



[Home](#) | [Table of Contents](#) | [List of Chapters](#) | [Committee Members](#) | [Index](#)  
[CMES](#) | [CMC](#) | [MCB](#) | [SID](#) | [MLPG I](#) | [MLPG II](#) | [EDEM](#)  
| [ICCES'05](#) | [Publisher](#) |

Advances in Computational & Experimental Engineering & Sciences

**Proceedings of the 2004 International Conference on  
Computational & Experimental Engineering & Sciences**

ISBN: 0-9657001-6-X

**Edited by:**

S.N. Atluri; A.J.B. Tadeu

**Index**

[Home](#)

[Table of Contents](#)

[List of Chapters](#)

[Committee Members](#)

[Publisher](#)

**ADVANCES IN  
COMPUTATIONAL &  
EXPERIMENTAL  
ENGINEERING &  
SCIENCES**

2004

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Satya .N. Atluri  
Antonio J.B. Tadeu

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[Home](#) | [Table of Contents](#) | [List of Chapters](#) | [Committee Members](#) | [Index](#)  
[CMES](#) | [CMC](#) | [MCB](#) | [SID](#) | [MLPG I](#) | [MLPG II](#) | [EDEM](#)  
| [ICCES'05](#) | [Publisher](#) |

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[Home](#) | [Table of Contents](#) | [List of Chapters](#) | [Committee Members](#) | [Index](#)  
[CMES](#) | [CMC](#) | [MCB](#) | [SID](#) | [MLPG I](#) | [MLPG II](#) | [EDEM](#)  
[| ICCES'05](#) | [Publisher](#) |

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 Computational & Experimental Engineering & Sciences**

ISBN: 0-9657001-6-X

---



---

## Chapter 1

Advanced Computational Algorithms for Shock,  
Impact, and Penetration Problems

**Organizer:**

Dr. A.M. Rajendran

---



---

[Transient Solution of a Non-Linear Thermoelastic Instability Problem](#)

Abdullah M. Al-Shabibi

---



---

[Comparison of Impact between Experimental and Simulation Results in Flexible Elements](#)

Gabriel Emiliano Barrientos; Luis Alejandro Baeza; Rubens Sampaio; Mario Italo Razeto

---



---

[Key Issues of Computational Weld Mechanics with Applications](#)

F.W. Brust; J.C. Kennedy

---



---

[2-D Analysis of a Building Frame under Gravity Load and Fire](#)

Dat Duthinh

---



---

[Characterisation of a Composite Material for Ballistic Protections](#)

Fernando José Ferreira; Mário Augusto Vaz; Francisco Queiros de Melo; Jorge Justo

---



---

[On the design and evaluation of lightweight metal protection concepts against blast loading using LS-DYNA](#)

Augustin Gakwaya; Geneviève Toussaint; Patrice Gaudreault; Kevin William; Robert Durocher

---



---

[Numerical Evaluation of the Monotonic and Cyclic Behavior of a Welded Beam-to-column Joint](#)

Sandra Jordão; Luis Simões da Silva; Rui Simões

---



---

[A Study on the Impact Absorbing Characteristics for Rubber and Metal Layered Structures](#)

Wan-Doo Kim; Dong-Jin Kim; Young-Shin Lee

---



---

[Massively Parallel Computations by a General-Purpose Finite Element Analysis Code - IPSAP](#)

Seung Jo Kim; Chang Sung Lee; Jeong Ho Kim; Jin Woo Park

---



---

[Lining Load Development Due to Time-Dependent Rock Mass Behaviour](#)

Florian Krenn; Stefan Kainrath-Reumayer; Johann Golser

---



---

[Adiabatic Shear Bands in Functionally Graded Particulate Composites](#)

B. M. Love; R. C. Batra

---



---

[Dilatation of AD995 Alumina Impacted by Two Consecutive Stress Pulses during a SHPB Experiment](#)

Hui Yang Luo; Weinong Wayne Chen

---



---

[Matlab/Simulink Model of a Slip Energy Recovery System in a Cement Plant](#)

Maria Teresa Barroca Outeiro; Eduardo Sousa Saraiva

[Study and Simulation of Fragmentation Phenomena of Concrete Structures Under Stuffy Explosion](#)

Hugues Romero; Franck Jourdan; Frederick Dubois

[Advances in Nonlinear/Linear Computational Dynamics: The Concept of Algorithms by Design](#)

Kumar Tamma

[Scalable Coupling of TFA and Paradyne Analyses for impact Modeling of 3-D Woven Composites](#)

Rama R. Valisetty; Namburu Raju; Rajendran M. Arunachalam; Bahei-El-Din Yahya

**Chapter 2**

## Air Traffic Management Research

**Organizer:**

Dr. Paul Tan

[Computational Modeling of Trajectory-Oriented Air Traffic Management](#)

Todd J. Callantine

[Non-Parametric Approach to a Paired Data Hypothesis Test in Trajectory Accuracy Analysis](#)

M. M. Paglione

[Virtual Reality in Air Traffic Control Research for US Federal Aviation Administration](#)

Michael A. Pomykacz

[Rapid Prototyping and Exploration of Advanced Air Traffic Concepts](#)

Thomas Prevot; Todd Callantine; Paul Lee; Joey Mercer; Everett Palmer; Nancy Smith

[Modeling Patterns of Performance in Air Traffic Control Operations](#)

Roger W. Remington; Seung Man Lee; Ujwala Ravinder; Benjamin Willems; Michael Freed

[From Concept to Implementation - Modeling and Simulation in Air Traffic Management](#)

A. Schwartz; S. Magyarits

**Chapter 3**

## Biomechanics, Biomolecular Engineering, and Bionanomechanics

**Organizers:**

Professor Gang Bao, Dr. Huajian Gao, &amp; Dr. I.S. Raju

[Nanostructured Molecular Probes for Gene Detection in Living Cells](#)

Gang Bao

[Knee Ligaments Constitutive Model and Computational Stress Analysis During Walking and Cycling](#)

Constantin Bratianu; Lucian Gruionu

[Microstructure of Round-Hole-Fiber Distribution in Insect Cuticle and Biomimetic Research](#)

Bin Chen; Xianghe Peng; Jinghong Fan

[Flaw Tolerant Bulk and Surface Nanostructures of Biological Systems](#)

Huajian Gao; Baohua Ji; Markus J. Buehler; Haimin Yao

[Remodeling of a Carotid Artery in Response to Flow Overload](#)

C.A. Herrera; X. Lu; Q. Dang; S. Atluri; G. Kassab

[Heterojunctions of Multi-Walled Carbon Nanotubes and Semiconducting Nanocrystals for Electronic Device Applications](#)

Cengiz S. Ozkan

[Hybrid Nanosystems: Their Application in Biology and Engineering](#)

Mihri Ozkan

[Models for Cell Adhesion and Cell Mechanics Applying Micro- and Nanoscopic Tools](#)

Joachim P. Spatz

[Insights into how to Engineer Biominerals at the Nanoscale](#)

Viola Vogel

## Chapter 4

### Boundary Element Methods

#### Organizers:

Professor Jan Sladek & Professor Choon-Lai Tan

[Contact Mechanics and BEM](#)

Ramon Abascal; Jose A Gonzalez

[Recent Advances in the Application of BEM to Damage Tolerance Assessment of Airframe Structures](#)

Ferri M. H. Aliabadi

[Multiwavelet Collocation Boundary Element Solution of Laplace's Equation](#)

Siamak Amini; Rabea Elmazuzi; Steven P. Nixon

[Application of Boundary Element Method to Elasto-plastic Analysis of 2-D Orthotropic Plates](#)

Zhangzhi Cen; Xiushan Sun; Lixin Huang; Yinghua Liu

[Boundary Integral Equations for Thermoelastic Plates](#)

Igor Chudinovich; Christian Constanda

[Frictionless Unilateral Contact by Symmetric Boundary Element Method](#)

Filippo Cucco; Teotista Panzeca; Silvio Terravecchia; Liborio Zito

[Analysis of Interface Crack Problems in Dissimilar Anisotropic Media using the Boundary Element Method](#)

Seila Vasti Faria de Paiva; Paulo Sollero; M. H. Aliabadi; William Portilho de Paiva

[Fast Multipole Accelerated BE Techniques for 3D Stokes Flow](#)

Attilio Frangi; Arturo di Gioia; Giorgio Novati

[Effective Range of V-line Extrapolation Method to Calculate SIF of a Three Dimensional Crack Near to a Surface](#)

Wataru Fujisaki

[Dynamic Crack Interaction in 2-D Piezoelectrics](#)

Felipe Garcia-Sanchez; Andres Saez; Jose Dominguez

[Boundary Integral Equations with the Divergence Free Property for Elastostatics Problems](#)

J. Jackiewicz

[Boundary Element Method for Convective Heat Transfer in a Tall Porous Cavity using Forcheimer Model](#)

Renata Jecl; Leopold Škerget

[On the Continuity of Methods of Fundamental Solutions](#)

Xin Li

[On Fracture Mode Mixity Measures in Interface Cracks. An Application to BEM Analysis of Fibre/Matrix Debonding in Composites](#)

