# OFW11

11th OpenFOAM® Workshop

Guimarães 2016

## BOOK OF ABSTRACTS



Dear FOAMers,

All started one year ago... The challenge was to organize a workshop according to the standards of the previous editions. Just a few weeks were enough to realize that, similarly to the spirit of the OpenFOAM®community, these type of organizations cannot be undertaken by just one person. It was the beginning of the `sweat4Foam`, a group that was much more than a set of event organizers.

At the beginning it started with a slow convergence and it seemed to be very stable, however closer to the OFW11 the convergence rate increased but with visible instabilities.

We gave our best and finally reached convergence. Now its the time for V&V.

We hope you find useful the time spent at the OFW11 and we also hope that you enjoy (and return in the future to) Guimarães.

Finally, it is important to mention that this workshop would not be possible without the generous support of the OFW11 sponsors.

Miguel Nóbrega,

In representation of the `sweat4Foam team`.

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# OpenFOAM Workshop Committee

| COMMITTEE MEMBER | AFFILIATION | COUNTRY |
| --- | --- | --- |
| Bernhard Gschaider | ICE Strömungsforschung GmbH | Austria |
| Eric Paterson | Virginia Tech | USA |
| Eugene de Villiers | Engys.eu | UK |
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| Gavin Tabor | The University of Exeter | UK |
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| Henrik Rusche | Wikki GmbH | Germany |
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| Shin-Hyung Rhee | Seoul National University | Korea |
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# Local Organising Committee

| | | |
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| Bruno Santos | blueCAPE Lda | Portugal |
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| Luís Ferrás | University of Minho | Portugal |
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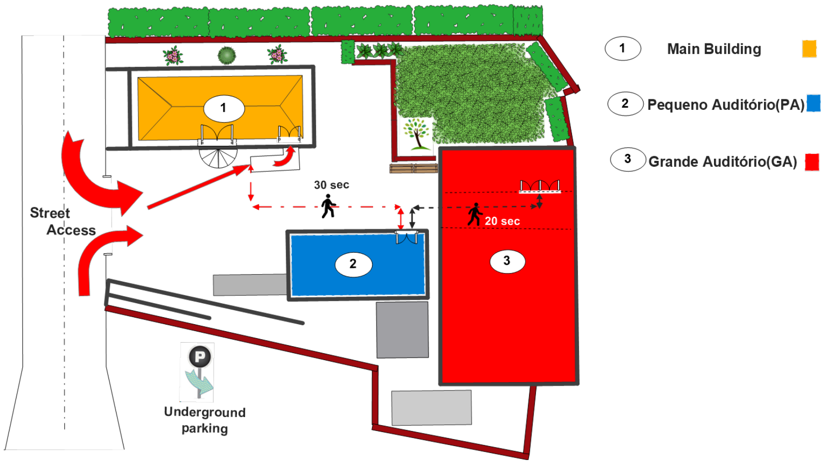
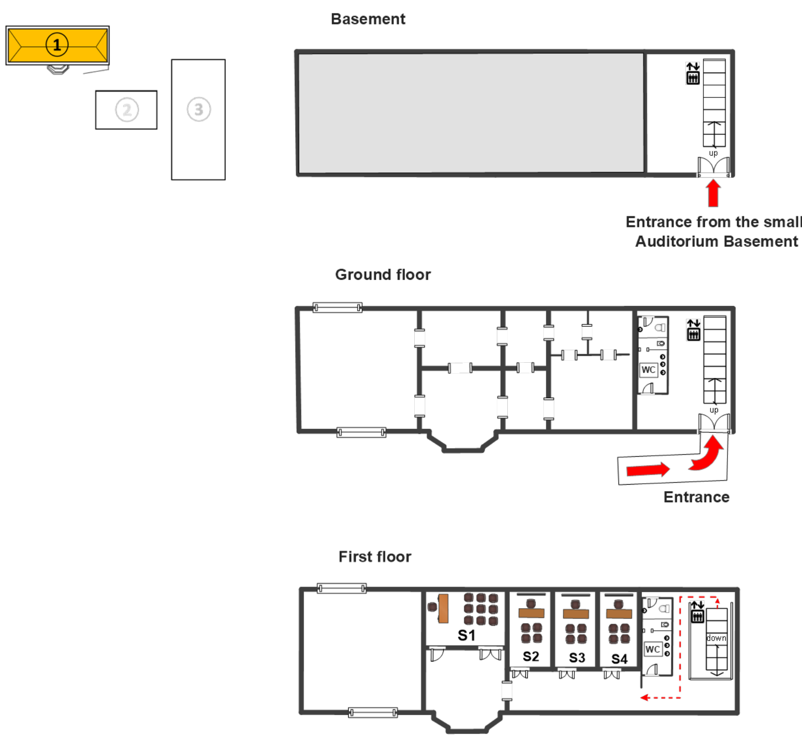
| Rui Gomes | Bosch | Portugal |
| Sacha Mould | University of Minho | Portugal |
| Sérgio Gonçalves | Guimarães Town Council | Portugal |
| Susana Costa | University of Minho | Portugal |

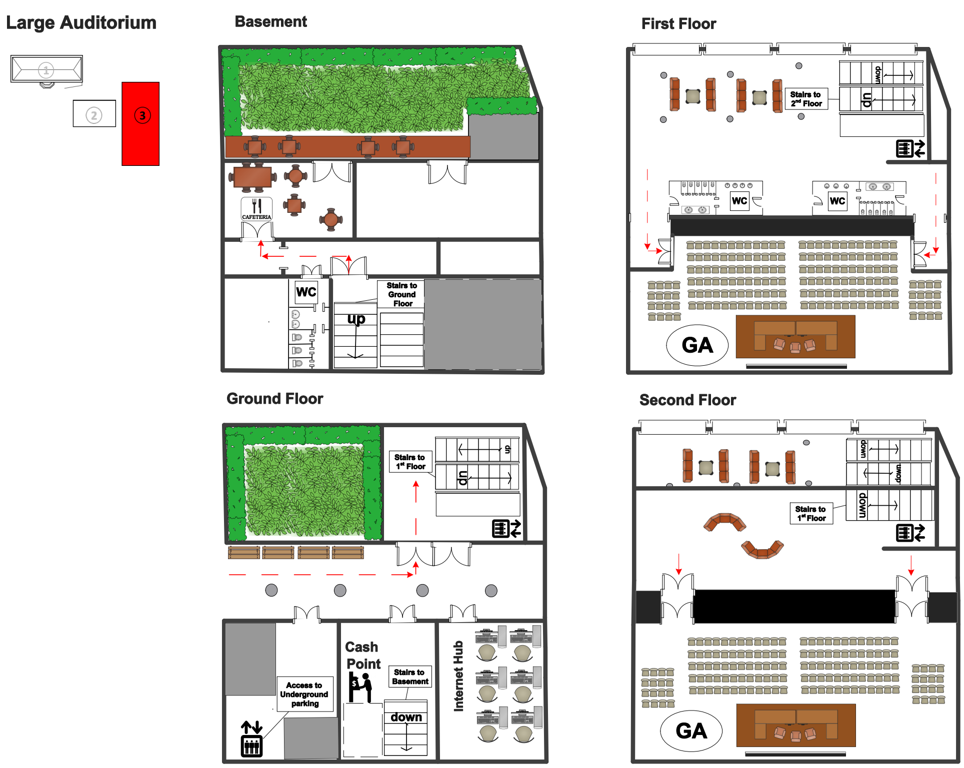
# Palácio Vila Flor (Conference Venue)



