Simulation of Combustion Noise Using Nektar++ APESolver

Kilian Lackhove

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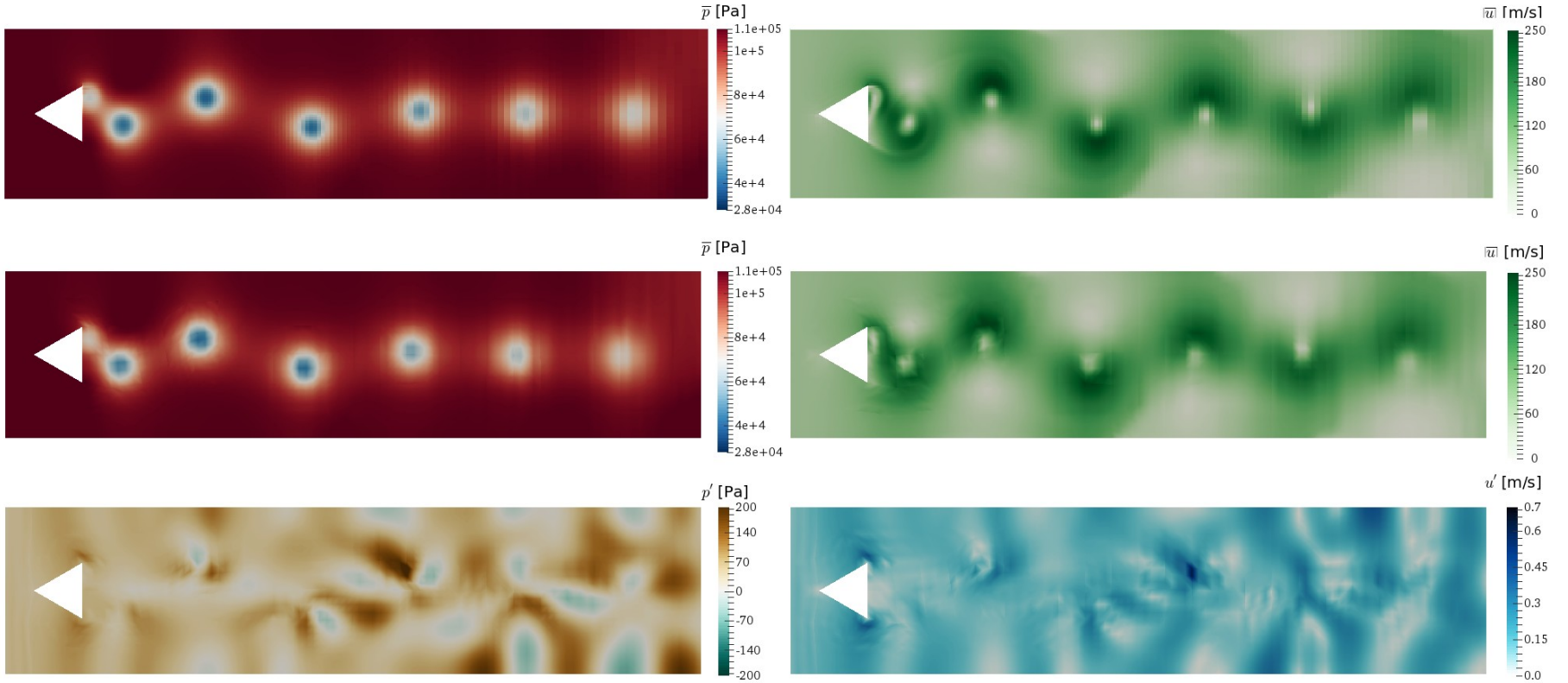

Outline

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- Introduction
- APESolver
- Coupling
- Summary & Outlook