Vladislav Mantic; Federico Paris; E. Correa

[Boundary Element Analysis of Heat Transfer in Anisotropic Functionally Graded Materials](#)

Juan Pablo Nunez; Vladislav Mantic; Federico Paris; John Berger

[Directly Derived Non-Hyper-Singular Boundary Integral Equations I: Petrov-Galerkin Schemes](#)

Zhongyan Qian; Z.D. Han; P. Ufimtsev; S.N. Atluri

[Directly Derived Non-Hyper-Singular Boundary Integral Equations for Acoustic Problems II: The Collocation Implementation](#)

Zhongyan Qian; Z.D. Han; P. Ufimtsev; S.N. Atluri

[On Frictionally Constrained Cracks](#)

Patrick Selvadurai

[2.5D Transient Heat Transfer \(Conduction and Convection\) Using the BEM](#)

Nuno A. V. Simões; António J. B. Tadeu

[Advanced Meshless LBIEM for Thermoelastic Analysis of Non-homogeneous Solids](#)

Jan Sladek; Vladimir Sladek; Chuanzeng Zhang

[Scaled Boundary Finite-Element Solutions for Singular Stress Fields in Multi-Material Wedges](#)

Chongmin Song

[BEM Anisotropic Thermoelastic Analysis of Bi-material Interface Cracks](#)

Choon-Lai Tan; Yui-Chuin Shiah

[Extension of New Local Error Estimators for Panel Methods in 2-D Potential Flow Problems](#)

Marcelo O. Violato; Ariosto B. Jorge; Nelson Manzanara Filho

[Fast Multipole Boundary Element Method for Simulation of Composite Materials](#)

Zhenhan Yao; Haitao Wang; Pengbo Wang

## Chapter 5

### Composite Materials: Experiments, Analysis, and Applications

#### Organizers:

Professor David H. Allen, Professor Michihiko Nakagaki,  
Professor Anthony M. Waas & Professor Zhenhan Yao

[Experiments on Buckling and Postbuckling Behavior of Laminated Composite Stringer Stiffened Cylindrical Panels](#)

Haim Abramovich; Ariel Grunwald; Pavel Pevsner; Tanchum Weller; Adrian David; Gila Ghilai; Anthony Green; Nisson Pekker

[A Model for Predicting the Evolution of Multiple Cracks on Multiple Length Scales in Heterogeneous Viscoelastic Solids](#)

David H Allen; Chad R Searcy

[Geometric Imperfection Based Design Criteria for Composite Shell Buckling](#)

Damodar R. Ambur; Mark W. Hilburger; Michael P. Nemeth

[Modeling of Damage Growth in Composite Laminates](#)

Shiladitya Basu; Anthony M. Waas; Damodar R. Ambur

[Energetic-Statistical Size Effect in Composites and Sandwich Structures](#)

Zdenek P. Bazant; Alessandro Beghini

[Thermomechanical Wrinkling in Sandwich Panels with a Nonuniform Temperature Distribution](#)

Victor Birman

---

[Buckling and Postbuckling Behavior of Stringer Stiffened Laminated Composite Curved Panels Subjected to Shear](#)

Chiara Bisagni; Potito Cordisco; Haim Abramovich; Pavel Pevsner

---

[Residual Strength of Repaired Composite Materials Subjected to Compression Fatigue Loading](#)

R. Carvalho; M. De Freitas

---

[Contact Buckling and Post-buckling of Delaminated Plates](#)

Herzl Chai

---

[Mechanics of Atomic Scale Interfaces in Carbon Nanotube Reinforced Composites](#)

Namas Chandra; Sirish Namilae

---

[Analytical Solution for ITZ's Thickness around Convex Shaped Aggregate Grains based on Section Analysis Method](#)

Huisu Chen; Wei Sun; Piet Stroeven; L.J. Sluys

---

[The Study of Reversible and Irreversible Impact Loading on Symmetrical and Unsymmetrical CFRP Composite Laminates](#)

Opukuro A. David-West; David H. Nash; William M. Banks

---

[The Compressive Strength of Fiber Composites](#)

C. K. Hari Dharan; Chun-Liang Lin

---

[Modelling Postbuckling Composite Structures](#)

Brian G. Falzon; Marco Cerini

---

[A Crack Along the Interface Between Two Transversely Isotropic Materials - the +/- 45 degree Pair](#)

Yuval Freed; Leslie Banks-Sills

---

[Analysis of Stress Concentrations in 2x2 Braided Composites](#)

Deepak Goyal; John D Whitcomb

---

[Response of CFRP Laminates under High Strain Rate Compression until Failure](#)

Rui Miranda Guedes; Fernando José Ferreira; Mário Augusto Vaz; Pedro Henrique Magalhães

---

[Advanced FRP Composites in the Civil Infrastructure: New Tools for Old Threats](#)

Gilbert A. Hegemier

---

[Coupled Electro-Stretching-Bending Analysis of Holes in the Electro-Elastic Composite Laminates](#)

Chyanbin Hwu; M.C. Hsieh

---

[Edge Effects on Sandwich Composites](#)

Moussa Karama; Sébastien Mistou

---

[Stress Gradient Effects in the Failure Criteria for Textile Composites](#)

Ryan L. Karkkainen; Bhavani V. Sankar

---

[Delamination Behavior of Composite T-Sections with Z-Fibers](#)

Hakan Kilic; Som R. Somi

---

[Experimental and Numerical Analysis of Delamination Growth in a Graphite/Epoxy Specimen Caused by a Ply Cut](#)

Manfred Koenig; Ronald Krueger; Edmund Kohler; Manfred Kurz; Thomas Ruckstuhl

---

[Multi-Objective Optimization of Composite Stiffened Panels: Computations and Experiments](#)

Luca Lanzi

---

[Simulation of Sensor Application and Shape Control of Piezoelectric Structures at Large Deflections](#)

Sven Lentzen ; Ruediger Schmidt

[Homogenisation and Damage Mechanics for a Variety of Layered Systems](#)

L. Neil McCartney

[Characterization of Internal State Variable for Fiber Fracture in UD Composite](#)

Modris Megnis; Povl Brondsted; Saif A. Rehman; Tanveer Ahmad

[Instabilities and Loss of Ellipticity in Fiber-Reinforced Nonlinearly Elastic Solids Under Plane Deformation](#)

Jose Merodio; Raymond W. Ogden

[Finite Element Modelling of Viscoelastic Core Sandwich Panels](#)

Rui Silva Moreira; José Dias Rodrigues

[Composite Material Model with Circular Inclusion under Imperfect Interface Conditions](#)

Michihiko Nakagaki; Ryosuke Matsumoto; Yoshihiro Nakamichi; Shuji Takashima

[Mode II Interlaminar Fracture of Carbon/epoxy Multidirectional Laminates](#)

A.B. Pereira; A.B. Morais; A.T. Marques; P.M.S.T. de Castro

[Composites for Marine Structures - Challenges and Recent Advances](#)

Yapa D.S. Rajapakse

[Design of Composite Layers with Curvilinear Fiber Paths Using Cellular Automata](#)

Shahriar Setoodeh; Zafer Gurdal; Mostafa M Abdalla

[Compression Strength of Textile and Wavy Fiber Composites](#)

Kunigal Shivakumar

[Non-Dilute Multiple Coated Fiber Composites with BCC Microstructures: Effect of Shape and Fiber Orientation](#)

H. M. Shodja; Farshid Roumi

[Environmental Exposure of Glass-fibre Reinforced Composites](#)

Nirvan Karam Sookay; Christopher Julian von Klemperer; Viktor Verijenko

[Modelling of Multi-Layer Damage in Composite Laminates Under Static or Fatigue Loading](#)

C. Soutis; M. Kashtalyan

[A Mechanistic Model for Fatigue Life of Polymer Matrix Composites](#)

Kevin R. Uleck; Anthony J. Vizzini

[Crush Response of Composite Conical Frustrum - Experiments and Modeling](#)

H. Yang; V. Karbhari

[The Electro-Mechanical Response of Electrostrictive Composite Laminates due to Actuation](#)

N. Yu; Y. M. Chang; T. Somphone

## Chapter 6

### Computational Fluid Dynamics

[Numerical Simulation of a Flow Conditioner](#)

Husam Farag Abdulrahman; Andrea Frattolillo; Nicola Massarotti

[Application of the Advection-dispersion Equation to Characterize the Hydrodynamic Regime in a Submerged Packed Bed Reactor](#)

Antonio Albuquerque; Aderito Araujo; Ercilia Sousa

[Numerical Simulation of Wind Flow in the Vicinity of Forest Block](#)

Tomas Bodnar; Ivo Sladek; E. Gulikova

[Entropic Lattice Boltzmann Models](#)

Bruce Michael Boghosian

[A Fully Coupled Resolution Method for Computing Laminar and Turbulent Flows](#)

E. Didier; A.R.J. Borges

[Finite Element Flow Simulations for Three-Dimensional Incompressible Viscous Fluid](#)

Kazuhiko Kakuda; Naoki Hara

[New Features in the Fluid-Dynamics of Floating Zones Under Marangoni Effect](#)

