
# Industrial use of DualSPHysics: past, present and future

George Fourtakas

Department of Fluids and Environment,

The University of Manchester, Manchester, UK

# Overview

- Historical background of the solver
- The DualSPHysics project and group
- Numerical framework
- Academic development and target applications
- Industrial R&D use
- Future research
- Summary

# Historical background of the solver

- An initiative after the realisation:

  - SPH had enormous potential in wave mechanics

    (*why, will become apparent in a minute*)

  - Research groups kept developing in-house solvers with very short timespan

    (*some of those inhouse codes are now well developed, see GPUSPH and Simcenter SPH solver (Siemens*)

  - Formulations varied widely between implementations

    (*Sometimes literature reported different results for the same formulation*)

# Historical background of the solver

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- The solver has an open-source philosophy released in 2007 and named

SPHysics

- A two-part journal publication accompanied the solver
  - Gómez-Gesteira, M., et al. "SPHysics–development of a free-surface fluid solver–Part 1: Theory and formulations." Computers & Geosciences 48 (2012): 289-299.
  - Gómez-Gesteira, M., et al. "SPHysics–development of a free-surface fluid solver–Part 2: Efficiency and test cases." Computers & Geosciences 48 (2012): 300-307.

- It was decided that only well validated and peer reviewed developments will be included in the solver – reproducibility was, and is, paramount

# Historical background of the solver

SPHysics

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first gen

- Core developers:

Prof. Robert A. Dalrymple
Prof. Moncho Gómez-Gesteira
Dr Benedict Rogers
Dr Andrea Panizzo
Dr Alejandro Crespo
Dr Muthukumar Narayanaswamy

- Why wave mechanics? Please check names and usual suspects!

# Historical background of the solver

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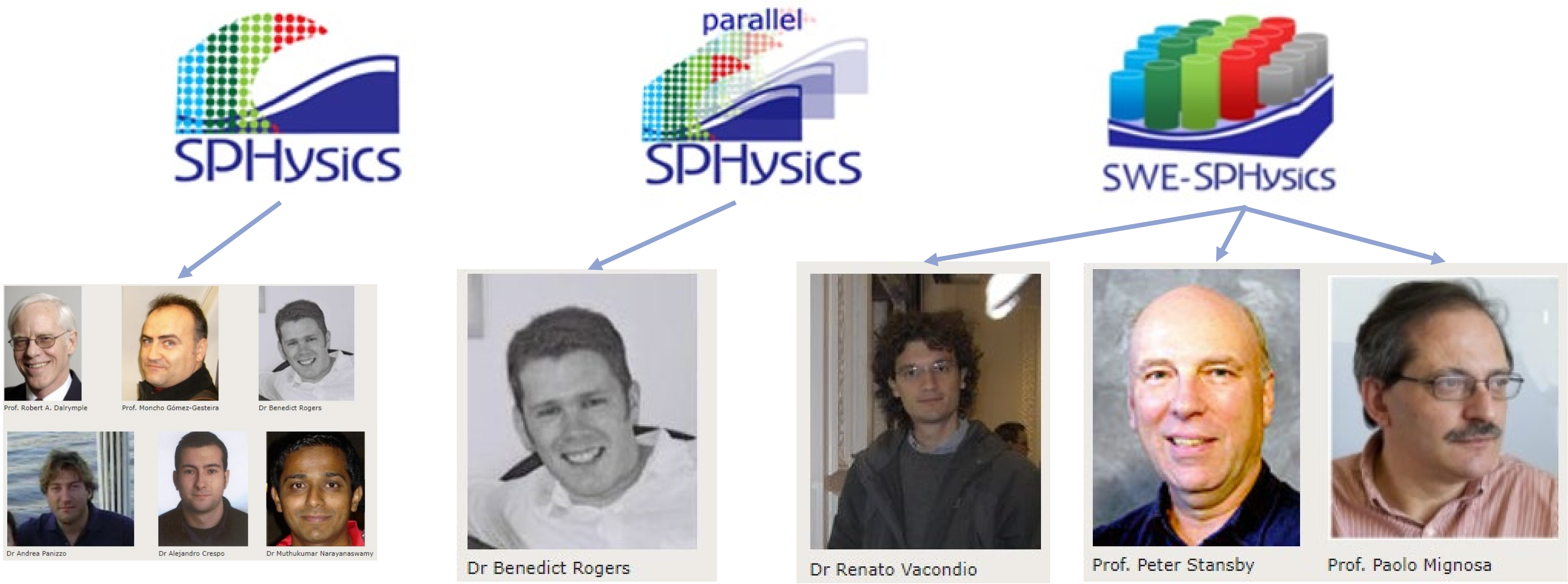
- A number of releases and variants followed:




gen 1 ½

# Historical background of the solver

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- The following question became obvious:
  - What if we can take our discretisation to 5 million particles possibly 6 million?
  - In less than a day (or week) of compute time?
  - GPU acceleration was becoming a possibility around late 2006+
  - DualSPHysics was born:

# Historical background of the solver

- Main developer (*coder*) (CUDA and OpenMP)

  Dr José M. Domínguez - Universidade de Vigo, Spain (PhD project)

Supervisors

- A significant change in direction
  - Language: Fortran to C++
  - First level of parallelisation: OpenMP
  - Second level of parallelisation: NVIDIA CUDA

  - Code released in 2011

# Historical background of the solver

- Second gen (*coders around 2011*)

  Dr Athanasios Mokos

  Dr George Fourtakas

  Dr Anxo Barreiro

  Dr Ricardo Canelas

- Third gen (*coders*)

  Dr Stephen Longshaw

  Dr Angelo Tafuni

  …

  https://dual.sphysics.org/developers/ (<- all listed here)