RECORD Project

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RECORD

Research on **Co**re Noise **R**e**d**uction

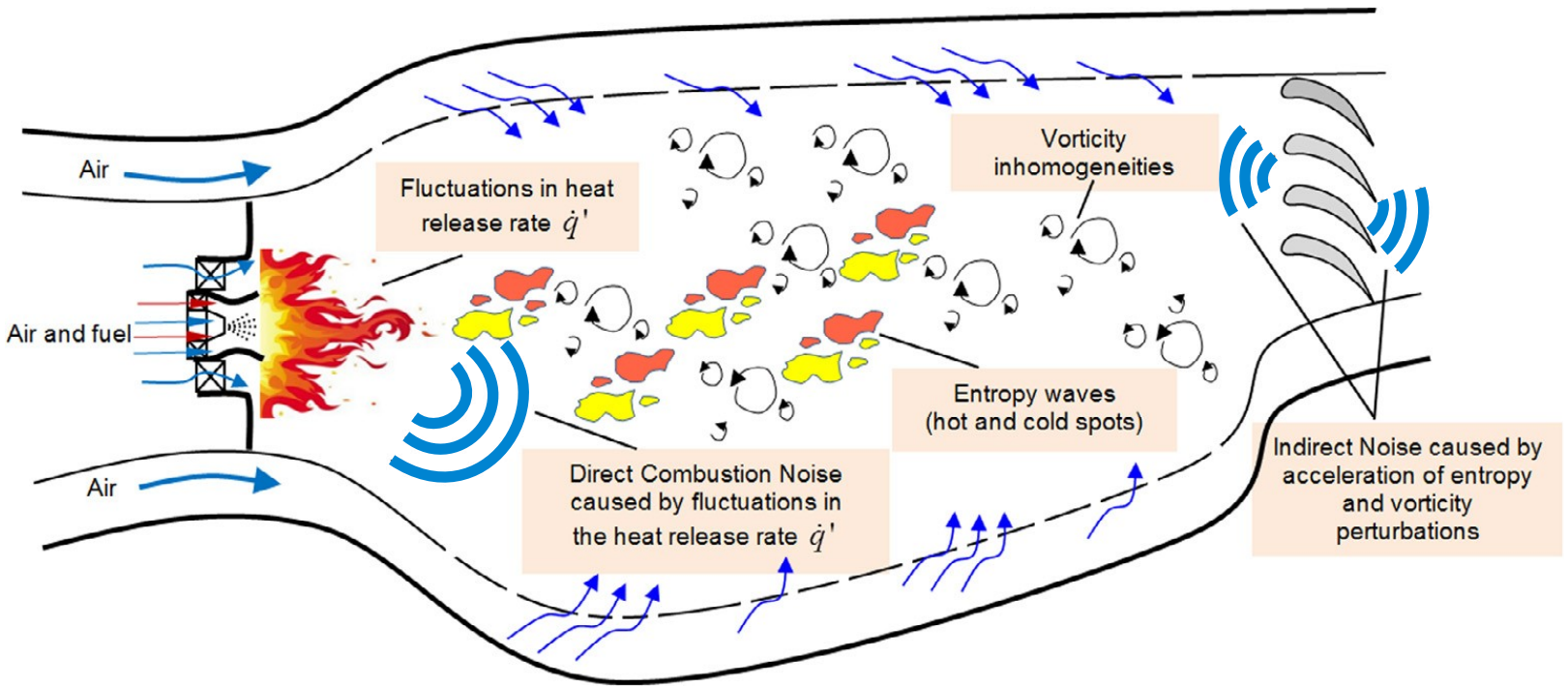
SEVENTH FRAMEWORK PROGRAMME

Partners

CNRS, AVIO, CERFACS, ONERA, Rolls-Royce Deutschland, Rolls-Royce UK, Turbomeca, Technische Universität Darmstadt, Technische Universität München, University of Cambridge

