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UNSTRUCTURED MESH GENERATION FOR EXASCALE SYSTEMS: A PROXY APPLICATION APPROACH

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NumPEx workshop organization

- **Meeting every month since September 2024.**
- **Many contributors:**
  - IFPEN: Ani Anciaux Sedrakian, Laurent Astart, Guillaume Enchery, Jean-Marc Gratien, Stéphane De Chaisemartin,
  - ONERA: Gabriel Staffelbach, Eric Savin, Susanne Claus,
  - CEA: Nicolas Lelong, Marc Perache, Félix Kpadonou, Jérôme Charousset,
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  - TotalEnergies: Henri Calandra, Stefano Frambati,
  - CNRS: Jean-Pierre Vilotte,
  - Université de Picardie: Mark Asch,
  - Cemosis: Patrick Lemoine, Thomas Saigre.
- **Workshop git repository: https://gitlab.inria.fr/numpex-pc5/wp2-co-design/Working-Groups-Playground**
- **Feel free to join us! (julien.vanharen@inria.fr)**

Context and challenges

1. **Handle *very complex geometries*:**
   - Requires automatic unstructured mesh generation.
2. **Predict complex physical phenomena with high-fidelity:**
   - Requires accurate and fast numerical methods on unstructured meshes,
   - Requires anisotropic mesh adaptation.
3. **An do it efficiently:**
   - Requires a massively parallel environment which handles anisotropic unstructured meshes.