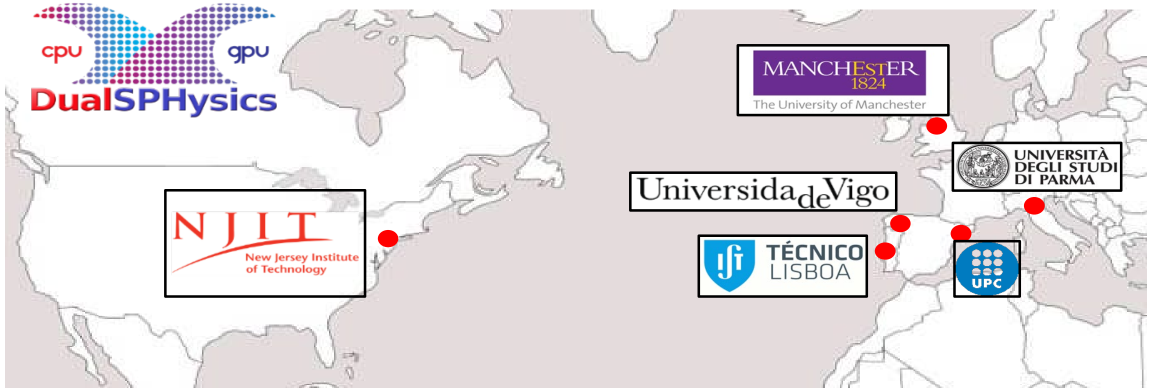





# DualSPHysics consortium

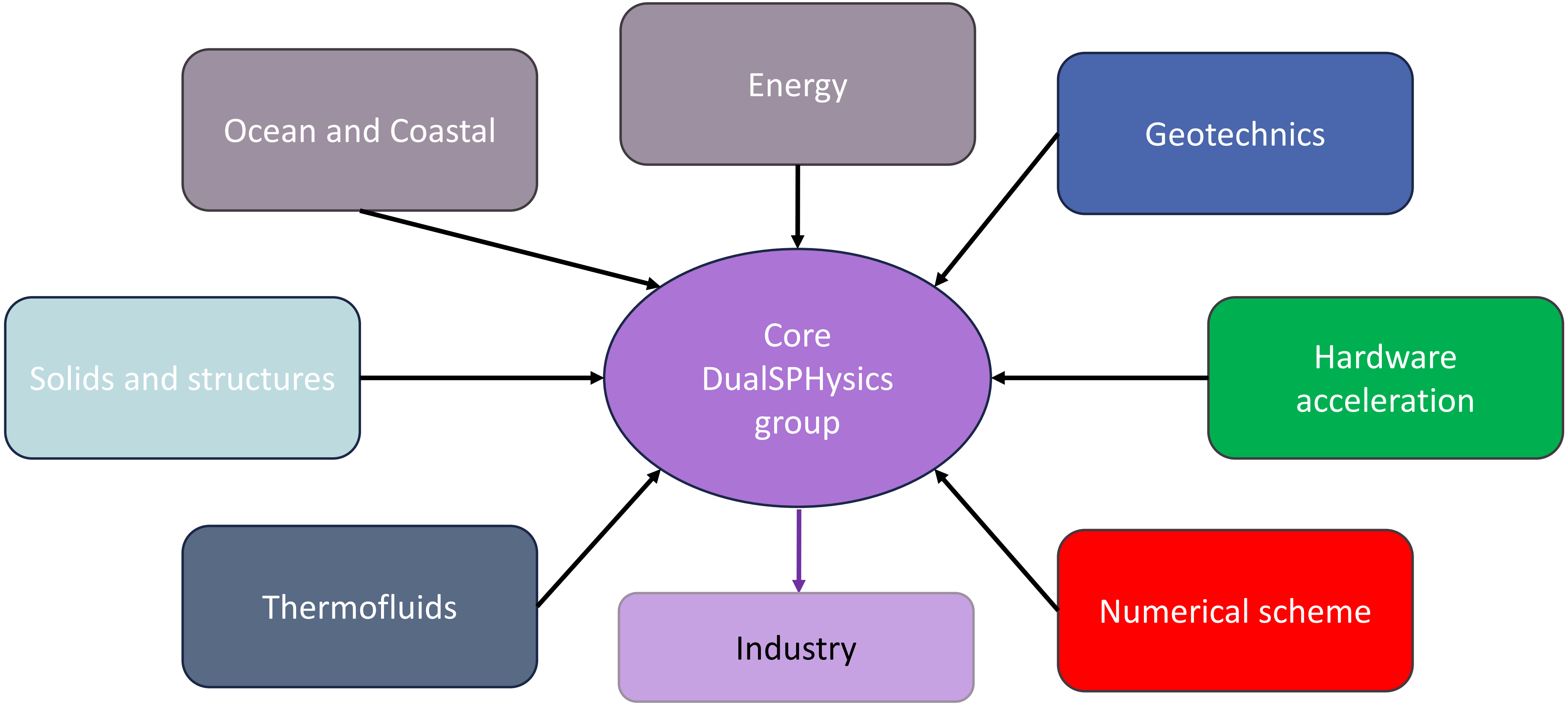
- Academic institutions in Europe and US

  - University of Vigo, Spain
  - University of Manchester, UK
  - University of Parma, Italy
  - University Polytechnic Catalunya, Spain
  - New Jersey institute of Tech., USA




Institutions are currently the Project Leaders

# DualSPHysics consortium



# DualSPHysics consortium

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- Each leading institution has specific expertise that shares with the core group*
  - **University of Vigo**

    Hardware acceleration, coupling, coastal-ocean, renewable energy
  - **University of Manchester**

    Numerics, model development, thermofluids, structures, geotechnics, HPC
  - **University of Parma**

    Numerics, model development, SWE, HPC
  - **UPC**

    Wave mechanics numerical and experimental, coastal-ocean, validation
  - **NJIT**

    Numerics, model development, thermofluids, HPC

*List not extensive and just an example

# Numerical and computational framework

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## Numerical formulation

- Weakly compressible SPH, fully explicit

**Conservation of Mass**

$$\left\langle\frac{d\rho}{dt}\right\rangle = \rho_i \sum_j \frac{m_j}{\rho_j} m_j(\mathbf{u}_i - \mathbf{u}_j) \cdot \nabla_i W_{ij} + hc_0\mathcal{D}_a$$

