SIMULATION CHALLENGES FOR GREENER AIRCRAFT ENGINES

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Objectif

- **Les capacités de calcul continuent d'augmenter selon la loi de Moore, ce qui permet d'accroitre encore la complexité des problèmes traités**
  - **Taille, modèles physiques avancés, fidélité (ex. instationnaire), pluridisciplinaire, …**

- **Mais, pour répondre au besoin de développement, les progrès en simulation ne doivent pas se concentrer uniquement sur le HPC**
  - **Besoin de modèles adaptés à chaque phase du développement**

- **Cette présentation tente d'illustrer le lien simulation – produit**
  - **Quel est l'apport concret de la simulation au développement produit**
  - **En quoi elle contribue à les rendre plus « verts »**

Aeronautic industry requires a green breakthrough

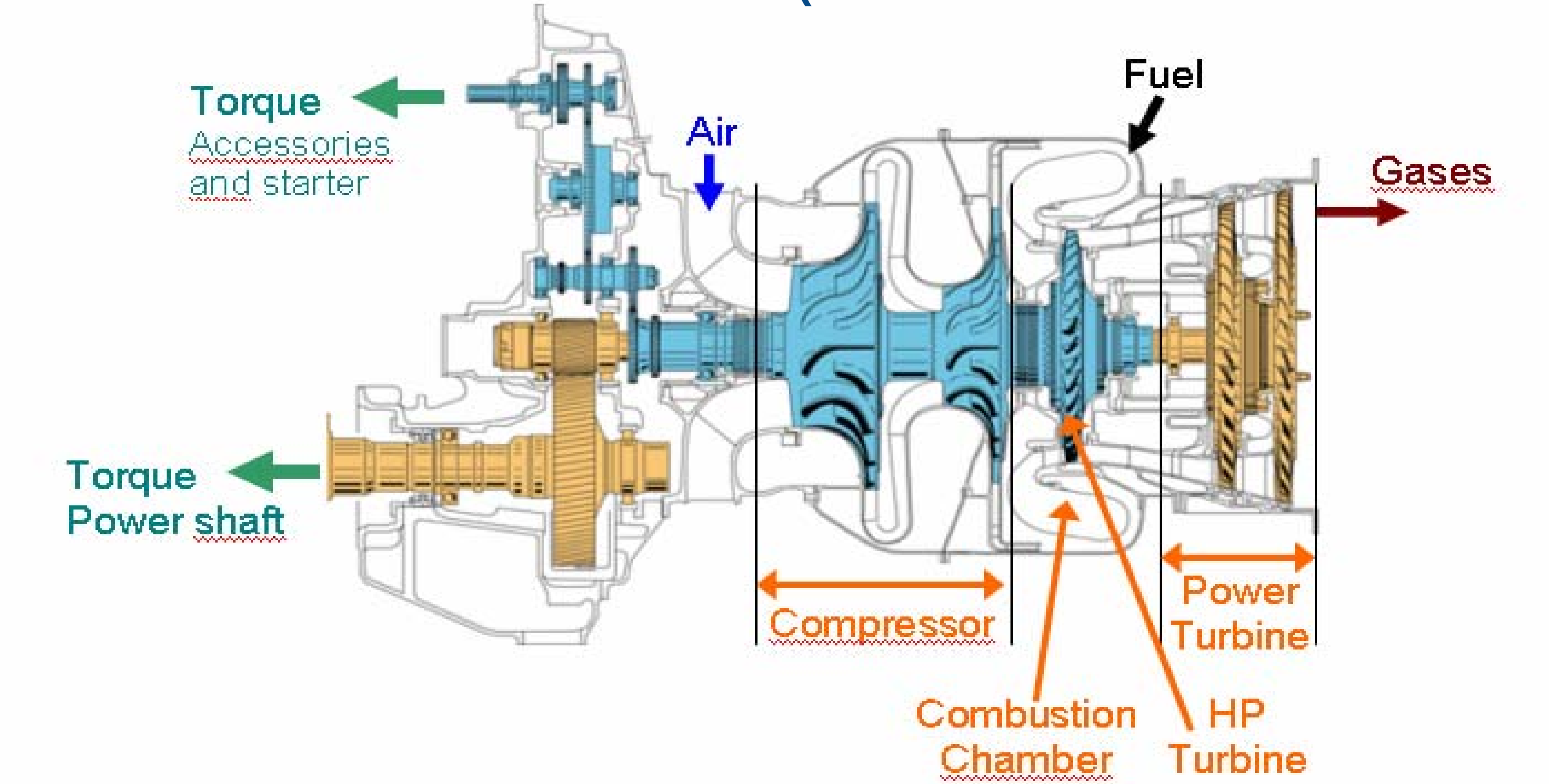
- **Aeronautic industry contributes only few percents to the global CO_2 emissions (less than 3%)**
  - **An A380 fuel consumption is 3,6l/100km/passenger**
  - **The average car consumption in Europe is 6l/100km with 1,8 passenger/car**

