Airbus Amber

Recent Developments in Waves Simulation

JOSO 2025

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Outline

– Industrial Context
– Waves Applications
– Overview of current works
From formulations…
… to HPC solvers
– Perspectives & Conclusion

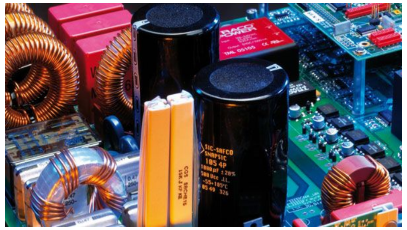
Airbus CRT (Central Research & Technology)

- Cross-divisional R&T organization
- Preparing the company's long-term technological capabilities
- ~160 people (60% PhDs)
- Located in 3 countries

6 CRT sites in Germany, France, UK

- 5 domains:

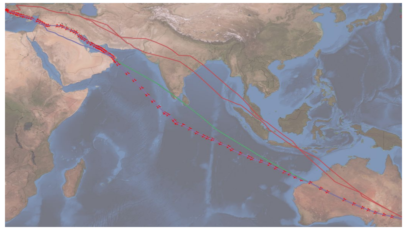
ELECTRIFICATION



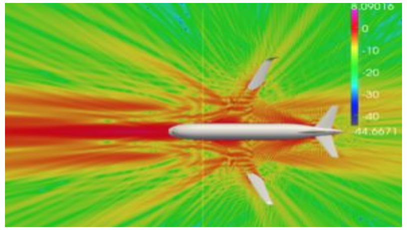
COMMUNICATION TECHNOLOGIES

MATERIALS

ARTIFICIAL INTELLIGENCE



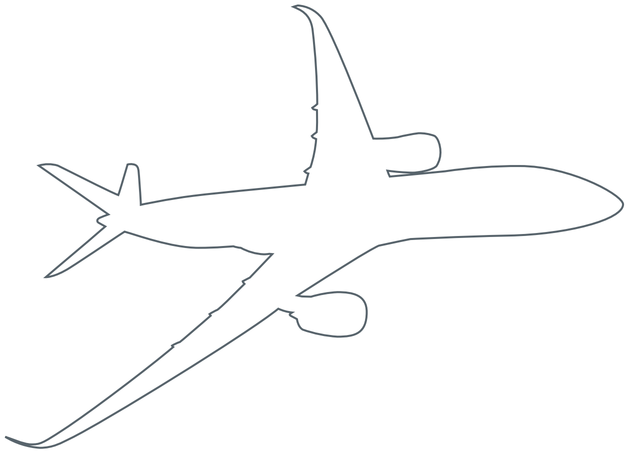
VIRTUAL PRODUCT ENGINEERING



Virtual Product & Engineering

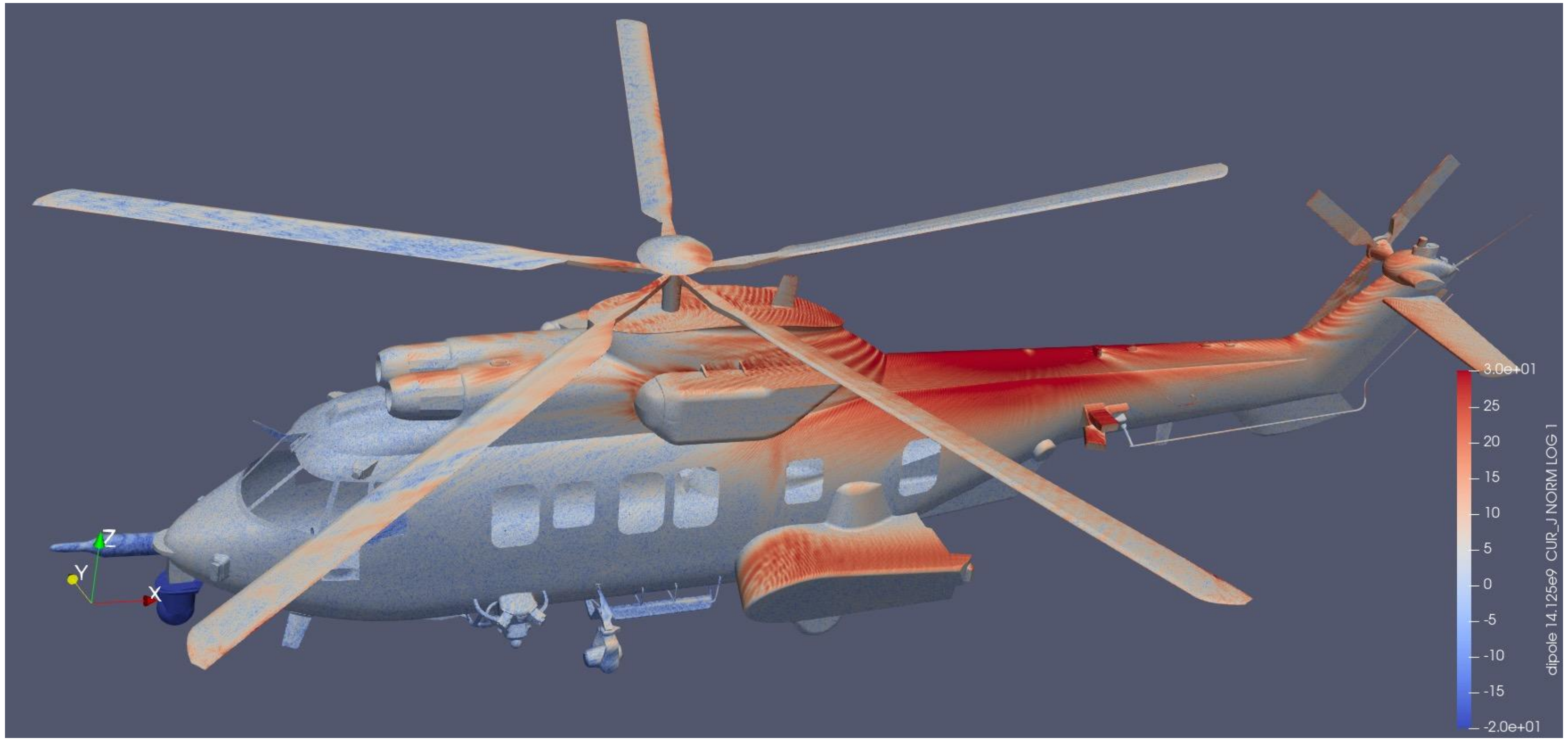
- Upstream research in modelling and simulation for our products, systems and operations.
- ~40 peoples