**Conservation of Momentum**

$$\left\langle\frac{d\mathbf{u}}{dt}\right\rangle = -\sum_j m_j \left(\frac{P_i+P_j}{\rho_i\rho_j}\right) \nabla_i W_{ij} + \left\langle\frac{1}{\rho}\nabla\cdot\tau\right\rangle + hc_0\mathcal{U}_a$$

$$\frac{d m_i}{dt} = 0 \qquad p = f(\rho, \gamma, c_0)$$

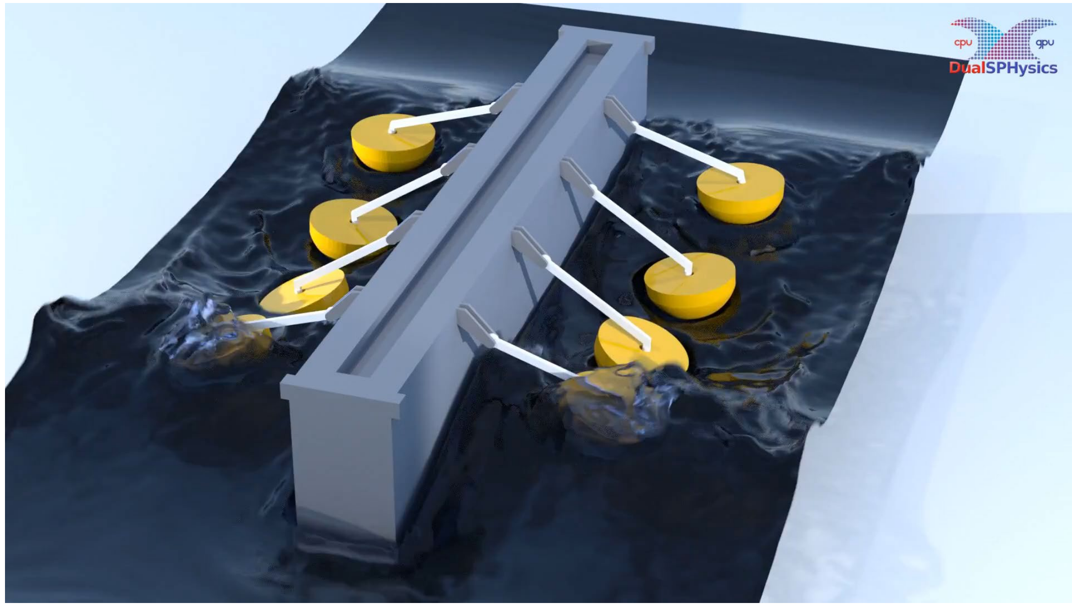
Using a $c_0$ of: $c_0 = 10u_{max} = 10\sqrt{gh}$

Plus numerical models: see https://github.com/DualSPHysics/DualSPHysics/wiki

# Numerical and computational framework

Main physical models:

- Single and multiphase solvers
- FSI with flexible structures
- DEM solver incorporated
- Three rigid interaction algorithms
- Advanced wave mechanics
- Coupling with external libraries
    - Chrono project, MoorDyn, SWASH, etc.




Canelas et al., (2018)

# Development and applications

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## Development is driven by Research funding

- Base code and single-phase solver
  - Programa de Consolidación e Estructuración de Unidades de Investigación Competitivas, Spain
  - European Regional Development Fund & Ministerio de Economía y Competitividad, Spain
  - EPSRC & Research Councils, UK
- Multiphase (gas-liquid)
  - EPSRC & Research Councils, UK
- Coupling with Chrono project
  - EU and Portuguese Foundation for Science (FCT), Portugal
  - Water JPI, Portugal
  - European Regional Development Fund & Ministerio de Economía y Competitividad, Spain

# Development and applications

The University of Manchester

## Development is driven by Research funding

- Coupling with MoorDyn library
  - Programa de Consolidación e Estructuración de Unidades de Investigación Competitivas, Spain
  - European Regional Development Fund & Ministerio de Economía y Competitividad, Spain
  - European MaRINET2 EsfLOWC project (EU H2020)
- DEM solver
  - Portuguese Foundation for Science and Technology (FCT), Portugal
  - Programa de Consolidación e Estructuración de Unidades de Investigación Competitivas, Spain
  - European Regional Development Fund
- Turbulence (LES) and variable resolution
  - National Science Foundation, USA

# Development and applications

Development is driven by Research funding

- Surface tension and thermal effects
  - Joint CSC & University of Manchester scholarship, UK & China
- Geotechnics
  - CSC scholarship, China
- Diffusion terms
  - EPSRC, UK
  - Ministry of Education, Universities and Research, Italy
  - Programa de Consolidación e Estructuración de Unidades de Investigación Competitivas, Spain
  - European Regional Development Fund & Ministerio de Economía y Competitividad, Spain
- Wave mechanics
  - Marie Curie (Eu) & Ramón y Cajal (Spain)

# Development and applications

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## Industry is involved when solver is established

- Non-Newtonian multiphase solver
  - Industrial CASE – EPSRC & **National Nuclear Laboratory**, UK
- Thermal Flows and mixing
  - Industrial CASE – EPSRC & **National Nuclear Laboratory**, UK
- mDBC
  - **Unilever** and EPSRC, University of Manchester, UK
  - Ministry of Education, Universities and Research, Italy
  - Programa de Consolidación e Estructuración de Unidades de Investigación Competitivas, Spain
  - European Regional Development Fund & Ministerio de Economía y Competitividad, Spain
- Variable resolution with nested domains
  - **General Motors**, USA

# Development and applications

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## Industry* uptake and use of the solver

- Motorsport companies
  - Fuel tanks
- Automotive
  - Gearbox
  - Jets
- Governmental bodies (consultancy)
  - Coastal protection
- Clean energy
  - Wave energy converters

