw-Hill, New York  
Kuroski PM (2004) Finite element analysis for design engineers. SAE International, Warrendale  
Reddy JN, Gartling DK (2010) The finite element method in heat transfer and fluid dynamics. CRC Press, Boca Raton



# Inter-cylinder Distribution of Di-Ethyl-Ether Injected into the Intake Manifold of a Diesel Engine Using CFD Simulation

Victor Iorga-Siman, Adrian Clenci, Rodica Niculescu and Alina Trică (Tuță)

**Abstract** This paper is a consequence of a study on assessing the cold-starting performance of a compression ignition engine fuelled with different blends of fossil diesel fuel and biodiesel. Through experimental investigations, it was found that the engine starting at  $-20\text{ }^{\circ}\text{C}$  was no longer possible in the case of using B50 (50 % diesel + 50 % biofuel made from sunflower oil). In order to determine the engine starting in this particular situation, Di-Ethyl-Ether (DEE) was injected into the intake manifold. DEE being a highly flammable substance, the result was a sudden and explosive engine starting, the peak pressure in the monitored cylinder in the first successful engine cycle being almost twice the one which is usually considered as normal. As a consequence of this observation, we wondered what happened in the other 3 engine's cylinders which were not monitored with pressure sensors. Since the cause of the sudden and explosive engine starting was the DEE, our question is in which way the DEE injected into the intake manifold was distributed to each of the 4 cylinders of the engine. Does the extremely high peak of pressure occur in the other 3 cylinders, as well? Since only one cylinder was monitored with a pressure sensor, the method which was used to find the answer to the question mentioned before was to use a CFD approach. Thus, this paper's objective is to present the method used in order to find the inter-cylinder distribution of the injected DEE.

**Keywords** Biodiesel · Cold start · DEE · DEE inter-cylinder distribution · CFD

## Notations

Bx Biodiesel blend ratio (*i.e.* for  $x = 0$ , B0, meaning no biodiesel; for  $x = 100$ , B100, meaning no diesel fuel)  
CAD Computer Aided Design  
CFD Computational Fluid Dynamics

---

V. Iorga-Siman · A. Clenci (✉) · R. Niculescu  
University of Pitesti, Pitesti, Romania  
e-mail: adrian.clenci@upit.ro

A. Trică (Tuță)  
Renault Technologie Roumanie, Ilfov, Romania

CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
DEE	Di-Ethyl-Ether
HC	Unburned hydrocarbons
NO <sub>x</sub>	Nitric Oxides
P <sub>max</sub>	In-cylinder absolute pressure peak, [bar]
PM	Particulate Matter
PN	Particulate Number

### **Turbulence model notations**

Z	Normalized wall-normal velocity scale
$\kappa$	Turbulent Kinetic Energy, TKE [ $\text{m}^2 \text{s}^{-2}$ ]
$\nu$	Fluid kinematic viscosity
$\omega$	Turbulent dissipation
f	Elliptic relaxation function
RNG	Re-normalisation Group
SST	Shear Stress Transport
y	Dimensionless wall distance

## **Introduction**

The main challenges of today's automotive transport are first the reduction of pollution (CO, HC, NO<sub>x</sub>, PM and PN) and then the reduction of greenhouse emissions (e.g. CO<sub>2</sub> emissions). The reduction of the energetic dependency on petroleum products is another challenge. And finally, the transportation industry needs to find a solution in acceptable economic conditions; therefore biofuels appear to be a good answer.

In 2010, biofuels represented about 3 % of the worldwide energy consumption in the automotive transport. In the future, several scenarios are proposed going from 5 to 15 % in 2025. In Europe 10 % of energy for the transport sector should be renewable in 2020.

The work presented in this paper is part of a larger research program that is running at the University of Pitesti (Niculescu and Clenci 2009–2011). Its purpose is to highlight one of the problems encountered when blending biodiesel with commercial petroleum diesel: the deterioration of the cold starting performance of the compression ignition engine. Worldwide there are many areas where really low sub-zero ambient temperatures are encountered during winter (countries at high latitudes, regions at high altitudes and far from the moderating effect of the open sea). In this case, the engine start time and repeatability become the key performance attributes.

In this context, one goal of the authors was to assess the starting performance at  $-20\text{ }^{\circ}\text{C}$  of a common automotive compression ignition engine, fuelled with different blends of fossil diesel fuel and biodiesel. Another goal was to determine the biodiesel blend ratio limit at which the engine would not start at  $-20\text{ }^{\circ}\text{C}$ , and subsequently, to investigate the impact of di-ethyl-ether (DEE) injection into the intake manifold on the engine's start (Clenci et al. 2014a).

