TURBOMACHINERY SIMULATIONS using SU2

An overview

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1st SU2 Developers Meeting, September 5th, 2016

AULA Conference Center, Delft University of Technology

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SU2 for Turbo: a Team Effort

- Initiated at the end of 2014 by few people visiting Stanford
- First 3D NICFD cascade simulation achieved in 2015
- Now fairly large team: 4 PhDs, 5 staff, under-graduates

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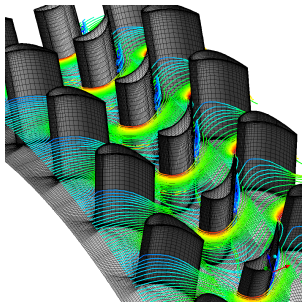

Stanford | ENGINEERING
Aeronautics & Astronautics

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Scientific Computing
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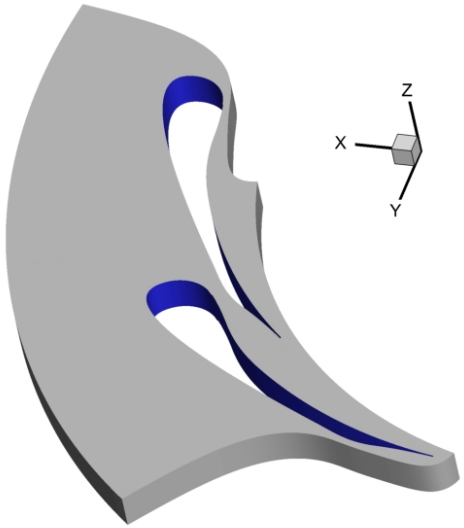
The Beauty of Unknown

- Ever increasing complexity in turbomachinery design
- Need for disruptive shapes to improve efficiency

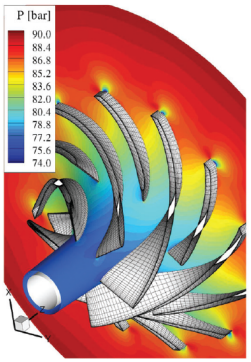
Courtesy of Rolls-Royce

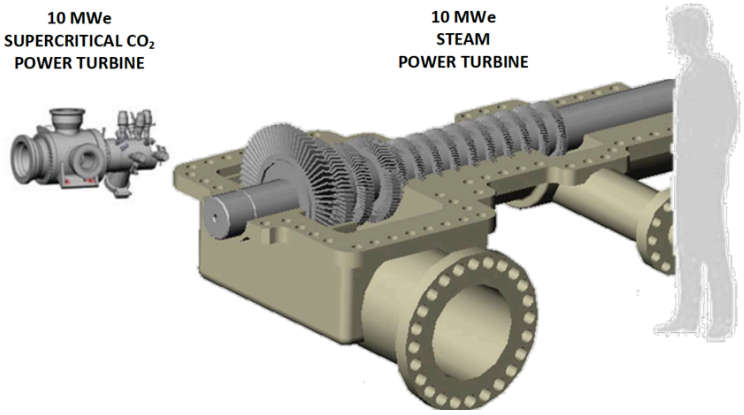
Unconventional Turbomachinery

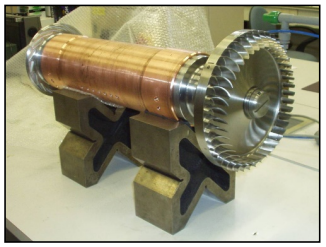
- Large interest for renewable power (ORC, $scCO_2$, …)
- NICFD greatly complicates turbomachinery design

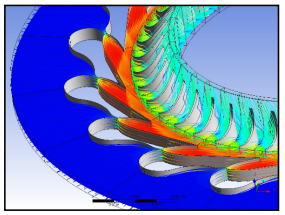


ORCHID stator, P&P









Courtesy of Triogen

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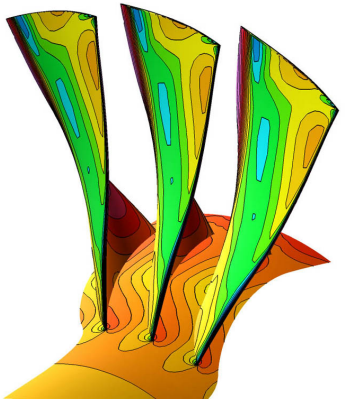
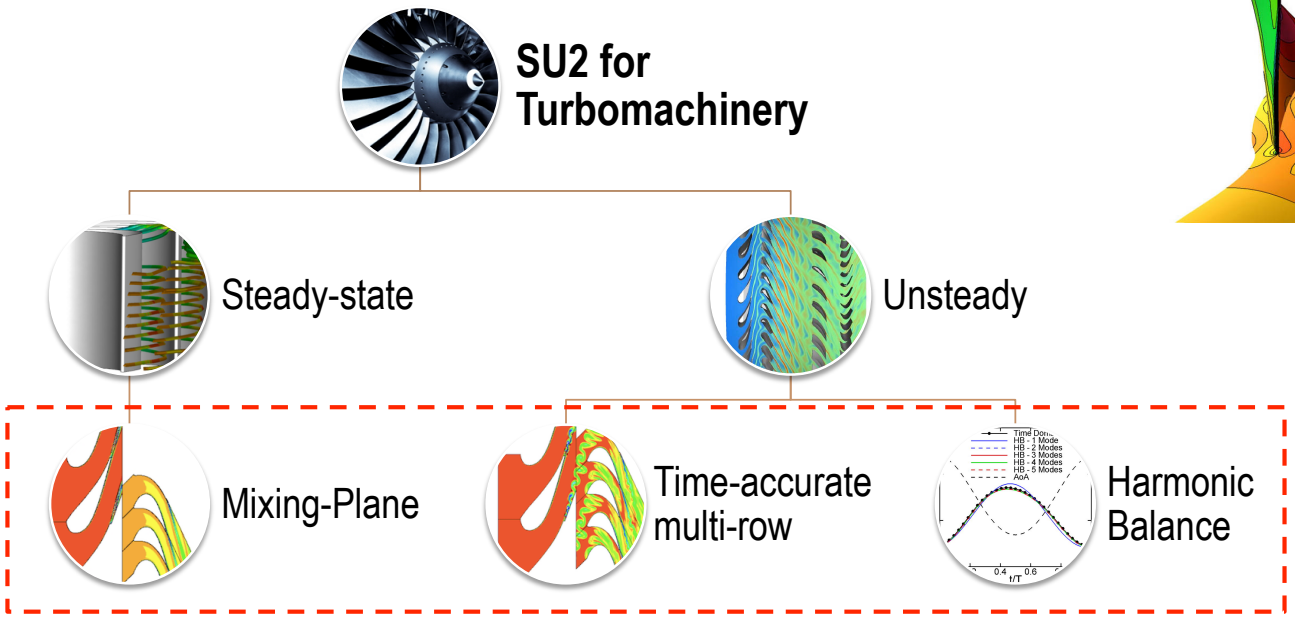
What do we need for this?