### Industrial interest:

NASA JSC, BAE Systems, Volkswagen AG, GM, AIRBUS, BAE, EDF, Steyr, Forum NOKIA, NVIDIA, AECOM, HDR Engineering, ABPmer, DLR, CFD-NUMERICS, BMT Group, Oak Ridge National Laboratory, Rainpower Norway, Shell Company, ABB, ARUP, FEMTO Engineering, National Nuclear Laboratory, ALTAIR, Kitware (Paraview), and many others…

- Software industry
  - **Consultancy**

*Company names are "protected"

# Industrial R&D and use

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## DualSPHysics philosophy and interaction with industry

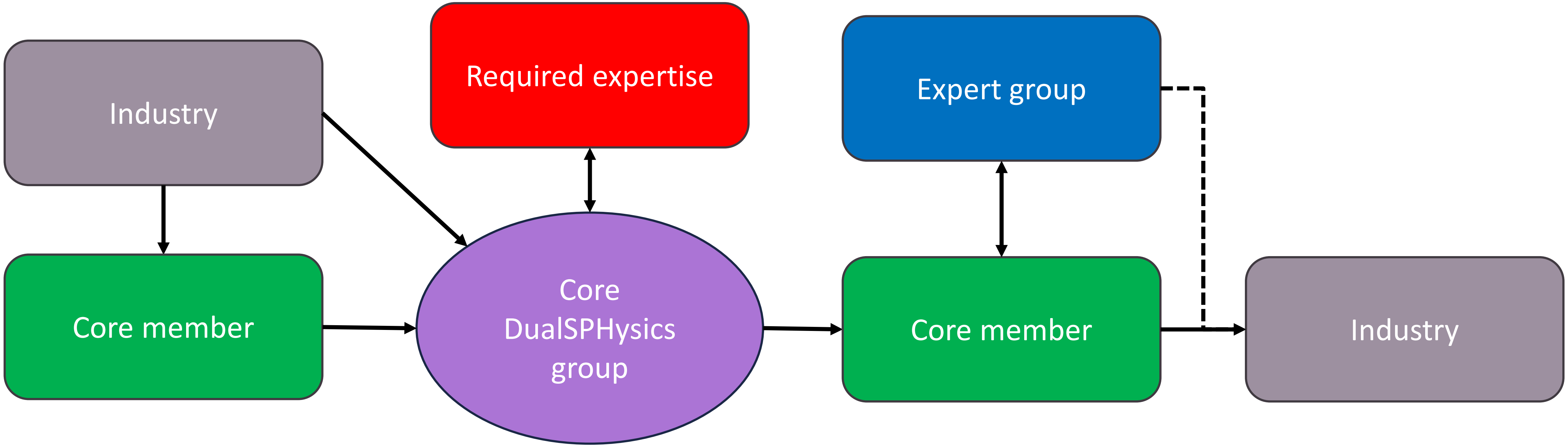
- Academic collaboration
  - Academic & Industrial solver
    - Developments are initially of academic interest
    - Applicable to industrial applications
- Open-source – freely available code
  - Peer-reviewed
  - Validated
  - Reproduceable results
  - LGPL
- Our interest is scientific and not monetary

# Industrial R&D and use

- Avenues for industrial collaboration
  - PhD funding
    - CASE award (part-funded  with contribution form Research councils)
    - Part-funded from industry supplemented by academic institution
    - Part-funded from industry supplemented from competitive scholarships
    - Full funds provided by industry
  - Research associate (Postdoc)
    - Impact accelerator awards
    - SMB governmental awards
    - Research council proposals with industrial support
  - Consultancy

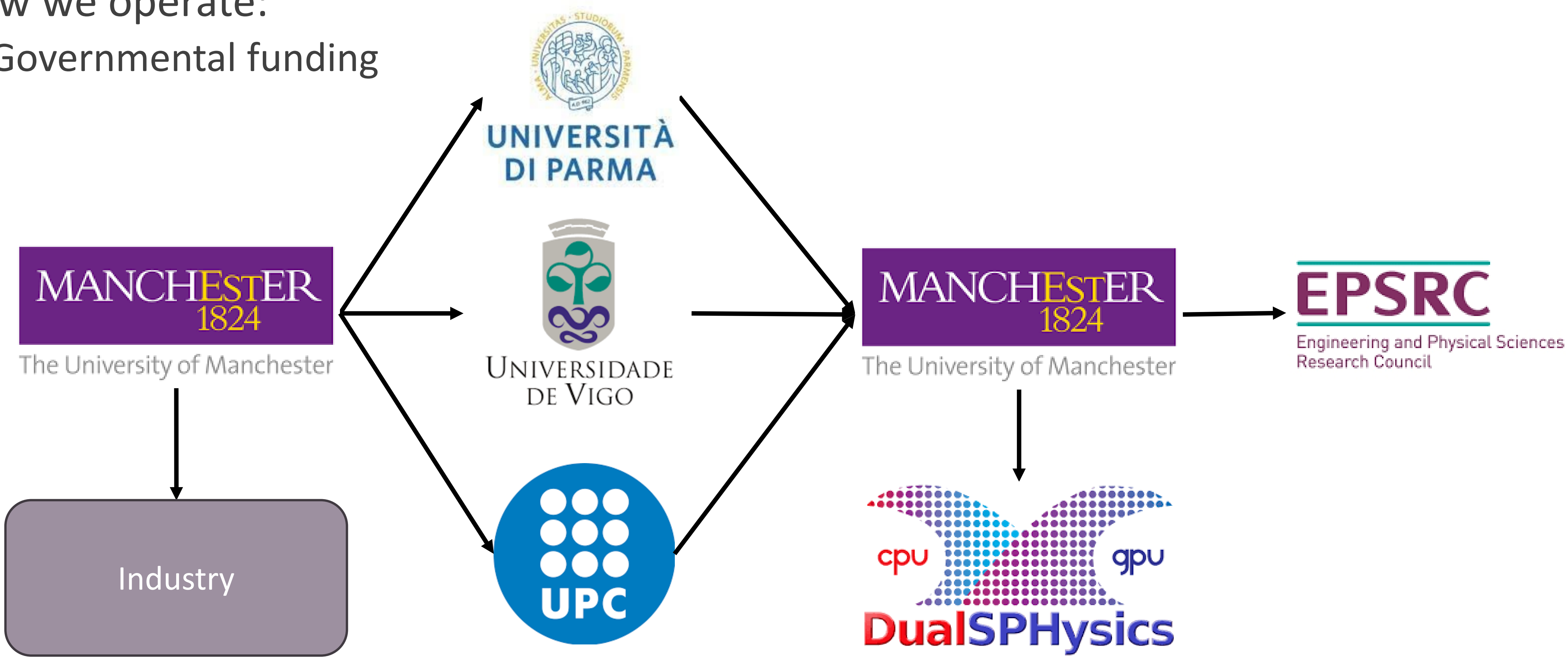
# Industrial R&D and use

- How we operate:



# Industrial R&D and use

- How we operate:
  - Governmental funding



# Industrial R&D and use

- How we operate:
  - Formula 1 team

# Industrial R&D and use

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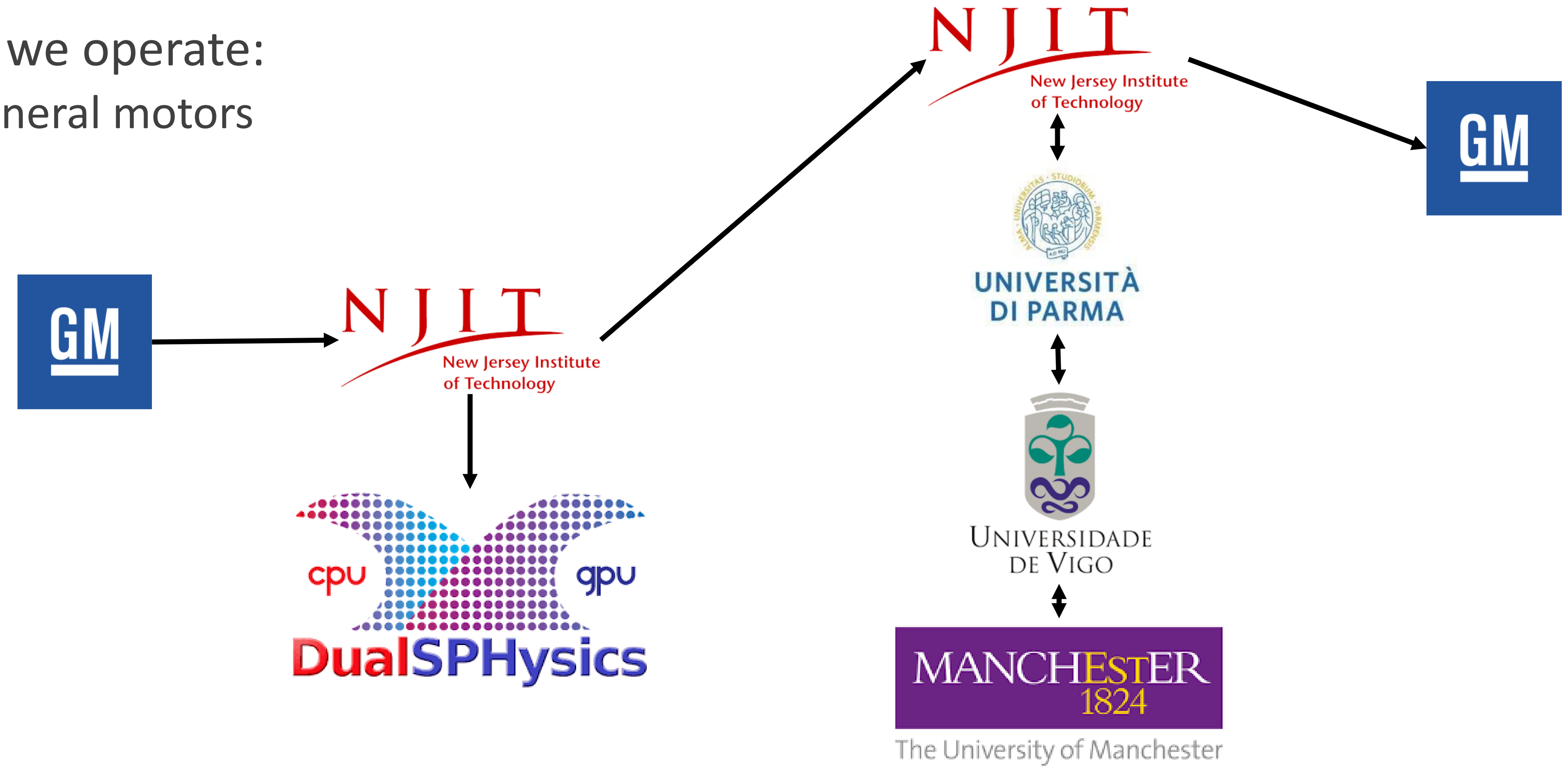
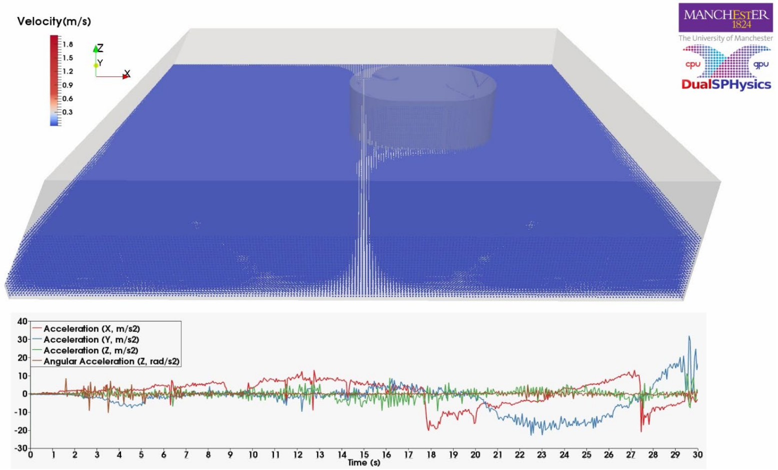
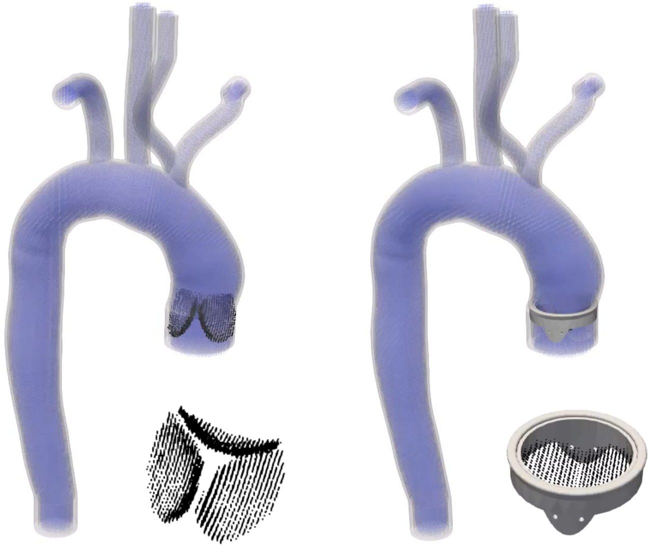
- How we operate:
  - General motors