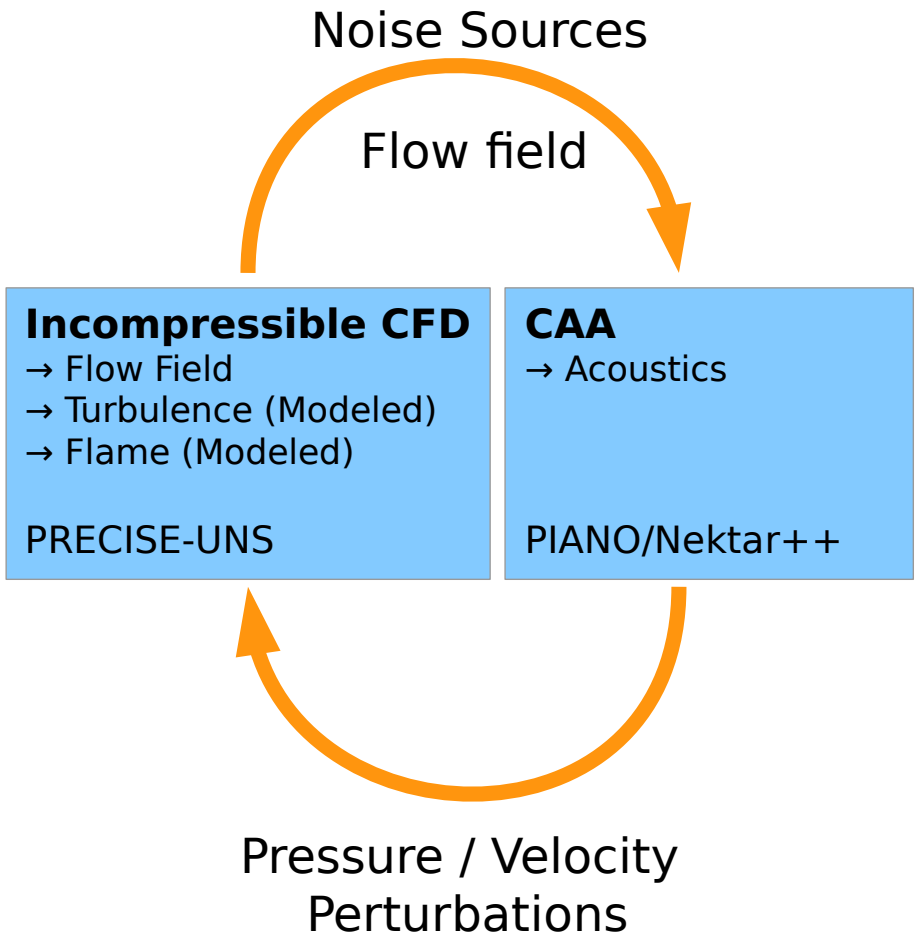
Improvement and validation of core noise modeling methods

Core Noise



Dowling, A. P., & Mahmoudi, Y. (2015). Combustion noise. In Proceedings of the Combustion Institute (Vol. 35, pp. 65–100). San Francisco

Coupled/Hybrid approach



Advantages

- Larger time steps → Reduced computational effort
- Best numerical schemes for each situation
- CAA and CFD domain can be different
- Use of proven tools

Challenges

- Two-way coupling is an open scientific question

Why Nektar++?

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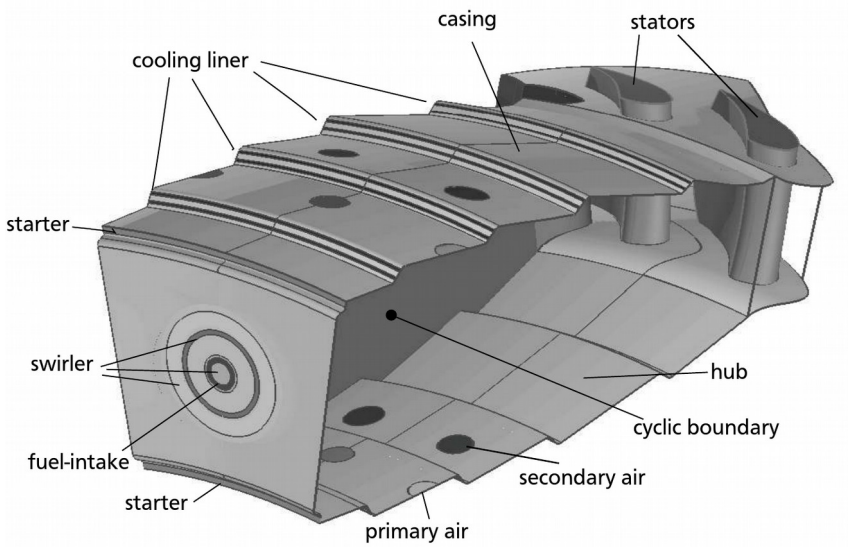
Spectral/hp Element Method

- Low Dispersion Error → High Order
- Unstructured Grid

Nektar++

- APE Solver Already Present
- Fast and Robust
- Actively Developed



Klapdor, V. (2011). Simulation of Combustor-Turbine Interaction in a Jet Engine. TU-Darmstadt.