SU2
The Open-Source CFD Code

- **Analysis capability** (massively parallel)
- **Tightly integrated design capability**
- Automated, cheap, and flexible optimization algorithms
- Integration with other tools for MDAO
- Open environment to implement new knowledge

Development Roadmap





Devise automated design capability for steady and unsteady flows including non-ideal thermodynamics and multi-row interactions

STEADY-STATE COMPUTATION

Methodology

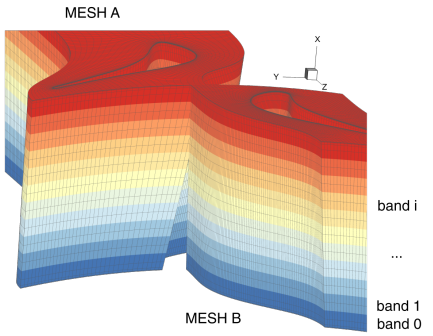
Single Cascade and Mixing-Plane

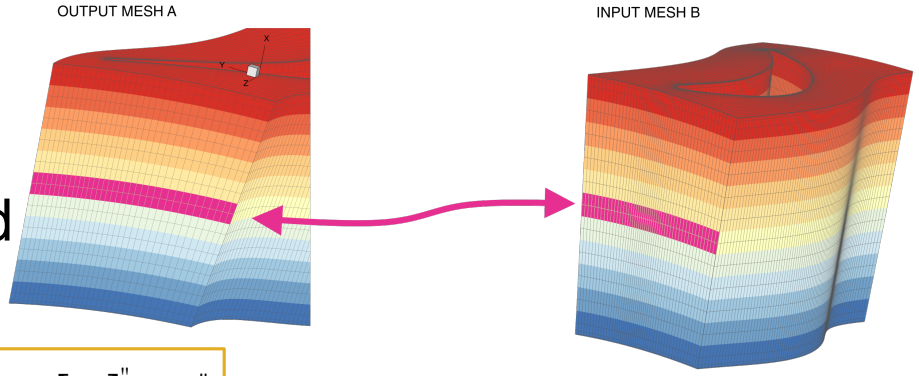
- New vertex structure for different turbo architectures (e.g. axial, radial)
- Non Reflecting Boundary Conditions for NICFD
- Flux-Conservative Mixing-Plane
- Steady-state Discrete Adjoint formulation for single blade and multi-stage

Methodology

Mixing-Plane Interface

- Global ordering span-wise
- Ordering pitch-wise
- Parallelized
- General for unstructured grid





$$1)\ \Delta C = [\Lambda]' \underbrace{\Delta C'}_{[L]_{\text{prim}}\Delta P} + [\Lambda]'' \Delta C''$$