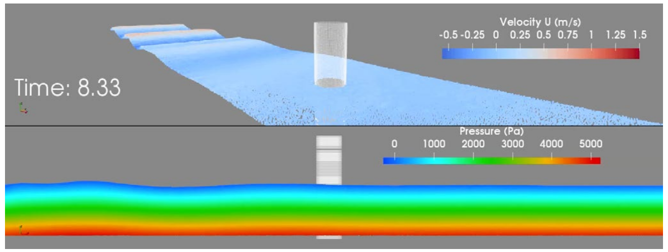
# Industrial use examples

Longshaw & Rogers (2015)

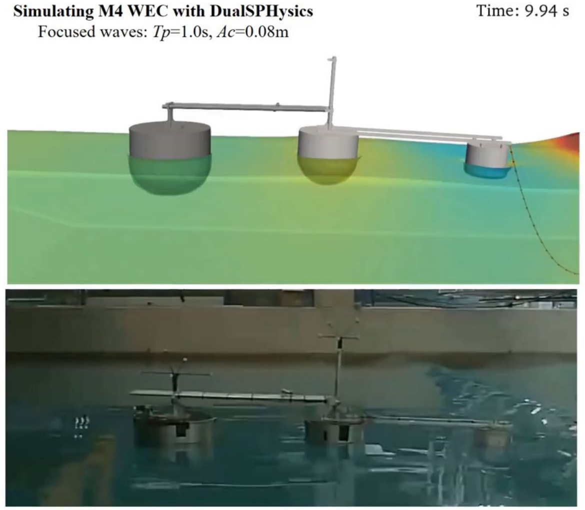


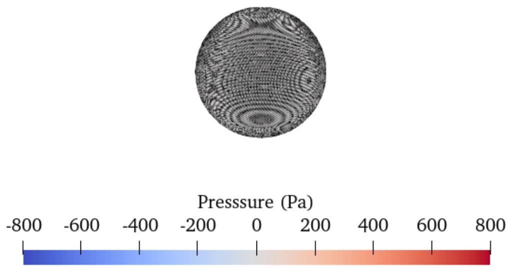
Laha et al., (2024)



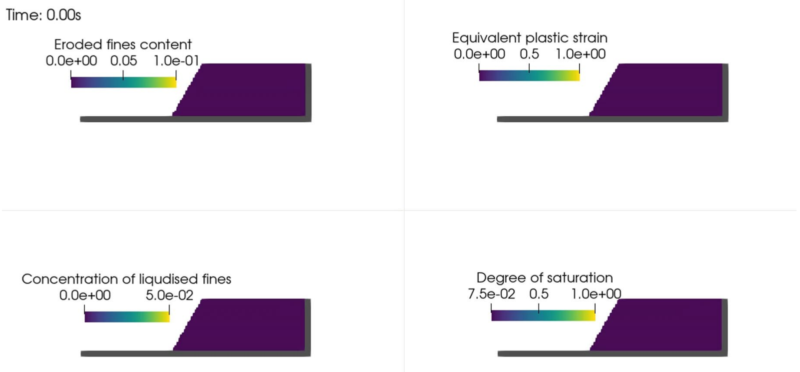

Chow et al., 2019




Carpintero et al., (2020)