APESolver

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APESolver

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- **C**omputational **A**ero **A**coustics
- Governing Equations: **A**coustic **P**erturbation **E**quations 1/4
- Deived from linearising the Euler Equations around a base state

$$\frac{\partial p'}{\partial t} + \bar{c}^2 \frac{\partial \bar{\varrho} u_i'}{\partial x_i} + \bar{c}^2 \frac{\partial \bar{u}_i p'/\bar{c}^2}{\partial x_i} = \bar{c}^2 q_c$$

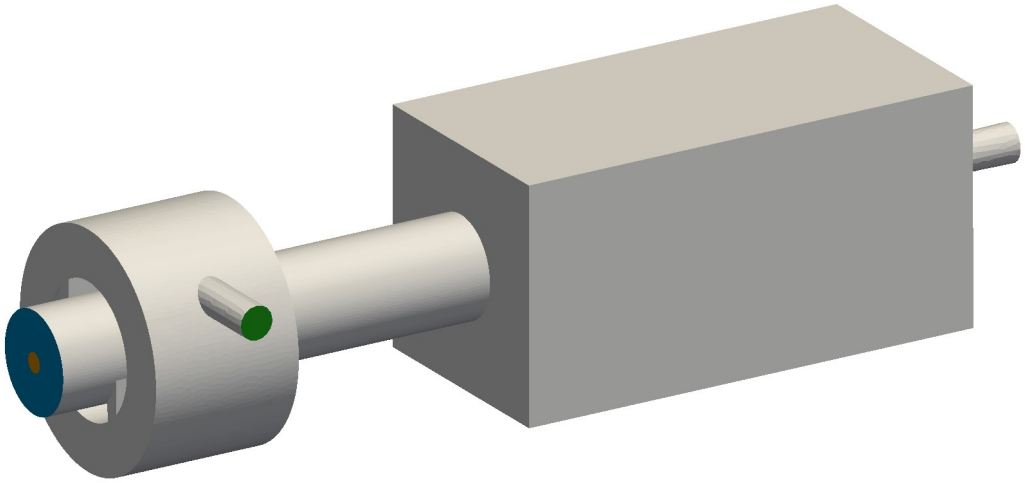
$$\frac{\partial u_i'}{\partial t} + \frac{\partial \bar{u}_j u_j'}{\partial x_i} + \frac{\partial p'/\bar{\varrho}}{\partial x_i} = U_i$$

Current Features

- 1D/2D/3D
- DG Projection only
- Exact & Lax-Friedrichs Riemann Solver
- BCs: Rigid Wall (Slip) and Open End

APESolver: 3D

- **Ported** `APE` and `APESystem` classes to `UnsteadySystem`
  - → Filters
  - → Simplified Code
  - → **Parallel**
- **DG** Projection only
- **Lax-Friedrichs** Riemann Solvers
- Extended APE class to account for **1D/3D** problems



APESolver: Variable Speed of Sound

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Original APE4-Equations

$$\frac{\partial p'}{\partial t} + \bar{c}^2 \frac{\partial \bar{\varrho} u_i'}{\partial x_i} + \bar{c}^2 \frac{\partial \bar{u}_i p'/\bar{c}^2}{\partial x_i} = \bar{c}^2 q_c$$