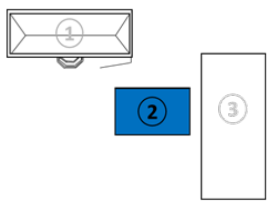

# Main Building

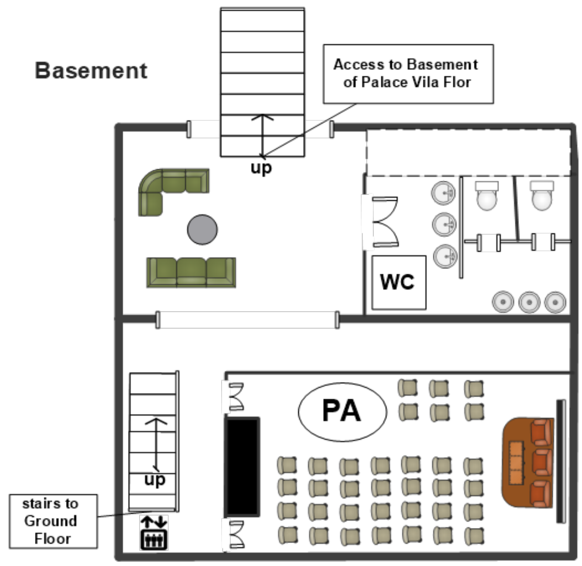


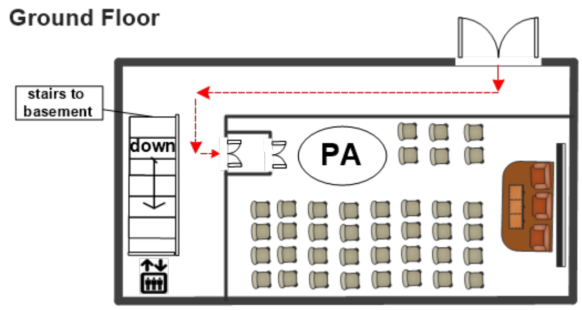
# Grande Auditório (Large Auditorium)



# Pequeno Auditório (Small Auditorium)



## Program at a glance

| Day | Time | GA | PA | S1 | S2 | S3 | S4 |
|---|---|---|---|---|---|---|---|
| | | **Rooms** | | | | | |
| Monday June 27th | 8:30 - 9:00 | Opening Session | - | - | - | - | - |
| | 9:00 - 10:30 | Plenary Lectures | - | - | - | - | - |
| | 10:30 - 11:00 | **Coffee Break (Foyer)** | | | | | |
| | 11:00 - 13:00 | - | Free Surface Flows | General CFD I | Pre&Post-processing, Meshing and User Environ. I | Acoustics / Compressible Flows | Turbulence Modelling |
| | 13:00 - 14:30 | **Lunch (Restaurant)** | | | | | |
| | 14:30 - 14:45 | Feature Pres. | - | - | - | - | - |
| | 14:45 - 15:30 | Plenary Lecture | - | - | - | - | - |
| | 15:40 - 17:00 | - | Fluid-Structure Interaction I | General CFD II | Disperse Multiphase Flows I | Optimization and Control | Naval Hydrodynamics / Coastal / Offshore I |
| | 17:00 - 17:30 | **Coffee Break (Foyer)** | | | | | |
| | 17:30 - 19:30 | **Poster (Foyer) + Wine Tasting (Garden)** | | | | | |
| Tuesday June 28th | | **GA** | **PA** | **S1** | **S2** | **S3** | **S4** |
| | 8:30 - 10:00 | Courses | | | | | |
| | 10:00 - 10:30 | **Coffee Break (Foyer)** | | | | | |
| | 10:30 - 12:00 | Courses | | | | | |
| | 12:00 - 13:30 | **Lunch (Restaurant)** | | | | | |
| | 13:30 - 15:00 | Courses | | | | | |
| | 15:00 - 16:30 | Courses | | | | | |
| | 16:30 - 17:00 | **Coffee Break (Foyer)** | | | | | |
| | 17:00 - 18:30 | Courses | | | | | |
| Wednesday June 29th | | **GA** | **PA** | **S1** | **S2** | **S3** | **S4** |
| | 8:30 - 10:00 | Plenary Lectures | - | - | - | - | - |
| | 10:10 - 11:10 | - | Fluid-Structure Interaction II | General CFD III | Pre&Post-processing, Meshing and User Environ. II | Complex Materials | Aerodynamics I |
| | 11:10 - 11:40 | **Coffee Break (Foyer)** | | | | | |
| | 11:40 - 12:40 | | Chemistry & Reacting Flows | General CFD IV | Pre&Post-processing, Meshing and User Environ. III | Nuclear | Aerodynamics II |
| | 12:40 - 14:00 | **Lunch (Restaurant)** | | | | | |
| | 14:00 - 14:15 | Feature Pres. | - | - | - | - | - |
| | 14:15 - 15:00 | Plenary Lecture | - | - | - | - | - |
| | 15:10 - 16:30 | - | Heat and Mass Transfer I | Turbomachinery | Disperse Multiphase Flows II | Multiphase Flows I | Naval Hydrodynamics / Coastal / Offshore II |
| | 16:30 - 17:00 | **Coffee Break (Foyer)** | | | | | |
| | 17:00 - 18:20 | - | Heat and Mass Transfer II | Phase Change | Automotive/Solid Mechanics | Multiphase Flows II | **Naval Hydro Pack Dem. Session 16:30 - 18:30** |
| | 19:30 - 23:00 | **Banquet** | | | | | |
| Thursday June 30th | | **GA** | **PA** | **S1** | **S2** | **S3** | **S4** |
| | 8:30 - 9:00 | Plenary Lecture | - | - | - | - | - |
| | 9:00 - 10:30 | Clinics Sessions | | | | | **HELYX® Open Seminar 9:00 - 12:00** |
| | 10:30 - 11:00 | **Coffee Break (Foyer)** | | | | | |
| | 11:00 - 12:30 | Clinics Sessions | | | | | |
| | 12:30 - 14:00 | **Lunch (Restaurant)** | | | | | |
| | 14:00 - 15:30 | Birds-of-a-feather Meetings | | | | | **GOMPUTE Open Seminar 14:00 - 15:00** |
| | 15:30 - 16:00 | **Coffee Break (Foyer)** | | | | | |
| | 16:00 - 17:30 | Special Interest Groups - Meetings | | | | | |
| | 17:30 - 18:00 | **Closing Session** | | | | | |