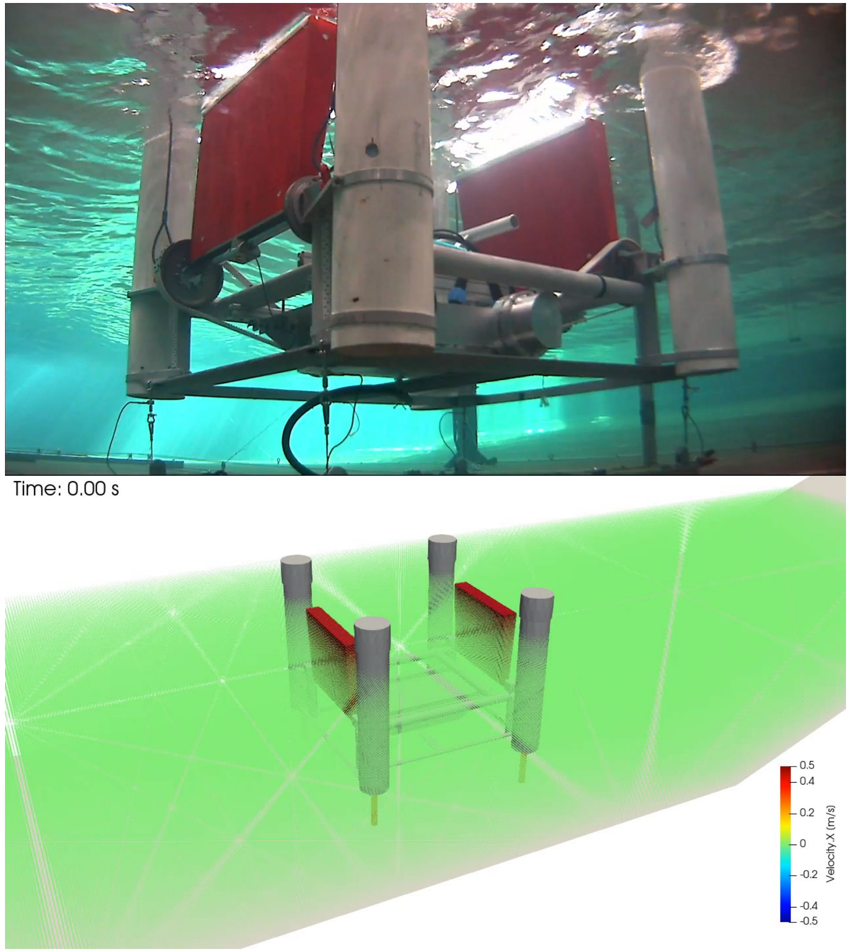



Cen et al., (2023)

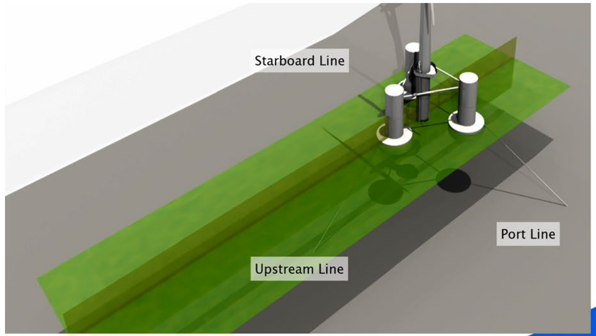



Feng et al., (2023)

# Industrial use examples




Tagliafierro et al., (2020)




**Movie 2:** Fluid vorticity field representation in the x-z and x-y planes.

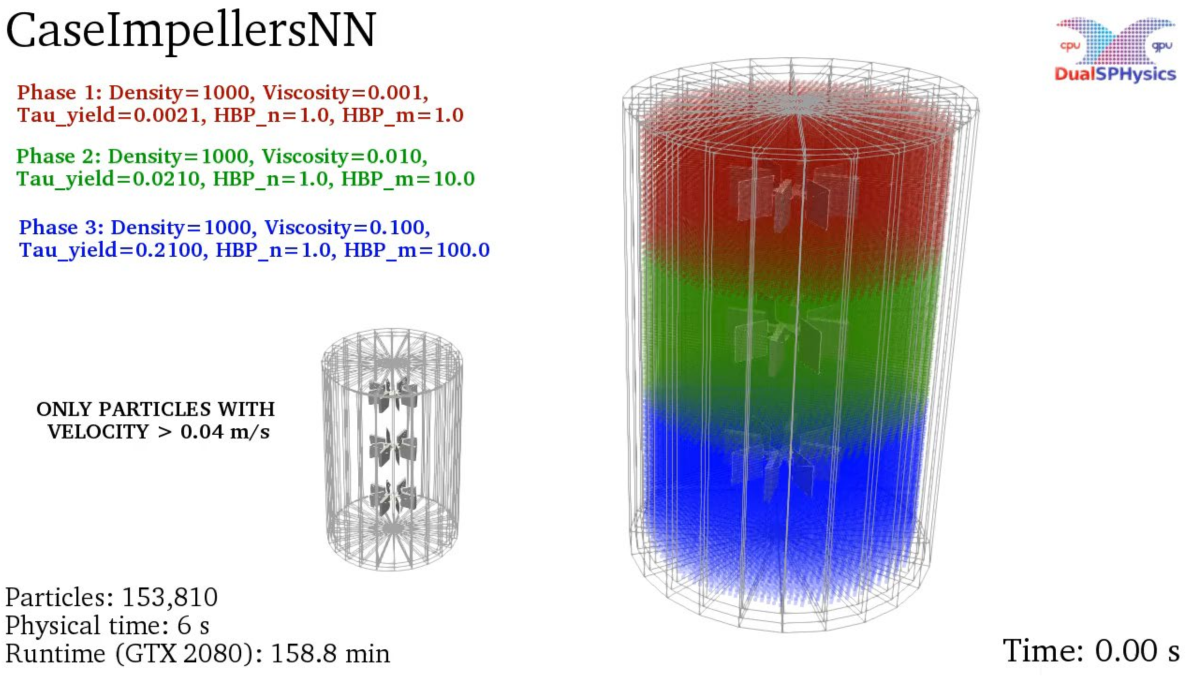

**Movie 1:** DeepCwind platform with a 5-MW wind turbine under a focused wave train. The surface coloring reflects the fluid velocity.

Tagliafierro et al., (2023)

