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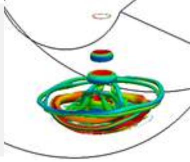

Multi-phase flows
Modelling and Simulation

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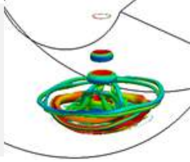


Numerical Tools & Facilities

In-house Computational Codes

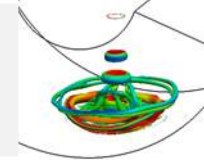
- FV Code *T-FlowS*
  - ✓ Fully unstructured
  - ✓ Incompressible
  - ✓ DNS, LES, URANS, Hybrid LES-RANS
- FE Code *P-Track*
  - ✓ Particle tracking
  - ✓ Particle Cloud tracking
- FD Code *NSF*
  - ✓ Block-structured
  - ✓ Compressible and Incompressible
  - ✓ DNS, LES
  - ✓ Multiphase, 1-, 2-, 4-way coupling

Open Source Codes

- Open-Foam
  - Moving Grids
  - Compressible

Computational Facilities

- Cluster *Iron*
  - ✓ 64 cores
  - ✓ 128 GB Ram
- Cluster *TU Berlin*
  - ✓ 544 cores
  - ✓ 8700 GB Ram
- Access on
  - ✓ ENEA Supercomputing Facilities, Cineca Fermi in Italy
  - ✓ HLRS, HLRN, LRZ, in Germany



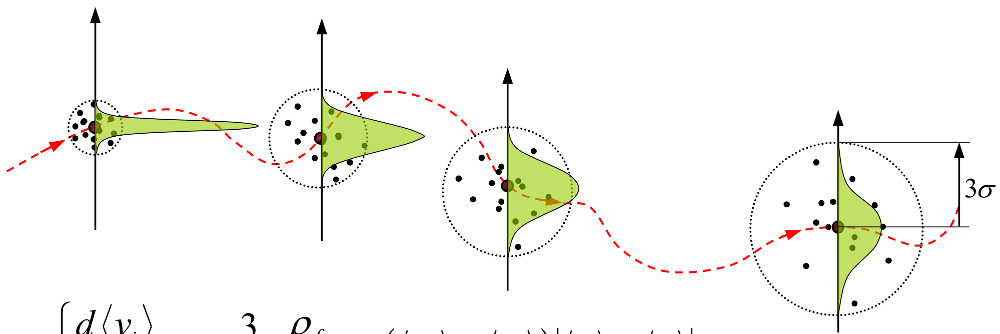
Particle Tracking

- ✓ Single Particle tracking

$$m_p \frac{d\vec{v}}{dt} = \vec{F}_D = -\frac{1}{8}\pi d_p^2 \rho_f C_D \left(\vec{u}-\vec{v}\right)\left|\vec{u}-\vec{v}\right|$$

Hypotesis: spherical, non-rotating, non-reacting

- ✓ Cloud Particle tracking

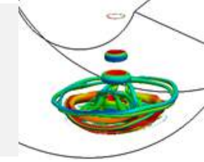


Gaussian distribution of particles within each cloud

$$\begin{cases} \dfrac{d\langle v_i\rangle}{dt} = -\dfrac{3}{4d_p}\dfrac{\rho_f}{\rho_p} C_D \left(\langle u_i\rangle - \langle v_i\rangle\right)\left|\langle\vec{u}\rangle - \langle\vec{v}\rangle\right| \\ \langle x_i(t)\rangle = \int_0^t \langle v_i(t)\rangle dt + \langle x_i(0)\rangle \end{cases}$$

$$C_D = \frac{24}{\mathrm{Re}_p}\left(1+0.15\,\mathrm{Re}_p^{0.687}\right)$$

(Shiller and Naumann, 1933)



Particle Wall Interaction

✓ Deposit Model: Thornton and Ning (1998) now extended to take in account temperature effects

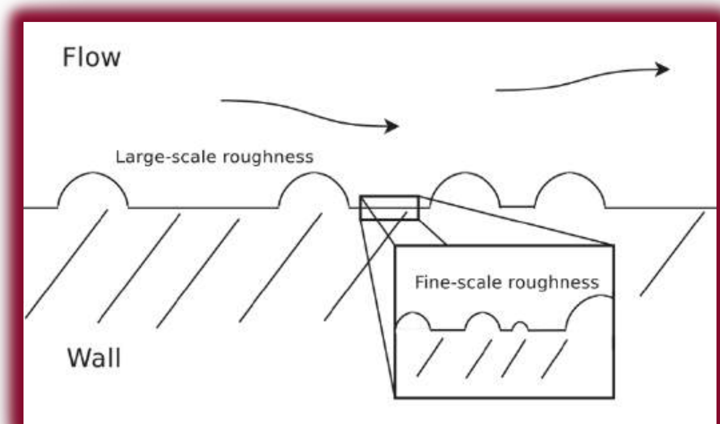
- Baseline: Elastic-plastic adhesion (based on impact mechanics) and Temperature-based adhesion (critical viscosity statistical model)
- Advanced: Elastic-plastic oblique adhesion and Temperature-based elastic-plastic adhesion

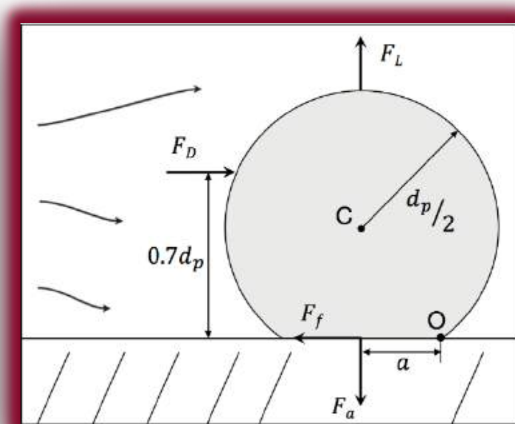
✓ Erosion model: Tabakoff (1979)

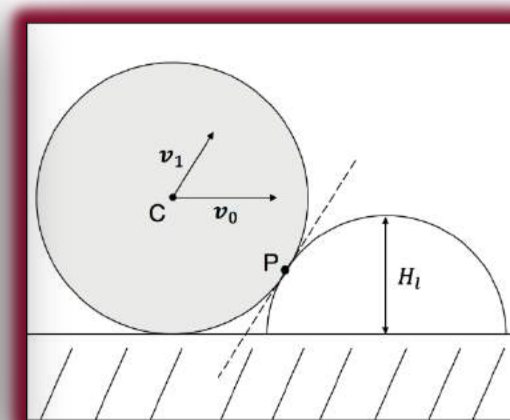
- Baseline: Erosion on ductile materials
- Advanced: Rain erosion of wind turbine blades
- An in-house Multiphase Solver and Adaptive-mesh Interface (MaSAI) was developed to account for the change in target body geometry during erosion/depositon processes

✓ Resuspension: Guingo and Minier (2008)

- Particle lift: FL>Fa
- Particle slip: FD>ks(Fa-FL)
- Paricle roll: Mrot>Mres





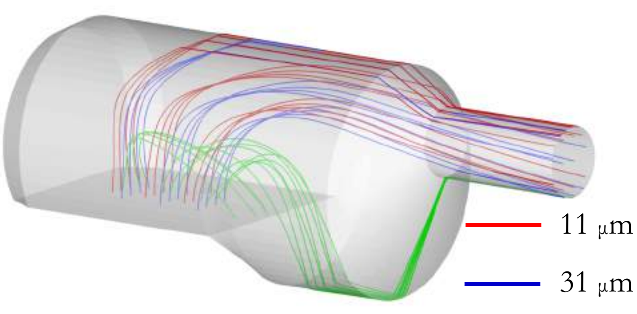


Prediction of deposit formation in biomass fed boilers

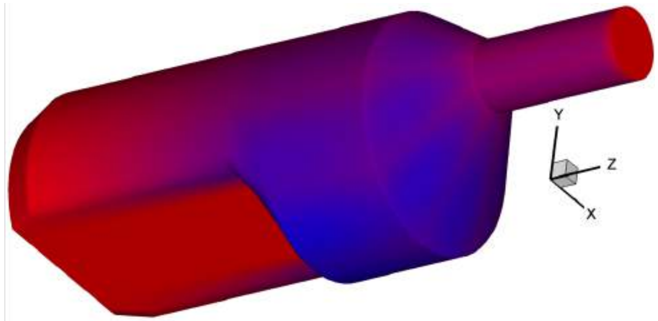
PON-PIBE (Piattaforma Integrata Bioreflui e Energia) Project

Particle tracking approach: original PCT

Adhesion model: temperature-based (critical viscosity)



Cloud trajectories

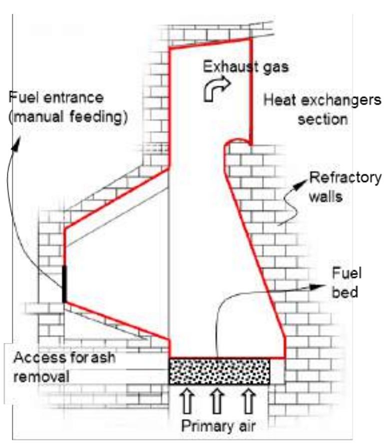


Total deposit [kg/m²h]