## Monday, June 27th

| | Plenary Lectures (Grande Auditório) |
|---|---|
| 8:30 - 9:00 | **Opening Session** |
| 9:00 - 9:45 | **A Year in Review** (Hrvoje Jasak, Wikki Lda/ Univ. Zagreb) |
| 9:45 - 10:30 | **Fighting bugs with HPC – the latest challenges in designing and demonstrating aseptic performance of filling machines for milk** (Ulf Lindblad, Tetra Pak) |
| 10:30 - 11:00 | **Coffee-Break** |

| | Free Surface Flows | General CFD I | Pre-processing, Post-processing, Meshing and User Environments I | Acoustics / Compressible Flows | Turbulence Modelling |
|---|---|---|---|---|---|
| | *(Room PA)* | *(Room S1)* | *(Room S2)* | *(Room S3)* | *(Room S4)* |
| 11:00 - 11:20 | MODELLING FREE-SURFACE DYNAMICS IN THE RIBBON GROWTH ON SUBSTRATE PROCESS (RGS) (P Beckstein, V Galindo, G Gerbeth) | CFD WITH OPEN SOURCE SOFTWARE -- A COURSE WHERE THE STUDENTS BECOME TEACHERS AND CONTRIBUTE TO GLOBAL LEARNING (H Nilsson) | OPTIMIZATION OF FINITE VOLUME MESHES USING SPHERICITY (P Alexias, E Villiers) | SIMULATION OF THE ACOUSTIC WAVE PROPAGATION IN STEEL COMPONENTS - VALIDATION AND VERIFICATION (M Rehm, P Kodet, S Bouachrine, H Rusche) | IMPLEMENTATION OF A DIVERGENCE-FREE TURBULENT SPOT METHOD FOR SYNTHESIS OF TURBULENT VELOCITY FIELDS INTO OPENFOAM (H Kröger, N Kornev) |
| 11:20 - 11:40 | IMPLEMENTATION OF A FLEXIBLE AND MODULAR VOLUME OF FLUID MULTIPHASE FRAMEWORK FOR NON-ISOTHERMAL INCOMPRESSIBLE FLOWS (P Capobianchi, M Oliveira, M Lappa) | EPIC: LINKING EXPERTS WITH USERS AND DATA (M Turner, J Appa, J Sharpe, D Standingford) | MESH MOTION STRATEGIES AND MULTI-COUPLED MESH INTERFACES FOR THE 3D SIMULATION OF EXTERNAL GEAR PUMPS (JM Rubio, F Piscaglia, A Montorfano) | A NUMERICAL APPROACH TO POSSIBLE IDENTIFICATION OF THE NOISIEST ZONES OF A WALL SURFACE WITH A FLOW INTERACTION (K Charly, M Yann, P Raymond) | COUPLING OF OPENFOAM® AND OPEN DYNAMICS ENGINE TO DESCRIBE DUST TRANSPORT AND DEPOSITION IN A TURBULENT ATMOSPHERIC FLOW (A Ukhov) |
| 11:40 - 12:00 | SIMULATION OF A SUPER-CRITICAL BATHTUB VORTEX: COMPARISON WITH EXPERIMENTAL DATA (G Fourestier, T Santagostini, ML Boulluec, P Magaldi, YM Scolan) | RECENT ADVANCES IN PRESSURE-VELOCITY COUPLED SOLVER (T Uroić, V Vukčević, H Jasak) | A DUALISED HEX-MESH GENERATOR WITH CELL QUALITY OPTIMISATION (A Jackson, E Villiers, P Alexias) | ACOUSTIC ANALYSIS OF A TURBULENT FLOW AROUND A BLUFF BODY (M Cianferra, S Ianniello, V Armenio) | HYBRID RANS/LES OF TURBULENT STRUCTURES EVOLUTION IN A DYNAMIC GEOMETRY (A Montorfano, Y Wu, F Piscaglia) |
| 12:00 - 12:20 | STUDY OF OPENFOAM VOF METHOD CAPABILITIES FOR NUMERICAL SIMULATION OF DROPLET IMPACT ON THICK LAYER AT LARGE FROUDE NUMBERS (E Davydova, V Korchagova) | NUMERICAL ASSESSMENT OF THIRD-ORDER ACCURATE HIGH RESOLUTION SCHEMES IN OPENFOAM (D Shanmugam, T Chourushi) | DYNAMIC HEXAHEDRAL REMESHING AND FLOW SOLVING (D Winkler, J Gould) | EFFECT OF TRAILING EDGE MODIFICATION ON NOISE GENERATION OF NASA ROTOR 67 AXIAL COMPRESSOR (J Mosiezny) | FLOW SIMULATION IN SUPERSONIC COMBUSTION CHAMBER (I Gudich, O Feodoritova, N Novikova, K Manukovskii, V Zhukov) |
| 12:20 - 12:40 | EFFECTS OF SURFACE TEXTURES ON GRAVITY DRIVEN LIQUID FLOW ON INCLINED PLATE (M Isoz) | IMPROVING THE NUMERICAL STABILITY OF STEADY-STATE DIFFERENTIAL VISCOELASTIC FLOWS (C Fernandes, M Araújo, LL Ferrás, JM Nóbrega) | GAP-TOLERANT MESHING IN ICONHEXMESH (D Martineau, J Gould, J Papper) | EXTENDING OPENFOAM COMPUTATIONAL AEROACOUSTICS CAPABILITIES (I Evdokimov, M Kraposhin, A Epikhin) | MODELING OF TURBULENT FLOWS IN RECTANGULAR DUCTS OF CONSTANT SECTION USING OPENFOAM (R Faria, AD Ferreira, AMG Lopes, ACM Sousa) |
| 12:40 - 13:00 | | SIMULATION OF VISCOELASTIC SINGLE- AND TWO-PHASE FLOWS AT HIGH WEISSENBERG NUMBER USING A GENERIC NUMERICAL STABILIZATION FRAMEWORK (M Niethammer, H Marschall, C Kunkelmann, D Bothe) | MESH CONVERGENCE STUDY WITH FOAM-EXTEND 3.1 FOR HYDRAULIC TURBINE DRAFT TUBE (C Devals, T Vu, Y Zhang, J Dompierre, F Guibault) | STABILITY IMPROVEMENTS OF PRESSURE-BASED COMPRESSIBLE SOLVER AND VALIDATION FOR INDUSTRIAL TURBO-MACHINERY APPLICATIONS (H Rusche, H Jasak, S Schmitt) | A ROBUST APPROACH TO GENERATING INFLOW CONDITIONS FOR SCALE-RESOLVING SIMULATIONS OF TURBULENT BOUNDARY LAYERS (T Mukha, M Liefvendahl) |
| 13:00 - 14:30 | **Lunch** | | | | |