Marcello Lappa; R. Savino

[An Improved Inverse Design Method for Blades of Finite Thickness](#)

Jose C. Pascoa; Antonio C. Mendes; Luis M.C. Gato

[Simplified Numerical Computation of Flow in Rearing Tank of Marine Fish Larvae](#)

Shigeaki Shiotani; A. Hagiwara; Y. Sakakura, H. Chuda

[Computational Modeling of Gas-Particle Two-Phase Jet by a 3-D Vortex Method](#)

Tetsuhiro Tsukiji; Yohei Yamamoto

**Chapter 7****Computational Intelligence and Advanced Info Technologies in  
Engineering Science & Advances in Imaging**[Extending Workflow Systems with QoS Management](#)

Jorge S. Cardoso

[Public Key Algorithm Comparison](#)

María de Miguel de Santos; Carmen Sánchez Ávila; Raúl Sánchez Reillo

[A Microcalcification Detection System for Digital Mammography using the Contourlet Transform](#)

A. Manzano-Lizcano; C. Sánchez-Ávila; L. Moyano-Pérez

[Generating and Rendering Images Using the X-slits Projection](#)

Nuno Cid Martins; Helder Araújo

[E-learning + ITS + CBR + Simulation a New Perspective of Learning](#)

Nelson Pincho; Viritato Marques; Torres Farinha; António Brito

[New Images from 3D Scanning](#)

João Ramos; Nuno Cid Martins; Fernando Silva

[Villages, Towns and Cities - an E-Government Case Study](#)

Cláudio Jorge Vieira Teixeira; Johnny Santos; Joaquim Sousa Pinto; Joaquim Arnaldo Martins

**Chapter 8****Earthquake Structural Engineering****Organizer:**

Professor A. Kappos

[Seismic Rehabilitation of an Historical Monument Based on Computational Monitoring](#)

Gabriela Maria Atanasiu; Nicu Curcudel

[Effect of Surface Waves on Dam-Reservoir Interaction During the Earthquake](#)

Reza Attarnejad; Homayoun Zahedi

[On the Seismic Strengthening of Old Masonry Buildings](#)

Rita Bento; M. Lopes; R. Cardoso

[One Dimensional Nonlinear Analysis of Steel Tubular Columns](#)

Masashi Iura; Toshiki Ishizawa

[Derivation of Fragility Curves Using Inelastic Time-History Analysis and Damage Statistics](#)

A.J. Kappos; C.G. Panagiotopoulos; G. Panagopoulos

[Seismic Assessment of a Major Bridge using Modal Pushover Analysis and Dynamic Time-history Analysis](#)

A. J. Kappos; T.S. Paraskeva; A.G. Sextos

[Seismic Rehabilitation of Reinforced Concrete Beam-Column Connections by FRP Material](#)

Athanasios Karabinis; Theodoros Rousakis

[Optimum Translational Vibration of Multi-Storey Buildings with Vertical Mass Axis](#)

Triantafyllos K. Makarios; Chariton Xenidis

[Seismic Response of Piles and Pile Groups in Viscoelastic and Poroelastic Soils](#)

Miguel A. Millan; Jose Dominguez

[Parametric and Harmonic Instability Interaction](#)

Verica Raduka

[Web Shear Deformations of R/C Walls with Flexural Failure Subjected to Cyclic Loading](#)

Thomas N. Salonikios

[Effectiveness of CFRP-Jackets and R/C-Jackets in Post-Earthquake Retrofitting of Beam-Column Subassemblages](#)

Alexander G. Tsonos

[Seismic Behaviour of Infilled Existing RC Buildings](#)

Elizabeth Vintzileou; Christos Zeris; Constantinos Repapis

## Chapter 9

### Finite Element Analysis in Engineering: Analysis, Design, & Manufacturing

[Numerical Approach to the Evaluation of Calibration Uncertainty of Contact Temperature Sensors](#)

Fausto Arpino; Andrea Frattolillo; Nicola Massarotti

[Computation of the Dynamical Behaviour of Faulty Rotor Systems](#)

Nicolò Bachschmid; Paolo Pennacchi; Andrea Vania; Ezio Tanzi

[Finite Elements Method in Electromagnetism for Actuator Design and Dynamic Behavior Prediction](#)

M. Rosário Alves Calado; Carlos P. Cabrita

[Exact Static Stiffness Matrix for a Deep Beam Embedded in an Elastic Medium](#)

William Paul Howson

[Finite Element Analysis of Elastica](#)

Kyohei Kondo; Koichiro Kuramoto

[Comparasion of Accuracy in DEMs at Different Resolutions](#)

Leonor Maria Oliveira Malva

[Numerical Modelling of Soft Soils](#)

Paulo J.V. Oliveira; Paulo A.L.F. Coelho; Luís J.L. Lemos

[Computation of Incompressible Flows with Immersed Bodies on Unstructured Cartesian Grids](#)

Dartzi Pan

## Chapter 10

## Finite Strain Theory and Cyclic Plasticity

### Organizer:

Professor Koichi Hashiguchi

---

---

#### [Mechanical Behaviors of Clay and Sand in terms of Active Soil Skeleton Structure](#)

Akira Asaoka; Toshihiro Noda; Masaki Nakano

---

---

#### [Hardening Behavior of an Aluminum Alloy in Simple Shear](#)

Frederic Barlat; Jeong-Whan Yoon

---

---

#### [Model for Cyclic Simple Shear Behavior of Sands Accounting for Principal Stress Rotation and Finite Strain Deformation](#)

Marte S. Gutierrez

---

---

#### [The Novel Concept "Tangential Relaxation"](#)

Koichi Hashiguchi

---

---

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Koichi Hashiguchi

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#### [Axisymmetric Bifurcation Analysis with Tangential Plasticity](#)

Mehdi Khojastehpour; Koichi Hashiguchi; Yukitaka Murakami

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#### [Finite Element Simulation on Uplift Problem of Ground Anchor](#)

Takashi Okayasu; Koichi Hashiguchi; Toshiyuki Ozaki; Daiki Yajima; Shingo Ozaki

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#### [Elastoplastic Finite Element Analysis of the Trapdoor Problem](#)

Toshiyuki Ozaki; Takashi Okayasu; Koichi Hashiguchi; Daiki Yajima

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#### [Uplift Behavior of Shallow Circular Anchor in Two-layered Sand](#)

Toshinori Sakai; Tadatsugu Tanaka; Saiichi Sakajo

---

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#### [Formulation and Numerical Post-bifurcation Analysis of Frictional Dilatant Materials at Finite Strains](#)

Keisuke Satoh; Yuki Yamakawa; Yasuyuki Miyaki; Kunio Torii

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Hideki Setouchi; Koichi Hashiguchi; Takeshi Shikanai; Takashi Okayashu

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Mohammed Saiful Alam Siddiquee; Tadatsugu Tanaka

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#### [Cyclic Elasto-plastic Constitutive Model and Finite Element Analysis](#)

Tadatsugu Tanaka

---

---

#### [Non-proportional Loading Behavior of Elastoplastic Solids](#)

Seiichiro Tsutsumi; Koichi Hashiguchi; Masahiro Toyosada; Koji Gotoh

---

---

#### [Deformation Analysis of Cohesive Soft Ground with Solidified Surface under Fill Construction](#)

Tetsuji Yoshimaru; Koichi Hashiguchi; Takashi Okayasu; Saiichi Sakajo

## Chapter 11

### Innovative Aircraft Design

#### Organizers:

Professor Luigi Morino & Professor Wesley Harris

---

---

#### [Advanced Characterization to Parameterize Material Properties for Multiscale Design](#)

Edoardo Bemporad, F. Carassiti

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#### [From Aeronautical to Nautical Modeling and Design](#)

Paolo Bulgarelli

[From Aeronautics to the Aerodynamic Design of a Formula 1 Car](#)

Ferdinando Cannizzo

[Sequential Multi--Disciplinary Optimization for the Conceptual Design of a Blended--Wing--Body Aircraft](#)

Giampietro Carpentieri; Michel van Tooren; Giovanni Bernardini; Luigi Morino

[Materials Selection in Multidisciplinary-Multiscale Design](#)

Fabio Carassiti

[Technical Note: An Automatic Pilot to Make Perfect Loops Varying only Gflyup through the Loop](#)

José Barahona da Fonseca

[Technical Note II: An Automatic Pilot to Make Perfect Horizontal Loops Varying only Gflyup through the Horizontal Loop](#)

José Barahona da Fonseca

[Technical Note III: The Risk of G-LOC and the Time to G-LOC Meter](#)

José Barahona da Fonseca

[Technical Note IV: Exact Flyup Altitude + Risk of G-LOC= Anti-G-LOC GCAS](#)

José Barahona da Fonseca

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Stefano De Rossi; Chiara Pecchio; Edoardo Bemporad

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Aldo Frediani

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Giuseppe Gatta; Fulvio Romano; Luigi Di Palma; Modesto Pecora

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Massimo Gennaretti; Alessandro Carvai

[Aircraft-based Responsive Launch System for Small Payloads](#)

Michel Kamel

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Luigi Morino; Giovanni Bernardini; Daniele De Gregorio; Karen E Willcox; Wesley L. Harris