- Human Focused Technology
- Systems Engineering
- **Modeling**
- **Computing for Simulation**
- **Applied Mathematics for Modeling & Simulation**



Waves Applications @ Airbus

- Electromagnetism: Antenna placement, EMC, RCS
- Acoustics: Noise propagation around aircrafts
- CRT position: not in competition with commercial softwares



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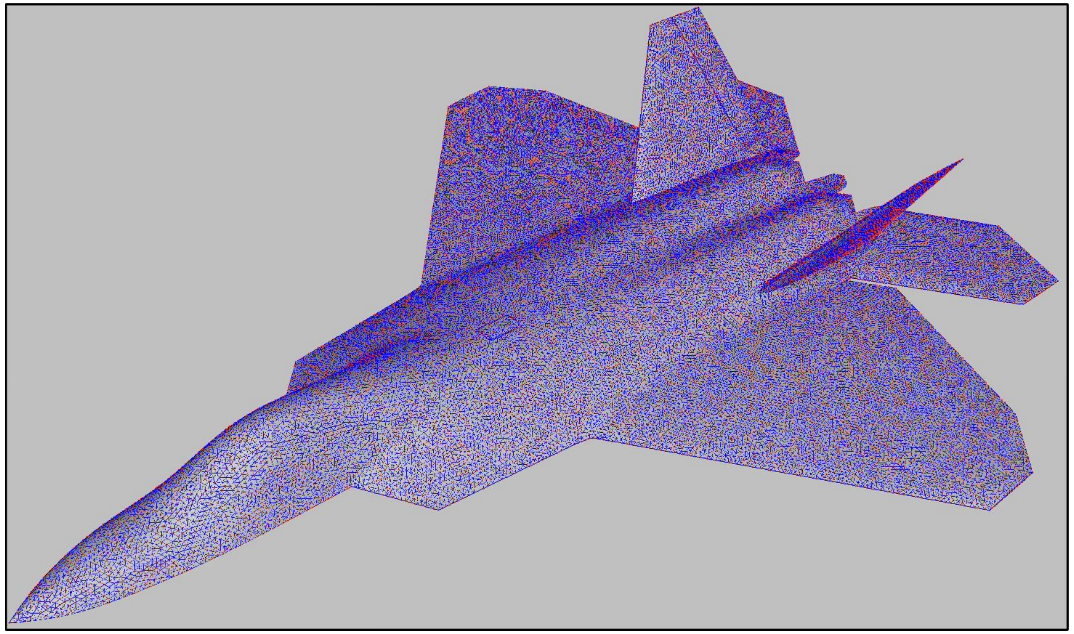
Mathematical Formulation

- Problems of similar sizes in both physics
- Integral Equations solved by Boundary Element Method
  + extra “refinements” when needed
- Advantages: Accuracy, easier to mesh.
- Drawbacks: dense linear system, only homogeneous propagation media.



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Existing Methods & Tools

- **BEM** formulation coupled with (volume) **FEM** formulation for heterogeneous parts
- Fast dense solver using **Hierarchical** Matrices (or FMM, but not in this talk !)
- Using High Performance Computing

Limitations / Difficulties

- Scalability (for H-matrix)
- Modelling of heterogeneous domains
- Modelling/meshing of complex details

