AeroTraNet

MARIE CURIE ACTIONS

ENHANCEMENT TURBOMACHINERY CABABILITIES: DEVELOPMENT & VALIDATION

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Imagination at work

Contents

Introduction

A DIGITAL INDUSTRIAL COMPANY

With more than 300,000 people operating in 175 countries, GE is the world's Digital Industrial Company, transforming industry with software-defined machines and solutions that are connected, responsive and predictive. GE is organized around a global exchange of knowledge that we call the GE Store. It's through the GE Store that each business shares and accesses the same technology, markets, structure and intellect. At GE, each invention further fuels innovation and application across our industrial sectors. With people, services, technology and scale, GE delivers better outcomes for customers by speaking the language of industry.

POWER	ENERGY MANAGEMENT	RENEWABLE ENERGY	OIL & GAS	AVIATION	TRANSPORTATION	HEALTHCARE	APPLIANCES & LIGHTING
~$30B	~$11B	~$9B	$18.7B	$24B	$5.7B	$18.3B	$8.4B

2014 REVENUES

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INNOVATION AT GE

GE Global Research was created to maintain the company's market edge and foster new discoveries and commercial applications

3,600 of the world's brightest scientists and researchers

& 9 state-of-the-art facilities around the world

Supporting $5B annual investment in R&D

& 50,000 engineers and technologists

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GE IN EUROPE

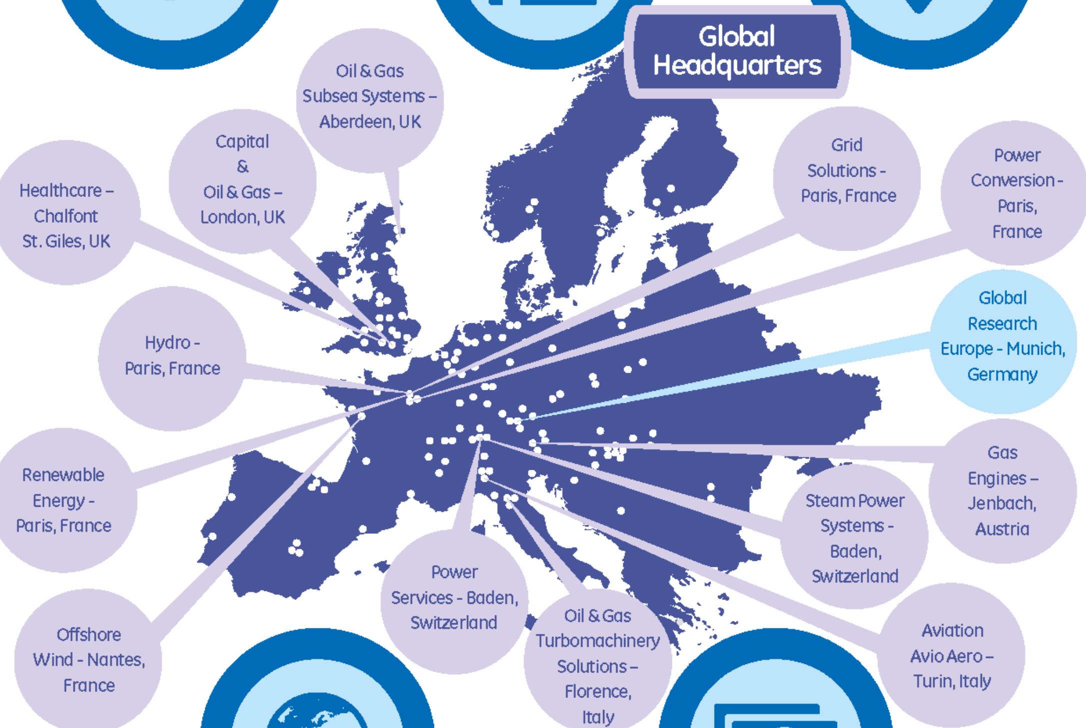
OUR BUSINESSES

Aviation | Capital | Digital | Energy Management | Healthcare | Lighting | Oil & Gas | Power | Renewable Energy | Transportation

100,000+ employees

100 manufacturing sites

1,000+ locations



100+ years in Europe

€25Bn revenue

Did you know?