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Luigi Morino; Giovanni Bernardini; Chiara Cerulli; Fabio Cetta

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Luigi Morino; Giovanni Bernardini; Franco Mastroddi

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Dimitris G. Mourikis; Vasilis A. Riziotis; Spyros G. Voutsinas

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Emanuele Rizzo; Aldo Frediani

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Teodoro Valente; Cecilia Bartuli

[Aircraft Design Support using Knowledge Engineering and Optimization Techniques](#)

Michel Van Tooren

**Chapter 12****Instabilities and Bifurcations in Fluid Mechanics****Organizers:****Professor Pinhas Bar-Yoseph & Professor Alexander Gelfgat**

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Pinhas Z. Bar-Yoseph; Alexander Yu. Gelfgat

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A. Bergeon; E. Knobloch

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Morten Brons; Anders Bisgaard

[From the Hopf Bifurcation to Fully Developed Turbulence in Incompressible Flows](#)

C. H. Bruneau

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Friedrich H Busse

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Jacob Cohen; D. Mourtazin

[Turbulent Dividing Flow on 60° Bifurcations](#)

Nuno P. Costa; Rodrigo Jorge Maia

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Arne Cröll; Peter Dold; Th Kaiser

[Instabilities of the Flow and the Temperature Field During Crystal Growth of Silicon from Melt](#)

Peter Dold; Arne Cröll

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Eyal Heifetz

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R. Hollerbach

[Multi-Scale Linear Stability Analysis](#)

B. C. Houchens; John S. Walker

[Effects of Gravity Variations on Thermocapillary Convection](#)

S. Hoyas; H. Herrero; A. M. Mancho

[Interconnection Between Spatial and Temporal Instability in a Forced Mixing Layer](#)

Eliezer Kit; Alexander Yu. Gelfgat

[Benard Surface-Tension-Driven Convection in Small Vessels](#)

M. J. Medale; P. J. Cerisier

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Jiro Mizushima; Tomohito Miura

[Convective Oscillations in a Two-Layer System Under the Combined Action of Buoyancy and Thermocapillary Effect](#)

A. A. Nepomnyaschy; I. B. Simanovsky

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Alexander Oron; Oded Gottlieb

[Stabilization Effect of a Rotating Magnetic Field on the Flow of a Conducting Liquid in a Cylindrical Container](#)

Janis Priede; Gunter Gerbeth

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Isaac Rubinstein

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Gregory J Sheard; Mark C Thompson; Thomas Leweke; Kerry Hourigan

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J. M.M. Sousa

[Oscillatory Flow of a Two-Fluid System Under Reduced Gravity](#)

Hermann Wilke; Andrew Cliffe; J. A. Pojman

[Vortex Shedding from Elongated Rectangular Plates at Low Reynolds Numbers](#)

Alexander Yakhot; Nikolai Nikitin; Heping Li

**Chapter 13**

Manufacturing Process Modeling

**Organizers:**

Dr. Frederick W. Brust, Professor Wen-Hwa Chen, & Professor Hidekazu Murakawa

[Identification of Equivalent Material Constants of a Printed Circuit Board](#)

Kun-Nan Chen; Hsien-Chie Cheng

[Optimal Thermal Design for Chip Placement in Multichip Modules](#)

Wen-hwa Chen; Hsien-Chie Cheng

[Determination of Residual Stress in GTA Multi-pass Welds in Stainless Steel Pipe by Means of Numerical Simulation and Comparison with Experimental Measurement](#)

Dean Deng; Hidekazu Murakawa

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Hidekazu Murakawa

[Virtual Reality Technology in Civil Engineering: The Wall's Construction Model](#)

Almeida Zita Sampaio; Pedro Gameiro Henriques; Pedro Studer Ferreira

**Chapter 14**

Mechanics of Geomaterials

**Organizers:**

Professor A. Tom Scarpas & Professor Patrick Selvadurai

[Geotechnical Properties of Cement Stabilized Oil-Contaminated Soils](#)

Amer Al-Rawas; Hossam Hassan; Ramzi Taha; Abdel Wahid Hago; Bader Al-Shandoudi; Yahia Al-Suleimani

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Erich Bauer; Jacek Tejchman

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Annamaria Cividini; Giancarlo Gioda

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Simona de Cicco; Maria Lippiello

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Samer H. Dessouky; Shadi Saadeh; Eyad A. Masad; Dallas N. Little

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Behrouz Gatmiri; Hasan Ghasemzadeh

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Nuno Costa Guerra; Manuel Matos Fernandes; António Silva Cardoso; António Gomes Correia

[Coupling Variable Permeability to Strain and Mass Transfer in Contaminated Clays](#)

Tomasz Hueckel

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Henny ter Huerne; Martin van de Ven; Andre Molenaar; Martin van Maarseveen

[Ionised Media](#)

Jacques M. Huyghe; Mathieu M. Molenaar

[Reduced Order Implicit Integration Algorithms for Frictional Materials](#)

C. Kasbergen; A. Tom Scarpas

[Development of a Finite Element Tool for Simulation of Ravelling of Asphaltic Mixes](#)

Niki Kringos; A. Tom Scarpas

[Constitutive Modelling of Elastoplastic Response of Sand](#)

Xueyan Liu; A. Tom Scarpas

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Eyad A. Masad; Aslam Al-Omari

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T. Milne; M. Huurman; C. Kasbergen; A. Tom Scarpas

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Markus Oeser; Sabine Werkmeister; Bernd Möller; Frohmut Wellner

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Luis Picado Santos; Rosa Conceição Luzia

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A. Tom Scarpas; Xueyan Liu; Niki Kringos

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Antony Patrick Selvadurai

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Kiichi Suzuki; Ajitha Wanninayake; Eiki Nakayama; Takeko Mikami

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Chunhe Yang; Guibin Wang

[Numerical Simulation of Beach Erosion Due to Storm Wave Actions](#)

Wohua Zhang; Yahua Dai; S. Valliappan

**Chapter 15****Meshless & Novel Computational Methods****Organizers:**

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Professor Vitor Leitão, & Professor Thanh Tran-Cong

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C. G. Biniaris; A.I. Kostaridis; D.I. Kaklamani

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Jin Yeon Cho; Jae Mo An; Chang Sik Kim

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Jin Yeon Cho; Sung Woon Woo; Jeong Ho Kim

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Csaba Gáspár

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Leevan L. Ling; Benny Y.C. Hon

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Andreas Karageorghis; C.S. Chen; Y.-S. Smyrlis

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Eisuke Kita; Yoichi Ikeda; Norio Kamiya

[A Locking-Free Meshless Local Petrov-Galerkin \(MLPG\) Formulation for Thick and Thin Plates](#)

Qiuzhan Li; J. Soric; T. Jarak; S.N. Atluri

[Analysis of Crack Tip Stress Using Compactly Supported Meshless Method](#)

T. S. Li; S. M. Wong; K. S. Chan

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Leevan Ling; Robert Alexander Schaback

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L. Mai-Cao; Thanh Tran-cong

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Nam Mai-Duy; Roger Tanner

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Ronald E. Meyers; Keith S. Deacon

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I. S. Raju

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Bozidar Sarler; Janez Perko; Robert Vertnik; Miha Založnik

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Bozidar Sarler; Robert Vertnik; Janez Perko

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Jurica Soric; Qiuzhan Li; Tomislav Jarak; Satya N. Atluri

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Carlos M. Tiago; Vitor M. A. Leitão

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S. M. Wong; T. S. Li; Y. C. Hon

[Solving Maxwell's Equations by Multiquadrics Method](#)

D.L. Young; T.K. Wong; C.W. Chen

## Chapter 16

### Multi-scale Modeling of Materials

#### Organizers:

Professor Fu-Pen Chiang, Professor Z. Xiao Guo,  
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 Professor Hiroshi Okada, Dr. Deepak Srivastava,

Dr. Vinod Tewary, Professor Yoshiro Tomita,  
& Professor Priya Vashishta

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G. Ananthakrishna

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Antonios N. Andriotis

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Tomas Arias

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---

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Lowell Baker; Nicolas G Hadjiconstantinou

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Davor Balzar; Nicolae C. Popa

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Miguel A. Blanco; Aurora Costales; Víctor Luaña; Ravindra Pandey

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Max O. Bloomfield; Timothy Cale

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Tahir Cagin

---

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[Modeling of CNT based Composites: Numerical Issues](#)

Namas Chandra; Chandrakanth Shet

---

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[Micro/Nanomechanics Mapping of Deformation Pattern of Lamellar of TiAl](#)

Fu-Pen Chiang

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[Ab-Initio Studies of Large Deformation Processes of Graphene](#)

Peter W. Chung

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Dana D. Dlott; Hyunung Yu; Shufeng Wang; Yanqiang Yang; Selezion A. Hambir

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[Studies of Defects and Strains Using X-Ray Topography and Diffraction](#)

Michael Dudley

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Alain Esteve

---

---

[Hydrogen Storage on Nanotubes and Nanoscrolls](#)

George E. Froudakis

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[Computational Materials at NASA Langley Research Center](#)