| | Plenary Lectures (Grande Auditório) |
|---|---|
| 14:30 - 14:45 | **Feature Presentation - Engys** |
| 14:45 - 15:30 | **Challenges on the Injection Molding Industry** (Marcos Sampaio, Celoplás/Nanologic) |

| | Fluid-Structure Interaction I | General CFD II | Disperse Multiphase Flows I | Optimization and Control | Naval Hydrodynamics / Coastal / Offshore I |
|---|---|---|---|---|---|
| | *(Room PA)* | *(Room S1)* | *(Room S2)* | *(Room S3)* | *(Room S4)* |
| 15:40 - 16:00 | LUBRICATED CONTACT MODEL FOR COLD METAL ROLLING PROCESSES (V Skuric, P Jaeger, H Jasak) | SIMULATING TANK-MIXER PROBLEMS USING A TIME-VARYING MAPPED FIXED VALUE APPROACH (J Müller, K Velten) | A COMBINED EULER-EULER EULER-LAGRANGE SLURRY MODEL (A Mackenzie, A Lopez, M Stickland, W Dempster) | CAD BASED PARAMETERIZATION FOR ADJOINT OPTIMIZATION (M Damigos, E Villiers) | NUMERICAL SIMULATION OF A SINGLE FLOATING POINT ABSORBER WAVE ENERGY CONVERTER USING OPENFOAM® (B Devolder, P Rauwoens, P Troch) |
| 16:00 - 16:20 | A FLUID-STRUCTURE INTERACTION ALGORITHM FOR SHIP HYDROELASTICITY (M Graham, J Mesa, K Maki) | FLOATING POTENTIAL BOUNDARY CONDITION IN OPENFOAM (N Lavesson, T Laneryd) | IMPLEMENTATION AND EVALUATION OF AHLERT-MCLAURY EROSION MODEL ON A CYCLONE PARTICLE SEPARATOR (N Casari, C Buratto, M Pinelli, N Aldi, A Suman) | SHAPE OPTIMISATION USING COMPUTATIONAL FLUID DYNAMICS AND EVOLUTIONARY ALGORITHMS (S Daniels, A Rahat, G Tabor, J Fieldsend, R Everson) | THE HARMONIC BALANCE METHOD FOR TEMPORALLY PERIODIC FREE SURFACE FLOWS IN MARINE HYDRODYNAMICS (V Vukčević, G Cvijetic, I Gatin, H Jasak) |
| 16:20 - 16:40 | ON OPENFOAM EFFICIENCY FOR SOLVING FLOW-STRUCTURE INTERACTION PROBLEMS (K Kuzmina, I Marchevsky) | CATALYTICFOAM AND ISAT FOR THE EFFICIENT SIMULATION OF FIXED BED CATALYTIC REACTORS (M Bracconi, A Cuoci, M Maestri) | CFD ANALYSIS OF NUTRIENT MIXING DURING WINE FERMENTATION (D Schmidt, K Velten) | DISCRETE ADJOINT SENSITIVITIES IN OPENFOAM (M Towara, A Sen, U Naumann) | ISOADVECTOR: A NEW GEOMETRIC VOF METHOD FOR ARBITRARY MESHES (J Roenby, H Bredmose, H Jasak) |
| 16:40 - 17:00 | PIMPLE ALGORITHM AND PARTITIONED FSI SOLVERS (P Vita, W Brandstätter) | VENTILATED CAVITY DYNAMICS BEHIND 2-D WEDGE IN INCOMPRESSIBLE FLOWS (H Choi, H Lee, SH Rhee) | MODELING OF MULTI-COMPONENT SPRAY IMPINGEMENT AND WALL FILM DEVELOPMENT IN CROSS FLOW CONDITIONS (L Nocivelli, G Montenegro, T Lucchini) | AUTOMATIC DESIGN EXPLORATION AND OPTIMIZATION USING CAESES AND OPENFOAM (C Fuetterer) | JOINT DEVELOPMENT PROJECT ON SEAKEEPING SIMULATIONS USING OPENFOAM - INDUSTRIAL PERSPECTIVE (GH Kim) |
| 17:00 - 17:30 | **Coffee-Break** | | | | |
| 17:30 - 18:30 | **Poster Session** | | | | |
| 18:30 - 19:30 | **Wine Tasting** | | | | |