New Implementation

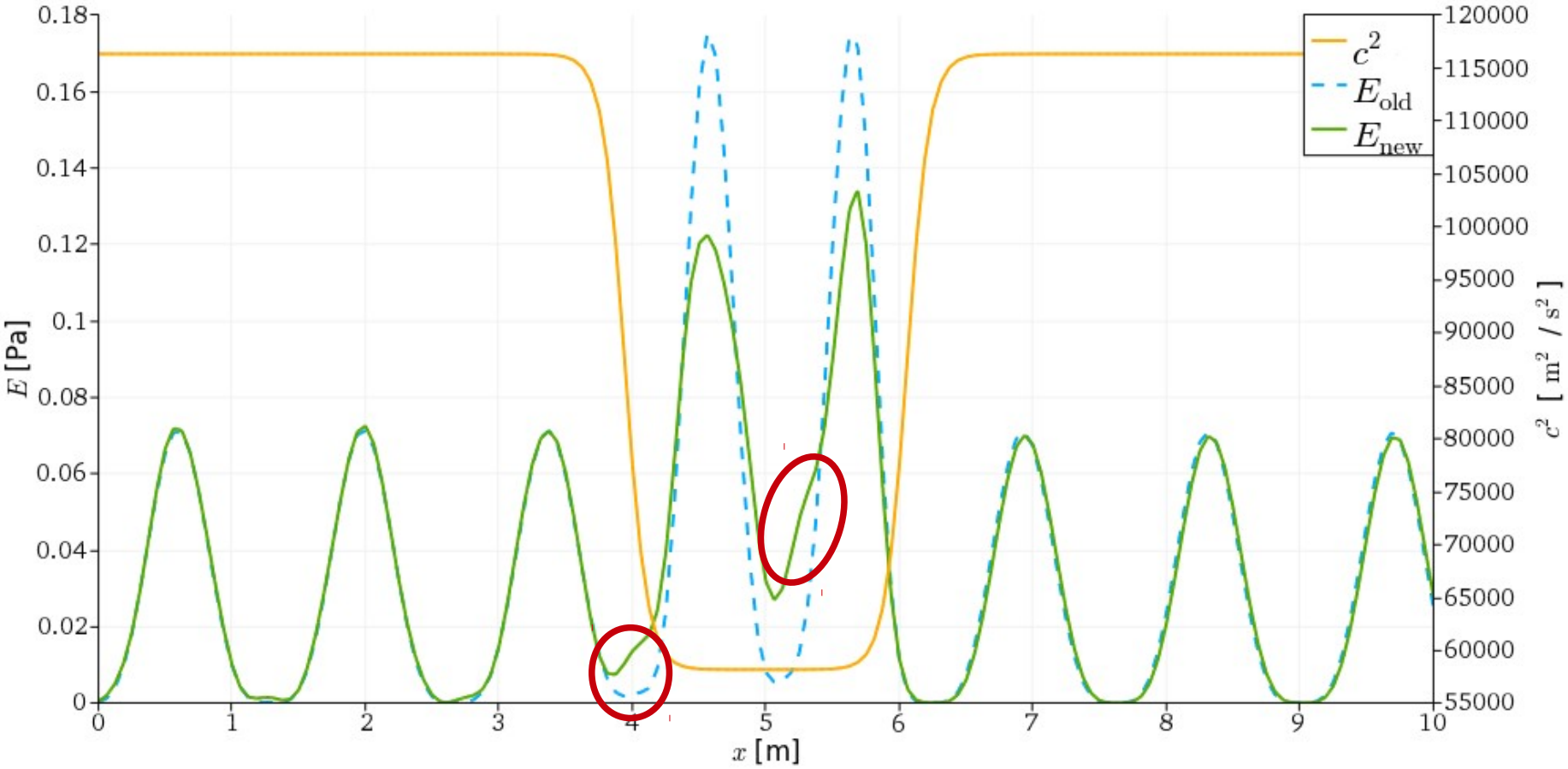
const $\bar{c}^2$

$$\frac{\partial p'}{\partial t} + \frac{\partial \bar{c}^2 \bar{\varrho} u_i'}{\partial x_i} + \frac{\partial \bar{u}_i p'}{\partial x_i} - \left(\bar{\varrho} u_i' + \frac{1}{\bar{c}^2 \gamma^2} \bar{u}_i p' \right) \frac{\partial \bar{c}^2}{\partial x_i} = \bar{c}^2 q_c$$

$$\frac{\partial p'}{\partial t} + \frac{\partial \bar{c}^2 \bar{\varrho} u_i'}{\partial x_i} + \frac{\partial \bar{u}_i p'}{\partial x_i} = \bar{c}^2 q_c$$