$$2)\ \Delta P_{\text{b}} = [R]_{\text{cons}} \Delta C$$

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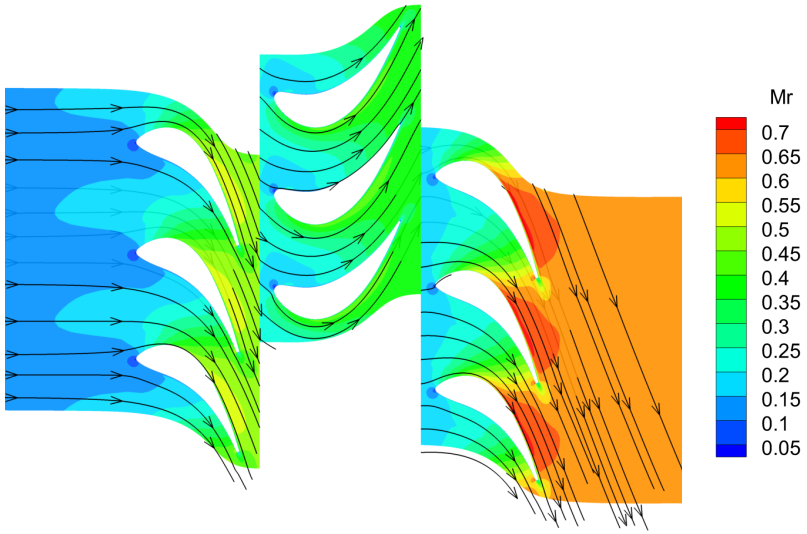
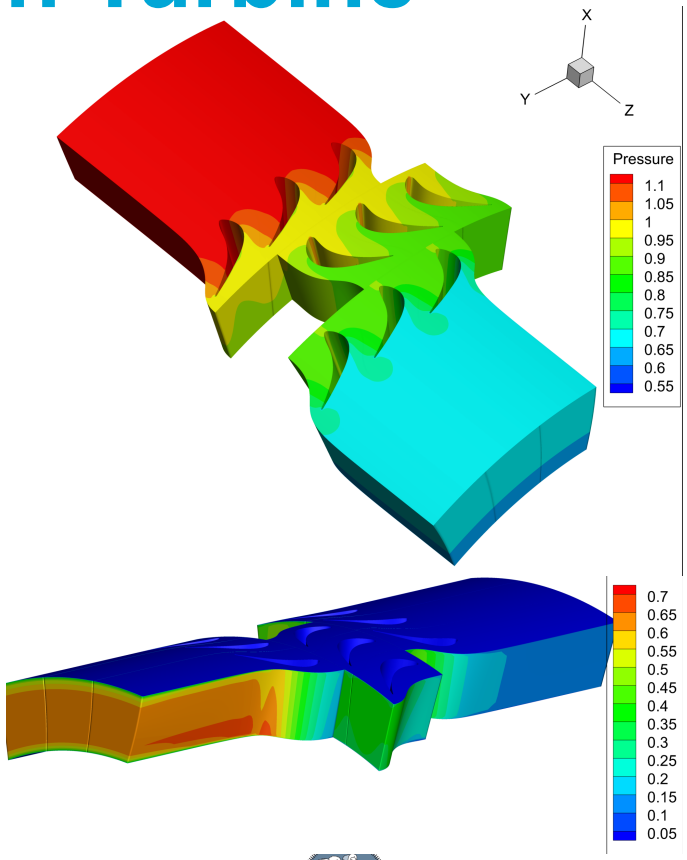
Verification: Aachen Turbine

- 1.5 lab turbine stage
- Used for CFD validations





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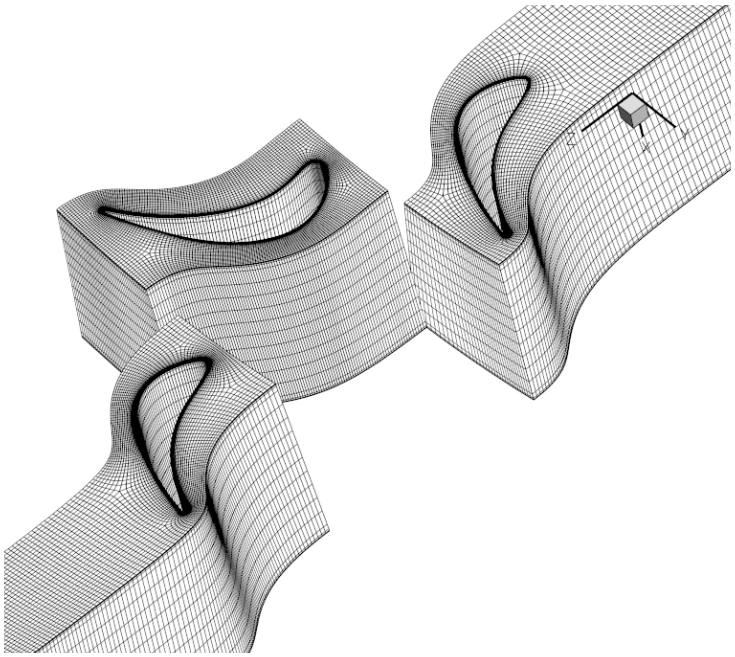
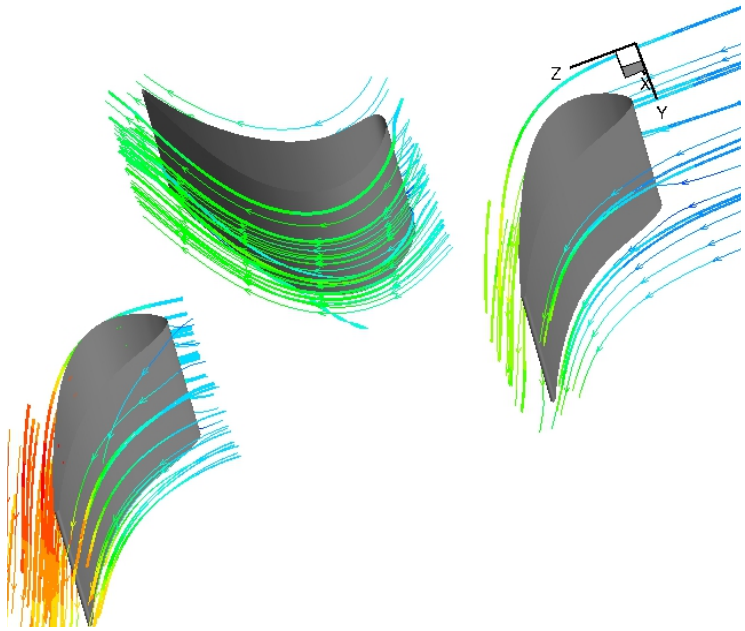
Flow Analysis