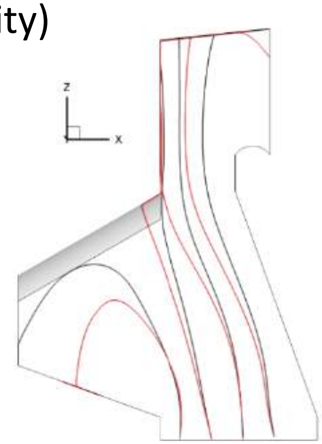
Furnace for panela production (International Cooperation Perù)

Particle tracking approach: modified (local velocity) PCT

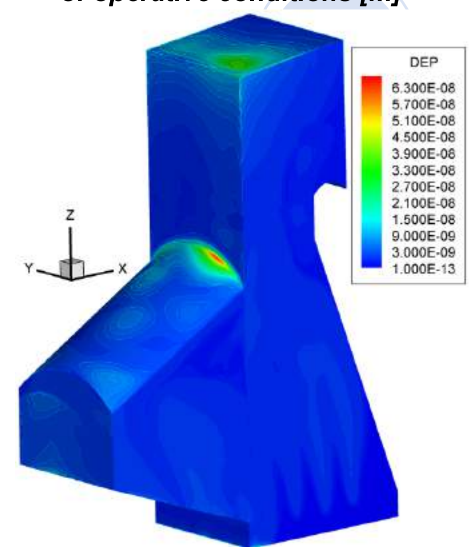
Adhesion model: temperature-based (critical viscosity)



Some particle trajectories: 25 μm (red), 75 μm (black)



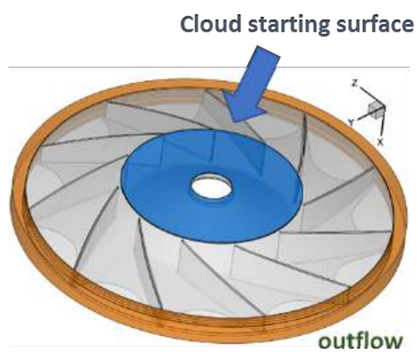
Deposit thickness after 1h of operative conditions [m]



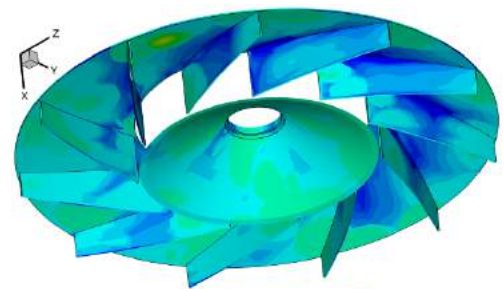
Prediction of erosion in turbomachinery applications

Particle erosion af a centrifugal fan (Flakt-Woods)

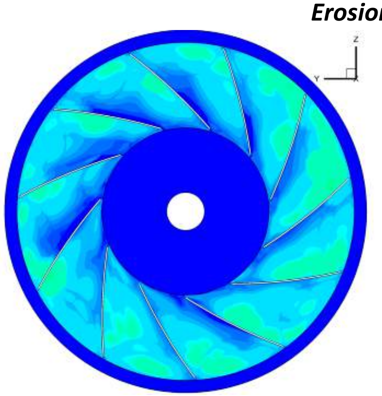
Flow solver: U-RANS
Particle tracking approach: PCT
Erosion model: semi-empirical (Tabakoff)



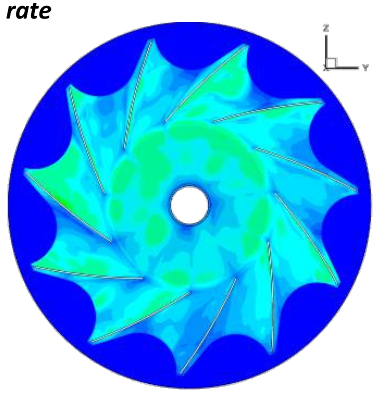
Erosion rate



Erosion rate

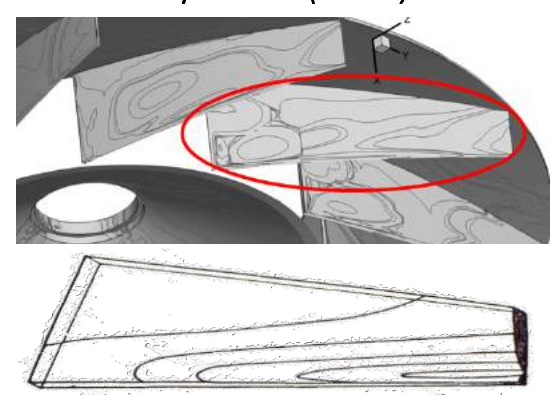


Shroud view



Hub view

Erosion patterns: simulation (top), experimental (bottom)

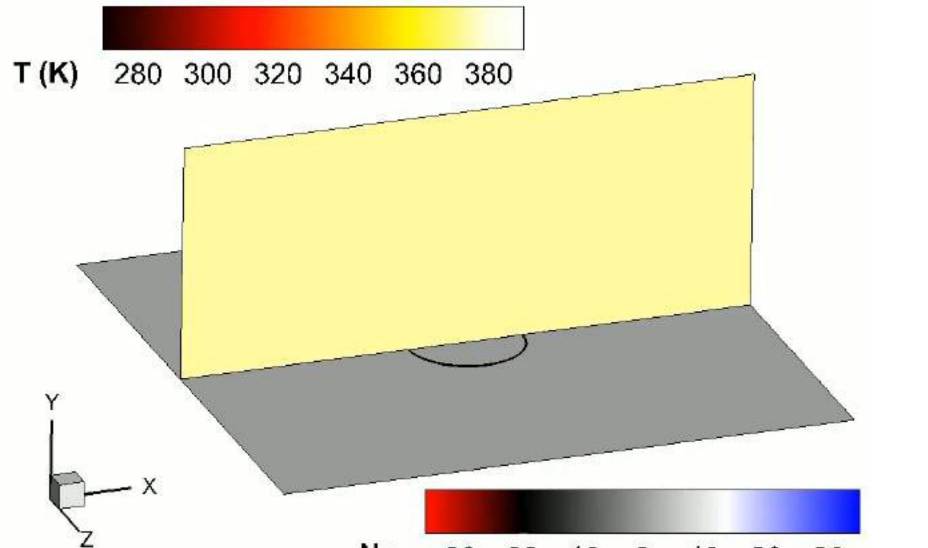


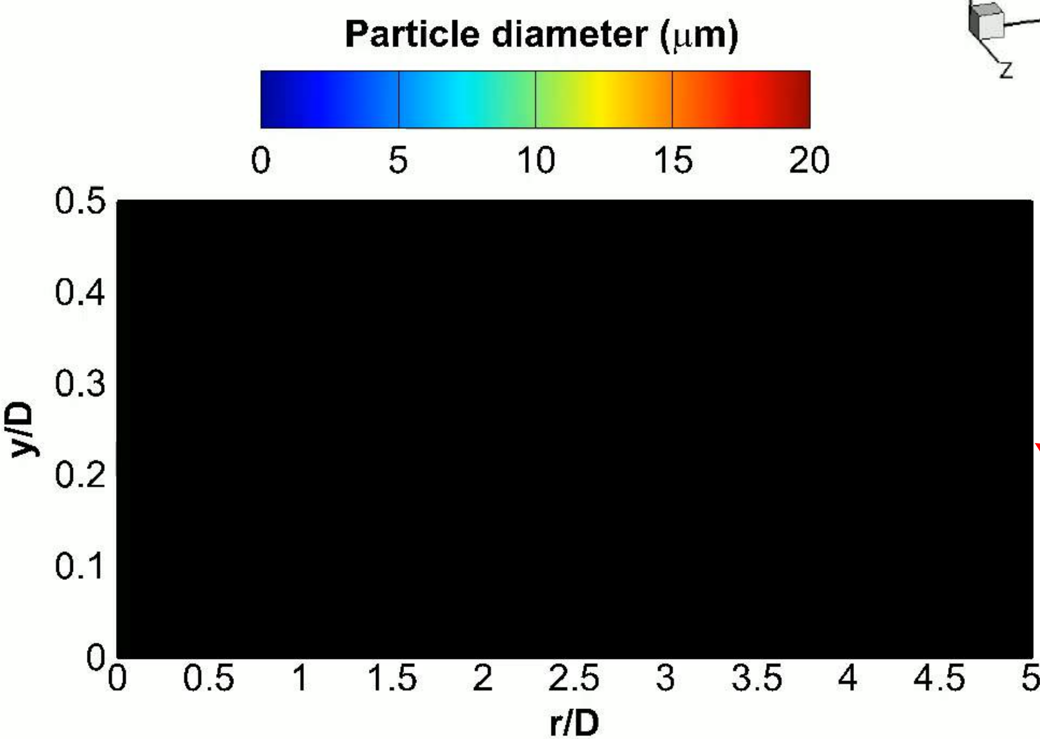
Particle resuspension in a LOVA accident (cooperation with TU Berlin, interest of GE Oil&Gas)