Thomas S. Gates

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Jaafar Ghanbari; Kambiz Behfar; Reza Naghdabadi

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[De Novo Multiscale Simulations of Materials](#)

William A. Goddard

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[Self-Assembled Semiconductor Nanostructures: Multi-Scale Experimentation](#)

Rachel S. Goldman

---

---

[Modelling of Interfaces for Biomedical Devices: Challenges Ahead](#)

Z. Xiao Guo

---

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Itsuo Hanasaki; Akihiro Nakatani; Hiroshi Kitagawa

---

[Interface Sliding and Migration in an Ultrafine Lamellar Structure](#)

Luke L. Hsiung

---

[Atomistic Simulations of Texture Evolution in Thin Films](#)

Hanchen Huang

---

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Tamio Ikeshoji

---

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Masahiko Katagiri; Hidehiro Onodera

---

[Interfacial Heat Flow in Carbon Nanotube Composites](#)

Pawel Keblinski

---

[Brownian Dynamics Simulation of Polymer Behavior in Nano- and Microfluidic Systems](#)

Satish Kumar

---

[Crystallographic Effects on Nano-plasticity on Copper Surfaces](#)

Haiyi Liang; Chung-Ho Woo; Hanchen Huang

---

[Iterative Solution Techniques for the Quasi-continuum Method](#)

Yu Liang; Ramdev Kanapady; Peter Chung

---

[On Micromechanical Behavior of Glassy Polymer Blended with Different Sized Rubber Particles](#)

Wei Lu; Yoshihiro Tomita

---

[Homogenized Elastic-Viscoplastic Behavior of Plain-Woven GFRP Composites Subjected to In-Plane Tensile Load](#)

Tetsuya Matsuda; Yuki Nimiya; Nobutada Ohno; Masataka Tokuda

---

[Molecular-dynamics Study on Crack Growth Behavior Relevant to Crystal Nucleation in Amorphous Metal](#)

Ryosuke Matsumoto; Michihiko Nakagaki; Akihiro Nakatani; Hiroshi Kitagawa

---

[Micromechanical Properties of Cement Pastes at Elevated Temperatures](#)

Jiri Nemecek; Lubos Kopecky; Zdenek Bittnar

---

[Microscopic Bifurcation and Post-Bifurcation Behavior of Periodic Cellular Solids](#)

Nobutada Ohno; Dai Okumura; Hirohisa Noguchi

---

[Surface and Interface Magnetic Structures of Thin Films Studied by X-ray Magnetic Circular Dichroism](#)

Toshiaki Ohta; Kenta Amemiya; Daiju Matsumura

---

[Applications of Element Overlay Technique to the Problems of Particulate Composite Materials](#)

Hiroshi Okada; Chi-Tsich Liu; Takashi Ninomiya; Yasuyoshi Fukui; Noriyoshi Kumazawa

---

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Dai Okumura; Nobutada Ohno; Takeshi Niikawa

---

[The Challenge of Modeling Multiple Scales: From DNA to Dislocations](#)

Rob Phillips

---

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N. Ramakrishnan

---

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Bhakta B. Rath

---

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James Robert Rustad

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Herbert R. Schober

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Shengping Shen; Satya N. Atluri

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Shengping Shen; Satya N. Atluri

[Nanomechanics and Plasticity of Nanotubes and Nanowires](#)

Deepak Srivastava

[Alloy Nanostructure Evolution Via Surface Diffusion](#)

Jerry Tersoff

[Multiscale Modeling of Quantum Nanostructures using Integrated Green's Function and Molecular Dynamics](#)

Vinod K. Tewary; David T. Read

[Multiscale Modeling of Microstructure and Macrostructure Evolution during Sintering](#)

Veena Tikare; Michael V. Braginsky; Jose G. Arguello

[Computational Simulation of Mesoscopic Deformation Behavior of Semi-Crystalline Polymer](#)

Makoto Uchida; Yoshihiro Tomita

[Multimillion Atom Simulations of Nanosystems and Interfaces on Parallel Computers](#)

Priya Vashishta; Rajiv K. Kalia; Aiichiro Nakano

[Atomic-scale Study of Surface-based Nanostructures: Formation and Decay](#)

E.G. Wang

[Effective Properties of Composites Whose Reinforcement has Microstructure](#)

John Whitcomb; Julian Varghese; Jae Noh

[Hybrid Atomistic-Continuum Formulations for Small Scale Hydrodynamics](#)

H. S. Wijesinghe; Nicolas G. Hadjiconstantinou

[Molecular Dynamics / Discrete Dislocation Dynamics Simulations on the Dislocation Behavior in Ni-Based Superalloys](#)

Kisaragi Yashiro; Yasushi Tabata; Fumiharu Kurose; Yoshihiro Tomita; Hussein M Zbib

[A Finite Element Analysis on the Residual Stresses in a Thin Film/Substrate System](#)

N. Yu; M. A. Jing

[A Micromechanics Model for the Elastic Properties of Carbon Nanotubes](#)

N. Yu; Z. H. Zhang

**Chapter 17****Numerical and Analytical Methods in Gradient Elastic Theory****Organizer:****Professor Demos Polyzos**[Wave Dispersion in Concrete due to Microstructure](#)

D. G. Aggelis; T. P. Philippidis; S. V. Tsinopoulos; D. Polyzos

[An Elasticity Solution for Functionally Graded Beams using Stress Function](#)

Mohsen Asghari; Artan Sheshmani

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Kamyar Ghavam; Reza Naghdabadi

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A. E. Giannakopoulos; E. Amanatidou; N. Aravas

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Jing Hu; Piet Stroeven

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Igor Karsaj; Carlo Sansour; Jurica Soric

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Pavel Kuklík; Michal Šejnoha; Jaroslava Vacek

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Jiri Nemecek; Pavel Padevet; Zdenek Bittnar

[BEM Solution of 3-D Dipolar Gradient Elastic Problems in Frequency Domain](#)

D. Polyzos

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San-Qiang Shi; X.N. Jing

[Mechanical Behavior and Structure-Properties Relationships in Amorphous Polymers Simulated by Molecular Dynamics](#)

Ricardo Simoes; Julio C. Viana; Gustavo R. Dias; Antonio M. Cunha

[Bending Design of RC Circular Cross Sections according to ENV 1992 Standard for strains  \$\epsilon\_{c2} > 1.35\%\$](#)

Matjaz Skrinar

## Chapter 18

### Optimization & Inverse Problems

[Fire Risk Analysis in Buildings](#)

António Leca Coelho

[A Memetic Algorithm for Operating Room Scheduling](#)

Hongying Fei; Abdelhakim Artiba ; Chengbin Chu

[Life-Cycle Cost Analysis System for Infrastructure Management](#)

Adelino Jorge Ferreira; Gerardo W. Flintsch

[Optimization of FFT Computation for Processors of the Pentium 4 Type](#)

Luis Filipe Figueiredo; Mário Freire

[Shakedown Design of Frames with Constraints on Deformations](#)

Francesco Giambanco; Luigi Palizzolo; Alessandra Caffarelli

[Two-dimensional Thermomechanical Analysis and Optimization of Functionally Graded Materials](#)

Andrew J. Goupee; Senthil S. Vel

[Monitoring Dam Performance through Neural Networks and the Box Jenkins Approach](#)

José Luis Carrasco Gutierrez; Celso Romanel

[Variational Determination of Eigenstrain Sources of Residual Stress](#)

Alexander Michael Korsunsky; Gabriel Regino; David Nowell

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Andrej Kotar; Pino Koc; Boris Stok

[Optimal Dispatch of Hydro Units Considering Head Dependency](#)

Silvio J.P.S. Mariano; Luis A.F.M. Ferreira

[Identification of Thermal Boundary Conditions Using a Transient Temperature History](#)

Kazunari Momose; Yoshikatsu Sawada; Hideo Kimoto

[Simple Procedures to Accelerate Analyses of Large-Scale Models for Sequential Tunnel Excavation](#)

Marcos Noronha; Ch. Duenser; G. Beer

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Orlando Camargo Rodríguez; Sérgio Machado Jesus

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Sabrina B.M. Sambatti; Haroldo F. de Campos Velho; Leonardo D. Chiwiacowsky; Stephan Stephany; Airam J. Preto

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Wigand Stransky; Bernd Möller; Wolfgang Graf

[Application of the Kalman Filter to Estimate an Elastic Parameter in Order to Improve Controller Performance](#)

Rolf Vargas; L.C. Gadelha DeSouza; Helio K. Kuka

**Chapter 19****Structural Integrity, Damage Mechanics & Damage Tolerance****Organizers:**

Professor Masanori Kikuchi, Professor Seung Jo Kim,  
 Professor Toshihisa Nishioka, Dr. Larry Russell,  
 & Professor Kunigal Shivakumar

[A Conceptual Structural Health Monitoring System for Fatigue Damage](#)

J.D. Achenbach

[Numerical Calculations of the Singular Stress Fields of Failing Mode-II Cracks in Comparison to Experiments](#)

A. Blázquez; J.F. Kalthoff; I. Palomino; A. Fernandez-Canteli

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Aires Camões; Barroso Aguiar; Said Jalali