- **Significant performance improvements are expected to mitigate the impact of the traffic growth (x2 in 2020 vs 2000)**
  - **On the aircraft, the engines and their integration, the power management, the air traffic management, etc …**
  - **ACARE 2020 proposes for the engine: -20% CO_2, -60% NO_x emission**
  - **European Emission Trade Scheme for Aeronautic in 2012**

- **Industry effort is supported by the European Community in the clean sky initiative combined with national supports**

Comment faire des Turbines plus “vertes”

- **Engine power is driven by, the air flow rate and TIT**
  - **SFC decreases when OPR increases (compressor aerodynamic simulation)**
  - **CO2/NOx emissions depends on the combustion condition in the chamber**
  - **Mass decrease when TIT increases TIT (aero-thermal-structural simulation)**



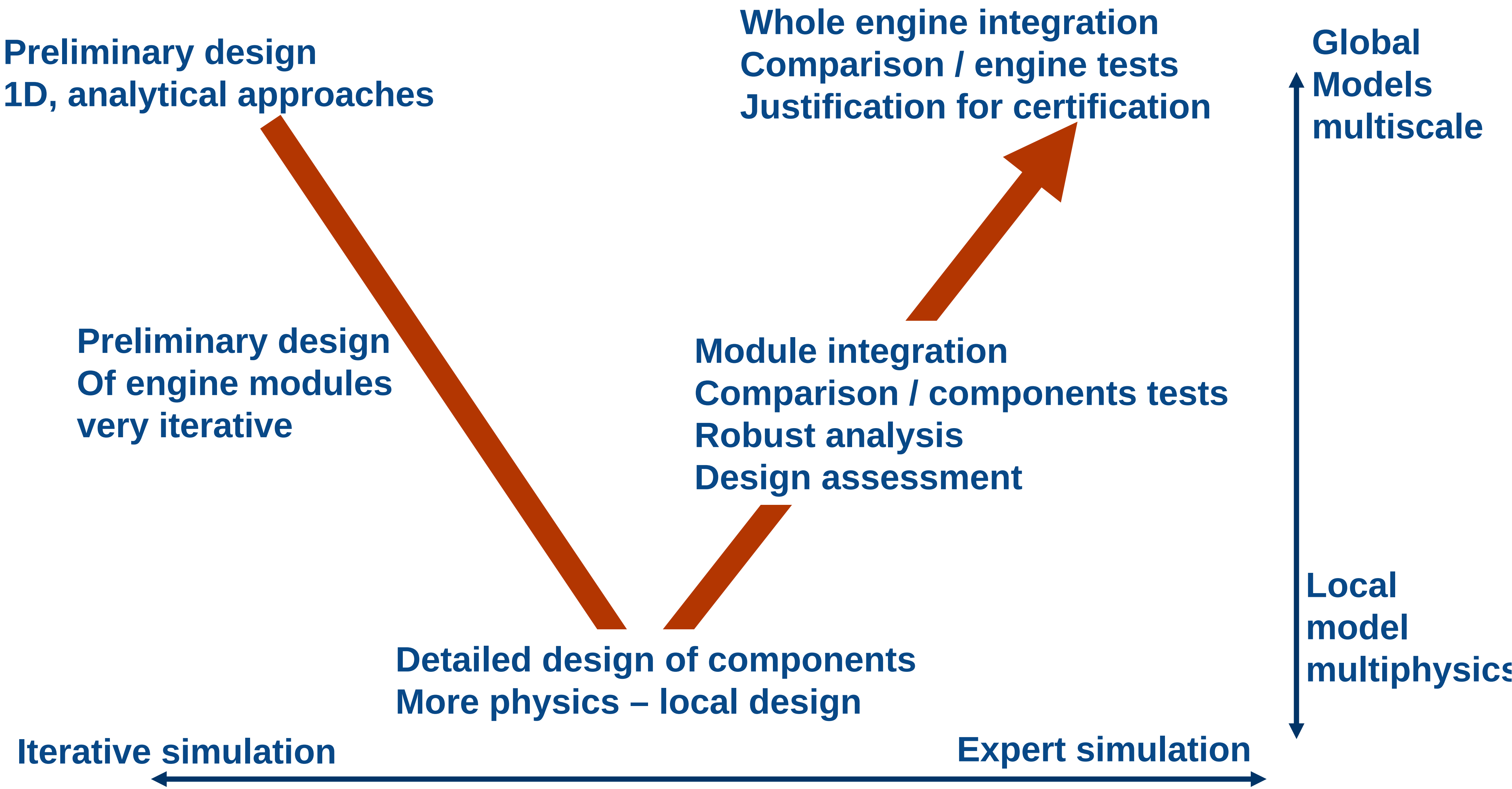
Summary

- **Simulation challenges for helicopter engine development**
  - **The design process**
  - **Various levels of complexity for simulation**