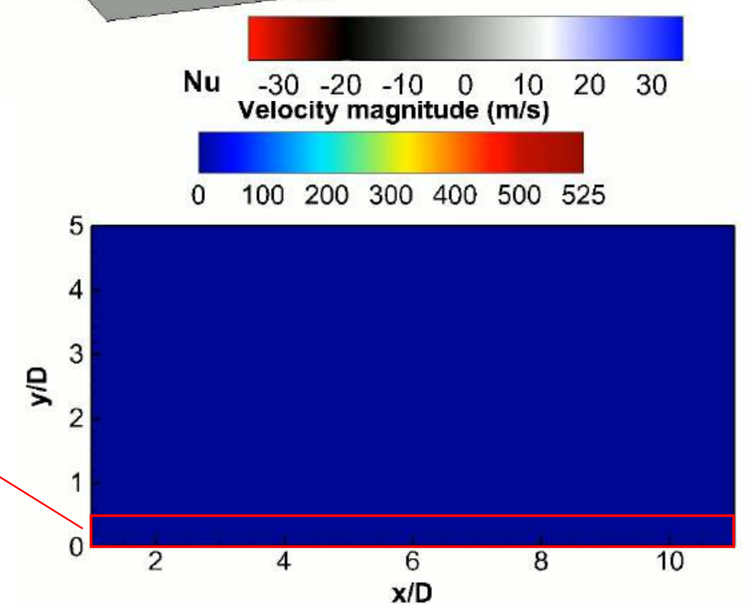
Flow solver: DNS - NSF

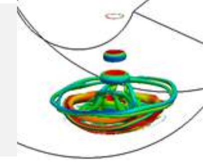
Particle tracking approach: PCT

Resuspension model: Guingo and Minier (2008)









Multi-physics flows in Turbomachinery applications

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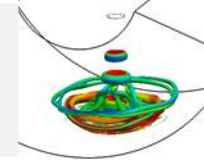
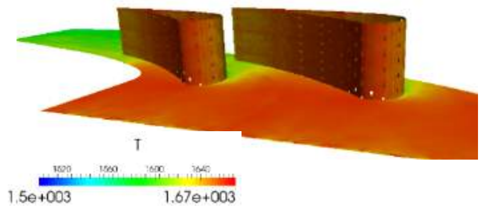
Transport Phenomena Section, Faculty of Applied Sciences, TU Delft