Original Implementation

APESolver: Variable Speed of Sound



Coupling

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Nektar++: Interpolation

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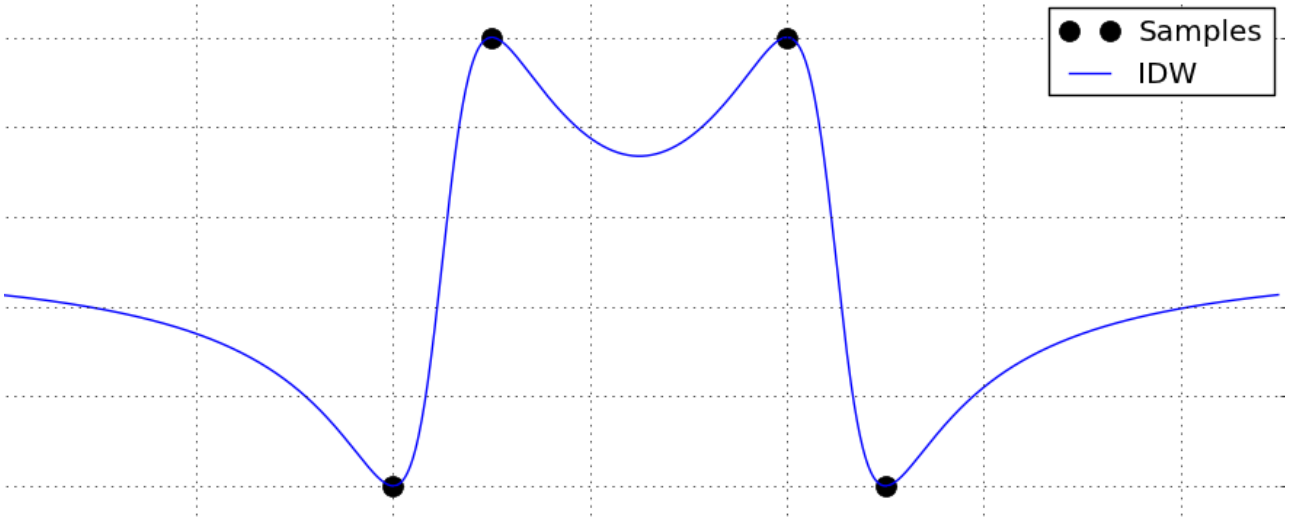
Interpolation

- CFD Cell Centers → Quadrature Points
- Inverse Distance Method (modified Shepard)
- Cached Weights
- Brute Force Algorithm→ First time step is slow



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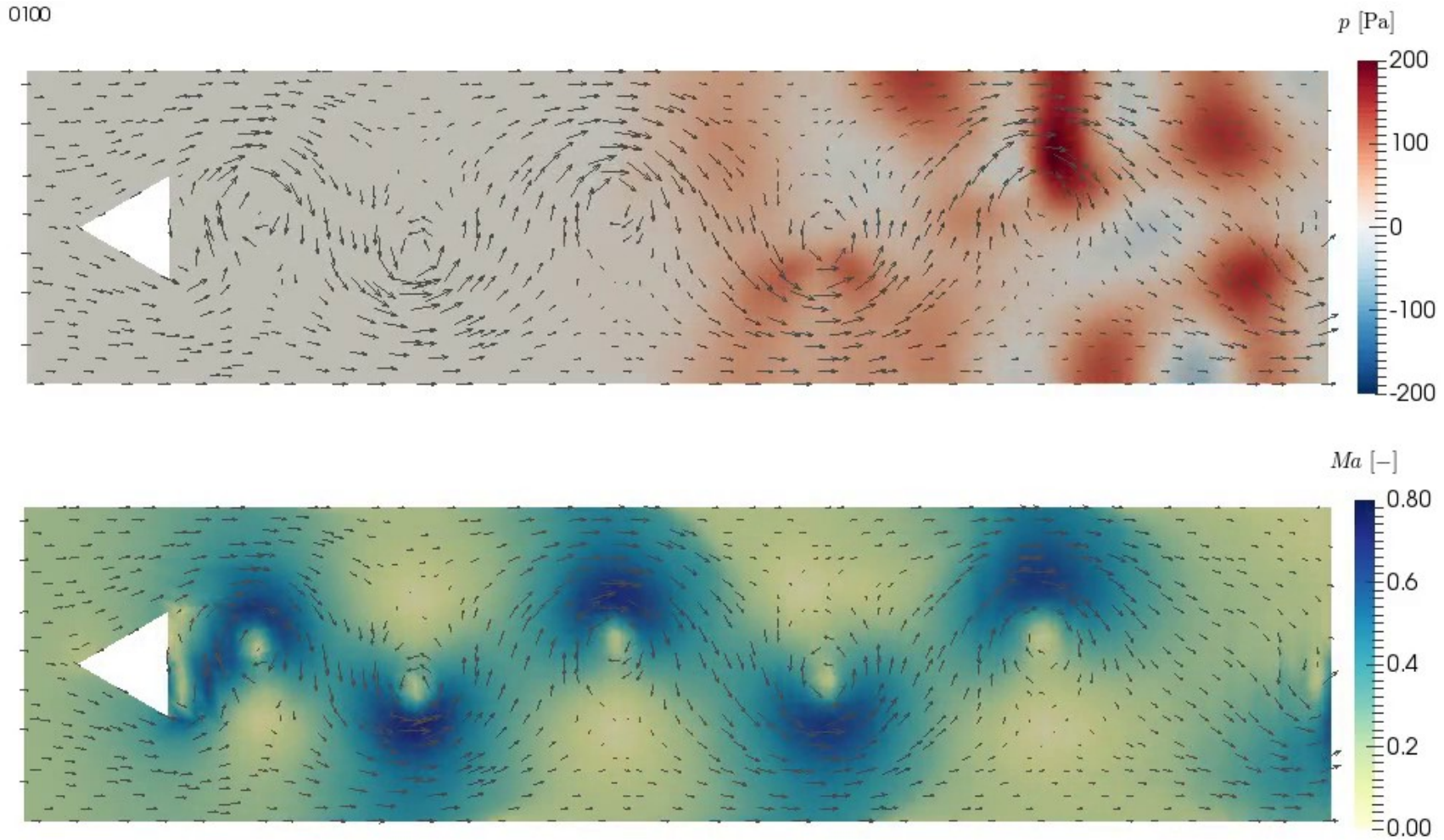
Nektar++: Interpolation



