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Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

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ICSC Innovation and Community Day

11 Novembre 2025

DAMA - Tecnopolo Data Manifattura Emilia-Romagna (Bologna)

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NOZZLE-TEC

Dario Campagna, ESTECO S.p.A.

ICSC Innovation and Community Day

NOZZLE-TEC: spray-NOZZLE TEChnical Characterization

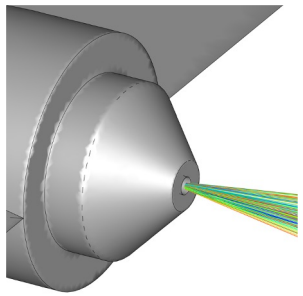
ESTECO S.p.A., CIRA S.c.p.a., Mare Group S.p.A.

PROJECT OBJECTIVE:

The Project aims to characterize the fluid dynamics and structural performance of a nozzle for injecting atomized water into the CIRA Icing Wind Tunnel, validating the developed method with numerical-experimental data available to the consortium.

CHALLENGES:

- ✓ Design of a nozzle optimized both structurally and in terms of fluid dynamics performance through the intensive use of HPC resources
- ✓ Improving methodologies for generating complex computational grids while minimizing human intervention
- ✓ Enhancing the efficiency of the CIRA IWT facility in terms of maintenance and power consumption



FEM Approach and Meshless Validation

Approach and advantages

Development of a **digital twin of the IWT** and **simulation of the nozzle using a meshless approach** (based on the RBF-FD method).

- Reduction of issues related to the traditional computational mesh/grid
- Ease of handling complex 3D geometries
- High-accuracy schemes

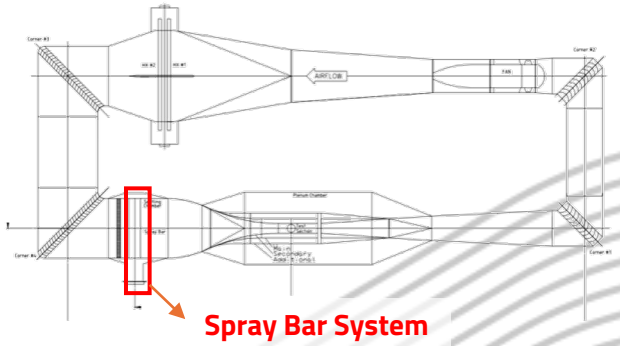
Objectives

- **Accurate simulation** of **two-phase flow** using conventional methods
- **Coupling** of **conventional fluid dynamics** and **structural** solutions through the **VOLTA** software platform
- **Development** and **validation** of the **meshless solver** for two-phase flow simulations
- **Coupling of meshless method with FEM model** for parametric studies to enhance nozzle efficiency and operational lifespan without incurring in geometric deformations