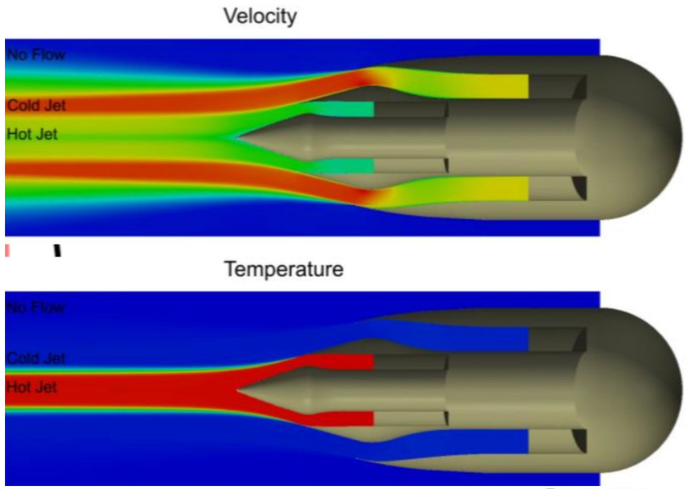
Active Researches

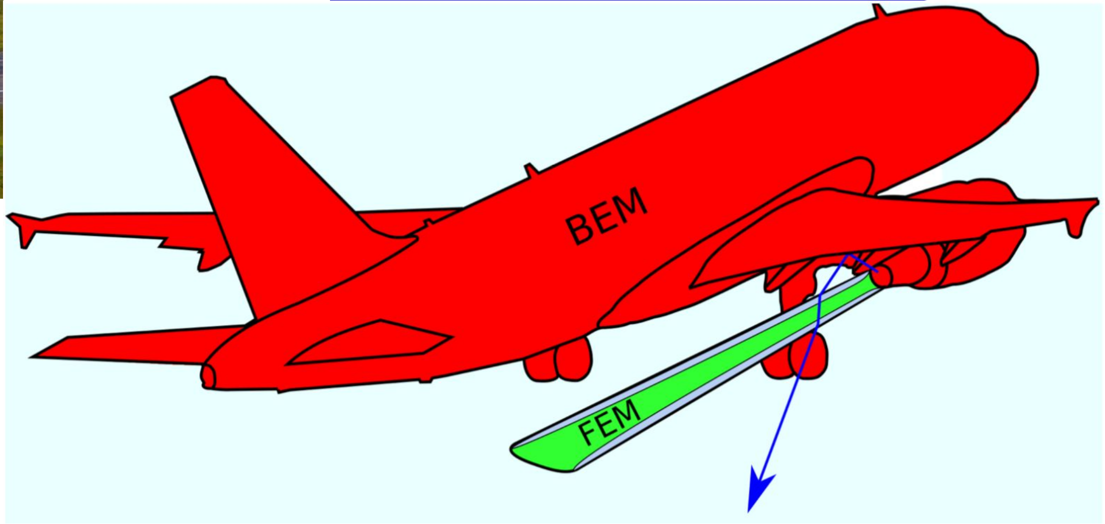
Working at different levels:

- Formulation/Modelisation
  - Quasi-Trefftz Discontinuous Galerkin Method
- Meshing / Data preparation
  - Learning Based Rank Estimator
  - Learning Approach to Geometry Simplification
- Solver / Hybridization of solvers
  - Upgrading H-matrix solver
  - Composability applied to FEM-BEM Coupling

Quasi-Trefftz Discontinuous Galerkin Method

- Application : wave propagation in partly homogeneous / partly heterogeneous domains (Jet flow, boundary layer)





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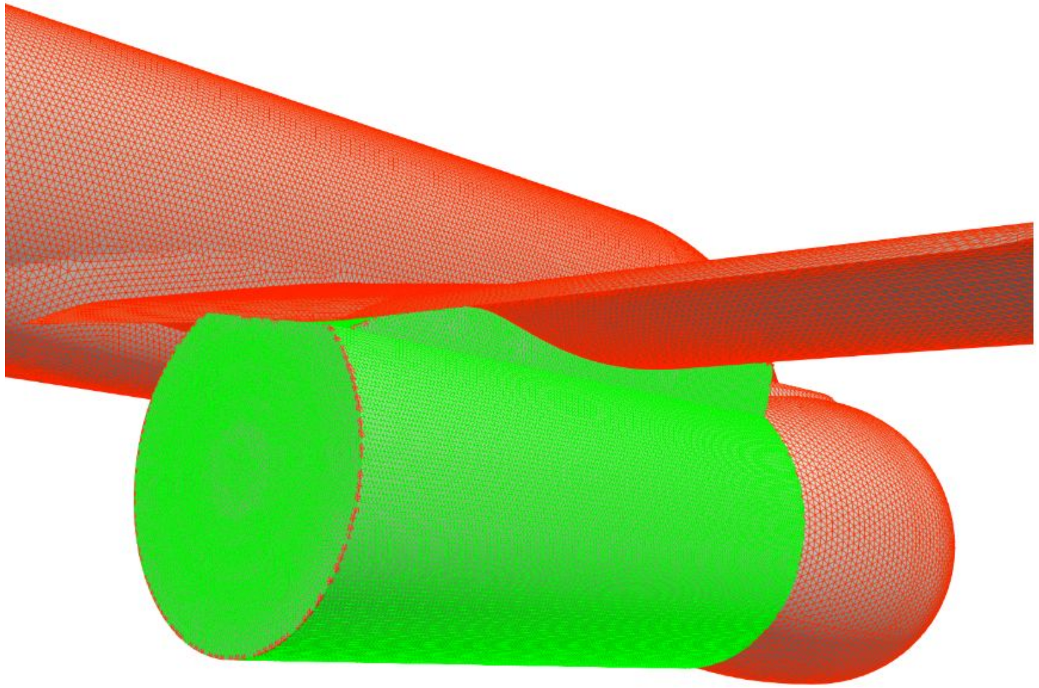
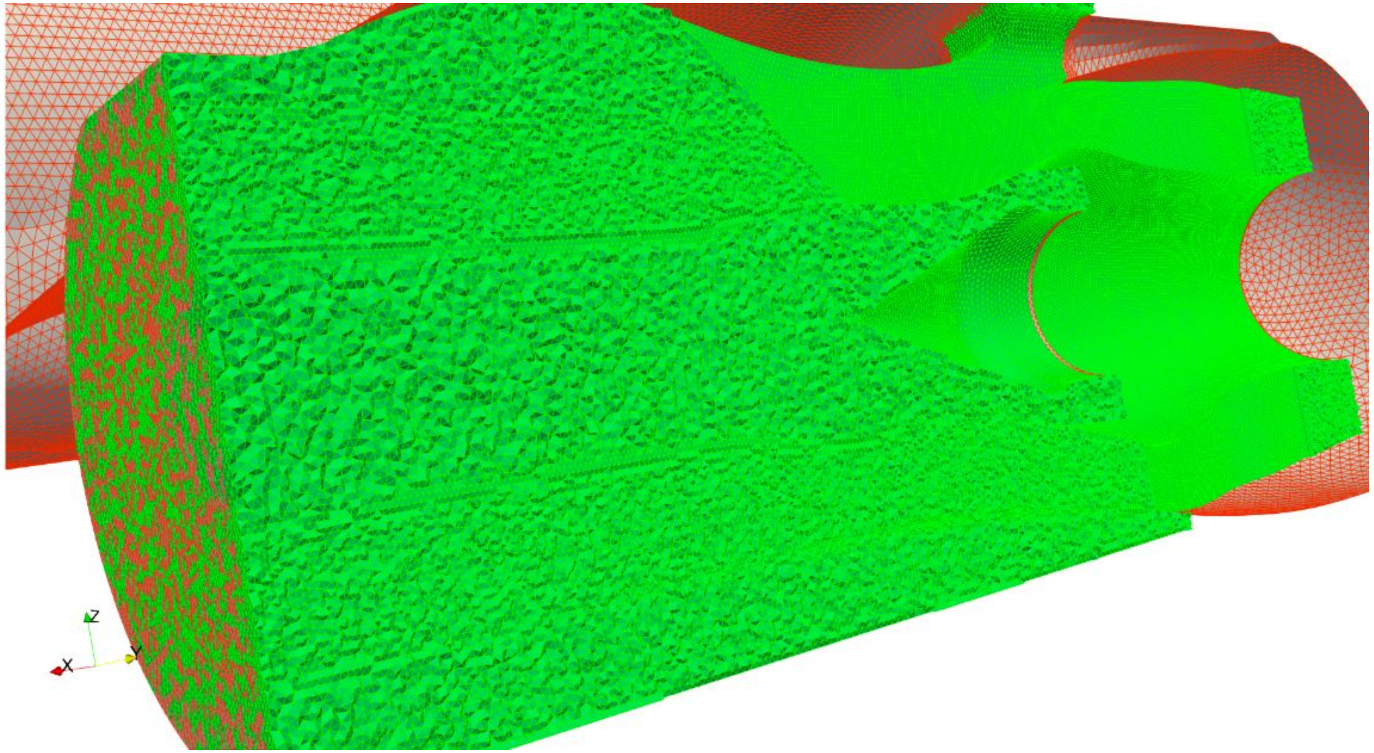
Quasi-Trefftz Discontinuous Galerkin Method