[Law of Void Evolution for Porous Materials](#)

Bin Chen; Z.H. Gao; X.H. Peng; J.H. Fang

[Determining Stiffness Matrix by the Adjoint Method](#)

L.D. Chiwiacowsky; H.F. deCampos Velho; P. Gasbarri

[Dynamic Constitutive Fracture Behavior of Nanocomposites](#)

Victor M. F. Évora; Nitesh Jain; Arun Shukla

[Software for Evaluating Probability-Based Integrity of Reinforced Concrete Structures](#)

Rui M. Ferreira; Said Jalali; Odd E. Gjorv

[Numerical Simulation of Dynamic Elasto Visco-plastic Crack Propagation with Wake Zone](#)

Takehiro Fujimoto; Toshihisa Nishioka

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Zhanqi Guo; Lambertus Johannes Sluys

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Abd-Nacer-Touati Ihaddoudene; Mohamed Chemrouk

[Study on the Thickness Effect of 3PB Specimen on Dimple Fracture Processes](#)

Masanori Kikuchi

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Jan Klusák; Zdenek Knésl

[Damage Detection with Finite Element Model Updating Using Experimental Modal Data](#)

Andreas Sebastian Kompalka; Stefanie Reese

[Fracture Mechanics of the Interface Crack in a Bimaterial Piezoelectric Wedge under Antiplane Deformation](#)

Thomas Jin-Chee Liu; Ching-Hwei Chue

[Output Only Modal Identification of a Laboratory Model](#)

Filipe Rodrigues Magalhães; Elsa Sá Caetano; Álvaro Ferreira Cunha

[Recent Advances in Hybrid Experimental-Numerical Methods for Dynamic Fracture Studies](#)

Toshihisa Nishioka

[T\\* Integral Analyses of Shell Structures with Through-Wall Cracks for Nonlinear Deformation Problems](#)

Toshihisa Nishioka; Takako Miyanishi; Takehiro Fujimoto

[Prediction Mode Numerical Simulation for Non-straight Propagation Crack in Elasto-plastic Material](#)

Toshihisa Nishioka; Soichiro Oka; Takehiro Fujimoto

[Numerical Investigation of the Multiple Dynamic Crack Branching Phenomena](#)

Toshihisa Nishioka; Stanislav Tchouikov; Takehiro Fujimoto

[Two-dimensional and Three-dimensional Moving Finite Element Analysis for High-speed Crack Propagation in Brittle Materials](#)

Toshihisa Nishioka; Ken Yamaguchi; H. Furuta; Takehiro Fujimoto

[A Failure Modeling for the Interfaces with Irregular Shape and its Numerical Simulation](#)

Xinrui Niu; Yilan Kang; Shou Wen Yu; Xi Qiao Feng

[Antiplane Stress Analysis of a Non-homogeneous Material Wedge](#)

Yi-Liang Ou; Ching-Hwei Chue

[Shear beams with Indirect Supports - Numerical Modeling and Experimental Assesment](#)

Mário Pimentel; Paulo Cachim; Joaquim Azevedo Figueiras

[Impact Response of Two-Layer Body Armors](#)

Arunachalam M. Rajendran; David J. Grove

[On Convergence of the Series Solution for the Crack Propagation in Stochastically Inhomogeneous Materials](#)

Natalia B. Romalis

[Fracture Properties of a Fire Resistance and Energy Absorbing Core Material](#)

Larry C. Russell; Kunigal N. Shivakumar

[A Total Fatigue Life Model for Composite Laminates](#)

Kunigal Shivakumar; Huanchun Chen

[Validation of Various Linear Spring Stiffness Definitions for a Simple Physical Model for Vibrational Analysis of Cracked Beam Elements Subjected to Uniform Transverse Loads](#)

Matjaz Skrinar; Tomaz Plibersek

[Compressive Instabilities in Woven Textile Composites](#)

Shunjun Song; Anthony M. Waas

[Computational and Experimental Analysis of Acetabular Reinforcement Devices](#)

P.M.A Talaia; C. Relvas; L. Almeida; J. Salgado; Jose Antonio Simoes

[Elastoplastic Analysis of External Axial Surface Cracks in Tubes](#)

Zdenko Tonkovic; Ivica Skozrit

[Charge-Free Zone Model and Failure Criterion for Conductive Cracks in Dielectric and Piezoelectric Ceramics](#)

Tong-Yi Zhang

## Chapter 20

Thin and Flexible Structures; Stability & Smart Structures

### Organizers:

Professor S.W. Lee & Professor Aditi Chattopadhyay

[Imperfection's Effect of Beam Element for Elastic Buckling Analysis](#)

Redouane Adman; Hamid Afra

[Damage Detection in Electrically Conductive Structures](#)

Damodar R. Ambur; Grady I. Lemoine; Todd A. Anderson

[Remotely Reprogrammable Wireless Sensor Networks for Structural Health Monitoring Applications](#)

Steven W. Arms; Adam T. Newhard; Jacob H. Galbreath; Christopher P. Townsend

[Development of a Novel Optimal Sensor Placement Technique for Structural Health Monitoring](#)

Aditi Chattopadhyay; Santanu Das

[Shape Optimization of Laminated Composite Shell](#)

Maenghyo Cho; Hyoncheol Kim; Hee Yuel Roh; Gun In Kim

[Metal Rubber - Free-Standing, Mechanically Robust Flexible Conducting Materials](#)

Richard O Claus; Jennifer Lalli; Andrea Hill; Bradley A. Davis; Richard Goff

[Reliability Analysis of Structures with Nonlinear Behavior Using Monte Carlo Simulation and Neural Networks](#)

João R de Almeida; Cosmin G Chiorean; João B Cardoso

[Structural Health Monitoring to Detect Fastener Failure](#)

Mark M Derriso; Steve Olson; William Braisted; Martin DeSimio; John Rosenstengel; Kevin Brown

[Smart Actuator for Aeronautical Application](#)

Luigi Di Palma

[Simple Neural Network Application for Traffic Monitoring](#)

Michael Fraser; Linjun Yan; Xianfei He; Ahmed Elgamal; Joel P. Conte; Tony Fountain

[3D Numerical Modeling of Continuity Equations for Abrupt HBTs at the Heterojunction Interface](#)

Antonio J. Garcia-Loureiro; Juan M. López-González

[A Research on Passive Control of Bridge Buffeting based on Multimode Coupling Buffeting Theory](#)

Dajian Han; Xianwu Zeng

[Computational Modeling of Fabric Surface Structure](#)

Seyed Abdolkarim Hossein; Mohammad Ghane

[Assumed Stress-Strain Four-Node Elements Based on the Finite Deformation First-Order Theory of Multilayered Shells](#)

Gennady Mikhailovich Kulikov; Svetlana V. Plotnikova

[Towards Hybrid Equilibrium Models for Large Displacements of Plates](#)

Edward Anthony Maunder; Bassam Izzuddin

[SMA-Activated Nail for the Fixation of Long Bone Fractures](#)

Giuseppe Mirone; Guido La Rosa

[Form and Structural Analysis of High-Rise Pneumatic Structures](#)

Hiroyuki Obiwa; Katsushi Ijima; Noriaki Kawasaki; Shin-ichi Iguchi

[Wiener-Haar Expansion of Stochastic Limit Cycles](#)

Chris L. Pettit; Philip S. Beran; Daniel Millman

[An Improved Procedure for the Evaluation of the Lateral-Torsional Buckling Resistance of Unrestrained Steel Beams in Case of Fire](#)

P.M.M. Vila Real; N. Lopes; L. Simões da Silva

[A Numerical Scheme for Post-Buckling Analysis of Thin-Walled Members in the Context of GBT](#)

P. Simão; Luís Simões da Silva

[Geometrical Nonlinear Analysis of Thick Plates with Rotation Fields by using Element-Free Galerkin Method](#)

Yoshitaka Suetake; Masashi Iura; Satya N. Atluri

[Active Vibration Suppression of Sandwich Beams using Piezoelectric Shear Actuators](#)

Senthil S. Vel; Brian P. Baillargeon

[Coupled Vibration of Thin Walled Beams](#)

Gabor M. Vörös

[Buckling of Spring Supported Tapered Columns allowing for Shear Deformation](#)

Andrew Watson; William P. Howson

**Chapter 21****Viscoplasticity, Creep, & Damage****Organizer:****Professor Wolfgang Brocks**[Boundary Layer in Moderately Thick Plates Under Creep-Damage Conditions](#)

Holm Altenbach; Konstantin Naumenko

[Modelling of Anisotropic Ductile Damage Using Gradient Theory](#)

Michael Brünig; Sabine Ricci

[A New Model for Porous Viscoplastic Solids Incorporating Void Shape Effects](#)

Laïla Flandi; Jean-Baptiste Leblond

[A Finite Strain Viscoplastic Law with Anisotropic Damage](#)

Ruo Cheng C. Lin; Wolfgang Brocks

[Shape Memory Alloy Composites - Modelling of the One-way Effect and the Fatigue Behaviour](#)