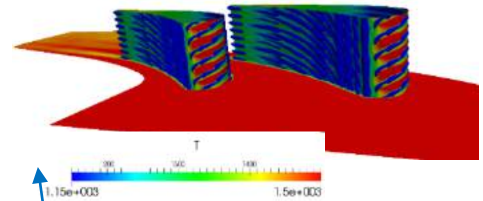
Blade cooling – Overview

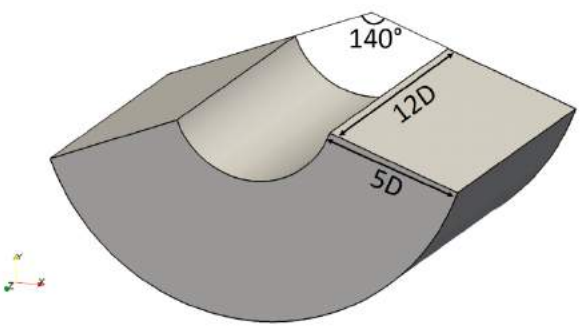


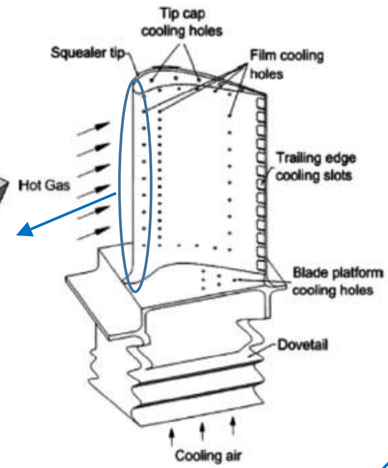
Without film cooling

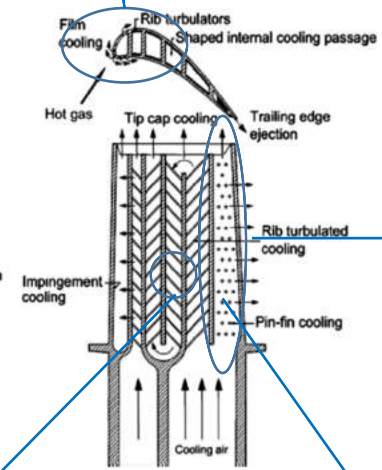


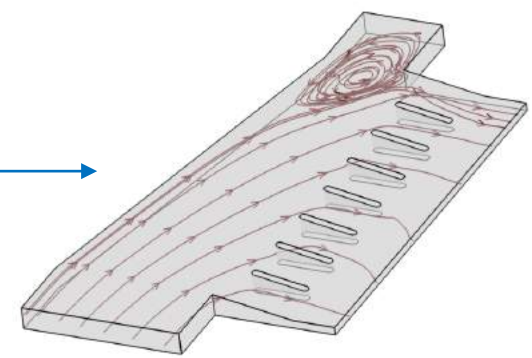
With film cooling



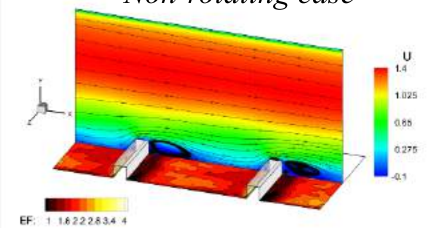




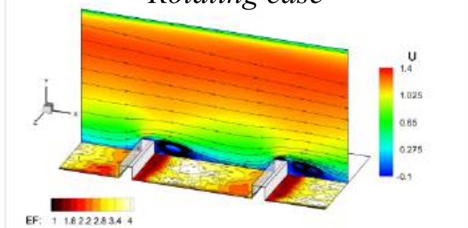


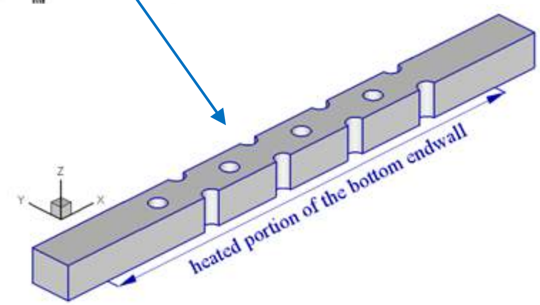


Non-rotating case

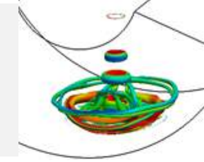


Rotating case



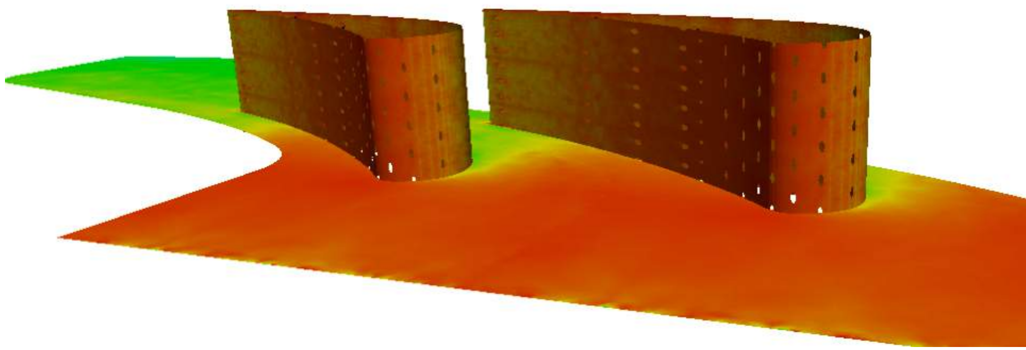


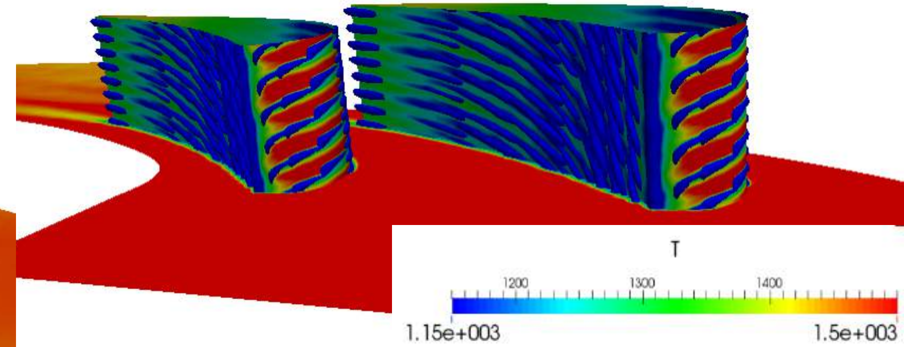
Film cooling

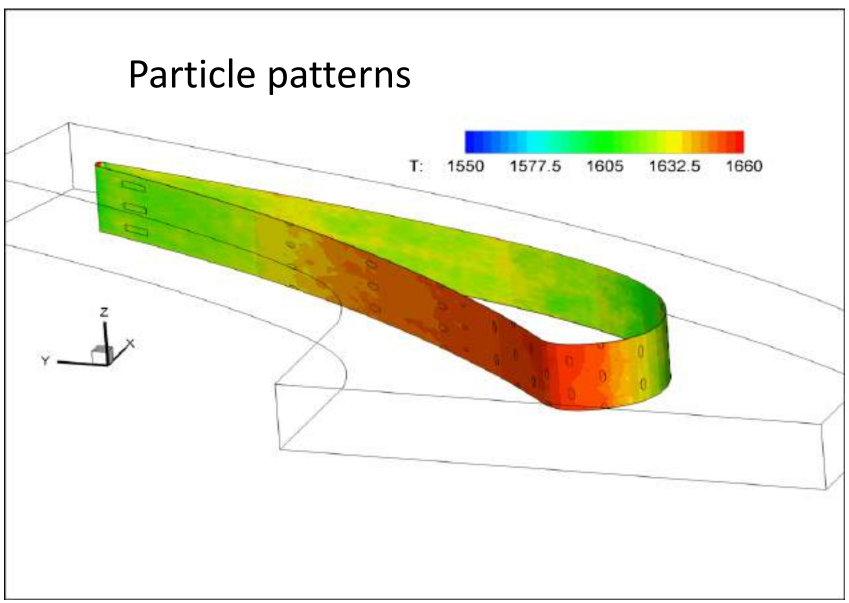


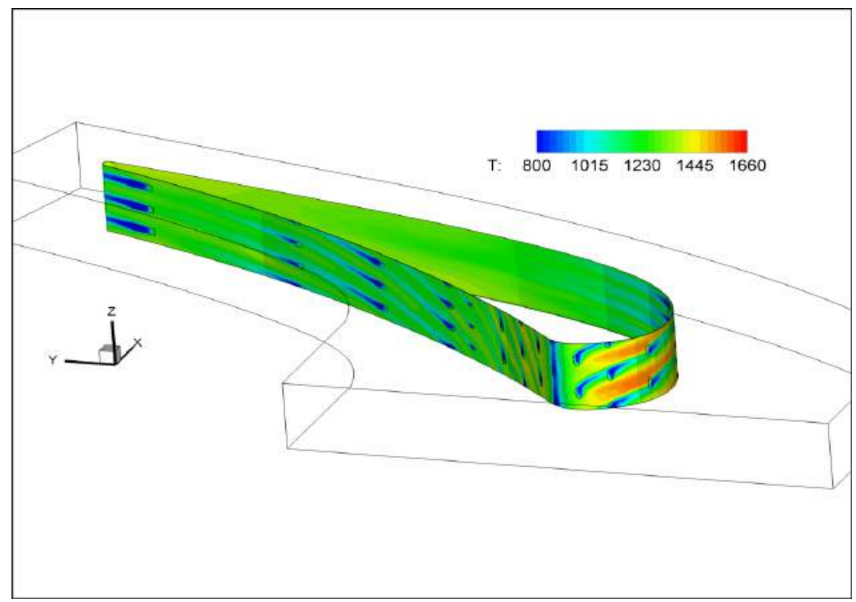
Multiphase flow and Blade temperature distribution (w and w/o film cooling:

- ✓ First stage vane blade of General Electric Energy Efficient Engine (E^3)
- ✓ Block structured grid, Compressible RANS – Open FOAM
- ✓ Expression of Interest from GE Oil & Gas, Included in the JETLAG MSCA-ITN project

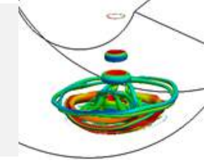






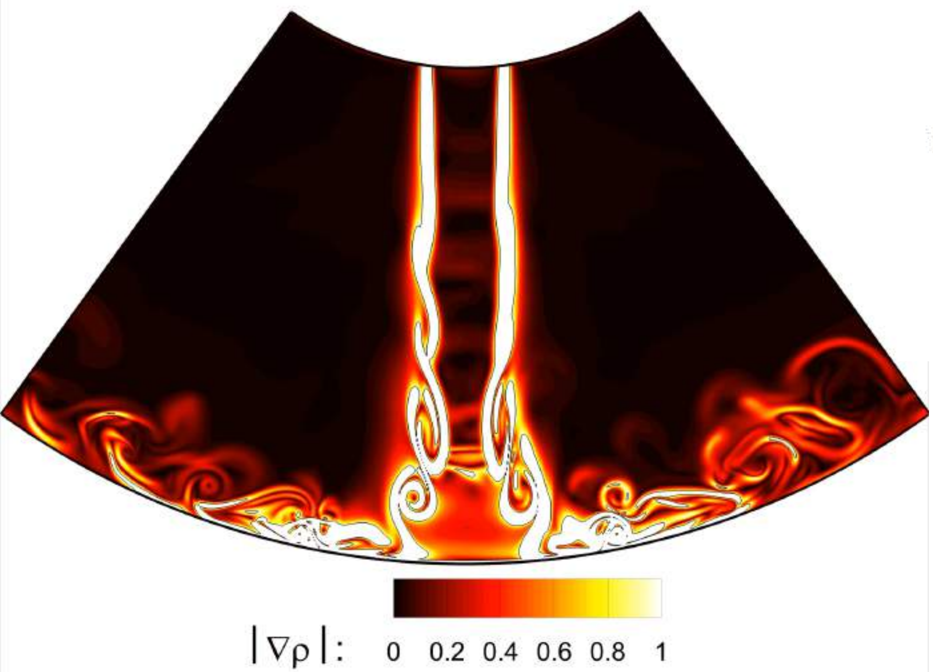


Internal cooling - Impingement

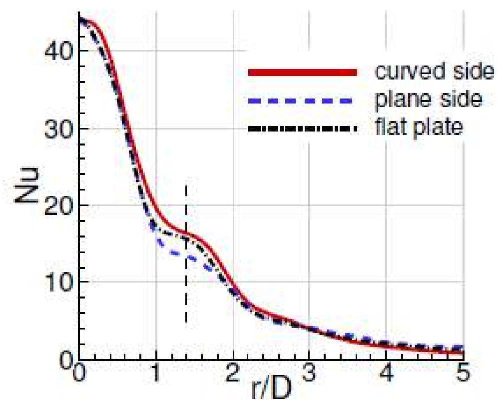


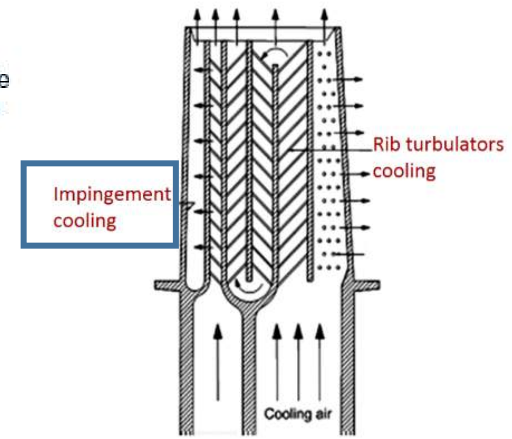
Leading edge impingement cooling on a cylindrical surface:

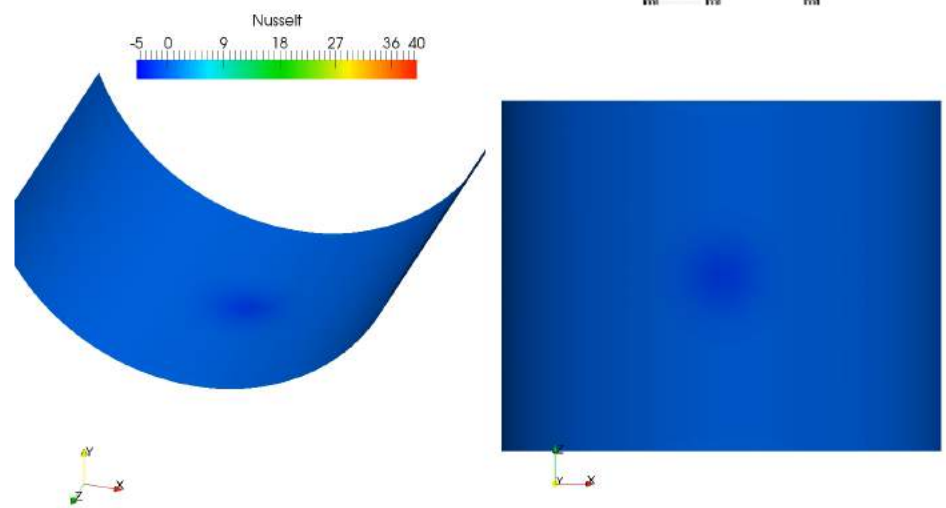
- ✓ Cartesian grid, Compressible DNS – NSF code
- ✓ Expression of Interest from GE Oil & Gas, Included in the JETLAG MSCA-ITN project