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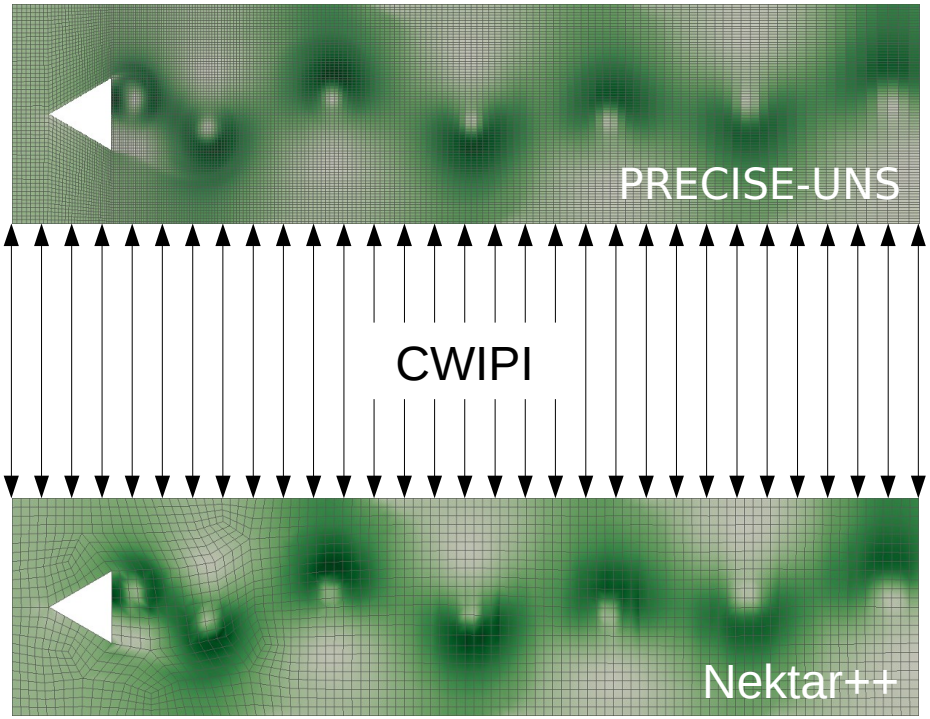
CWIPI

- Open Source (LGPL 3.0)
- C++ Library
- Developed at CERFACS, used for various projects
- Based on OpenMPI
- Decentralized
- 2nd Order Interpolation
- Handles non-conforming domains