Stefanie Reese; Daniel Christ; Klaus Neuking

[Epoxy Resin as a Bonding Agent in Polymer Matrix Composites: Material Properties and Numerical Implementation](#)

Michal Sejnoha; Richard Valenta

## Chapter 22

### Wave Propagation

#### Organizers:

Professor Chuanzeng Zhang & Professor Francisco Sanchez-Sesma

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[Numerical Determination of Eigenfrequencies and Eigenmodes Using the Method of Fundamental Solutions](#)

Carlos J.S. Alves; Pedro R. S. Antunes

---

---

[High Frequency Scattering of Steel Bars with Embedded Cavities via BEM](#)

Julieta Pires Antonio; António Barreto Tadeu

---

---

[Inverse Problems for Wave Propagation Studies](#)

Jacobo Bielak

---

---

[Boundary Element Formulations Applied to the Analysis of Anisotropic Cracked Plates Under Transient Loads](#)

Eder Lima de Albuquerque; Paulo Sollero

---

---

[Elastic-plastic Stress Waves in Ductile-hardening Materials using Finite Element Techniques and a Split-hopkinson Pressure Bar](#)

Fernando José Ferreira; Mário Augusto Vaz; Francisco Queiros de Melo; Joaquim Silva Gomes

---

---

[Spectral Element Simulation of Rupture Dynamics Along Planar and Non Planar Faults](#)

Gaetano Festa; Jean-Pierre Vilotte

---

---

[Fast BE Calculation of Acoustic Radiation from Vibrating Structures by Mortar Coupling](#)

Lothar Gaul; Matthias Fischer

---

---

[Optimal Reduction of Vibrating Substructures](#)

Dan Givoli

---

---

[High-Order Absorbing Boundaries for Time-Dependent Waves](#)

Dan Givoli; Vincent van Joolen; Beny Neta

---

---

[Dynamic Behaviour of 2.5D Multi-Layered Systems with Elastic and Acoustic Materials](#)

Luis M. C. Godinho; Antonio J. B. Tadeu; Julieta M. P. Antonio

---

---

[On Foundations of Ultrasonic Non-Destructive Method of Determination of Residual Stresses in Near-the-Surface Layers of Bodies](#)

A.N. Guz

---

---

[Hybrid Numerical Method for Transient Waves in Laminated Cylindrical Shells](#)

Xu Han; G.Y. Li; G.R. Liu

---

---

[Transient Behavior of Scattered and Reflected Wave Fields in Anisotropic Solids](#)

Sohichi Hirose; Alan Tan; Chuanzeng Zhang

---

---

[Wave Scattering from a Wavy Interface between Two Anisotropic Media](#)

Per-Ake Jansson; Tatiana Krasnova

---

---

[Study of Transient Wave Propagation in Plates using Double Pulse TV Holography](#)

Hernani Miguel Lopes; Rui Miranda Guedes; Mário Augusto Vaz; José Dias Rodrigues

---

---

[Numerical Solution of the Steady State Propagation of Nonlinear Diffusive Waves](#)

Paula de Oliveira; Ana Paula Mouro

---

---

[Approximate 3D Elastodynamic Greens Functions for an Inhomogeneous Elastic Medium](#)

Francisco Sanchez-Sesma; Leonardo Ramirez-Guzman; Francisco Luzon

---

---

[Sound Insulation Provided by a Single Wall Separating Dwellings Via BEM](#)

Paulo F. A. Santos; António J. B. Tadeu

---

---

[Crack Front Waves on a Shear Crack](#)

John R Willis

---

[Point Load Generated Surface Waves in a Transversely Isotropic Half-Space using Elastodynamic Reciprocity](#)

Anil C. Wijeyewickrema; Masataka Hattori; Sasikorn Leungvichcharoen

---

[Transient Analysis of Buried Dynamic Sources in an Anisotropic Elastic Half-Space](#)

Kuang-Chong Wu; Shy-Hour Chen

---

[Analysis of Elliptical Waveguides by Method of Fundamental Solutions](#)

D.L. Young; S.P. Hu; C.W. Chen; C.M. Fan

---

[Wave Scattering to the Crack Between Piezoelectric Medium and Substrate or Matrix](#)

Shouwen Yu; Bin Gu; Xuyue Wang

---

[Wave Propagation Analysis in FGMs](#)

Chuanzeng Zhang; Jan Sladek; Vladimir Sladek; Sohichi Hirose

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[Ultrasonic Characterization of the Mechanical Properties of Micro- and Nano-structured Thin Films](#)

Feifei Zhang; Sridhar Krishnaswamy

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## **Study of transient wave propagation in plates using double pulse TV holography**

H.M. Lopes<sup>1</sup>, R.M. Guedes<sup>2</sup>, M.A. Vaz<sup>2</sup>, J.D. Rodrigues<sup>2</sup>

### **Summary**

This work presents a numerical and experimental study of the transient response of an isotropic plate. A low mass impact is used to generate the bending wave propagation. Displacements due to the bending wave propagation were assessed using an out-of-plane double pulse TV holography set-up. A PZT transducer is used to record the impact force and its temporal evolution. A novel experimental technique is presented for determination of the stress field in the plate using the out-of-plane displacement field and image-processing techniques. A numerical simulation of the transient response on the plate was carried out with an explicit ABAQUS® module. Finally, the comparisons between numerical and experimental results are presented.

### **Introduction**

Nowadays, the composite materials have a wide use in structural applications. The high stiffness/weight ratio makes them well adapted for industrial applications, especially for the aerospace, aeronautical, automotive, sport and biomedical. Despite their higher mechanical properties, when compared with metallic materials, they are highly dependant on structural integrity. In the last years, several Non-Destructive-Inspection (NDI) techniques were developed for defect detection in composite structures. Some of these defects are already present, caused by the manufacturing process the others are due to in service loads. In this case, the high strength components are submitted to transient loads, together with its vulnerability to damages justifies a strong need for the dynamic characterization these materials under impulsive loads. Therefore, a quick and reliable monitoring technique must be developed to test these structures under impact loads. The Data obtained from these tests may be used to optimize the numerical algorithms used to simulate the dynamic response and also in the defects detection presents in these structures. The impact response in plates is determined by the mass ratio between the impactor and the plate. Small mass ratio creates very short time impact, for the order of wave propagation time through thickness, resulting in dilatation waves in the plate mass. Longer time impact, higher mass ratio, will create a transient response with flexure wave's propagation. For high mass ratio, longer time impact, enough for the wave to reach the boundary, bending and shear waves are generated and the response will be identical to a "quasi-static" loading case [1], [2]. The main objective of this work is the development of a numerical-experimental methodology that can be used to dynamically characterize polymeric matrix composite materials. A first approach to this goal is presented in this work using an isotropic and homogeneous plate.

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This work presents a numerical and experimental study of bending wave propagation in an aluminium plate, submitted to a small mass impact, being the analysis performed until the bending waves reach the boundaries. A description of the TV holography set-up used on the experimental measurement is presented, as well as the way to record the time evolution of the impact force, the trigger system and temporal evolution of all signals. Information that's required for the numerical simulation of response of the plate with ABAQUS® Finite Elements Method (FEM) code. Also, a robust methodology for the calculation of the stress field based on Kirchhoff theory for plates is presented. This methodology involves the filtering and the differentiation of the experimental data. As a final point, a comparison between the experimental and numerical simulation results and the discussion is presented.

### **TV holographic interferometry**

The TV holography is a non-contact field technique that can be used to assess, with very high resolution, the displacement/amplitude of an object surface. This technique is based on the interference between light wave fronts and can be applied over diffuse and complex geometry surfaces with a resolution of the order of a few tenths of a micrometer. Using continuous emission or pulsed lasers they can be applied in the study of quasi-static, periodic or transient phenomena [3] [4]. A CCD camera is used to record each hologram that results from the correlation between two or more wave fronts. In the interferogram, resulting from the correlation between holograms, a set of fringes indicate points undergoing equal displacement/amplitude. The correlation between holograms can be carried out in three different ways: real time, time-average and double exposure. The double exposure correlation is more committed to study transient dynamic phenomena and was used in this work. Double exposure correlation can be performed at any time after the recording of two or more holograms. However, the time between recordings should be carefully selected to capture the phenomena in the measurement range. From the wave fronts correlation a fringe pattern is obtained. These fringes represent points of equal displacement in the direction of the sensitivity vector [5]. These measurements generate an enormous quantity of Data that can be processed with image-processing techniques [6].

### **Experimental set-up**

The experimental tests were performed using the double pulsed TV holography setup presented in figure 1. A LUMONICS Ruby laser generates pairs of pulses with a time separation ranging from  $1\mu\text{s}$  to  $800\mu\text{s}$ . The double pulse holograms are recorded by a CCD camera. The interferograms, obtained by double exposure correlation, were post-processed using image processing techniques. To obtain the hologram phase distribution a special algorithm, based on the demodulation of a spatial carrier introduced in the primary fringes, is used. The out-of-plane displacement field results from the unwrapping the phase difference spatial distributions calculated from the pair of recorded holograms.