# Tuesday, June 28th

| | Course Track 1 (Room GA) | Course Track 2 (Room PA) | Course Track 3 (Room S1) | Course Track 4 (Room S2) | Course Track 5 (Room S3) | Course Track 6 (Room S4) |
|---|---|---|---|---|---|---|
| 08:30 - 10:00 | **Rotating machinery in FOAM-extend** Håkan Nilsson (Lecture) | **Using OpenFOAM fluid structure interaction library** Željko Tuković (Hands-On) | **Erosion modeling in OpenFOAM** Alejandro Lopez (Lecture) | **Introduction to OpenQBMM and quadrature-based moment methods** Alberto Passalacqua (Lecture) | **snappyHexMesh Theory and Application** Andrew Jackson (Hands-On) | **cfMesh** Tessa Uroić (Hands-On) |
| 10:00 - 10:30 | **Coffee-Break** | | | | | |
| 10:30 - 12:00 | **Pressure-velocity coupling in solvers** Hrvoje Jasak (N/A) | **Introduction to the programming language of OpenFOAM®** Vuko Vukčević (Hands-On) | **PyFoam for the lazy** Bernhard Gschaider (Lecture) | **New IHFOAM developments** Javier L. Lara (Lecture) | **Introduction to meshing with blockMesh** Vanja Škurić (Hands-On) | **Practical CFD applications using HELYX-OS** Paolo Geremia (Hands-On) |
| 12:00 - 13:30 | **Lunch** | | | | | |
| 13:30 - 15:00 | **Advanced dynamic mesh motion** Gianluca Montenegro (Lecture) | **Introduction to PyFoam and swak4Foam** Bernhard Gschaider (Hands-On) | **OpenFOAM® software bundles by CFDsupport** Jakub Benda (Lecture) | **Introduction to simulating real 3d flows: the DrivAer case** Gavin Tabor (N/A) | **Understanding and prototyping fvOptions** Jens Höpken (Hands-On) | **Introduction to solid mechanics with OpenFOAM** Philip Cardiff (Hands-On) |
| 15:00 - 16:30 | **Simulations with particles, using the Lagrangian method** (Lecture) Alejandro Lopez | **Extending Boundary Conditions at Runtime** Tomislav Maric (Hands-On) | **Design and Rationale of High Resolution Schemes in OpenFOAM** Holger Marschall (Lecture) | **Understanding and extending scalarTransportFoam** Henrik Rusche (N/A) | **Implementation of turbulence models** Luiz Fernando. L. R. Silva (Hands-On) | **Introduction to post-processing with ParaView** Philip Cardiff (Hands-On) |
| 16:30 - 17:00 | **Coffee-Break** | | | | | |
| 17:00 - 18:30 | **Introduction to numerical optimization using DAKOTA and OpenFOAM®** Joel Guerrero (N/A) | **Implementation of simple FSI model with functionObject** I. Marchevsky (Hands-On) | **Using EPIC to run OpenFOAM® online** **Mike Turner** (Hands-On) **Internet Room** | | **Implementation of acoustic analogy** Ilia Evdokimov (Hands-On) | **Learning how to use free surface flows in OpenFOAM 3.0** Victoria Korchagova (Hands-On) |

More details - http://www.openfoamworkshop.org/courses

## Wednesday, June 29th

| | Plenary Lectures |
|---|---|
| 8:30 - 9:15 | **CONTRIBUTING A PERSPECTIVE ON ONE OPEN-SOURCE AND COMMUNITY CONTRIBUTOR: WYLDCAT** (Bruno Santos, blueCAPE Lda) |
| 9:15 - 10:00 | **GROW YOUR OWN CFD BUSINESS** (Robin Knowles, CFD Engine) |

| | General CFD III | Pre-processing, Post-processing, Meshing and User Environments II | Fluid-Structure Interaction II | Complex Materials | Aerodynamics I |
|---|---|---|---|---|---|
| | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* |
| 10:10 - 10:30 | FURTHER DEVELOPMENTS ON THE GEOMETRIC IMMERSED BOUNDARIES (GIB) (G Karpouzas, E de Villiers) | VISUAL STORYTELLING AND DATA VISUALIZATION IN NUMERICAL SIMULATIONS (J Guerrero, G Bailardi, H Kifle) | ADDED MASS PARTITIONED FLUID-STRUCTURE INTERACTION SOLVER BASED ON ROBIN BOUNDARY CONDITION FOR PRESSURE (Z Tuković, M Bukač, H Jasak, A Ivanković) | FLUID DYNAMIC AND THERMAL MODELING OF THE INJECTION MOLDING PROCESS IN OPENFOAM® (J Nagy, E Kobler, G Steinbichler) | COMBINING AN OPENFOAM-BASED ADJOINT SOLVER WITH RBF MORPHING FOR SHAPE OPTIMIZATION PROBLEMS ON THE RBF4AERO PLATFORM (EP Kiachagias, K Giannakoglou, S Porziani, C Groth, ME Biancolini, E Costa) |
| 10:30 - 10:50 | QUADROTOR CYCLOGYRO AIRCRAFT IN FORWARD FLIGHT CFD MODEL (L Gagnon, G Quaranta, M Schwaiger, D Wills) | SCRIPTING AS AN APPROACH TO AUTOMATED CFD SIMULATION FOR PACKED BED CATALYTIC REACTOR MODELLING (J Fernengel, F Habla, O Hinrichsen) | THE DEVELOPMENT AND APPLICATION OF A MOORING LINE MODEL FRAMEWORK FOR CFD ANALYSIS (D Combest) | A SURROGATE MODEL TO BALANCE THE FLOW DISTRIBUTION IN COMPLEX PROFILE EXTRUSION DIES (A Rajkumar, L Ferrás, C Fernandes, OS Carneiro, M Becker, JM Nóbrega) | MHD SUPERSONIC FLOW CONTROL SIMULATION IN OPENFOAM (A Ryakhovskiy, A Schmidt) |
| 10:50 - 11:10 | MULTIPHASE VOF SIMULATION OF GASOLINE INJECTORS WITH TOPOLOGICALLY CHANGING GRIDS (F Piscaglia, A Montorfano, F Giussani, J Hélie, SM Aithal) | INTRODUCING THE NEW VERSION OF THE OPEN SOURCE GUI HELYX-OS (P Geremia, S Valeri, D Ciani) | SIMULATION OF THE FLOW AROUND AN ELASTIC SQUARE CYLINDER (E Tangermann, M Klein) | | WIND TURBINE DIFFUSER AERODYNAMIC STUDY WITH OPENFOAM (FS Palmer, A Figueroa, A Sanz-Andres, S Pindado) |