Aachen Turbine - Mixing-Plane 3D 1.5 stage

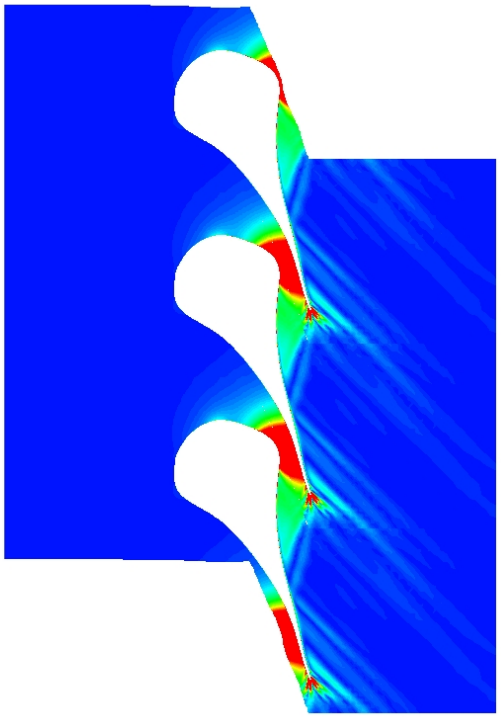


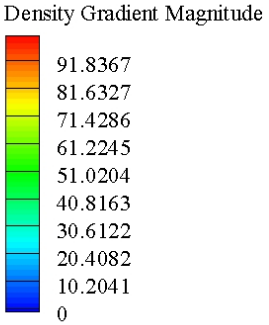


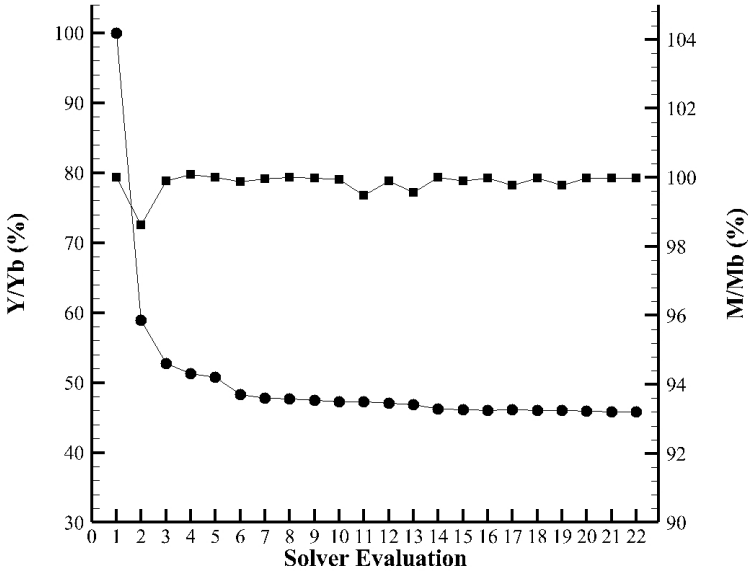
Mass Flow Diff. 0.01%

Optimization

Supersonic ORC cascade







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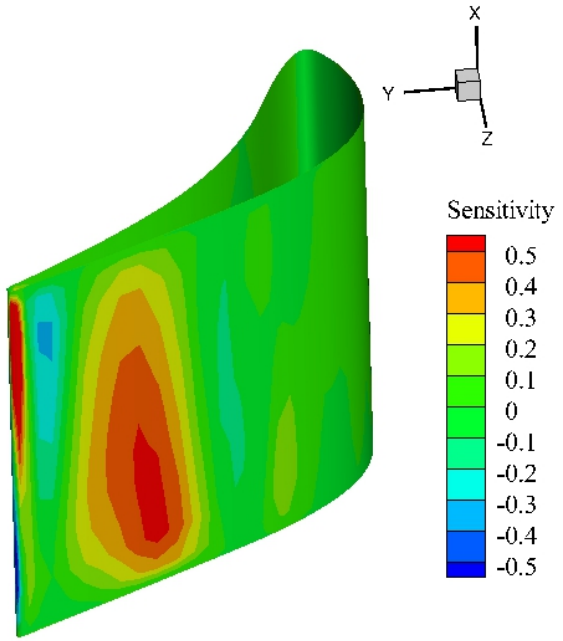
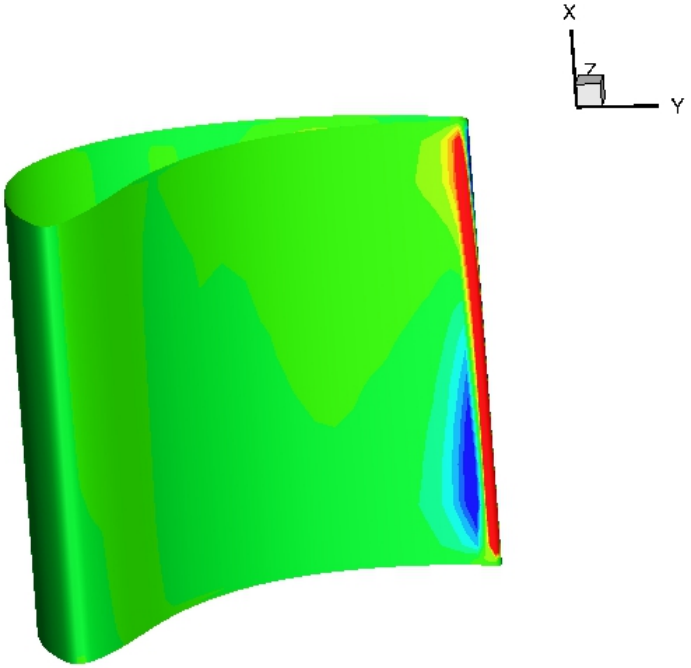
Optimization

Adjoint sensitivity 3D cascade





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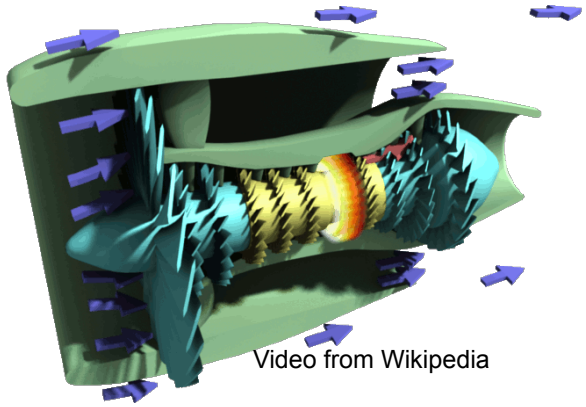
UNSTEADY COMPUTATION (Time-accurate)

Methodology

Sliding Mesh Interface



Video from Wikipedia

Time-accurate simulations for applications involving rotating parts can be achieved via a sliding mesh approach

Sliding mesh approach is key to turbomachinery simulation whenever sections, or part, of the computational grids move in time

Where are we now?