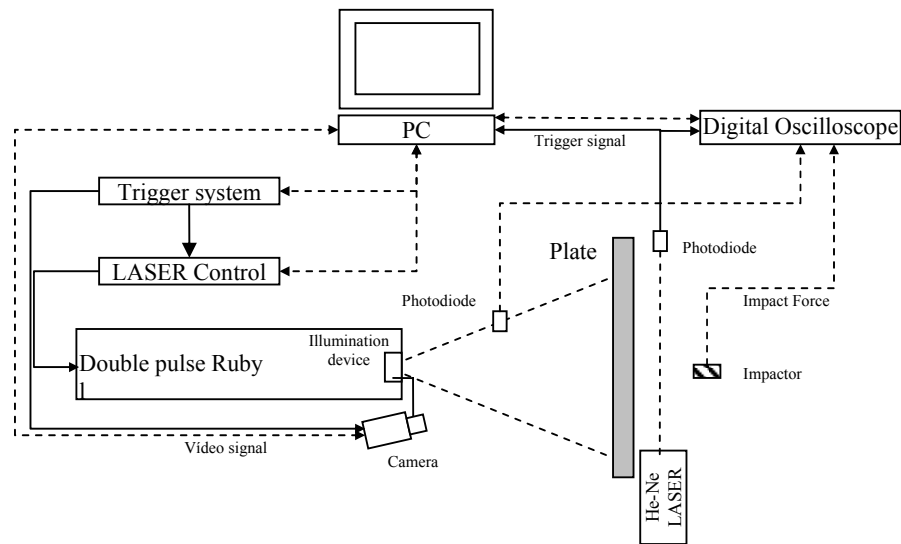


Figure 1: Double pulse TV-holography set-up;

A gravity pendulum hits the plate back side to generate the bending waves. The impact force evolution was measured with a force transducer and recorded in a digital oscilloscope to be inputted in the numerical simulation. A low-pass filter avoids the non-linearity response of the transducer force signal. The experimental set-up was triggered with a signal resulting from the interruption of a laser beam just before the impact. Varying the time between pulses and the laser fire time delay different instants of the wave propagation were recorded. The Figure 2 presents a general view of the set-up showing the aluminium plate and the LUMONICS Ruby laser used in this work.

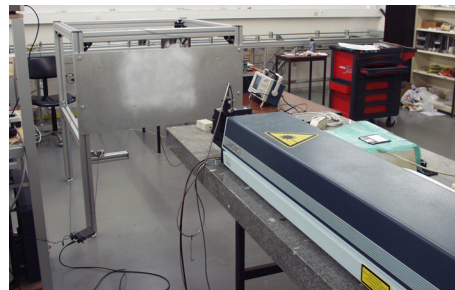


Figure 2: General view of the experimental set-up;

### Experimental tests

The generation of bending waves is conditioned by high mass ratio impactor/plate [1], [2]. For this reason, an 8 mm thickness aluminium plate was selected for this experiment. The impact was made into the centre of plate back side

the with 40g mass impactor. Several measurements were made with different time delays. In Figure 3, several phase maps recorded for different time delays are shown.

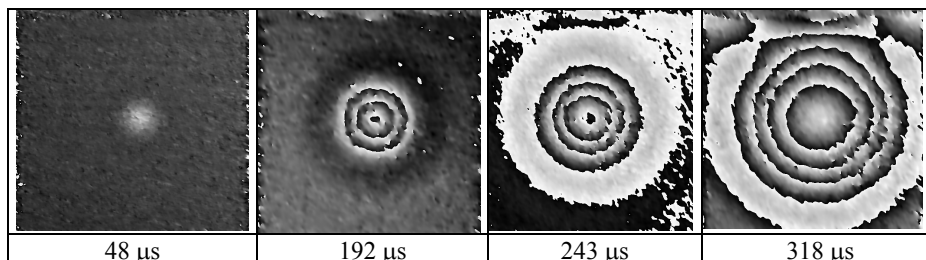


Figure 3: Different instants after impact of the bending wave propagation [7];

As expected, the bending waves are circular and concentric due to the isotropic properties of the aluminium. In the last image (318 $\mu$ s after impact), reflections from the top plate edge of the plate have already started. From the last figures, the displacement field can be obtained by removing the discontinuities present in the phase maps as can be seen in Figure 4.

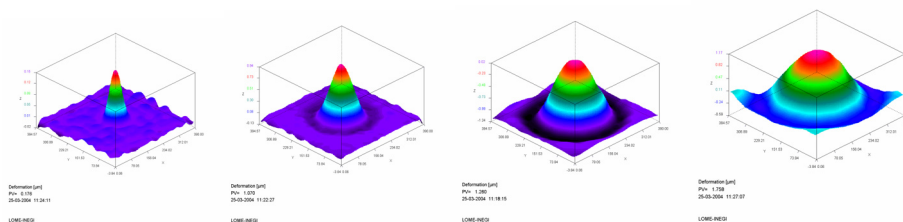


Figure 4: Displacement fields for different instants of the wave propagation.

### Numerical simulation

The numerical simulation was performed with the explicit module of the ABAQUS® code. The plate was simulated with a 2800 (S4R) shell elements mesh. No damping was considered and the applied load results from the signal recorded experimentally. The displacement field for the time step 243 $\mu$ s is represented in Figure 6 a). The comparison between displacement fields obtained by the numerical simulation and the experimental measurements showed that amplitude calculated in impact point is smaller than the measured one, as can be seen Figure 6 b). The differences of amplitude can be explained by an incorrect adjustment of the numerical model due to imprecision the impact force introduced, as result of the filtering process on the measurements.

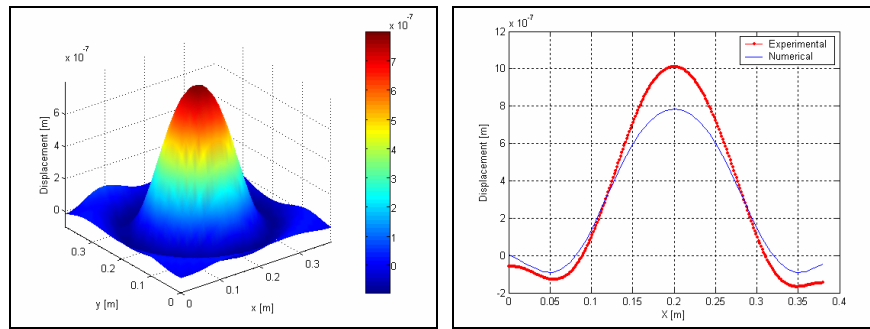


Figure 5: a) The displacement field in the time step  $243\mu\text{s}$  b) The displacement profiles obtained in the same position by ABAQUS® and experimentally.

### Stresses calculation

The stresses in the plate were calculated from the displacement field using a method based on the Kirchhoff plate theory. An algorithm was developed to obtain the spatial derivatives of the experimental displacements. Good results were achieved with the noisy data using a technique for simultaneous differentiation and filtering. After the adjustment of the displacement amplitude between the FEM calculation and the experimental data, the calculus of the stresses was carry out. The Figure 6 presents a comparison between the stress profiles obtained from experimental displacements and numerical simulation,  $243\mu\text{s}$  after impact.

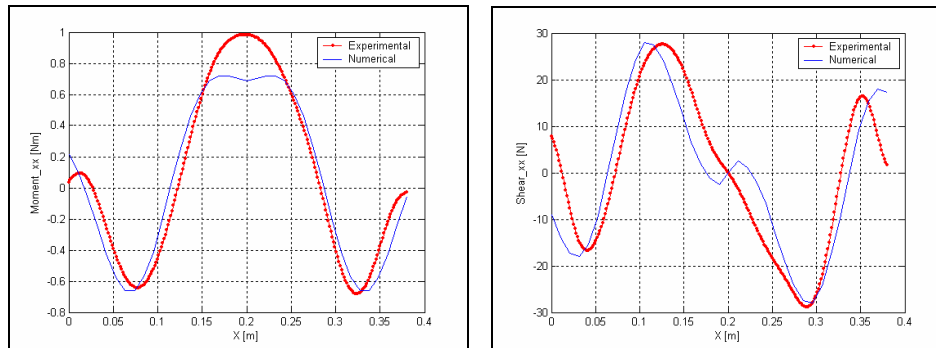


Figure 6: The stress profiles resulting from calculus and obtained from numerical differentiation of the experimental data.

As can be seen in the previous figures there is a good agreement between the results obtained from the calculation using FEM and experimental data. This proves that the methodology used for analysis of transient stresses in plates is appropriated for the proposed study.

### Conclusions and discussion

From the results obtained in this work with an isotropic plate the selected methodology proved to be well adapted to the objectives of the research program.

The calculations already completed with ABAQUS® code can be considered a quite good approximation to the wave propagation.

The methodology presented for stress calculation from the experimental data proved to be robust and immune to the noise. Future developments will be implemented to extend the application of this methodology to anisotropic materials. Experimental techniques are used to access the displacement field, being the stress calculation based on that information. If the material properties are known, this last step can be achieved by two different ways, either using an hybrid experimental-numerical technique or by direct differentiation of the measured displacements field. A major challenge will be to solve the problem inversely by using the experimental data to extract the material properties.

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