Context and challenges

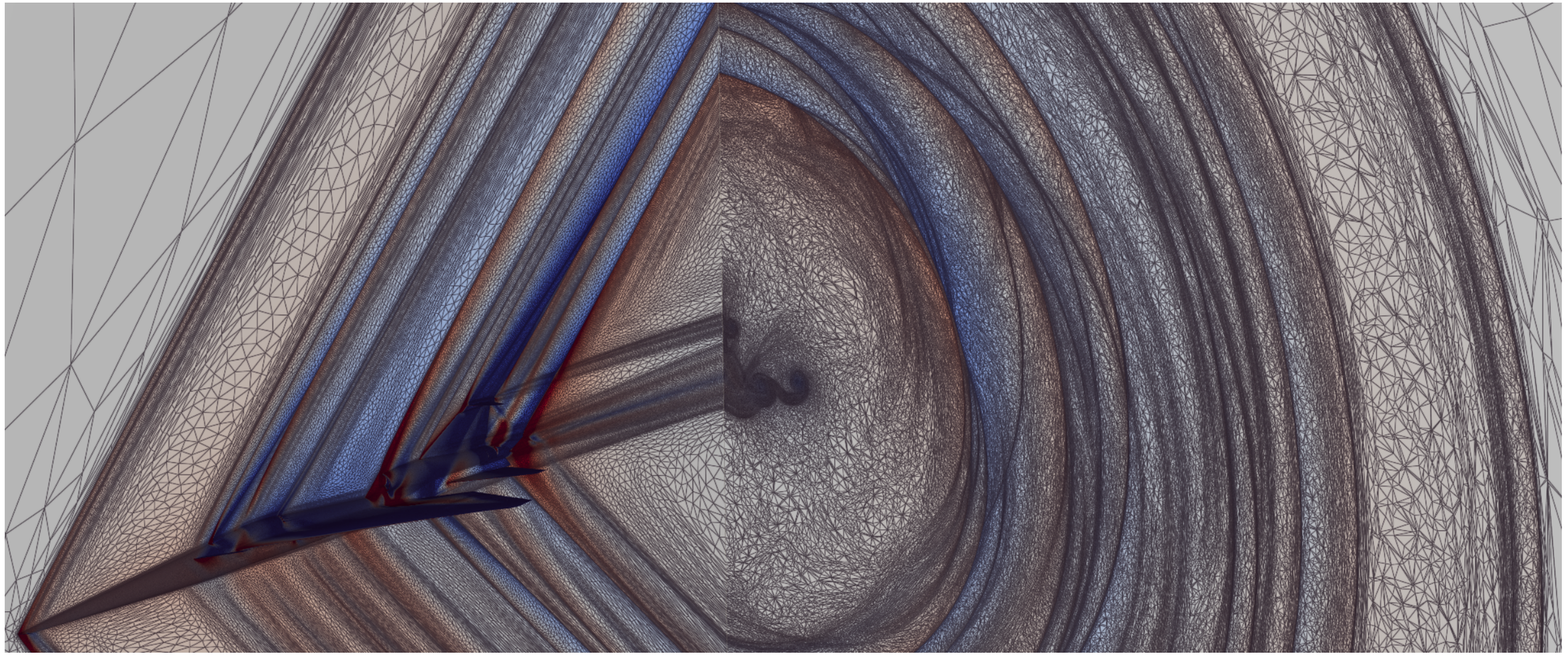

***Fig. 1*: C608 low-boom flight demonstrator solution on the finest adapted mesh (156M tetrahedra).**

Context and challenges

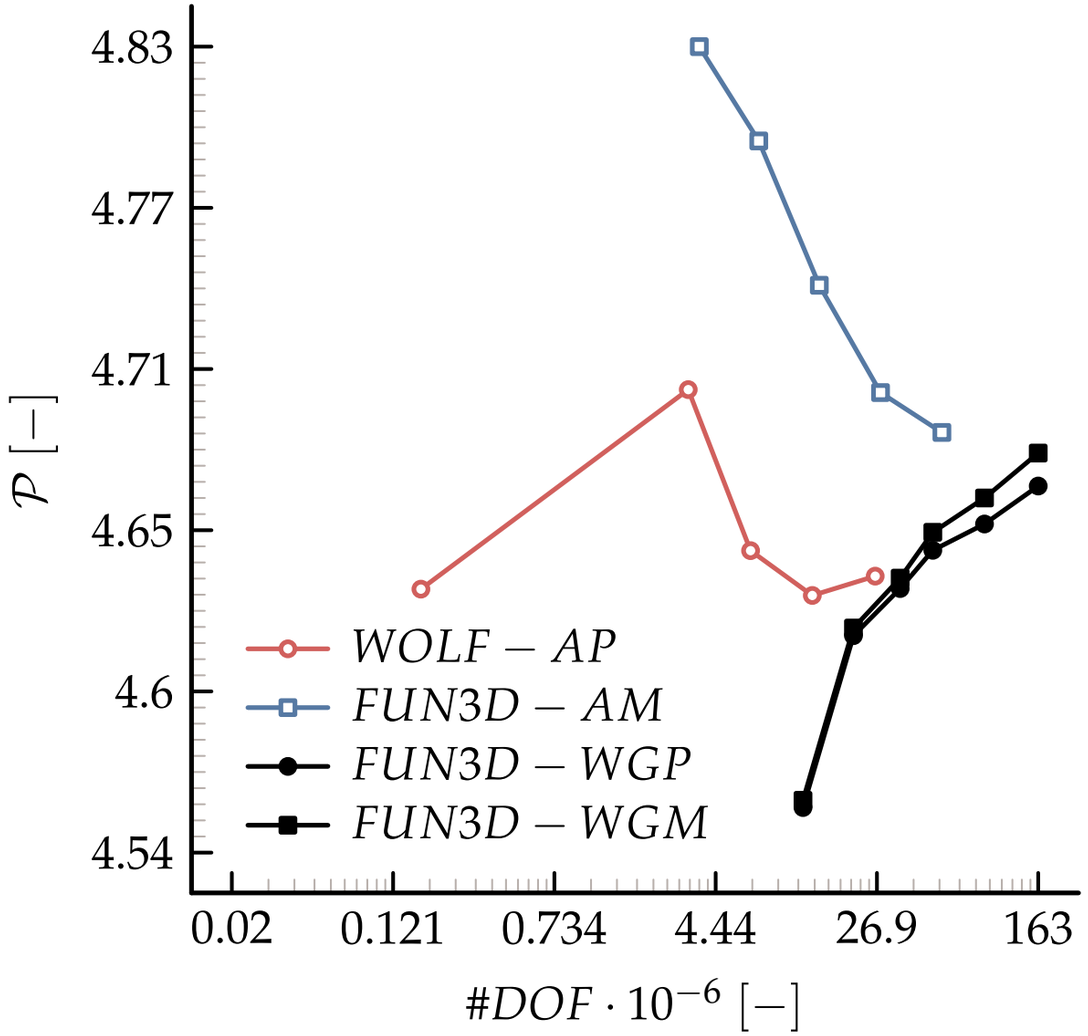

Fig 2: Mesh convergence of C608 low-boom flight demonstrator.

Proxy application objectives

- Generate unstructured meshes with tens of billions of elements,
- Provide a set of services to discretize partial differential operators.

Proxy application input

Coarse mesh comprising tens of million elements:

- From a few megabytes to several gigabytes,
- List of vertices defined by its 3D coordinates stored in double-precision floating-point format,
- List of canonical elements:
  - edges, triangles, quadrilaterals, tetrahedra, prisms, pyramids and hexahedra,
  - from the first- to the third-order,
  - each element is given by its connectivity,
  - each element has an associated flag called *reference*.

Proxy application workflow

- **MPI based environment / Coarse-grained parallelization**
  - Reading,
  - Partitioning,
  - Migrating,
  - Refining,
  - Dynamically re-partitioning for optimal load-balancing,
  - Providing a set of services for partial differential operators discretization.

Proxy application services

- **Topological operators:**
  - Looping over elements and retrieving the vertex data,
  - Looping over vertices and identifying all elements sharing the vertex,
  - Looping over faces of edges and retrieving neighboring elements,
  - Performing reductions on data associated with vertices or elements.
- **General formulation:**
  - Considering a *(d)* entity, get the list of *(d-k)* entities,
  - Considering a *(d)* entity, get the list of *(d+k)* entities.

Proxy application services

- **Customized tasks decomposition / Fine-grained parallelization:**
  - Renumbering,
  - Coloring,
  - Sub-partitioning.
- **Leveraging different C/C++ backends:**
  - CUDA, ROCm, OpenMP, ...
  - StarPU,
  - Kokkos, RAJA, ...
- **Leveraging Exa-SofT developments:**
  - Kokkos,
  - StarPU,
  - EZTrace+Pallas.

Proxy application

- **Arcane framework**
  - https://github.com/arcaneframework/framework
- **ShArc**
  - https://github.com/arcaneframework/sharc
- **Exa mesh gallery**
  - https://gitlab.inria.fr/numpex-pc5/wp2-co-design/exameshgallery
- **DocHub**
  - https://numpex-pc5.gitlabpages.inria.fr/wp2-co-design/doc-hub/index.html

Thank you for your attention!