Density gradient

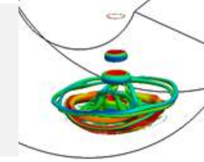






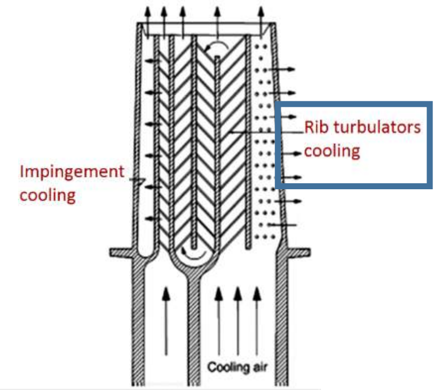
Nusselt fluctuation on the impinging wall

Turbine blade cooling – Internal cooling

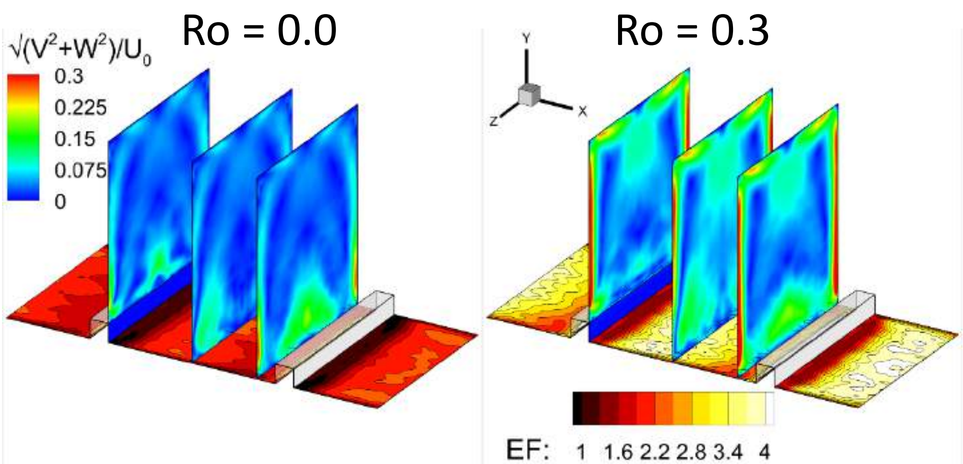


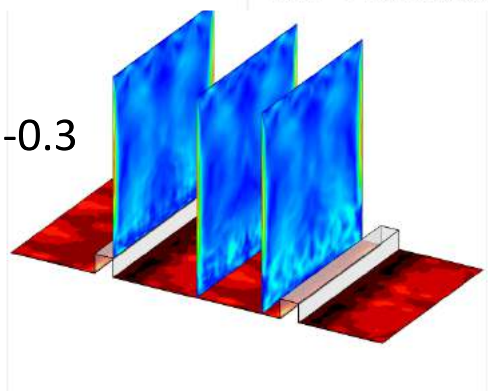
Rib turbulators

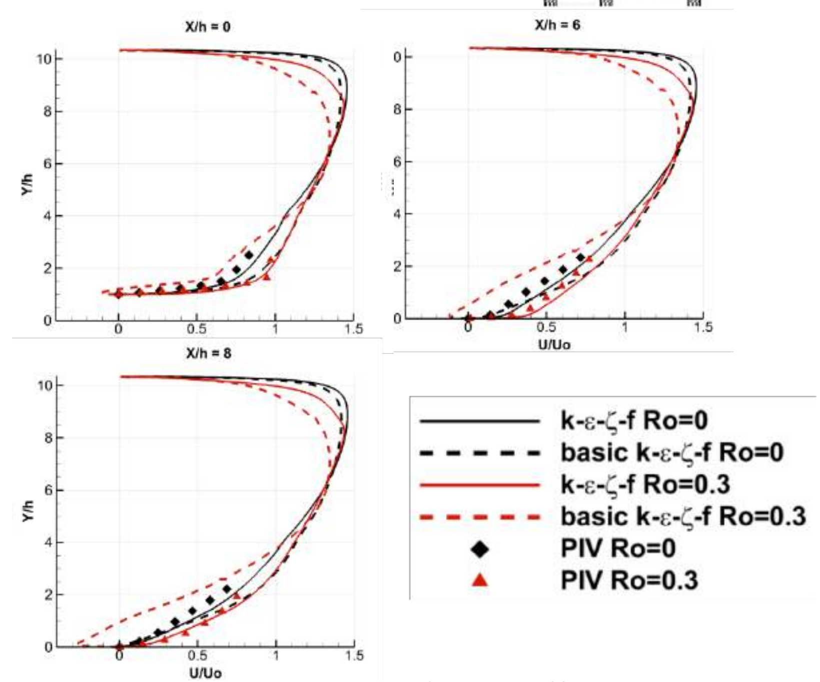
- ✓ Cartesian grid, LES – T-FlowS code
- ✓ Development of rotation sensitized RANS model
- ✓ Expression of Interest from GE Oil & Gas, cooperation with K. Hanjalic, TU Delft



Secondary motion and heat transfer





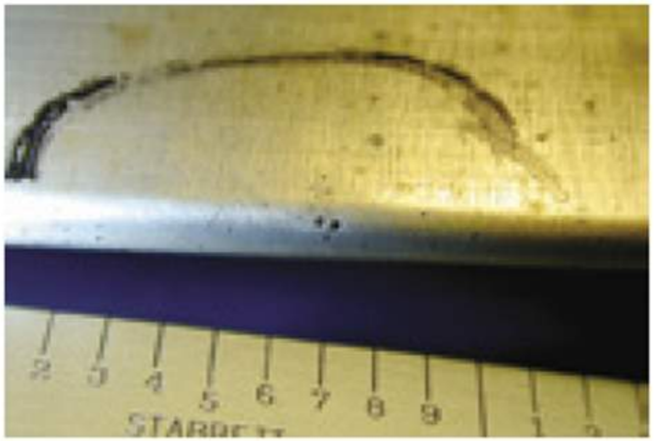


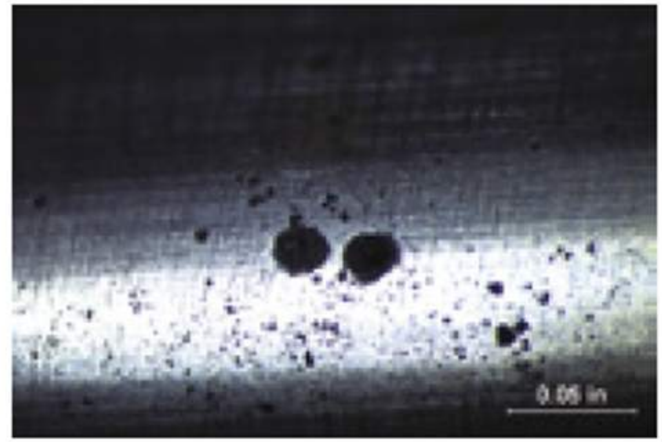
Streamwise velocity profile at different abscissa. Comparison between corrected and uncorrected model

Blade pitting

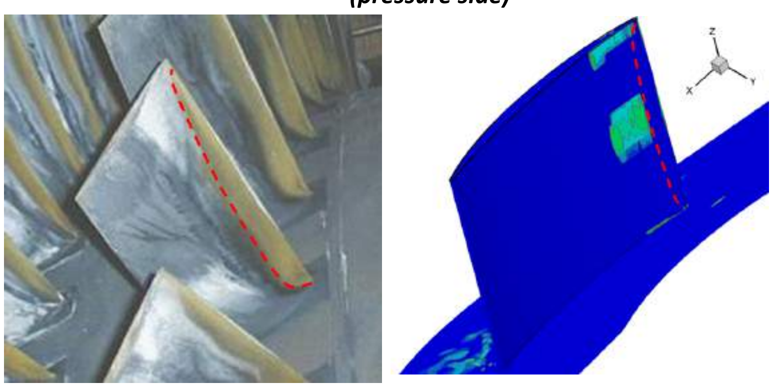
Blade pitting prediction

- ✓ Cartesian grid, U-RANS – T-FlowS/Commercial code
- ✓ GE Oil & Gas, cooperation with K. Hanjalic, TU Delft