Every 2 seconds, a GE- or CFM-powered aircraft takes off

Our Jenbacher gas engines produced and installed in Europe can power 29 million households

1/3 of GE Healthcare R&D investments are in Europe

Over 6000 wind turbines installed in Europe

GE POWER

~$28B '14 revenue ~65,000 employees >120 countries

Steve Bolze, CEO
Schenectady, NY

Gas Power Systems

High Efficiency, Scale Power

- Power Plants (combined & simple cycle)
- Gas Turbines
- Steam Turbines
- Generators & Controls
- Heat Recovery Steam Generators

Power Services

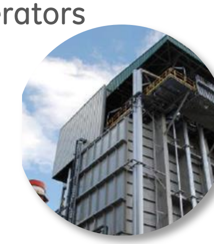
Optimizing Plant Performance

- Installation planning/execution
- Maintenance, repairs & outage solutions
- Multi-year service agreements
- Hardware/software blended upgrades
- Data-driven software solutions

Steam Power Systems

Advanced Steam Power Expertise

- Complete portfolio, turnkey power plants
- Widest range of generators & Steam Turbines
- Air Quality Control Systems (AQCS) including CCS
- Turbine Island Solutions for Nuclear



Distributed Power

Broad, Efficient Portfolio

- Reciprocating engines (0.1 to 10 MW)
- Jenbacher engines, power equip. & services
- High efficiency & fuel flexibility: Natural gas, CHP, oilfield power, diesel & special gas applications

GE Hitachi Nuclear

Advanced Reactor Technologies

- ESBWR, ABWR, PRISM
- Outage & Asset Optimization Services
- Fuels & Engineering Services

Water & Process Technologies

Energy Efficient Water Solutions

- Chemical & Monitoring Solutions
- Engineered Systems
- Mobile Water
- Build-Own-Operate Services

Digital Capabilities – Building for the Future

Turbomachinery challenges in CFD

Objective

Present the work to enhance the turbomachinery capabilities of OpenFOAM by:

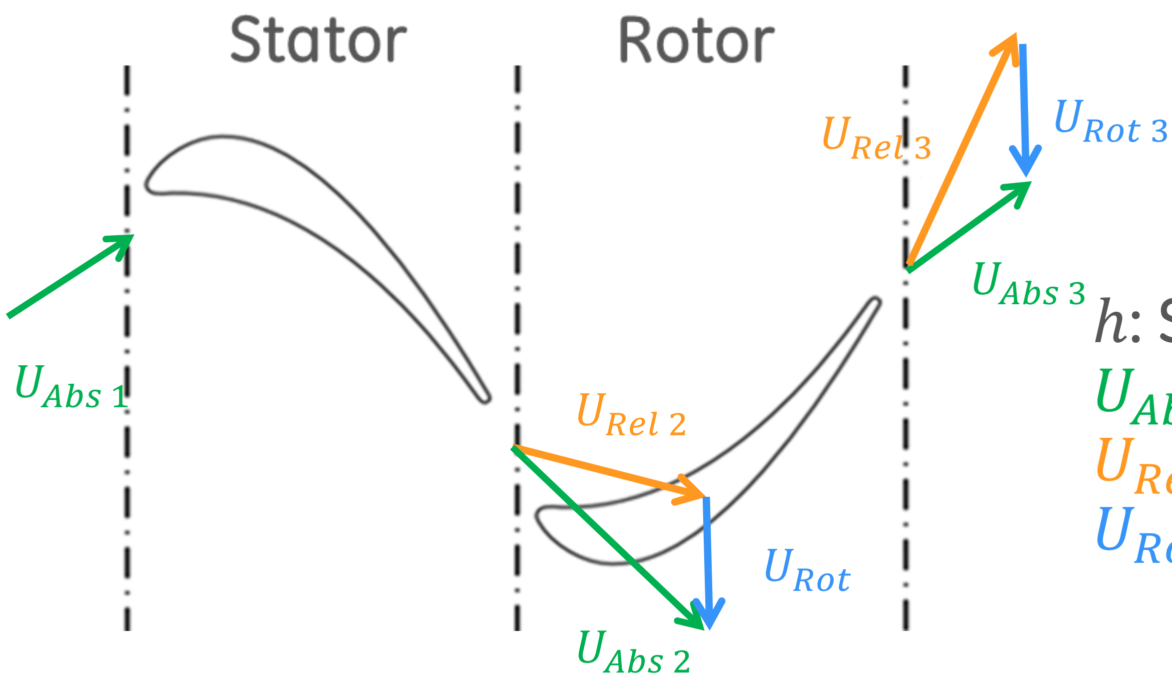
- Solving the rothalpy energy equation in a MRF solver
- Improving the rotor-stator interface boundary conditions in order to handle rothalpy correctly