Figure 1 presents the results obtained during a starting test at  $-20\text{ }^{\circ}\text{C}$ . For each of the tests performed (commercial petroleum diesel fuel, B30, B50), the glow plug states were the same i.e. all off, preheat, wait for cranking, cranking, post heat on, post heat finished.

As shown in Fig. 1, the engine did not manage to start with B50. Therefore, as already mentioned, the solution used to help the engine to start was the injection of 150 mg of DEE into the intake duct just before the air filter and before pushing the engine's start button. Concerning the effect of DEE on engine behavior, Fig. 1 shows that two cycles with very high peak pressures ( $>200\text{ bar}$ !) were recorded. As seen, it was enough to help the engine to start but at the cost of generating extreme mechanical stress. It is for this reason that the actuation of glow plugs is not recommended when using DEE as ignition improver.

As a consequence of this observation, we wondered what happened in the other 3 engine's cylinders which were not monitored with pressure sensors. Since the cause of the sudden and explosive engine starting was the DEE, our question is in which way the DEE injected into the intake manifold was distributed to each of the 4 cylinders of the engine. Does the extremely high peak of pressure occur in the other 3 cylinders, as well? Since only one cylinder was monitored with a pressure sensor, the method which was used to find the answer to the question mentioned

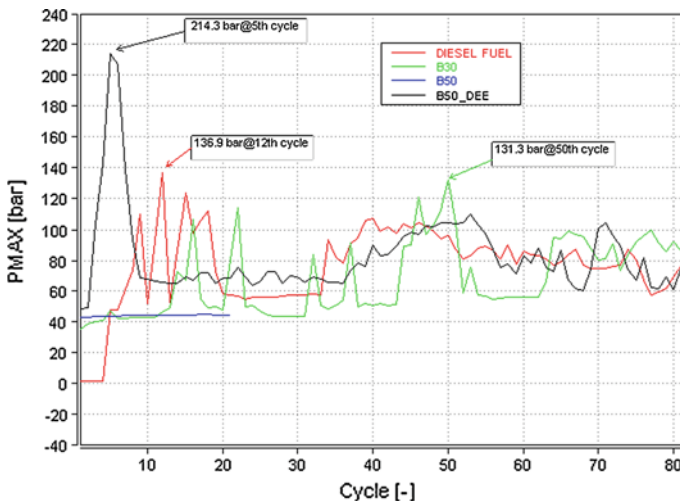


Fig. 1 Pressure peaks cyclic evolution, Clenci et al. (2014a)

before consisted in a CFD approach. Thus, this paper's main objective is to present the method used in order to find the inter-cylinder distribution of the injected DEE.

Our paper is organized in 2 sections, followed by the conclusions drawn from the study and future works. After this first section framing the work in the current context, Sect. 2 presents the Computational Fluid Dynamics (CFD) approach, which has been used in order to find the inter-cylinder distribution of the DEE injected into the intake manifold. This area is divided in two subsections: in the first one, the simulation is described and in the second one, the results are presented and discussed in detail.

## Computational Fluid Dynamics Simulation

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The fundamental basis of almost all CFD problems are the Navier–Stokes equations, which define any single-phase (gas or liquid, but not both) fluid flow. Despite considerable advances in computer technology and mathematical modeling during the past twenty years, this numerical method only aims to provide approximate results because the exact resolution of the Navier-Stokes equations under specified boundary conditions is still an impossible task. However the numerical approach is a good alternative in fluid flow study.

According to Clenci et al. (2014b), the experimental techniques of fluid flows investigation are able to provide high quality results (even the spatial structure and the temporal revolution of the velocity field) but require good optical access for large fields of view, high speed photography, innovative data analysis methods, and state-of-the-art equipment, which makes them quite expensive. Performing flow measurements in an engine can therefore be difficult because of the complexity of the equipment involved. The advantage of numerical investigations is that an expensive and time-consuming measurement set-up is not necessary. Thanks to the increasing power of computers, nowadays the processes occurring in an internal combustion engine can be modeled more and more accurately and simulated faster. One may note, however, that even the numerical simulations need significant computational cost.

In the current study, the CFD simulation was performed AVL-Fire® 2013 software. FIRE® is a powerful multi-purpose thermo-fluid dynamics software with a particular focus on handling fluid flow applications related to internal combustion engines and powertrains.

The details of the computer used to simulate the flow phenomena of the air-DEE mixture flow into the intake manifold of our engine are presented in Table 1.

As mentioned before, the aim of the simulations is to have an idea of the inter-cylinder distribution of the injected DEE; thus, to extrapolate on the effect of DEE in each of the engine's 4 cylinders.