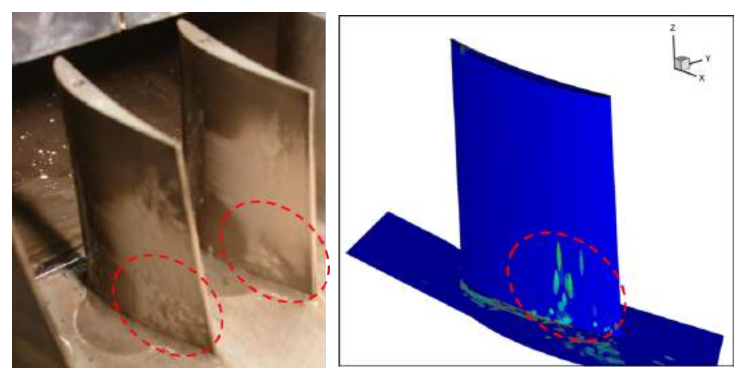




Qualitative comparison between actual and simulated eroded blade (pressure side)



Qualitative comparison between actual and simulated eroded blade (suction side)



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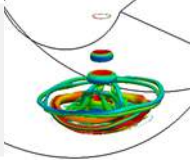

Energy Systems simulations

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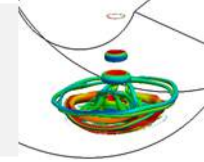
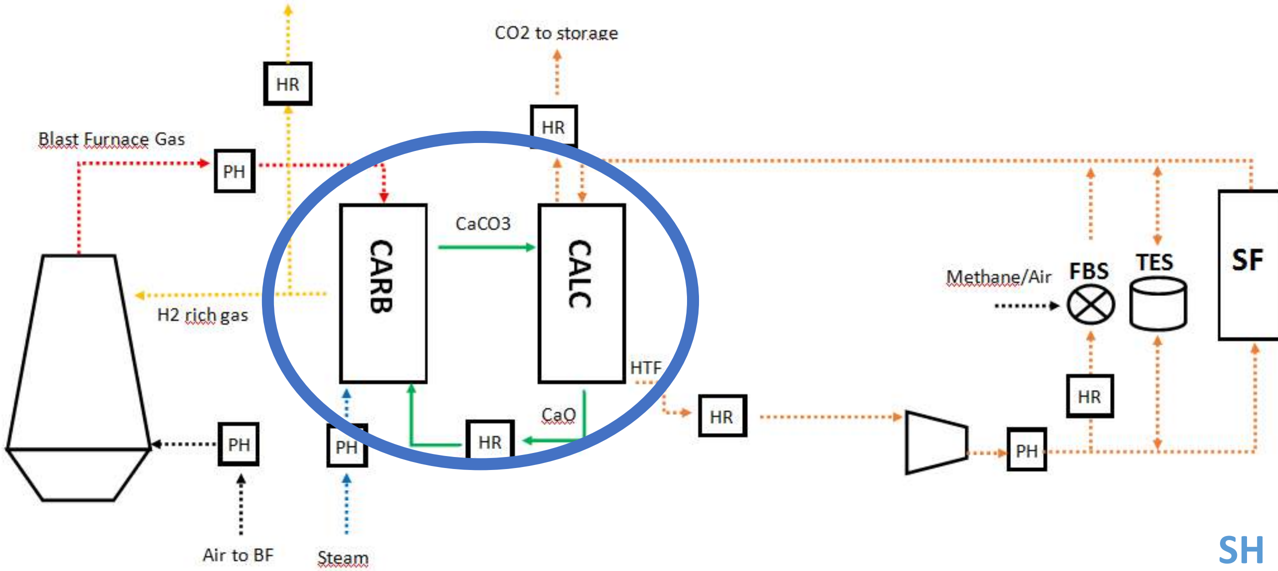
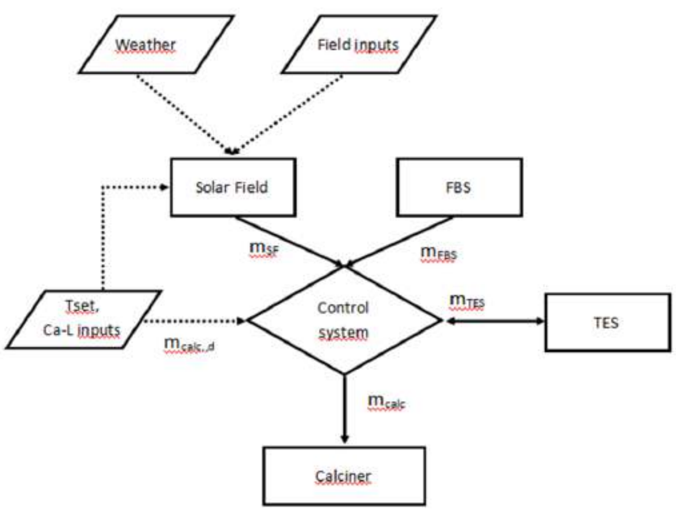


Calcium Looping in a blast furnace steel mill

✓ Chemcad code (PAR-ENEA)



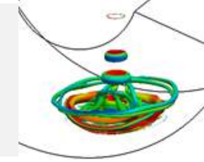


SH →

SM ↓

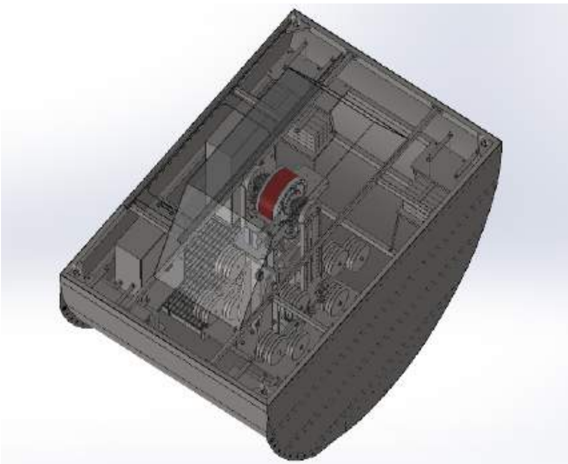
eCO2	0	2.7	5.5	11	Inf.
0.2	3012	3012	3012	3012	3012
0.7	2595	2595	2595	2595	2595
1.4	2405	2378	**2359**	2359	**2359**
2.1	2329	2212	2093	**2037**	**2037**
2.7	2285	2153	1983	1749	**1698**