Development

Basic Principles of Rothalpy

Rothalpy Definition:

$$i = h - \frac{1}{2}{U_{Rot}}^2 + \frac{1}{2}{U_{Rel}}^2$$



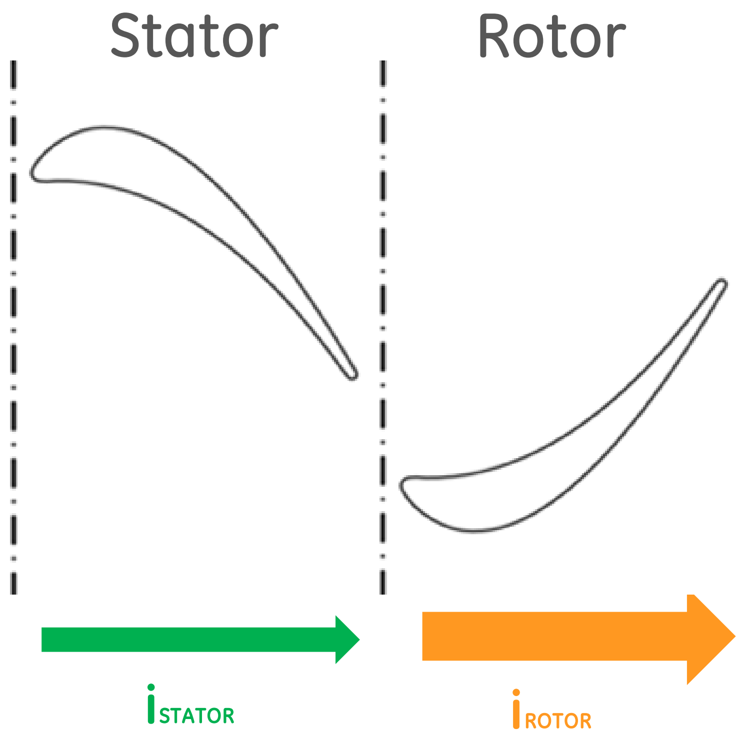
h: Static enthalpy

U_{Abs}: Absolute Velocity

U_{Rel}: Relative Velocity

U_{Rot}: Rotational Velocity

Why use the rothalpy equation?



Function that remains constant over a blade row

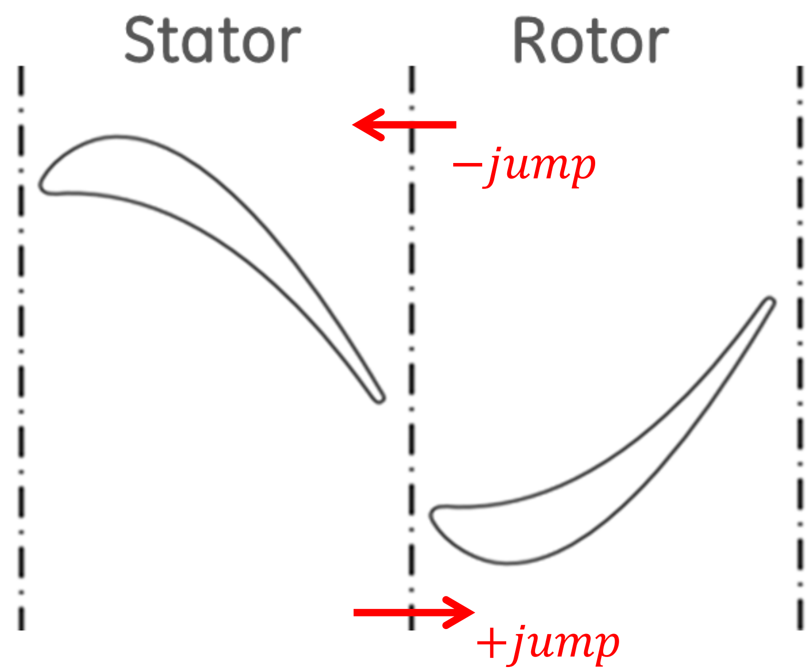
- Rothalpy is a quantity conserved over a stator or rotor, but not over a stage, stator and rotor.
- The value of rothalpy is not constant across the rotor-stator interface due to change of rotational speed between zones.