| | |
|---|---|
| 11:10 - 11:40 | **Coffee-Break** |

| | General CFD IV | Pre-processing, Post-processing, Meshing and User Environments III | Chemistry & Reacting Flows | Nuclear | Aerodynamics II |
|---|---|---|---|---|---|
| | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* |
| 11:40 - 12:00 | USE OF OPENFOAM® FOR INVESTIGATION OF MIXING TIME IN AGITATED VESSELS WITH IMMERSED HELICAL COILS (A Stefan, J Volkmer, HJ Schultz) | INTRODUCING A NEW CLIENT-SERVER FRAMEWORK FOR LARGE CFD MODELS (A Paroni, P Geremia, S Valeri) | REACTING POROUS MEDIA - SIMULATION OF THERMAL CONVERSION OF WOOD (K Kwiatkowski, PJ Zuk) | GEN-FOAM: AN OPENFOAM® BASED MULTI-PHYSICS SOLVER FOR NUCLEAR REACTOR ANALYSIS (C Fiorina) | INVESTIGATION OF ICE SHAPE CHARACTERISTICS FOR LOW-SPEED HIGH ALTITUDE LONG ENDURANCE AIRCRAFT IN ICING CONDITIONS (C Son, K Yee) |
| 12:00 - 12:20 | DEVELOPMENT OF CUSTOMIZED INDOOR AIR SIMULATOR USING OPEN SOURCE LIBRARIES (I Sohn, H Roh, J Kim) | A GENERIC APP GUI FOR OPENFOAM® AND VARIANTS (J Papper, S Geller) | SIMULATING POLYURETHANE FOAMS USING THE MODENA MULTI-SCALE SIMULATION FRAMEWORK (H Rusche, M Karimi, P Ferkl) | ONE- AND TWO-PHASE COUPLING OF OPENFOAM WITH THE THERMAL HYDRAULIC CODE ATHLET FOR NUCLEAR SAFETY ANALYSES (J Herb, F Chiriac) | CHARACTERIZATION OF SUPERSONIC INTAKE FOR SPIN-STABAILIZED FLIGHT VEHICLES ALONG A BALLISTIC TRAJECTORY USING CFD (A Steenkamp, M Combrinck) |
| 12:20 - 12:40 | MICRO-SCALE CFD MODELING OF TIGHT ROCKS (I Verri, AD Torre, G Montenegro) | AN UPDATE ON THE INTEGRATION OF ADIOS INTO OPENFOAM FOR HANDLING DISK I/O (K Meredith, A Heather, N Podhorszki) | DETAILED HOMOGENEOUS AND HETEROGENEOUS KINETICS IN OPENFOAM (A Cuoci, M Maestri) | DEVELOPMENT AND IMPLEMENTATION OF A NEW HIGH ORDER TURBULENCE MODEL IN OPENFOAM FOR LIQUID FUEL NUCLEAR REACTORS (MT Retamales, P Rubiolo, O Doche) | |

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| 12:40 - 14:00 | **Lunch** |

| | Plenary Lectures |
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| 14:00 - 14:15 | **Feature Presentation - Gompute** |
| 14:15 - 15:00 | **Open Source CFD Methodology, Research & Industrial Applications** (Torbjörn Larsson, Creo Dynamics) |

| | Turbomachinery | Disperse Multiphase Flows II | Heat and Mass Transfer I | Multiphase Flows I | Naval Hydrodynamics / Coastal / Offshore II |
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| | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* |
| 15:10 - 15:30 | HIGH SPEED MICRO TURBINE FOR SPECTROSCOPY APPLICATION (N Herzog, D Wilhelm, A Purea, F Engelke) | LES MODELING OF LIQUID ATOMIZATION IN OPENFOAM USING A SURFACE DENSITY FUNCTION (N Hecht, J Anez Perdomo, J Reveillon, FX Demoulin) | HEAT TRANSFER SIMULATIONS FOR A 3D PRINTED HEAT EXCHANGER (R Kahraman, G Tabor) | SOLVING NUMERICAL STABILITY PROBLEMS IN MULTIPHASE FLOWS WITH LARGE INTERPHASE HEAT TRANSFER (JL Favero, GGS Ferreira, LFLR Silva, PLC Lage) | NEAR-WAKE KINEMATICS OF A SURFACE PIERCING CYLINDER AT SUPERCRITICAL REYNOLDS NUMBERS AND LOW KEULEGAN-CARPENTER NUMBERS (A Edesess, D Kelliher, A Borthwick, G Thomas) |
| 15:30 - 15:50 | HARMONIC BALANCE METHOD FOR TURBOMACHINERY APPLICATIONS (G Cvijetić, H Jasak) | MODELING SUPERQUADRIC PARTICLES IN CFD-DEM USING A HYBRID FICTITIOUS DOMAIN - IMMERSED BOUNDARY METHOD (A Podlozhnyuk, F Municchi, C Goniva) | A FULLY IMPLICIT DISCRETIZATION OF THE DIFFUSION OPERATOR IN OPENFOAM (M Darwish, F Moukalled, L Mangani) | AN IMPLICIT SECOND-ORDER REGION COUPLING METHOD FOR DISCONTINUOUS VALUES AND TRANSPORT COEFFICIENTS (P Weber, S Silge, H Marschall, D Bothe) | EVALUATING POWER TAKE-OFF CONTROL ALGORITHMS FOR WAVE ENERGY CONVERTERS WITH AN OPENFOAM NUMERICAL WAVE TANK (J Davidson) |
| 15:50 - 16:10 | CFD ANALYSIS OF NON-NEWTONIAN FLUID PROCESSING PUMP (N Casari, N Aldi, M Pinelli, C Buratto, A Suman) | DRAG MODEL FOR COUPLED CFD-DEM SIMULATIONS OF NON-SPHERICAL PARTICLES (R Lohse, U Palzer) | HEAT TRANSFER ANALYSIS OF SLUG FLOW IN MICROCHANNELS WITH INTERFACE CAPTURING METHOD (K Matsuda, K Endoh) | TWO-WAY COUPLED EULER-EULER SIMULATION OF DRIFTING SNOW (Z Boutanios, H Jasak) | VALIDATION OF SEAKEEPING CFD SIMULATIONS IN HEAD AND OBLIQUE WAVES USING THE NAVAL HYDRO PACK (I Gatin, V Vukčević, H Jasak) |
| 16:10 - 16:30 | ENHANCED TURBOMACHINERY CAPABILITIES FOR OPENFOAM: DEVELOPMENT AND VALIDATION (ID Dominicis) | SIMULATION OF MOVING-BED AND FLUIDIZED-BED REACTORS BY DPM AND MPPIC IN OPENFOAM (K Jang, W Han, K Huh) | IMPLEMENTATION AND VALIDATION OF CONJUGATE HEAT TRANSFER AND SURFACE RADIATIVE HEAT TRANSFER USING P1 THERMAL RADIATION MODEL (C Cintolesi, H Nilsson, A Petronio, V Armenio) | DIRECT NUMERICAL SIMULATION OF FLUID INTERFACES INFLUENCED BY SOLUBLE SURFACTANT (C Pesci, P Weber, H Marschall, D Bothe) | CFD ANALYSIS AND OPTIMISATION OF TIDAL TURBINE ARRAYS USING OPENFOAM (G Tabor) |