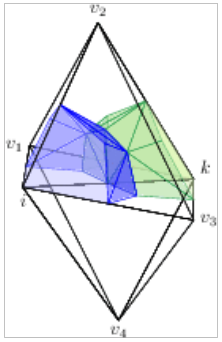
Nearest neighbor approach

Supermesh approach by Rinaldi et al. (2015)

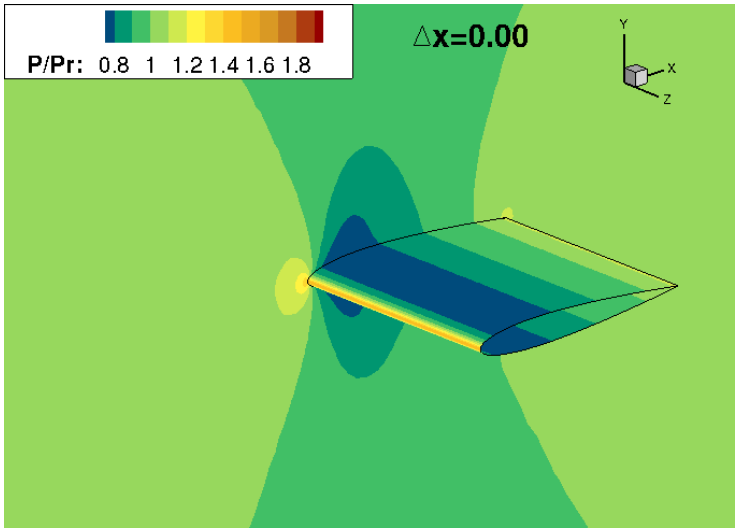
An inviscid fluid flows through rotating sections. The fluid moves at different Mach number: M = 3, red region, and M = 1.5, blue zone.

Where do we want to get?

Local mesh adaptation at sliding mesh interfaces to obtain conformity and thus guarantee the conservation of quantities plus higher accuracy



Workplan: local conservative adaptation at sliding interface in collaboration with Edwin van der Weide (TU Twente)



ALE (Arbitrary Lagrangian Eulerian) adaptation Approach of Re, Dobrzynsky, Guardone (2016)

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UNSTEADY COMPUTATION (Reduced Order Models)

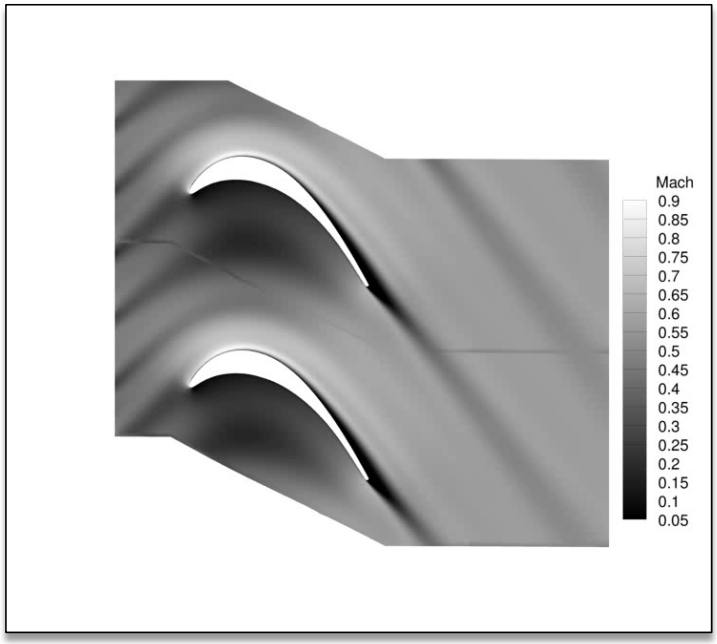
Methodology

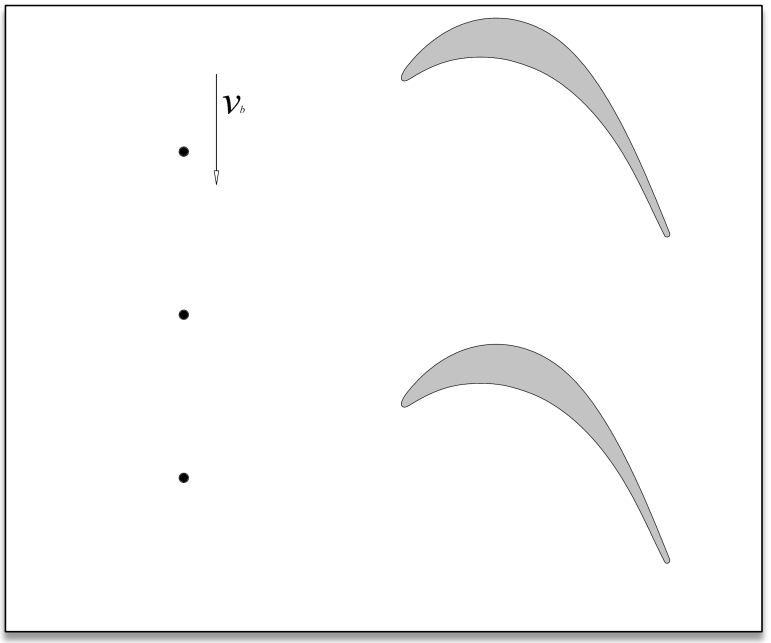
Turbomachinery TimeSpectral and HB in a nutshell…