Rothalpy jump between MRF zones

$$\begin{cases} i = h - \frac{1}{2}U_{Rot}{}^2 + \frac{1}{2}U_{Rel}{}^2 = h + \frac{1}{2}U_{Abs}{}^2 - \omega R U_{Abs\,\theta} \\ i = h + \frac{1}{2}U_{Abs}{}^2 + jump \end{cases}$$

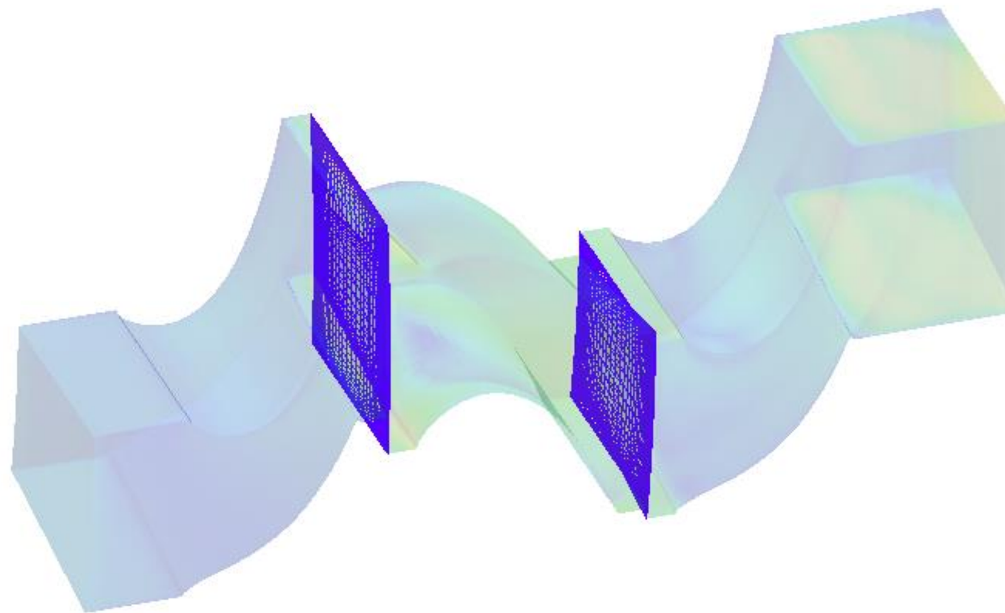
$$jump = -\omega R U_{Abs\,\theta}$$

ω: Static enthalpy
R: Radius
$U_{Abs\theta}$:Tangential Component of the Absolute Velocity



Rotor-stator Interfaces

- General Grid Interface (GGI): frozen rotor
- Partial Overlap GGI: for different rotor-stator pitch
- Mixing Plane: circumferential averaging of the solution at the rotor-stator interface



Prepare for GGI with Rothalpy Jump

- Set the case as usual for GGI/Partial Overlap GGI/Mixing Plane
- Include the rothalpy dictionary in the zero folder and choose the following **type** at the rotor-stator interface:

Partial Overlap GGI

```
outlet_st01
{
type          overlapGgiEnthalpyJump;
patchType     overlapGgi;
rotating      false;
value         uniform 306001.63;
}
inlet_ro01
{
type          overlapGgiEnthalpyJump;
patchType     overlapGgi;
rotating true;
value         uniform 306001.63;
}
```

Mixing Plane

```
outlet_st01
{
type          mixingPlaneEnthalpyJump;
patchType     mixingPlane;
rotating      false;
value         uniform 306001.63;
}
inlet_ro01
{
type          mixingPlaneEnthalpyJump;
patchType     mixingPlane;
rotating true;
value         uniform 306001.63;
}
```

Validation

Mathematical model

- In this work steadyUniversalMRFFoam has been used
- Numerical implementation based on foam-extend 4.0
- PIMPLE solution algorithm