- Convected Helmholtz Equation
- Today : FEM/BEM Coupling





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Quasi-Trefftz Discontinuous Galerkin Method

- Limitations:
  - PDE coefficients constant per element
  - Fine mesh (λ/15)
- Solution proposed (PhD of **Andrea Lagardère**)
  - Use Quasi-Trefftz functions in DGM coupled with BEM

Several kinds of quasi-Trefftz functions

- Amplitude based : $P(\boldsymbol{X})e^{i\boldsymbol{k}_0\cdot\boldsymbol{X}}$, $|\boldsymbol{k}_0|^2 = \kappa^2(\boldsymbol{x}_0)$,
- Phase based : $e^{Q(\boldsymbol{X})}$, $Q(\boldsymbol{X}) = i\boldsymbol{k}_0 \cdot \boldsymbol{X} + H.O.T.$,
- Polynomial functions : $R(\boldsymbol{X})$.

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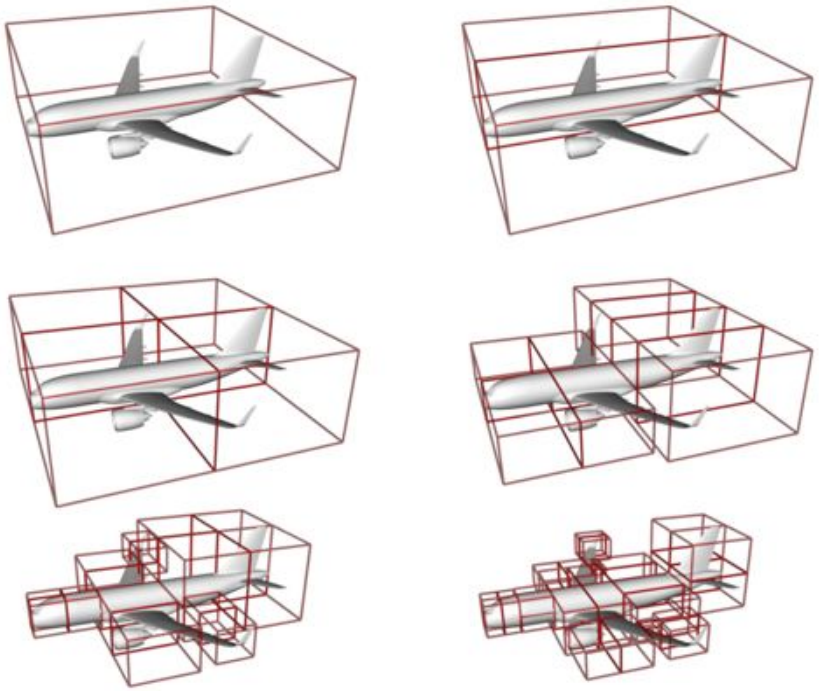
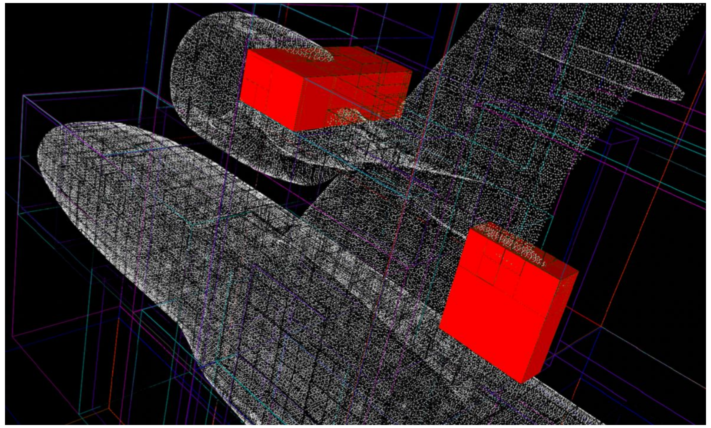
Quasi-Trefftz Discontinuous Galerkin Method

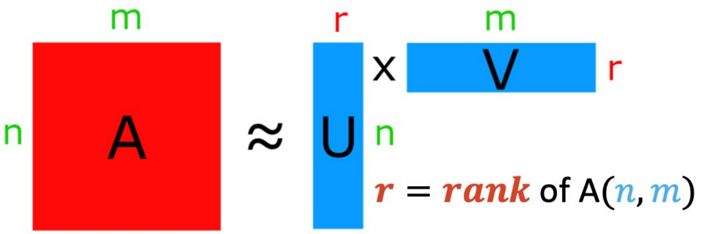
- Work in Progress (finishing 1st year of PhD)
- Pre-existing:
  - Airbus FEM-BEM code & application
  - L.M. Imbert-Gérard QT construction methodology
  - Makutu extensive knowledge of DGM
- Done:
  - Build QT function for heterogeneous Helmholtz (without convection) + mockup 2D
  - Theoretical work for convected Helmholtz in DGM
- Next:
  - Mockup for convected Helmholtz in 2D, 3D
  - Full testing (accuracy ? size of elements ? performance vs. FEM ?)
  - Coupling with BEM
  - Industrial Applications
  - etc.