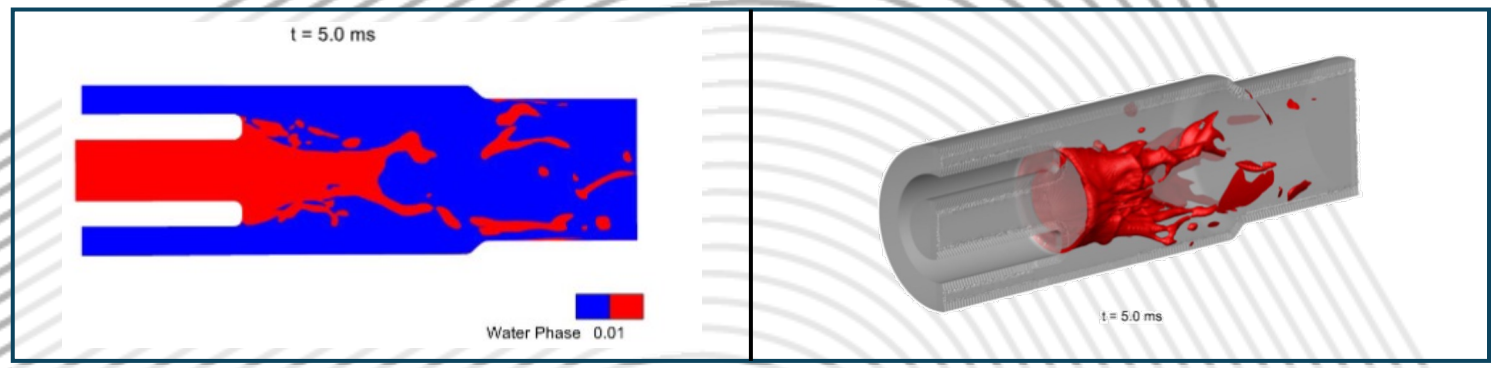
Conventional Fluid Dynamics Analysis

Understanding of the fluid and structure behavior in the CIRA IWT nozzle

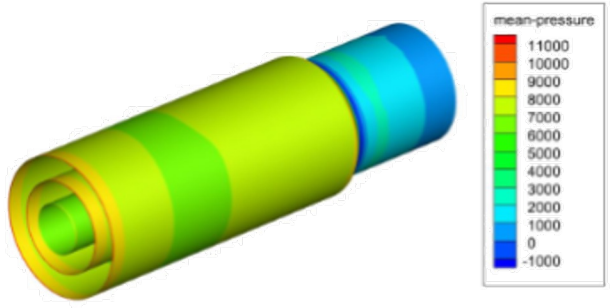
CIRA IWT: Schematic Drawing



- The CFD VOF model was solved to obtain the fluid atomization structures within the nozzle.
- The Pressure load on the nozzle was collected and used as boundary condition input for the structural analyses.



Ligaments and droplets peel off from the main bulk liquid due to the atomization process

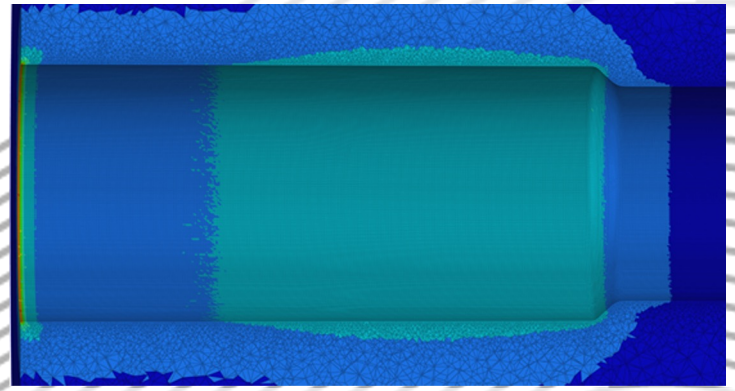


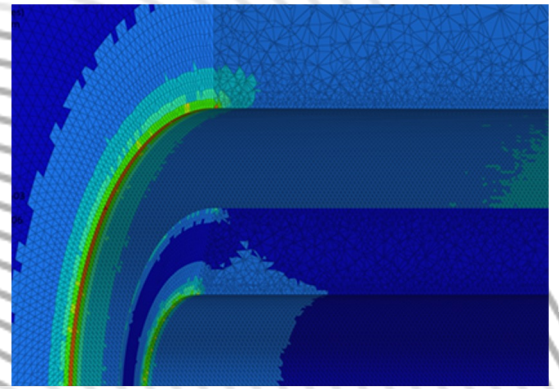
Pressure load on the nozzle boundary

Structural Analysis

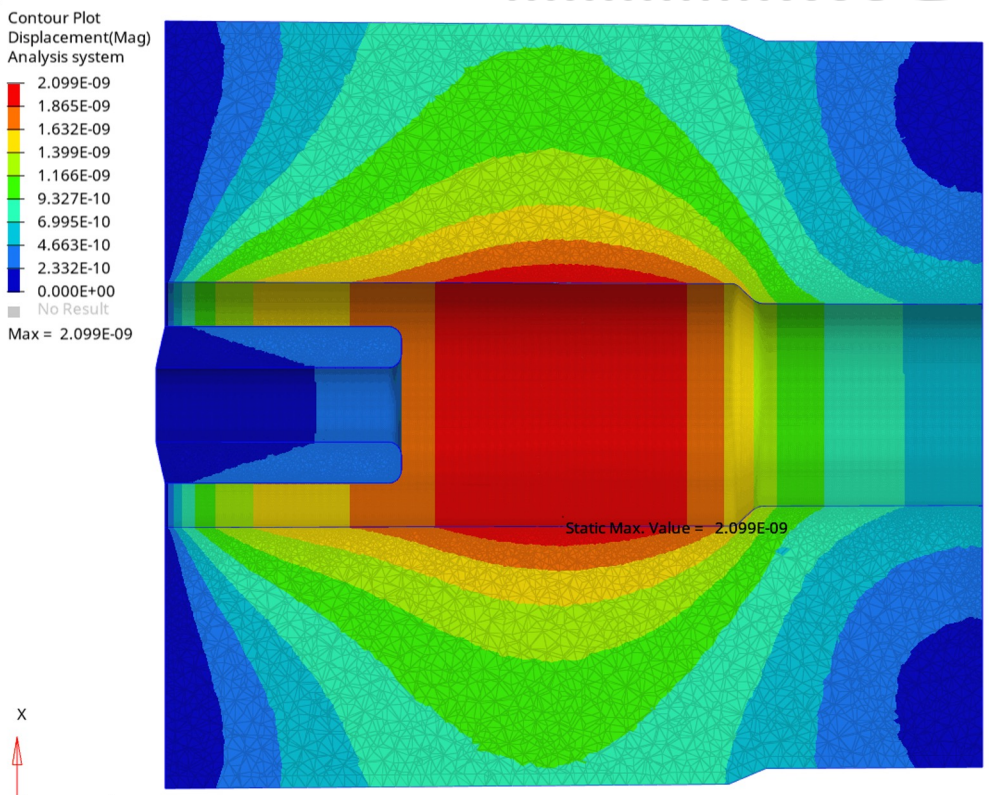
FEM simulation of the pressurized nozzle

- Generation of simplified 2D/3D meshes and import of pressure loads from CFD analyses.
- Mapping and validation of the applied loads within the FEM model.
- Evaluation of stress and deformation fields, identifying critical areas subject to wear.