Non-decarbonized steel mill: ~ **6200 ton/year**

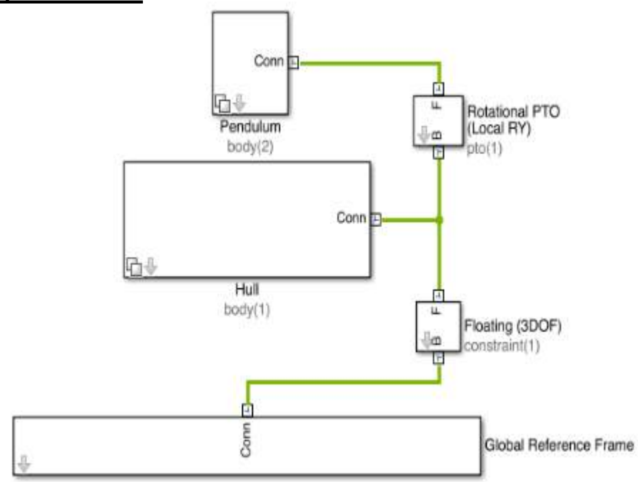


Wave Energy Converter PEWEC

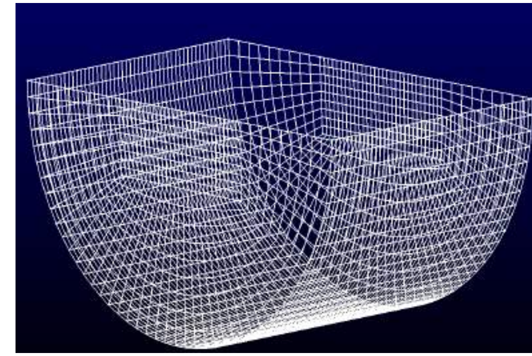
- ✓ WEC-Sim code PAR –ENEA, PoliTo



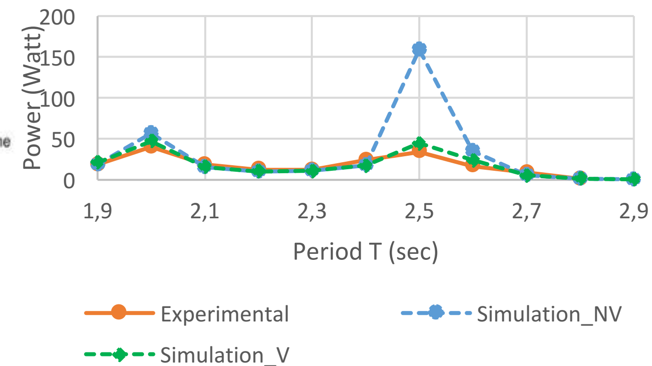
CAD



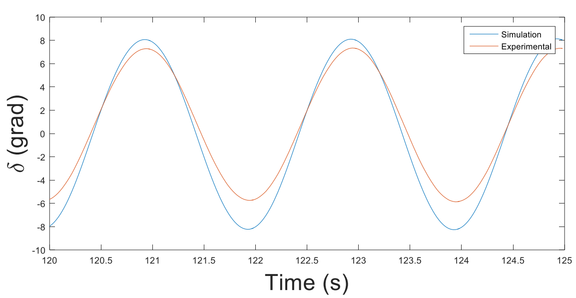
WEC-Sim scheme



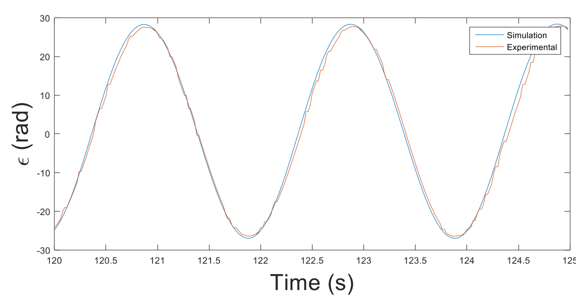
BEM discretisation



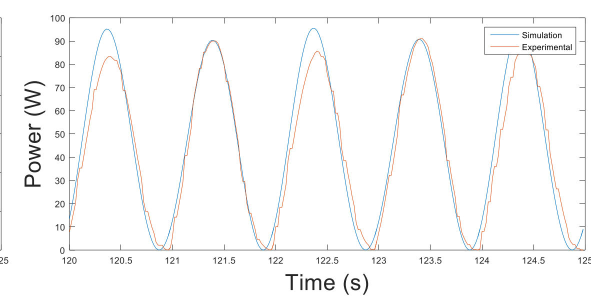
Hull



Pendulum



Power Take-off

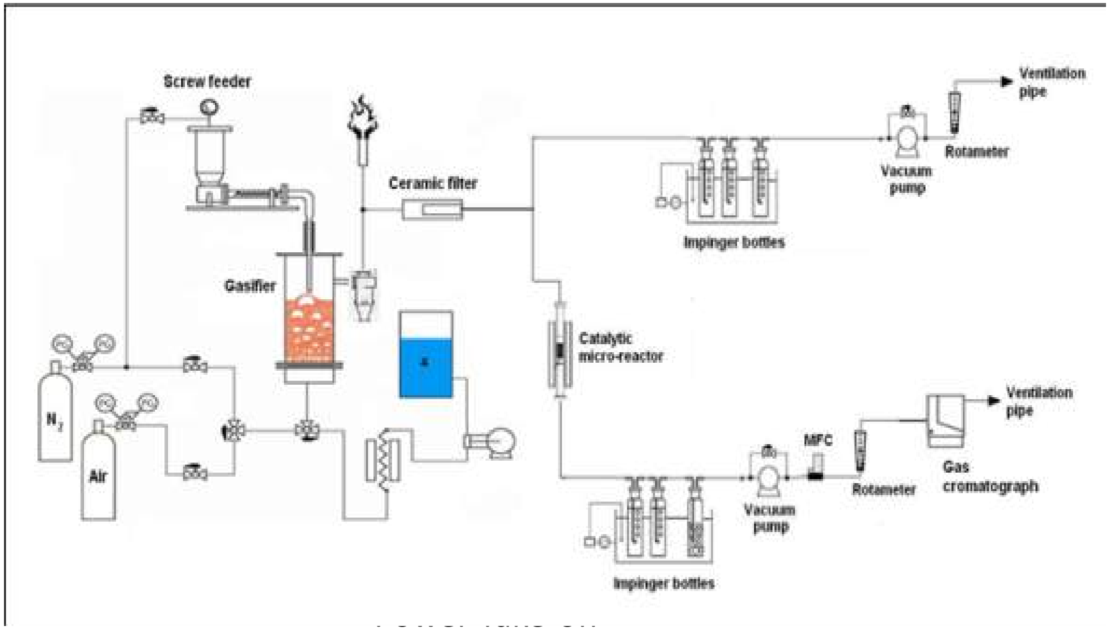


Biomass Gasification

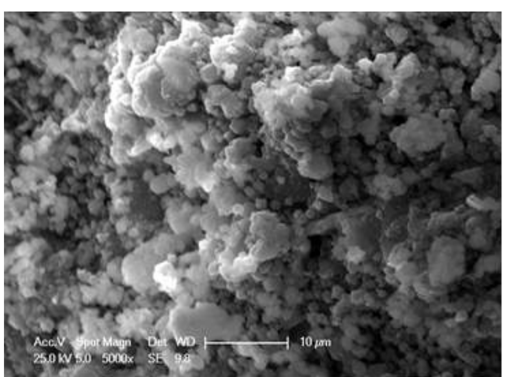
Catalyzers for tar reforming

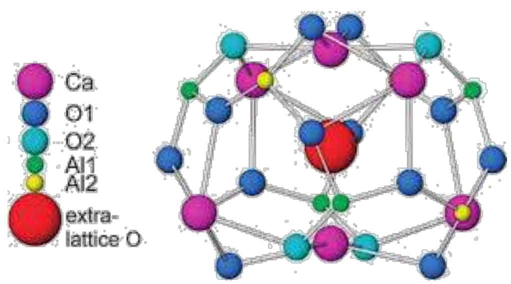
Plant-assisted Fitoremediation

- ✓ Experimental test-rig, cooperation with RESET s.r.l., CNR and ISPRA

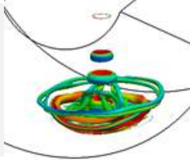


Ni-Mayenite catalyzer





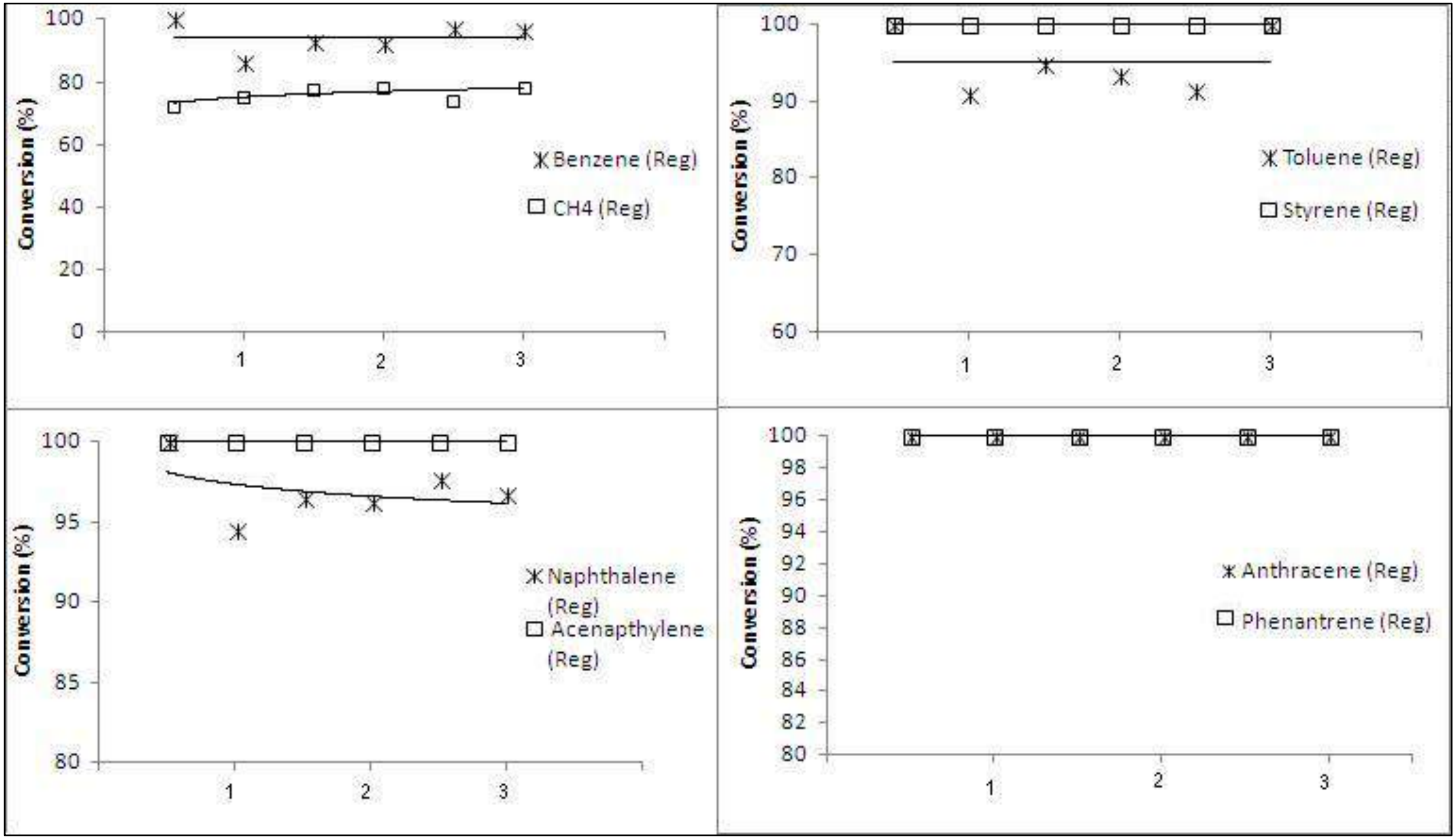
Mayenite structure



Catalyzers for tar reforming

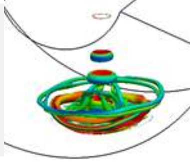
Plant-assisted Fitoremediation

✓ Experimental test-rig, cooperation with RESET s.r.l., CNR and ISPRA



SAPIENZA
UNIVERSITÀ DI ROMA

Direct Methanol Fuel Cell

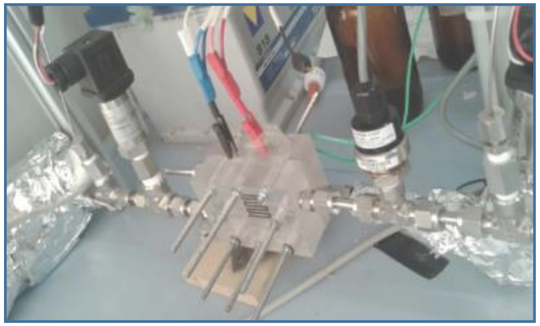


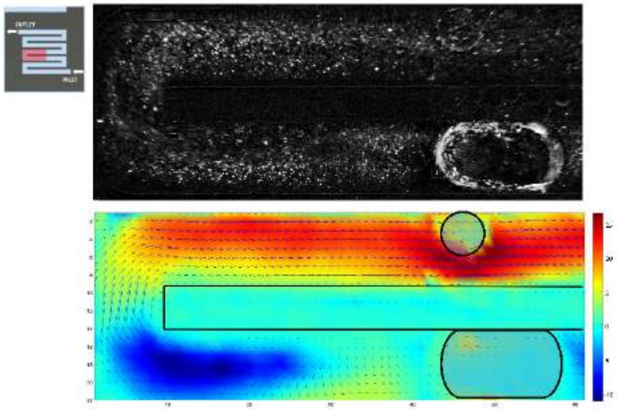
DMFCs are liquid powered fuel cells aiming to overcome the typical fuel storage issues associated with hydrogen fuel cells.

Main experimental research topics :

- Electrochemical characterization of single DMFCs and stacks (from mW up to 1.5 kW);
- Evaluation of the main DMFC sources of loss (fuel cross-over, CO_2 channels clogging);
- Evaluation of the temporary and permanent degradation;
- Design of hybrid energy systems for small power size in stand alone applications

DMFC1. *200 mW DMFC under PIV analysis and VI curve, pressure and temperature recording.*