Upgrading H-matrix solver

- CIFRE PhD “Composabilité en Algèbre Linéaire Haute Performance - Application à l'Aéroacoustique et à l'Électromagnétisme” started january 2025 by **Clément Peaucelle** (@Airbus, Issy)
- Push further the H-matrix approach
- Reminder : H-matrix is a hierarchical approximate low-rank matrix format, very efficient on dense matrices coming from IE+BEM



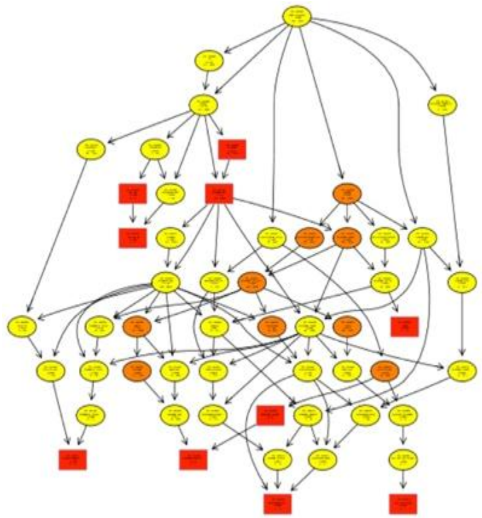




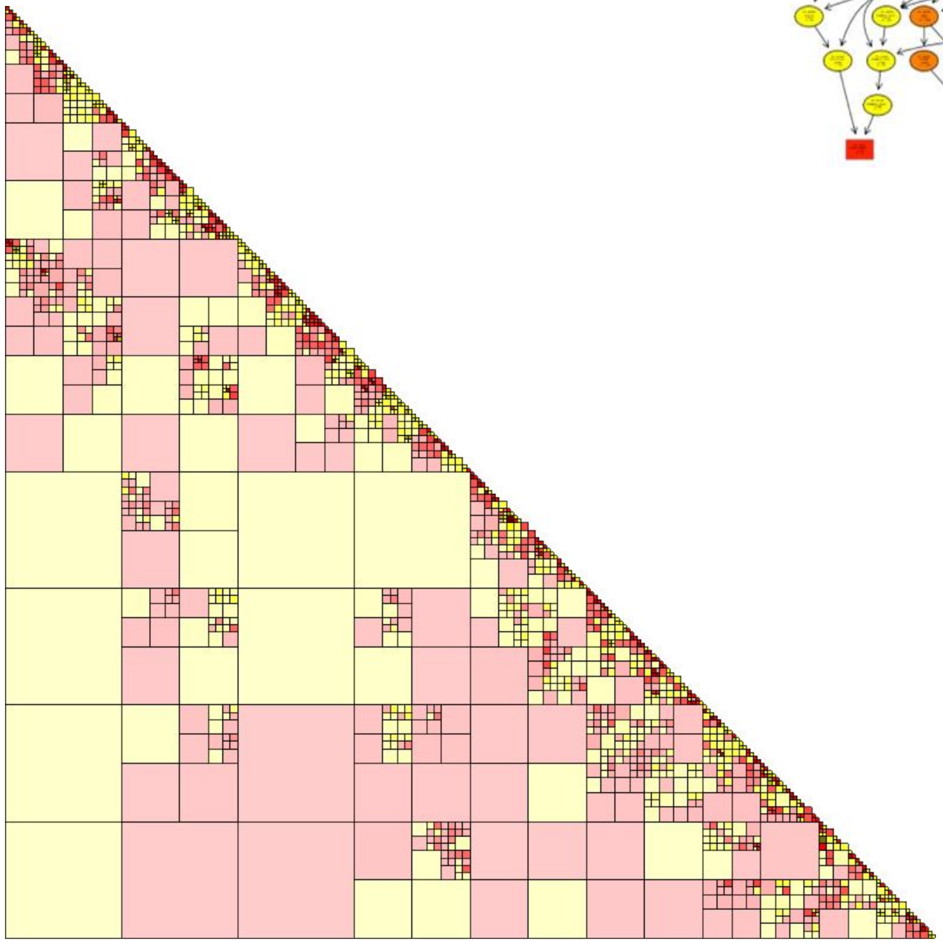
$$Memory\ footprint = rank * (n + m)$$

Approximate Low-Rank Block

Upgrading H-matrix solver



- Implemented with task-based programming on top of StarPU
- Factorisation in $\mathcal{O}(n^{\alpha} \log n)$ instead of $\mathcal{O}(n^3)$
- But…
  - Poor scalability
  - High memory consumption



Upgrading H-matrix solver

Directions investigated:

- Floating point lossy compression (e.g. https://szcompressor.org/)
  Ignore digits that are “beyond” the accuracy of our low-rank compression
  Potential to have memory reduction by a factor 3 or 4
  (in progress : see you at COMPAS 2025 https://2025.compas-conference.fr/)