Test case

1 $^{1}/_{2}$ Stage Turbine Calculation

Turbulence Model
→ Standard k-ε
→ Standard wall functions

Cell Zones
Cell Zone → st01
→ Stationary

Cell Zone → ro01
→ Rotating
→ Global X-Axis
→ -3501RPM

Cell Zone → st02
→ Stationary

Inlet
Total Pressure → 152125.0
Total Temperature → 305.66K
Flow Direction → Normal to Boundary
Turbulence Intensity → 10%
Turbulent Viscosity Ratio → 100

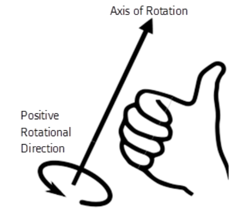
Zone st01:ro01 Interface
Interface → overlapGGI/mixingPlane
Patches → outlet_st01
→ inlet_ro01
Rotation → Global X-Axis
→ 10°

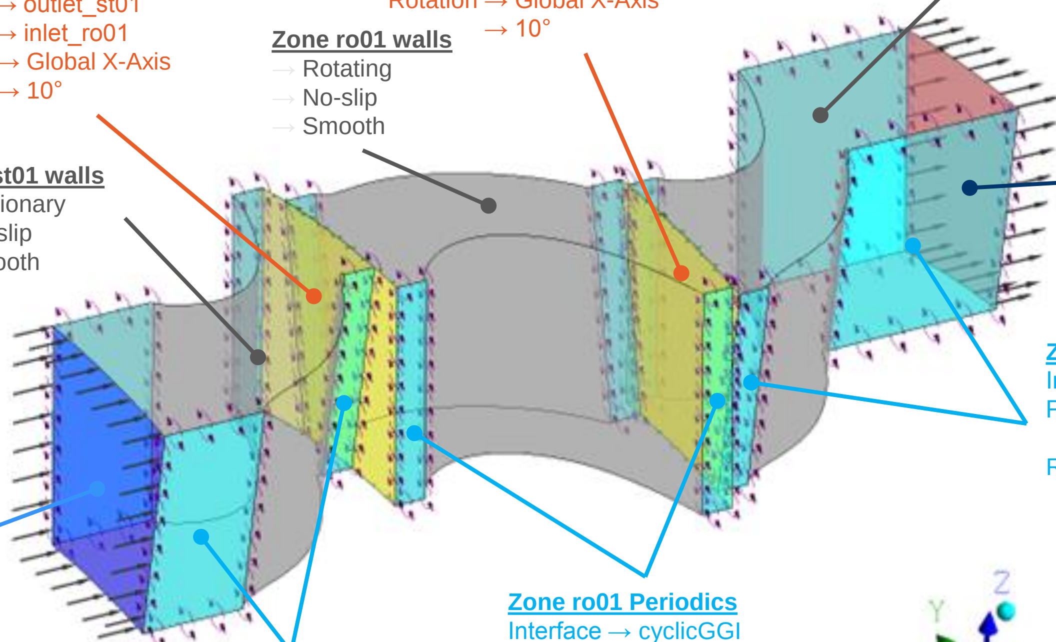
Zone st01 walls
→ Stationary
→ No-slip
→ Smooth

Zone ro01 walls
→ Rotating
→ No-slip
→ Smooth

Zone ro01:st02 Interface
Interface → overlapGGI/mixingPlane
Patches → outlet_ro01
→ inlet_st02
Rotation → Global X-Axis
→ 10°

Zone st02 walls
→ Stationary
→ No-slip
→ Smooth

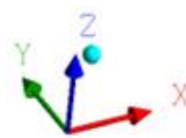




Zone st02 Periodics
Interface → cyclicGGI
Patches → periodic_st01
→ shadow_st01
Rotation → Global X-Axis
→ 10°

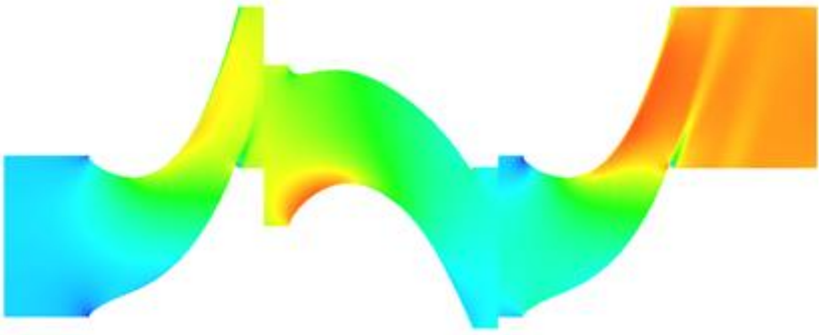
Zone ro01 Periodics
Interface → cyclicGGI
Patches → periodic_st01
→ shadow_st01
Rotation → Global X-Axis
→ 10°