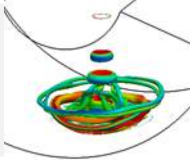




DMFC2. *Velocity field (PIV result) around a CO_2 bubble in the anode channel at low Re (<8) and high current density.*

DMFC3. *Test bench for small power size stack (< 380 W) characterization (VI curve, cross-over measurement).*

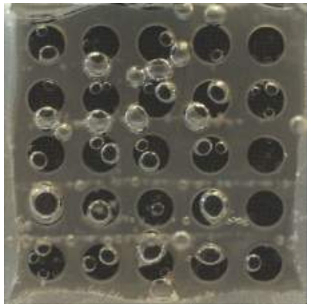
Direct Methanol Fuel Cell



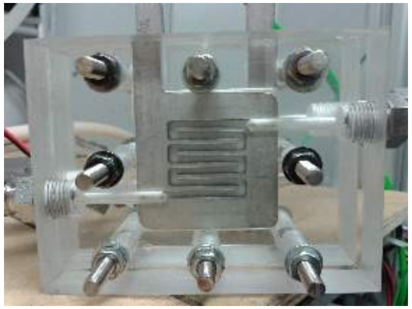
Projects:

- Ecocell, 2013-2014. Development of a test rig for a 120 W DMFC.
    a. Assembly and test of single DMFC
    b. Assembly of the test bench and test of a commercial short stack
- Stealth Energy, 2015-2016. Design of a 1.3 kW DMFC stack and assembly of a test bench for higher power.
- Far Seas, 2016-2017. Design of a DMFC system for an *AIP* (Air Indepndent Propulsion).
    a. Experimental tests measuring the permanent degradation over *800 h* of functioning on a commercial *1 kW* stack.
    b. Sizing of a DMFC system for a *240 kW*.

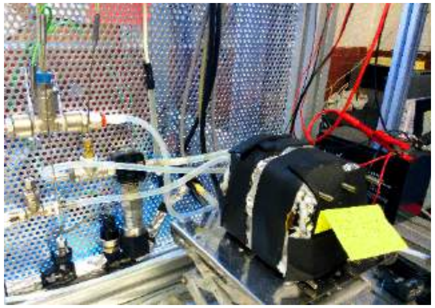
DMFC7. *Test rig for a 1.5 kW DMFC system for 800 h of permanent degradation test*



DMFC4. *Passive DMFC under high current density.*



DMFC5. *Active DMFC assembly*

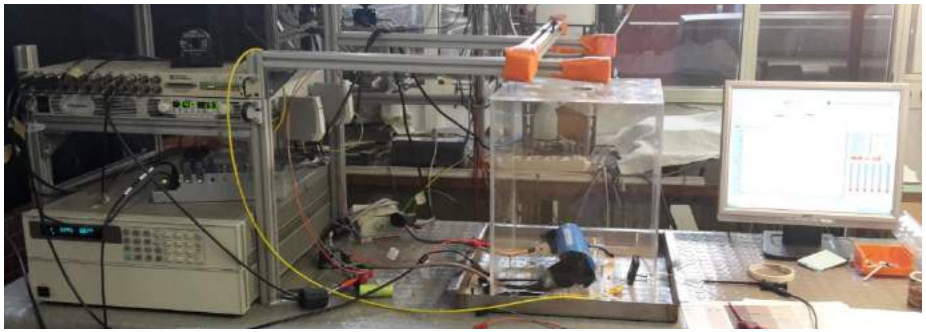


DMFC6. *120 W DMFC stack under test*

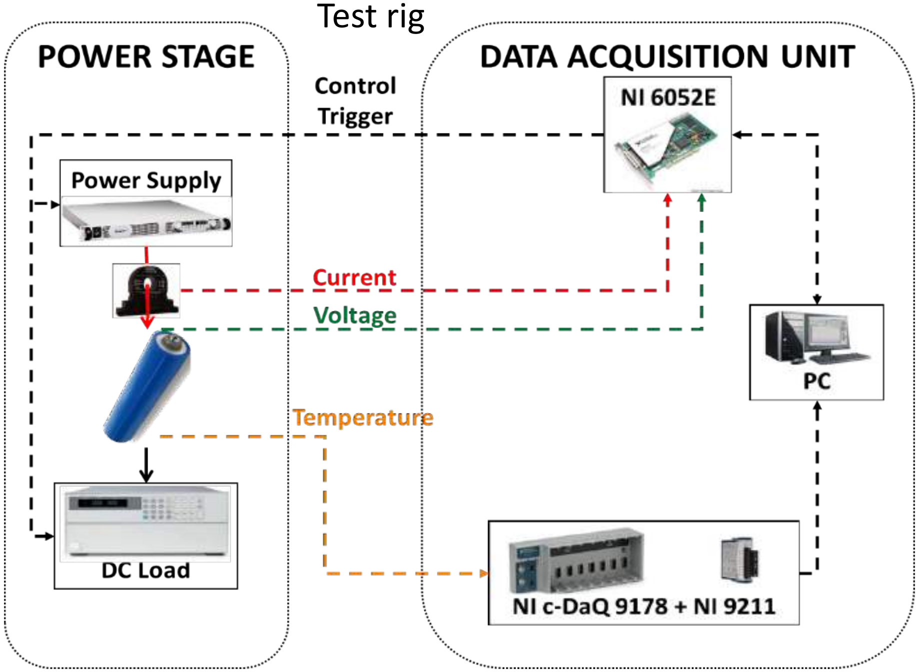
Battery Verification

Routine, short circuit and thermal runaway tests on LiFePo batteries

✓ Experimental test-rig, cooperation with Fincantieri and Marina Militare

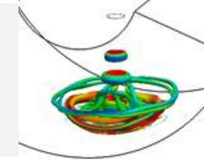


Test rig



Battery to be tested

Environmental studies



Use of recycled canvas from exhaust tyres for dispersed oil absorption

✓ Experimental analysis, with Ecoflora 2 and Regione Lazio

Recycled Fluff

Absorption capability

Intermediate scale