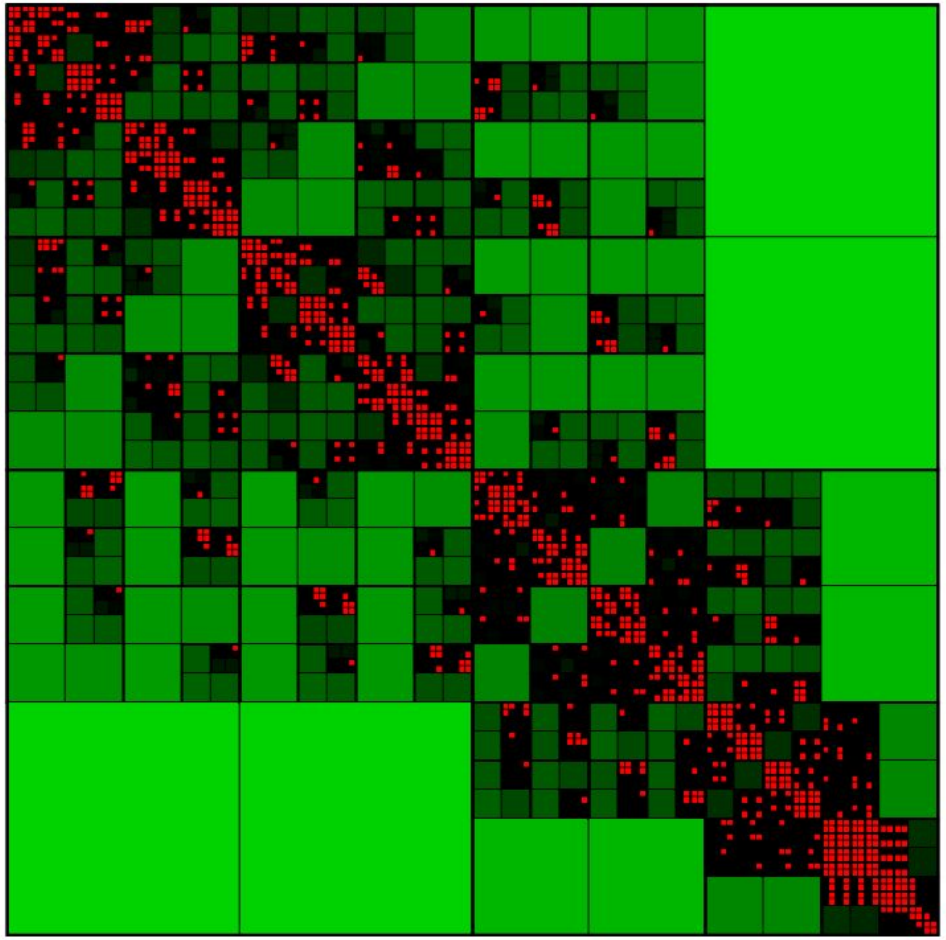
Next:

- Enhance **scalability** by splitting large low-rank blocks
  not in the *rows* or *columns* dimension, but in the *rank* dimension
  Side effect: allow larger blocks, hence memory reduction
- Use of GPU for some tasks
- Use of Randomized Algorithms
- etc.

Learning Based Rank Estimator

- In H-matrix solver: rank estimator needed
  - Does a low-rank block fit in memory ?
  - Should we keep it or subdivide it ?

- Today: basic estimator
- Let’s use learning-based methods !



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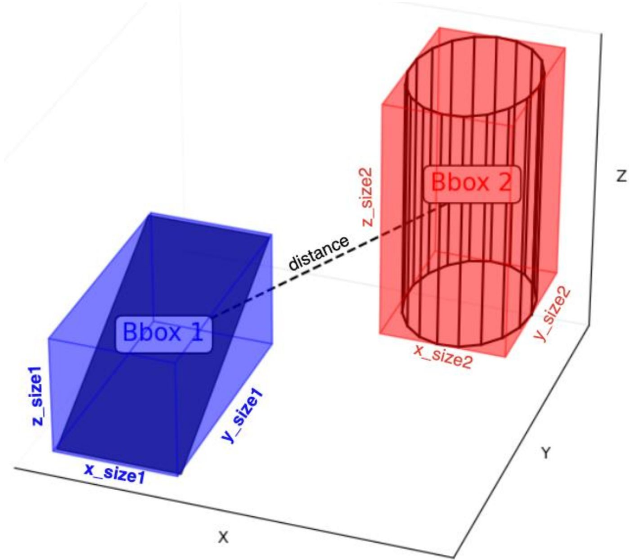
Learning Based Rank Estimator

- Objective: Given a block of matrix (set of row & columns unknowns), estimate the rank of the blocks with a cheap computation
- PhD of **Théo Briquet** (@Cerfacs, Toulouse)
- Features:
  - We don't have : the block content, the actual rank
  - We do have : geometry (bounding boxes, diameters, distance, visibility factor), physics involved (Maxwell, Helmholtz, Laplace, etc.), physical parameters (λ, ε, μ)