Coupling: Example

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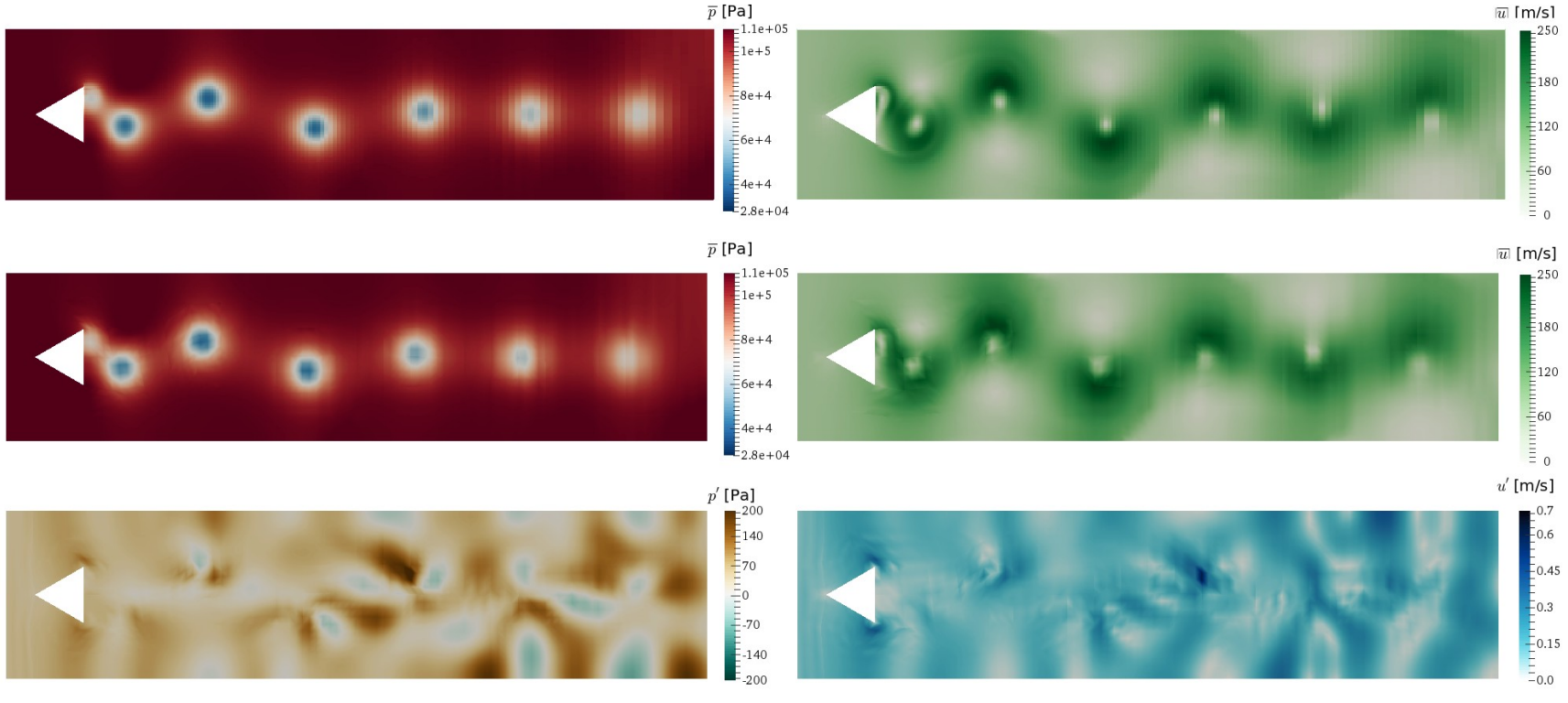
pressure

velocity

PRECISE

Nektar++



Summary & Outlook

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Summary

- RECORD: Improvement of Core Noise Modeling methods
- Hybrid Approach: Incompressible CFD + CAA
- APESolver: SMP & 3D, Variable Speed of Sound
- Nektar++: Timedependent Base Flow Fields, Shepard Interpolation

Outlook

- Large CAA of a Combustor Section
- Finish Noise Source Interpolation
- Backwards Coupling
- More Elaborate Boundary Conditions