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| 16:30 - 17:00 | **Coffee-Break** |

| | Phase Change | Automotive/Solid Mechanics | Heat and Mass Transfer II | Multiphase Flows II | |
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| | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* | *(Room TBA)* |
| 17:00 - 17:20 | EXTENSIBLE VOLUME-OF-FLUID SOLVER FOR PHASE-CHANGE HEAT TRANSFER (A Rattner, M Nabil) | A HYBRID SEMI IMPLICIT SOLVER USING REAL-GAS THERMODYNAMICS APPLICABLE TO A WIDE RANGE OF MACH NUMBERS (M Banholzer, M Pfitzner) | A NEW REGION-COUPLED FRAMEWORK FOR CONJUGATE HEAT TRANSFER (O Oxtoby, E Villiers, S Georgescu) | SIMULATION OF LIQUID METAL BATTERIES (N Weber, P Beckstein, V Galindo, W Herreman, S Landgraf, C Nore) | Naval Hydro Pack Demonstration Session 16:30 - 18:30 |
| 17:20 - 17:40 | SIMULATION OF PARTICLE FOULING AND ITS INFLUENCE ON FRICTION LOSS AND HEAT TRANSFER ON STRUCTURED SURFACES USING PHASE CHANGING MECHANISM (R Kasper, J Turnow, N Kornev) | MICRO-SCALE AND FULL-SCALE CFD SIMULATION OF AFTER-TREATMENT DEVICES FOR INTERNAL COMBUSTION ENGINES (G Montenegro, A Torre, A Onorati) | CFD CHARACTERISATION OF PRESSURE DROP AND HEAT TRANSFER INSIDE GYROID LATTICE STRUCTURES (E Meyers, D Bacheva, G Tabor, R Kahraman) | AROUND-CASTING SIMULATION WITH OPENFOAM®: VERIFICATION AND APPLICATION OF MODELS (A Vakhrushev, M Wu, A Ludwig, Y Tang, G Nitzl, G Hackl) | |
| 17:40 - 18:00 | VERIFICATION OF SOLIDIFICATIONMELTINGSOURCE FVOPTIONS FOR THE ISOTHERMAL SOLIDIFICATION (M Torabi Rad) | PERFORMANCE OF LAGRANGIAN FINITE VOLUME APPROACHES FOR LINEAR AND NONLINEAR SOLID MECHANICS ANALYSES (P Cardiff) | A FLAMELET GENERATED MANIFOLD MODEL FOR PARTIALLY PREMIXED LAMINAR FLAMES (A Cubero, C Montañés, N Fueyo) | DEVELOPMENT OF A SUB-GRID MODEL FOR SELF-AERATION (P Lopes, J Leandro, RF Carvalho, G Tabor) | |
| 18:00 - 18:20 | | SIMULATION OF THE PLASTIC DEFORMATION OF CONTACT PADS DURING MICROELECTRONIC TESTING (D Dickinson, M Schnaithmann) | NUMERICAL SIMULATION OF FLAME ACCELERATION AND TRANSITION FROM DEFLAGRATION TO DETONATION USING OPENFOAM (R Khodadadiazadboni, J Wen, A Heidari, S | APPLICATION OF HYBRID KT/PISO SCHEME FOR DIFFERENT COMPRESSIBLE FLOWS (M Kraposhin, S Strizhak) | |

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| 19:30 - 23:00 | **Banquet** |

# Symposium 9: Naval Hydrodynamics / Coastal / Offshore

# NUMERICAL SIMULATION OF A SINGLE FLOATING POINT ABSORBER WAVE ENERGY CONVERTER USING OPENFOAM®

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***Keywords:*** *OpenFOAM/IHFOAM, two-phase flow, floating body, wave-structure interaction*

## 1. INTRODUCTION

Wave energy from ocean waves is captured by Wave Energy Converters (WECs) and converted into electrical power. In this study, WECs of the floating point absorber (FPA) type are selected. Their geometry is represented by a cylindrical buoy with a spherical end. The focus of this study is limited to a free decay test of a single WEC.

## 2. NUMERICAL MODELLING

CFD-modelling is performed to study the behaviour of a single WEC in a wave field using OpenFOAM. Simulations of the two-phase flow field are performed by solving the incompressible RANS-equations. Wave generation and absorption at the boundaries of the numerical wave tank are implemented in the IHFOAM toolbox. The CFD-fluid solver is coupled to a motion solver in order to simulate rigid body motions. Only the governing motion of the WEC's behaviour is considered, the heave motion.

Important parameters of the WEC, such as the damping ratio $\zeta_d$, natural angular frequency $\omega_n$ and damped angular frequency $\omega_d$, are obtained from a free decay test. During such a free decay test, the body is placed out of equilibrium with an initial displacement. A damped oscillatory motion is started after releasing the WEC until all the forces acting on that WEC are in equilibrium. In order to validate the numerical model, experiments in a wave flume were conducted to measure the WEC's heave motion. Therefore, a steel shaft was installed through a vertical shaft bearing over the whole height of the WEC (see Figure 1a). Because of the complexity of meshing the shaft bearing inside the WEC, another methodology is formulated to obtain a grid around the WEC without that vertical shaft (see Figure 1b).

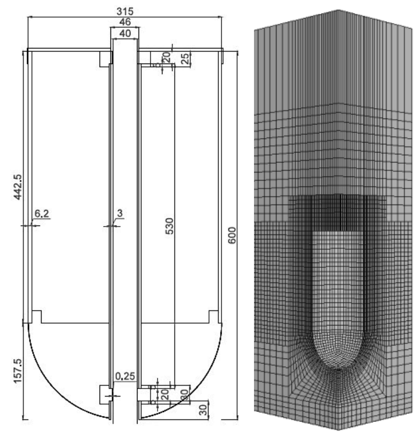


**Figure 1. (a) Cross-section of the physical WEC [1]. (b) 3D grid around the WEC.**

Firstly, the shaft inside the physical WEC reduces the water-plane area $A_w$ and changes the natural frequency $\omega_n$. Moreover, the natural frequency is dependent on the mass $m$ and added mass $m_a$. Therefore a WEC without shaft but with a modified mass $m_{num}$ is implemented in OpenFOAM. This is done to obtain the same natural frequency as the physical WEC, assuming that the damping ratio $\zeta_d$ and added mass $m_a$ are identical in both experimental and numerical models, see eq. (1). The modified-mass method can be derived starting from the expression in eq. (1). Subsequently, the damped frequency $\omega_d$ in both numerical and experimental models are rewritten by using eq. (2) and (3). Finally, this procedure returns eq. (4) which calculates the modified mass $m_{num}$ needed in the numerical model to satisfy eq. (1).

$$\omega_{d,num} = \omega_{d,\exp} \tag{1}$$

$$\omega_d = \omega_n \cdot \sqrt{1-\zeta_d^2} \tag{2}$$

$$\omega_n = \sqrt{\frac{\rho g A_w}{m + m_a}} \tag{3}$$

$$m_{num} = m_{\exp}\left[\left(1+\frac{m_a}{m_{\exp}}\right)\frac{A_{w,num}}{A_{w,\exp}} - \frac{m_a}{m_{\exp}}\right] \tag{4}$$