- Learning using random forests



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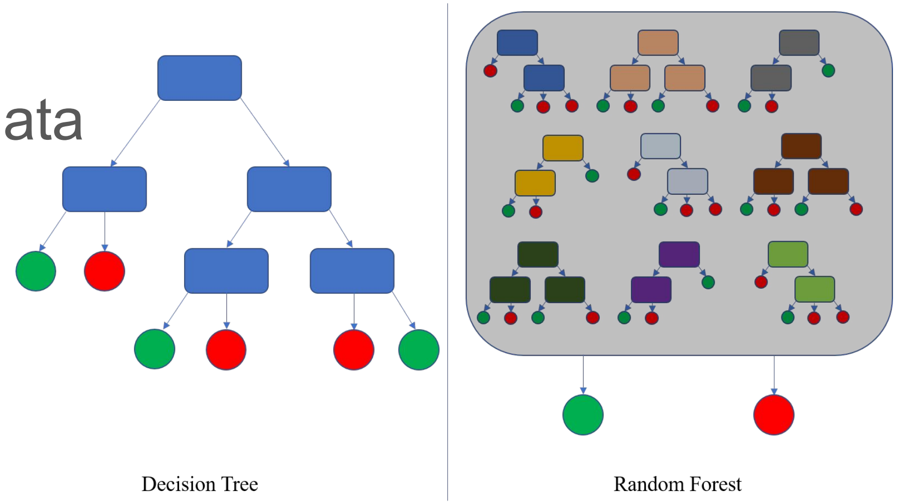
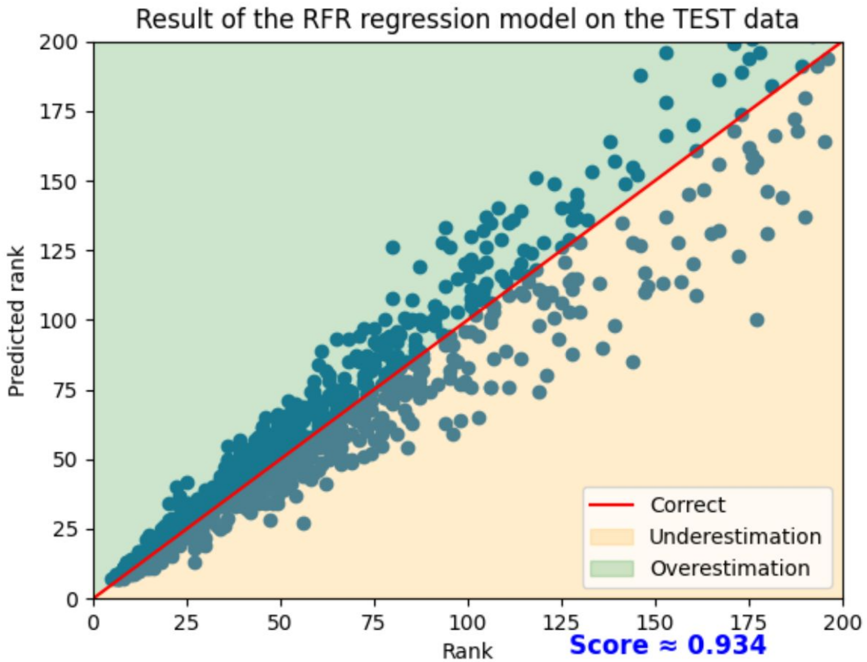
Learning Based Rank Estimator

- Each decision tree is built on a (random) subset of the data



- 2 separate studies (regression or classification)
  - Estimate the rank or
  - Estimate if the block fits in memory

- Next steps
  - Try other ML techniques
  - Connect to Applications
  - Industrial test-cases
  - More physics
  - etc.



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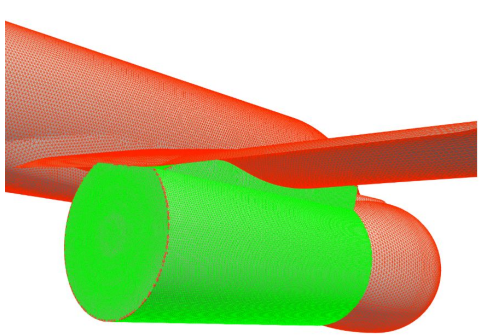
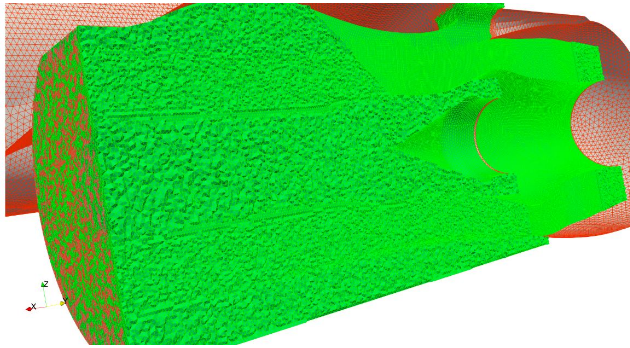
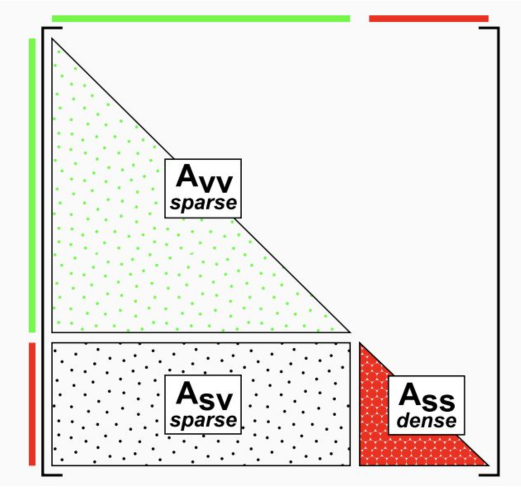
Composability applied to FEM-BEM Coupling





- Same application as QT DGM: Aeroacoustics…
  …but on the purely algebraic solver side

- Mixed Matrix with
  - BEM in homogeneous domain **s ~10^6 unknowns**
  - FEM in heterogeneous domain **v ~10^9 unknowns**



Too dense for sparse solvers, too large for dense solvers…
… need to develop new approaches

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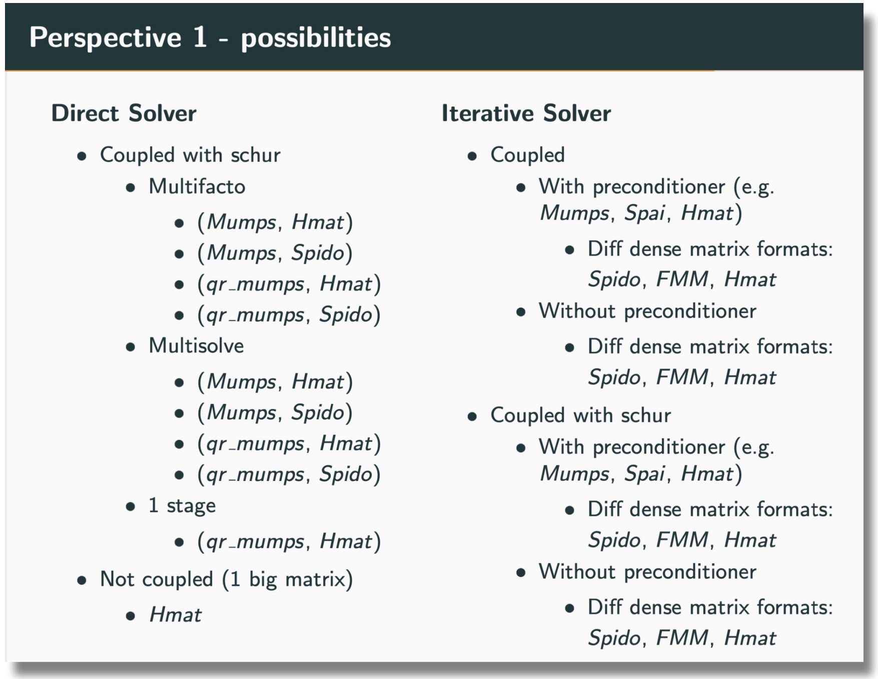
Composability applied to FEM-BEM Coupling