- Unsteady → Steady State + Source terms
- Solve just for blade passing frequency harmonics
- DFT to obtain interpolated time accurate solution
- Steady-state Discrete Adjoint formulation extended to multi-zone “in time” for unsteady shape optimization

Application

Wake-rotor interaction





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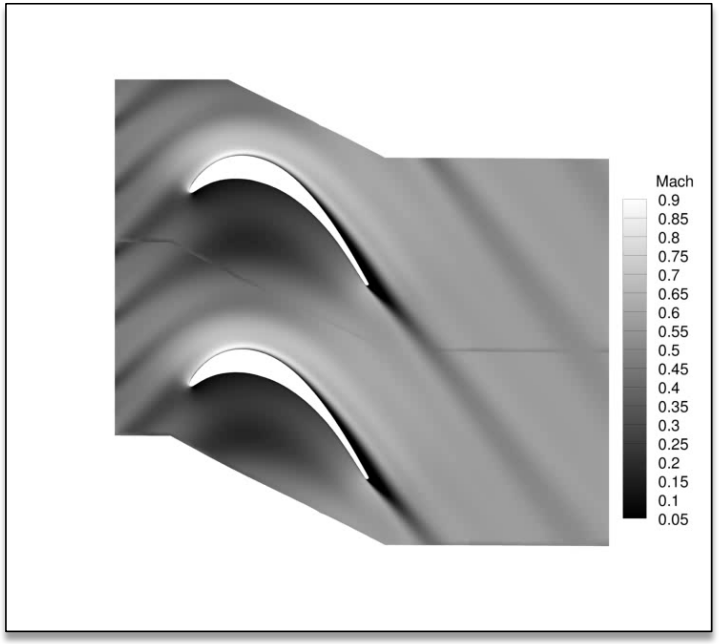

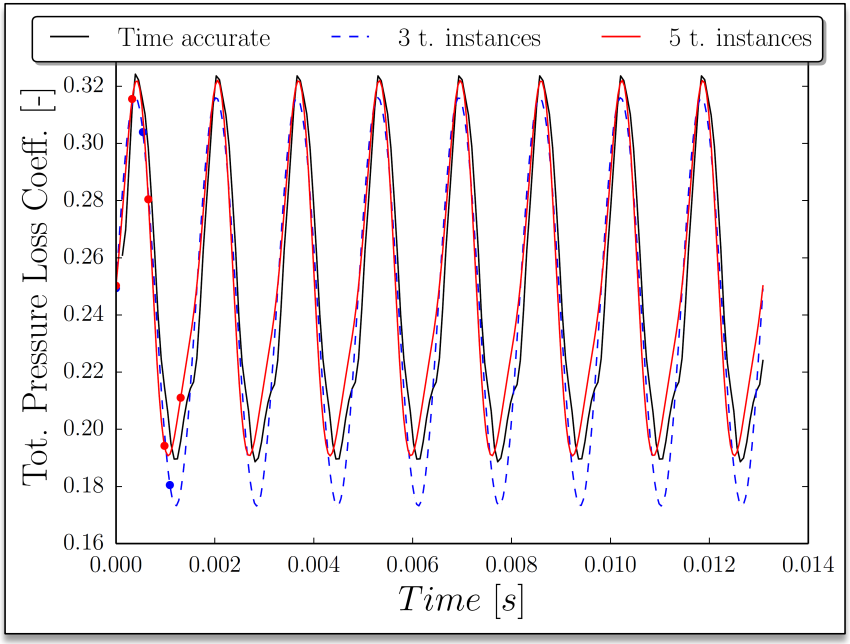

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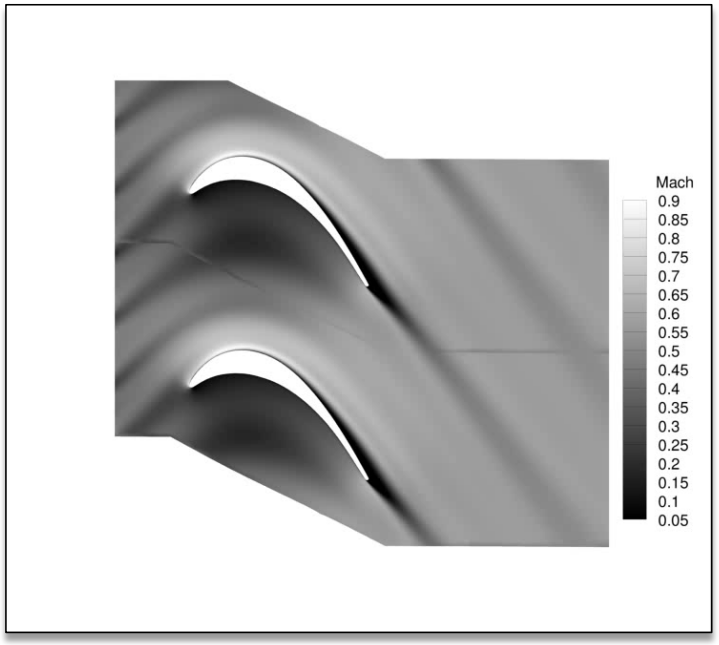