**Table 1** Specification of used computer

System	Manufacturer	Dell
	Type	X64
OS		Windows 7.6.1
Processor	Type	Intel Xeon X5650
	Speed	2.67 GHz
	# CPU(s)	6
RAM		24 GB

**Table 2** Technical characteristics of the engine

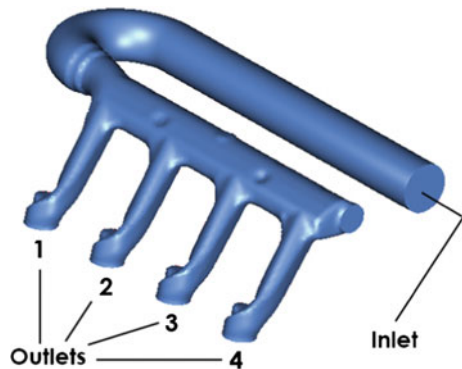
Characteristics	Values
# Cylinders	4
Total capacity (cm <sup>3</sup> )	1461
Volumetric compression ratio	17.9
Max. power (kW) @ speed (rpm)	48 @ 4000
Max. torque (Nm) @ speed (rpm)	160 @ 1700
Number of injector holes/hole diameter (mm)	5/0.15
Injection pressure (bar)	100–1400

The technical characteristics of the engine are presented in Table 2. Some of these technical characteristics are used in the AVL Fire tool calibration.

### *Mesh Generation and Simulation Description*

The intake manifold has been previously designed using commercial CAD software (CATIA)—Fig. 2. As seen from this figure, there is one inlet that corresponds to the injection surface. In reality, the DEE is injected before this surface, actually, at the entrance in the air filter. Thus, we considered the whole inlet surface as the injection

**Fig. 2** Description of the volume—Inlet/outlets



surface in order to obtain the largest cloud of DEE. The outlets correspond to the intake of the four cylinders and are numbered from 1 to 4 (the first being the nearest to the bend of the intake manifold, and the fourth, the farthest).

The first step is to mesh the computational domain. In order to study the effect of the meshing on the results, two different meshes have been made and analyzed: a coarse mesh, containing 96,863 cells and a fine mesh of 351,000 cells. For both cases, the structured grid with hexahedral shape cells was used. The numerical results are fairly close. However, the computational time and the average time per step are very different (Fig. 3). Generally, the mesh is a trade-off resulted from the need to obtain good results in reasonable simulation time.

Several selections in addition to inlet/outlets are required to study the inter-cylinder distribution of DEE. Indeed, the software is not able to calculate the mass fraction of DEE in a surface selection because the additional formula accounts for the volume of the cells. So, four cells selections have been added (Fig. 4): the finer the meshing is, the smaller these four volumes are.

The chosen turbulence model is the  $\kappa-\zeta-f$  recently developed by Hanjalic et al. (2004). It is a robust modification of the elliptic relaxation model. The aim is to improve numerical stability of the original  $\bar{v}^2-f$  model by proposing an eddy viscosity model, which solves a transport equation for the normalized wall-normal velocity scale  $\zeta = \bar{v}^2/k$  instead of  $\bar{v}^2$ . This turbulence variable ( $\zeta$ ) can be regarded as the ratio of the two time scales: scalar  $k/\varepsilon$  (isotropic), and lateral  $\bar{v}^2/k$  (anisotropic). It also introduces a more robust wall boundary condition for  $f$  equation, this time  $f_{wall}$  is proportional to  $1/y^2$  ( $y$  is a dimensionless wall distance) instead of  $1/y^4$  in the original  $\bar{v}^2-f$  model.

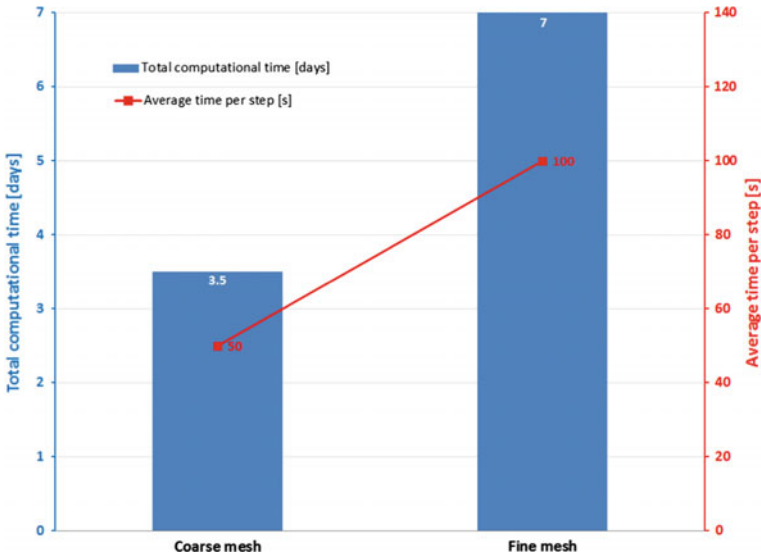


Fig. 3 Effect of the mesh on computational time