- In the past: coupling existing sparse & dense solvers (H-Matrix + MUMPS)
  - A lot of algorithms : multi-solve, multi-facto
  - Limited by the solvers interfaces

- Post doc of **Esragül Korkmaz** (@Inria, Bordeaux)

Ideas :

- Handle all the system with 1 H-matrix
- Use two task-based solvers (QR-MUMPS & H-mat)
- Compare all these possible approaches
- Industrial applications
- etc.



Perspective 1 - possibilities

Direct Solver

- Coupled with schur
  - Multifacto
    - (*Mumps*, *Hmat*)
    - (*Mumps*, *Spido*)
    - (*qr_mumps*, *Hmat*)
    - (*qr_mumps*, *Spido*)
  - Multisolve
    - (*Mumps*, *Hmat*)
    - (*Mumps*, *Spido*)
    - (*qr_mumps*, *Hmat*)
    - (*qr_mumps*, *Spido*)
  - 1 stage
    - (*qr_mumps*, *Hmat*)
- Not coupled (1 big matrix)
  - *Hmat*

Iterative Solver

- Coupled
  - With preconditioner (e.g. *Mumps*, *Spai*, *Hmat*)
    - Diff dense matrix formats: *Spido*, *FMM*, *Hmat*
  - Without preconditioner
    - Diff dense matrix formats: *Spido*, *FMM*, *Hmat*
- Coupled with schur
  - With preconditioner (e.g. *Mumps*, *Spai*, *Hmat*)
    - Diff dense matrix formats: *Spido*, *FMM*, *Hmat*
  - Without preconditioner
    - Diff dense matrix formats: *Spido*, *FMM*, *Hmat*

Learning Approach to Geometry Simplification

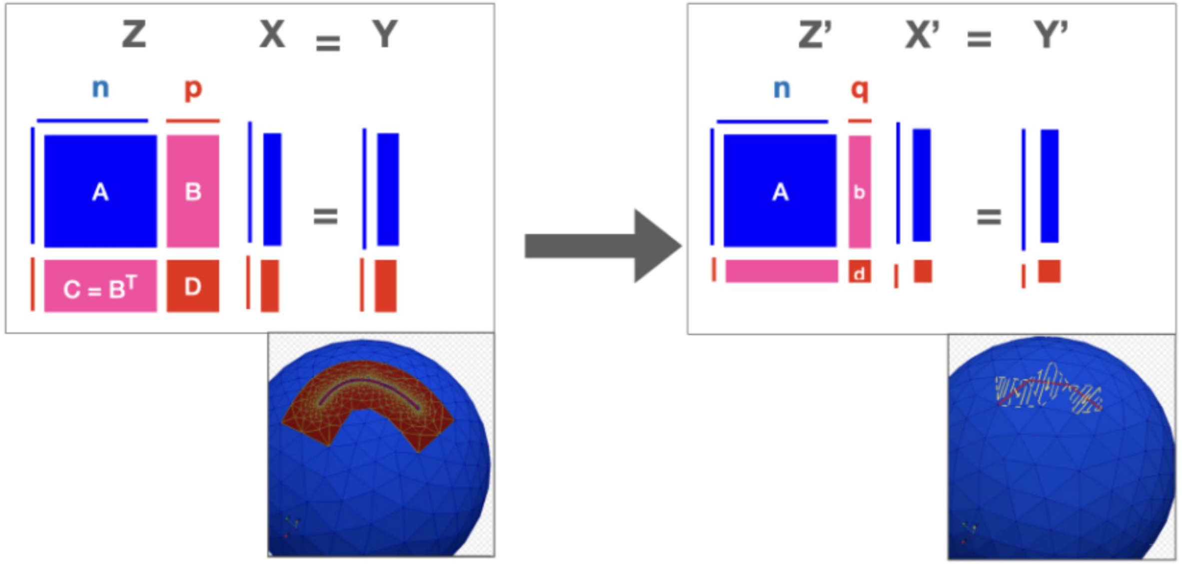
Some details on the structures (slots, wires, etc.) have to be finely handled

➜expansive data preparation & computation

Idea: use learning approach to find

Equivalent Models

Post-doc of **Augustin Leclerc** (@Airbus, Issy)



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Active Researches

Working at different levels:

- Formulation/Modelisation

  Quasi-Trefftz Discontinuous Galerkin Method

- Meshing / Data preparation

  Learning Based Rank Estimator

  Learning Approach to Geometry Simplification

- Solver / Hybridization of solvers

  Upgrading H-matrix solver

  Composability applied to FEM-BEM Coupling

Also in progress: PINN (PhD of **Joel SOFFO**)

Jobs available

- Apprenticeship in Issy (Paris area) on HPC/GPU
  Search “HPC” on airbus.com/en/careers

- Post-doc in Inria Bordeaux on Numerical Linear Algebra / Low Rank Algorithms
  https://recrutement.inria.fr/public/classic/fr/offres/2025-08695

Thank you