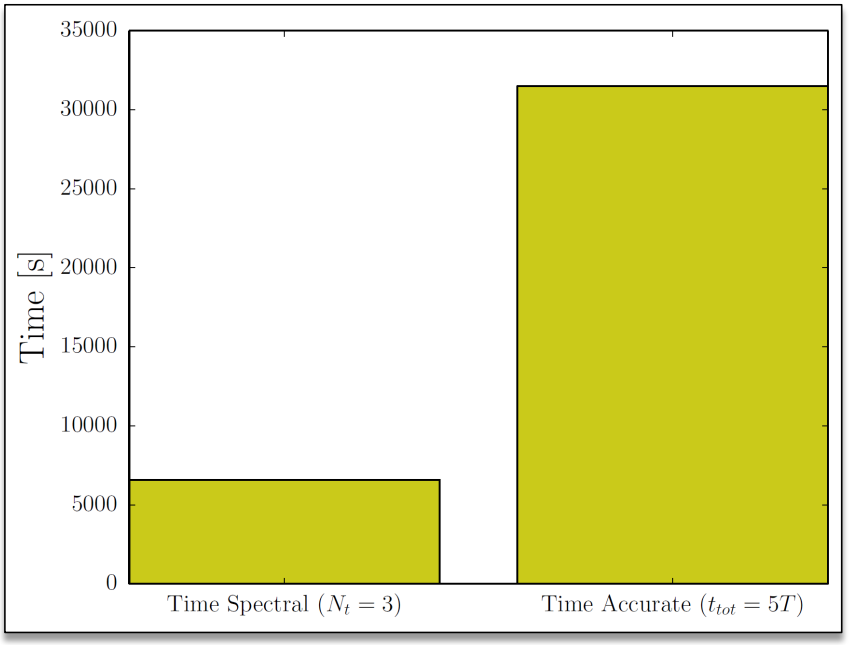

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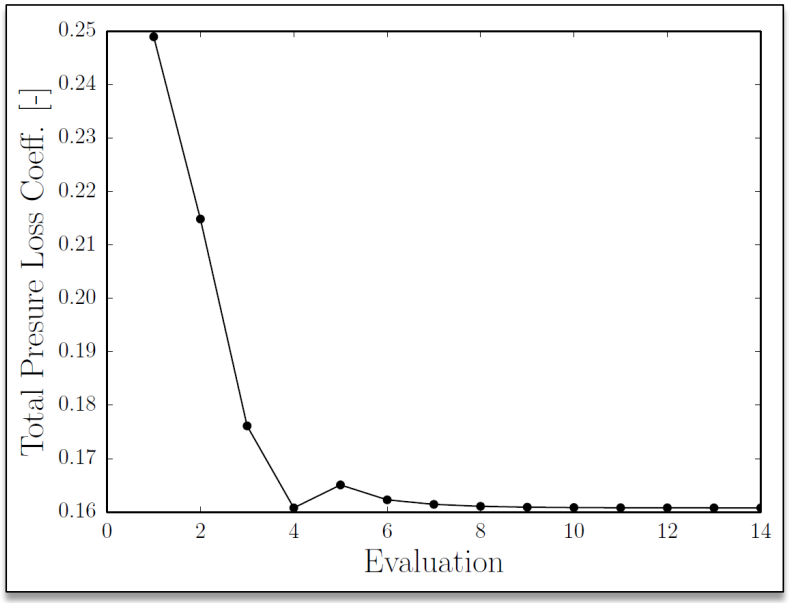
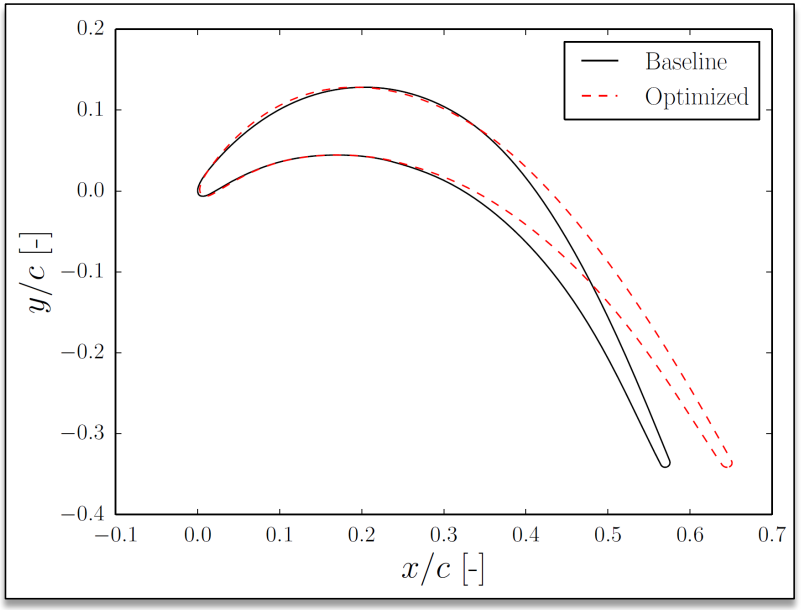
Optimization