Von Mises stress contours for the pressurized nozzle

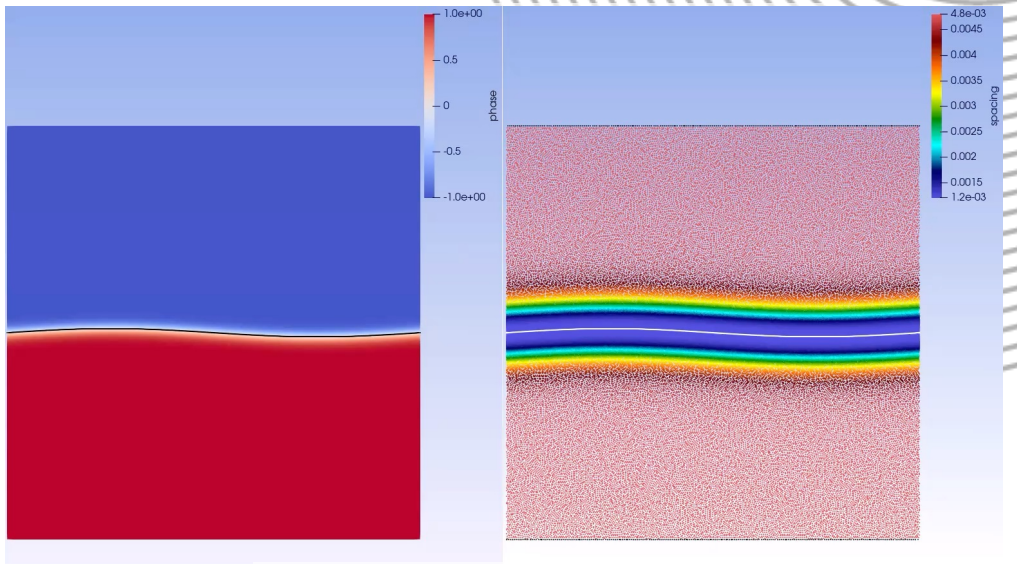


Deformed shape of the nozzle under CFD pressure load, amplified by 2×10^7

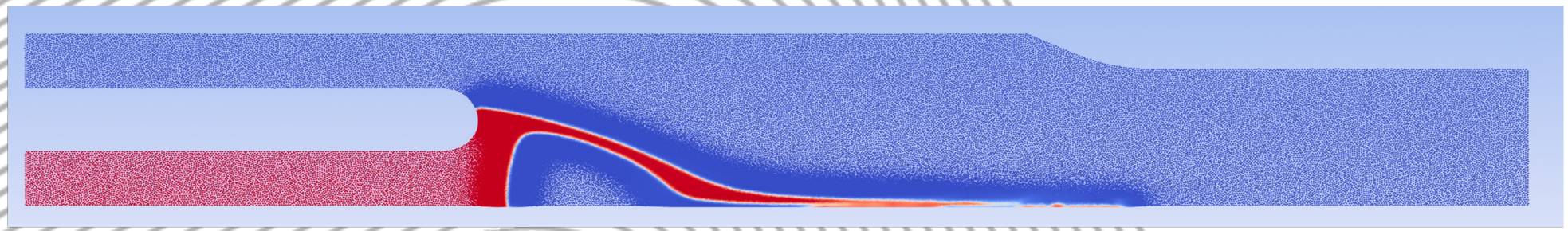
Meshless Solver

Interface capturing

- Ability to capture multiple interfaces
- Example studied: Rayleigh-Taylor and Kelvin-Helmholtz instabilities, rising bubble
- For the nozzle simulation, we are implementing the mixture model to properly account for the secondary phases, which play a crucial role



Kelvin-Helmholtz instability



Adaptive meshless nodalisation for interface capturing along the symmetry plane - nozzle simulation

Wrapping Up and Moving Forward

Final steps

- Finalization of the FSI workflow
- Meshless solver validation and integration
- Parametric studies with VOLTA on HPC resources

Future opportunities

- Evaluation of improvement to increase the efficiency of the IWT facility
- Use of VOLTA for future activities on the IWT facility
- Application of the meshless solver to new problems and advancement of its TRL

Grazie per l'attenzione

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