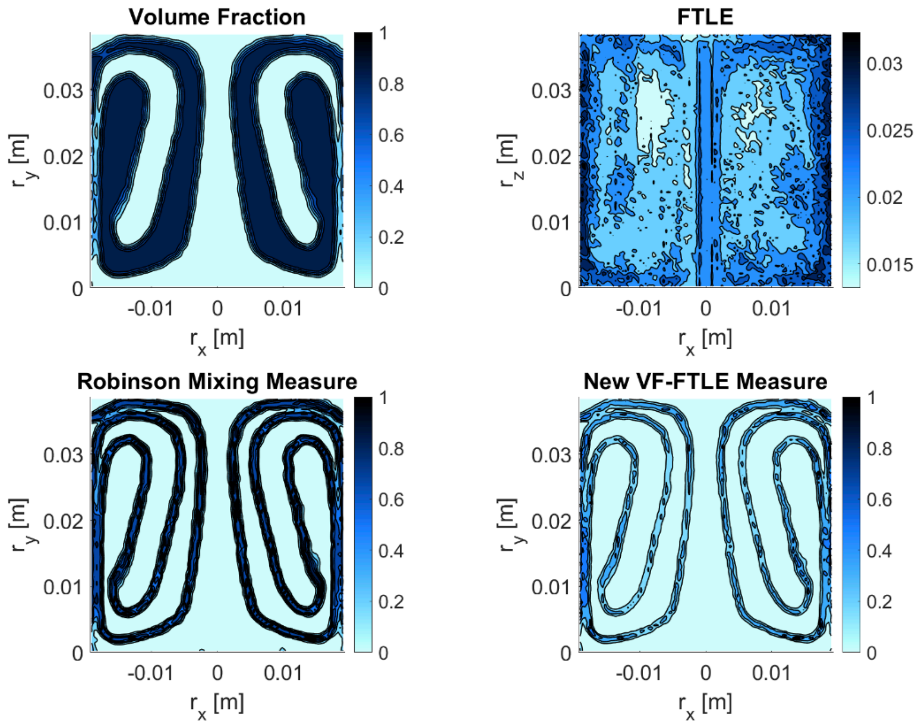
# Industrial developments

- National Nuclear laboratory, UK

Multiphase non-Newtonian solver




Mixture measures, thermal BCs & multi-component mixtures




Mixing measures at 120 s for three-dimensional two-component cylindrical tank.

Reece et al., (2024)

# Future research

Future research in Numerics

- Industry requires

**Accuracy**

A 2$^{nd}$ order scheme is sufficient

**Robustness**

Proprietary solvers provide an answer *which is not always the correct one*

New diffusion terms (see keynote 1)

- Density diffusion
- Divergence cleaning

Advanced discretisation

- Riemann solvers
- ALE (type) schemes
- h-p refinement

# Future research

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Future research in Physics

- Industry requires numerical models

**Model physics sufficiently**

Resolve only what is necessary, model everything else (DNS is very expensive)

**Robustness**

Provide and answer (*See k-ε and k-ω (SST) in StarCCM+ tunned for Aero applications)*

Turbulence

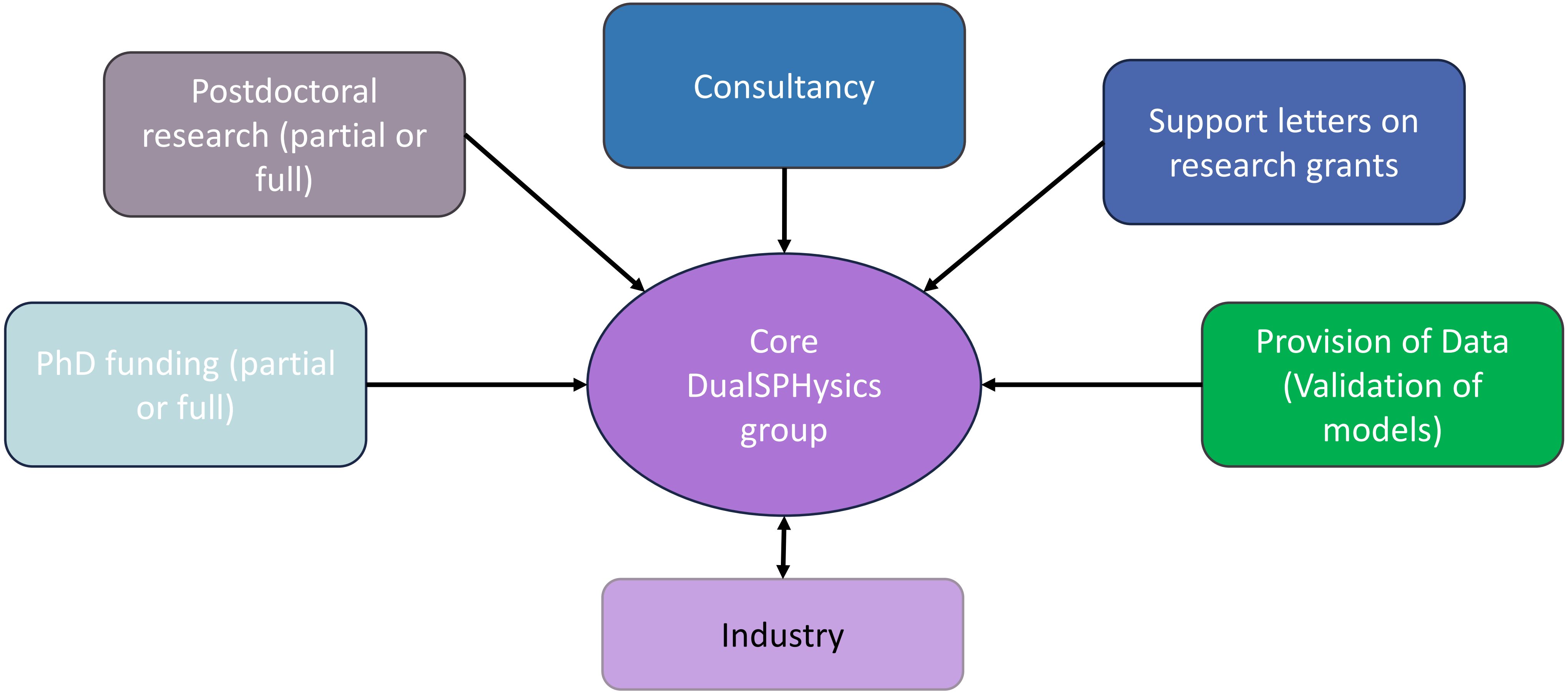
- RANS
- LES
- Lagrangian turbulence

Advanced discretisation

- High density ratio multiphase solvers
- Thermal flows
- Surface tension
- Coupling to other solvers

# Industrial collaboration

- Which options are available to collaborate with DualSPHysics:



# Summary

- The origins of the DualSPHysics solver is deeply ingrained to academia
- Hardware acceleration and advances in SPH allowed the solver to
  - Tackle industrial applications
  - Challenge established methodologies
- Academic and Industrial funding drives the research
- Industry has been fundamental in the development of the solver
- Currently, industry dictates the direction of our research
- There are many paths for industrial involvement

- Speak to us, we need to know!