Secondly, there is a motion of a viscous fluid, water, in the underwater space between the steel shaft and the shaft bearing. This flow can be simplified as a Couette flow between two parallel plates of which one is moving relative to the other. This Couette flow is responsible for a viscous force acting parallel to the motion of the moving plate (shaft bearing inside the WEC). This force is dependent on the viscosity of water, the space between the plates and the velocity. However, a simplified model is assumed by only including the velocity $v$ explicitly using a linear damper ($F = -c \cdot v$) in which c is the damping coefficient. As expressed in eq. (5), the WEC's damping ratio $\zeta_d$ is equal to the ratio of the damping coefficient $b_d$ and the critical damping coefficient $b_c$. The target damping coefficient $b_{d,target}$ is calculated by eq. (5) using the experimental damping ratio and the WEC's modified mass. Subsequently, the numerical damping coefficient $b_{d,num}$ is determined following the same eq. (5) but now using the numerical damping ratio. This numerical damping ratio is obtained from a CFD simulation without linear damper, so the Couette flow is neglected. Thereafter, the difference between both damping coefficients is used as the damping coefficient $c$ of the linear damper inside the motion solver to account for the Couette flow, see eq. (6).

$$\zeta_d = \frac{b_d}{b_c} = \frac{b_d}{2 \cdot \omega_n \cdot (m + m_a)} \tag{5}$$

$$c = \Delta b_d = b_{d,target} - b_{d,num} \tag{6}$$

## 3. RESULTS

The numerical model described in the previous paragraph is used to simulate a free decay test using the structured grid shown in Figure 1b consisting of solely hexahedral cells. Only the lowest and highest row of cells are distorted to prevent undesirable mesh deformation around the air-water-interface. Figure 2 presents the WEC's heave motion with respect to its equilibrium position. The continuous blue line represents the numerical result while the dashed red line shows the experimental data from the wave flume. The dashed-dotted black line depicts the analytical envelope [1]. In general, the figure proves that this numerical result is extremely close to the experimental decaying motion. After 13 s, some small discrepancies in the phase of the signal are observed between CFD and the experiment due to the different absorption methodology between IHFOAM and the physical wave flume. Moreover, the motion of the WEC generates radiated waves, which are shown at five locations (Figure 3a) for both numerical and experimental results in Figure 3b. Although these small-amplitude waves (< 1 cm), both results are very similar in the first 10 seconds of the signals. Thereafter, some deviations between both results are observed. Numerical results obtained from simulations using a smaller time step or a denser grid are converging towards a time- and grid-independent solution. All these observations show that OpenFOAM/IHFOAM is a robust and suitable toolbox to research wave-structure interaction.

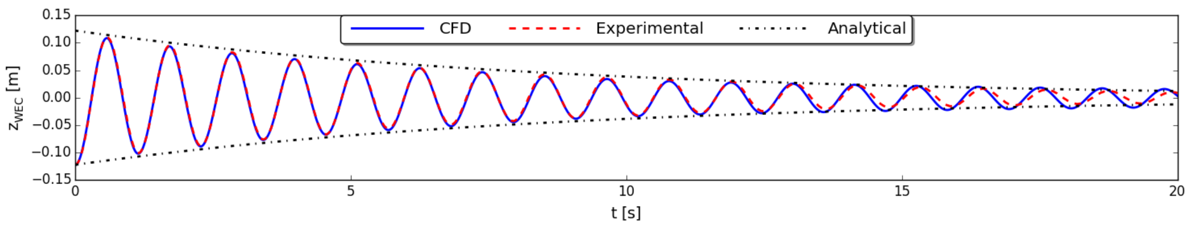


**Figure 2: The WEC's vertical position during a free decay obtained with CFD (continuous blue line, $\Delta t$ = 0.001 s, $\Delta z$ = 0.02 m) compared to the experimental decaying motion (dashed red line) and the analytical envelope (dashed-dotted black line).**

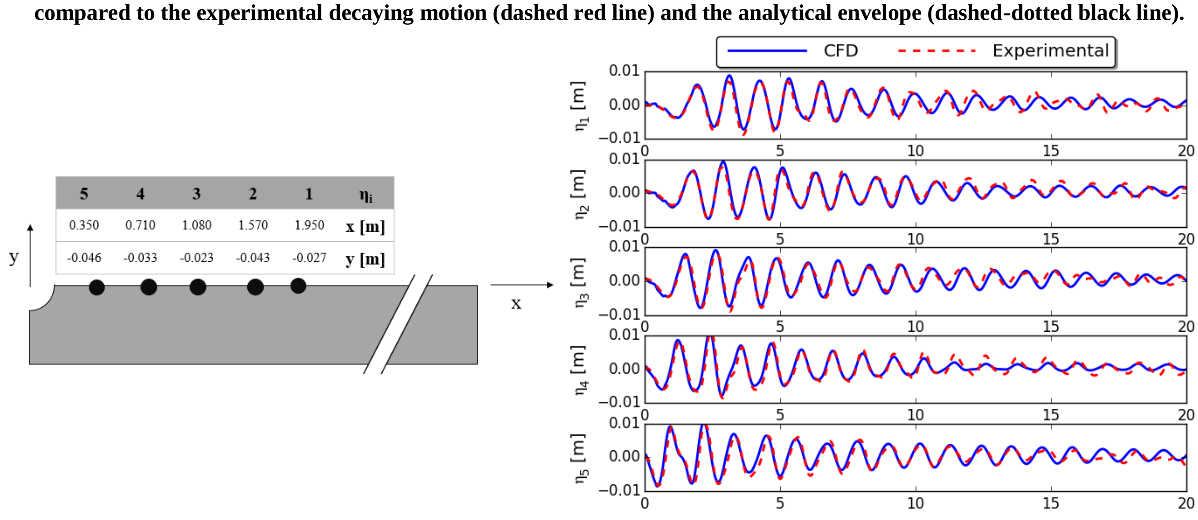


**Figure 3: (a) Plan view of the five wave gauges inside the numerical wave flume. The WEC's centre (x = 0 m ; y = 0 m) is located at the upper left corner while the absorbing wave boundary condition is located at the right side of the domain (x = 4.95 m). (b) The radiated wave field represented by the surface elevation $\eta_i$ in function of time t ($\Delta t$ = 0.001 s, $\Delta z$ = 0.02 m).**

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**References**

[1] V. Stratigaki, "Experimental study and numerical modelling of intra-array interactions and extra-array effects of wave energy converter arrays," Ph.D. dissertation, Dept. Civ. Eng., Ghent Univ., Ghent, Belgium, 2014.