Wake-rotor interaction – Discrete Adjoint





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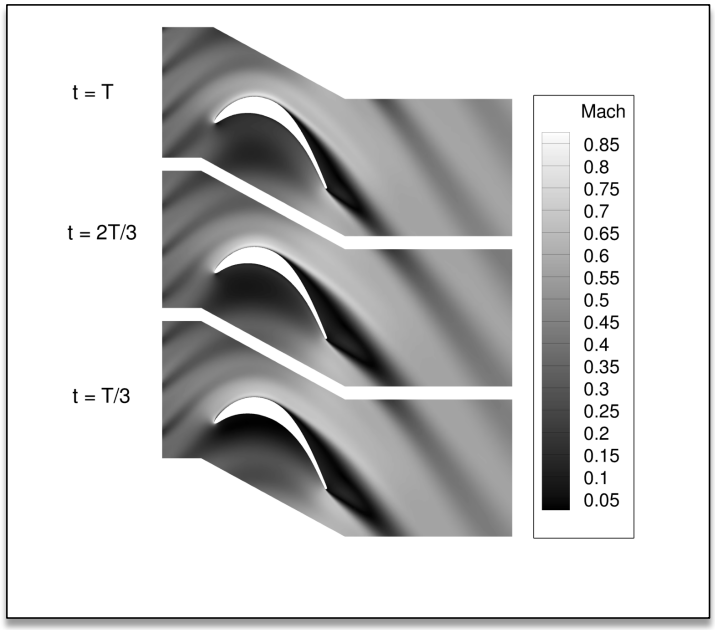
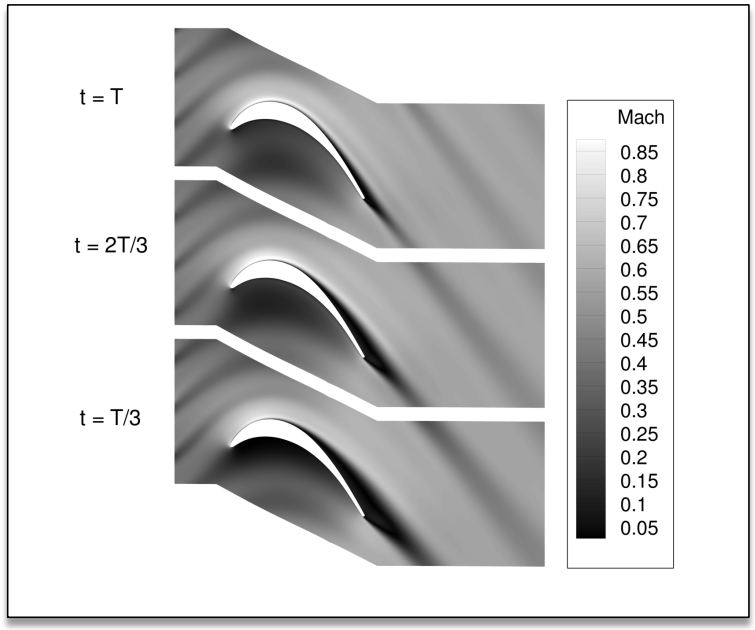
Optimization

Wake-rotor interaction – Optimized TS solution





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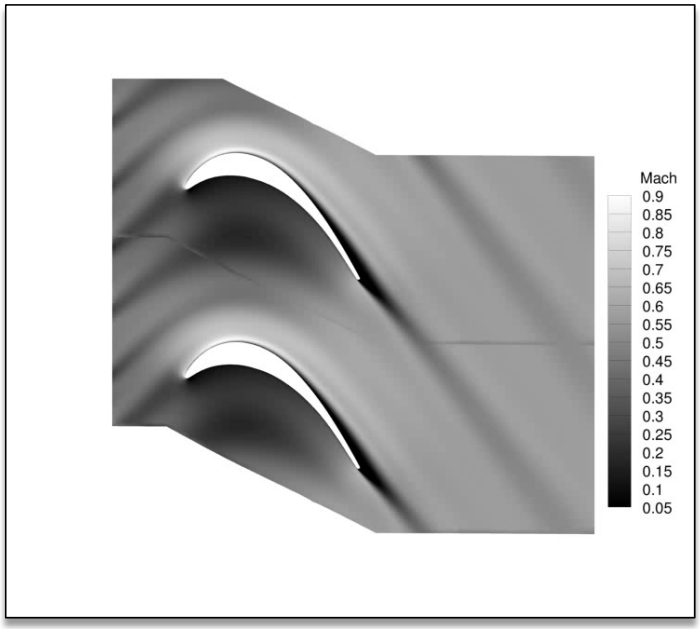
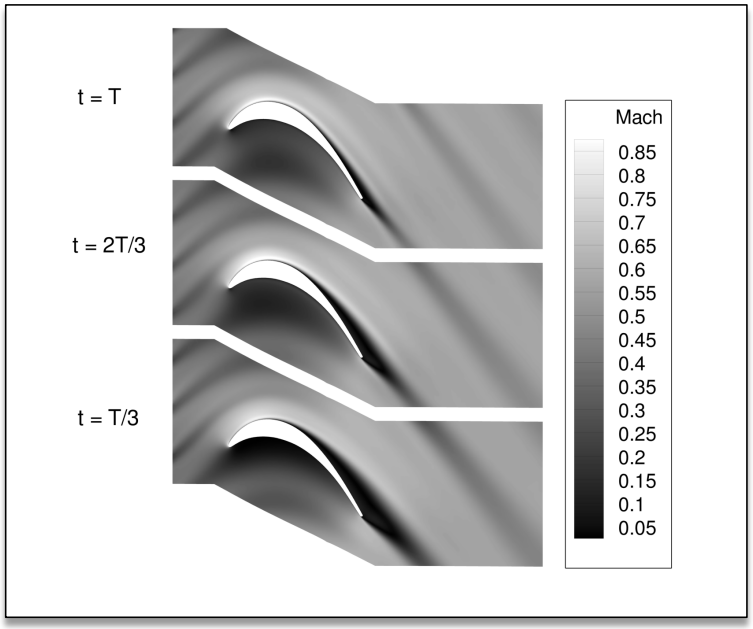
Optimized Time-Accurate vs Time Spectral solution





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Future Directions

- Extensive V&V campaign → industrial test cases
- Higher fidelity → 3D multi-rows (unsteady)
- 3D steady and unsteady design capability
- **SU2 release for turbomachinery** (v. 5.0?)

Thank you!