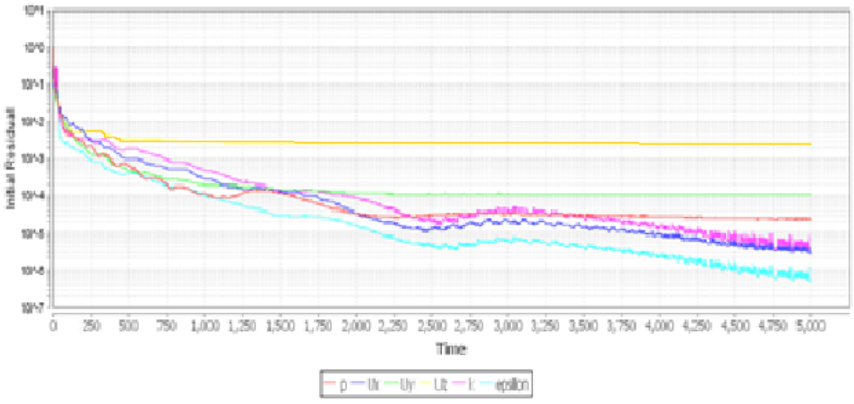
Zone st01 Periodics
Interface → cyclicGGI
Patches → periodic_st01
→ shadow_st01
Rotation → Global X-Axis
→ 10°



Mach number value

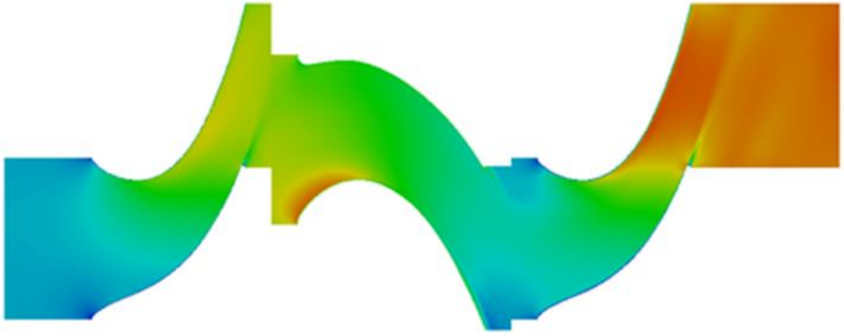
In-house CFD tool



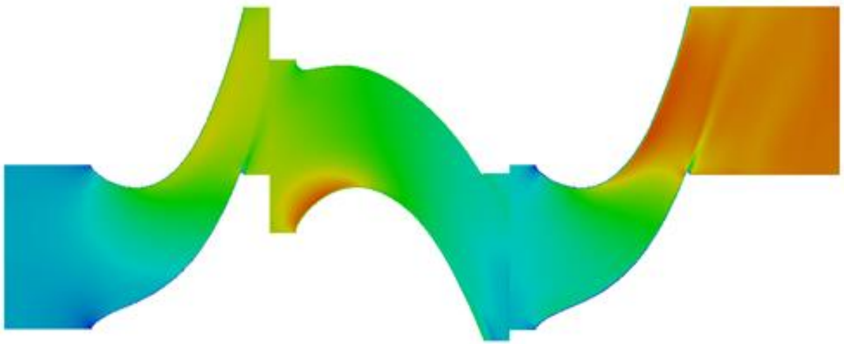


OpenFOAM

- Partial Overlap GGI Interface



- MixingPlane Interface



Conclusions

Conclusions

- Improved OpenFoam (foam-extend) capabilities for turbomachinery simulations:
  - Implementation of the rothalpy energy equation for a MFR solver
  - Enhancement of the rotor-stator interface, GGI, Partial Overlap GGI and Mixing Plane, in order to include the rothalpy jump between different MRF zones
- Initial validation results


Q&A