- **Illustration on few chosen applications**
  - **Thermal behavior of turbines**
  - **Aerodynamic simulation in compressors**
  - **HPC for combustion**
  - **Fast transient dynamic for safety and mass reduction**

- **Conclusion**
  - **Supercomputing strategy**

The V-cycle of the design process



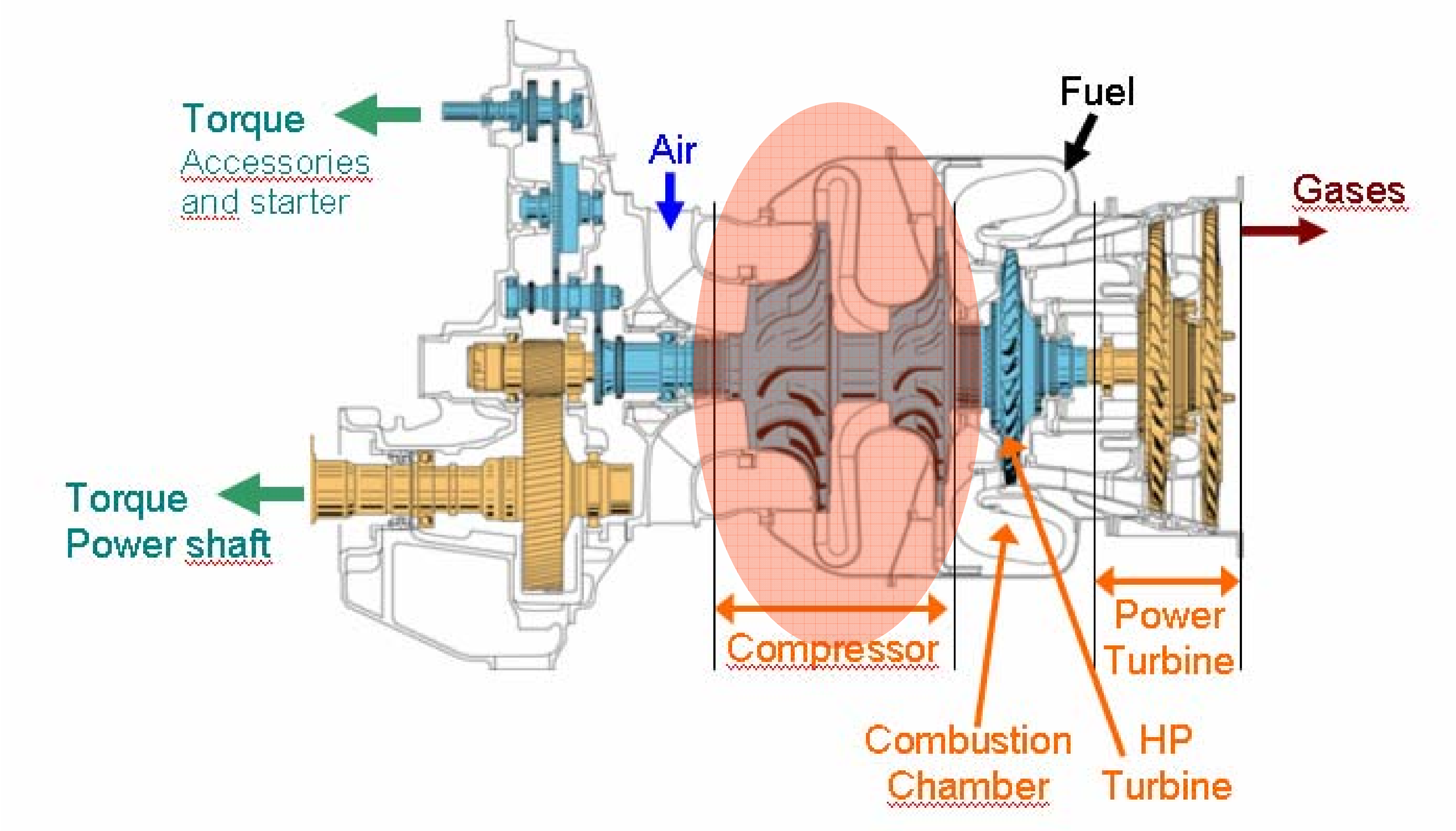
The simulation needs

- **1D simulation is the key of the design**
  - **The major design choices are performed**
  - **No geometric model available**
  - **Analytical approaches with adequate physics**

- **Component design**
  - **Very iterative: requires HPC to prospect the various solutions**
  - **Results in the definitive components geometries**
  - **Allows to launch component manufacturing (strong time constraint)**

- **Assessment phase: check the component design and the integration choices: HPC is required by model complexity**
  - **Connected with the test results (model updating)**
  - **Detailed physics, pluridisciplinary approaches**
  - **Multi scale problems (in time, in space)**

Simulation challenges for gaz turbines



Compressor performance drives SFC

- **The pressure ratio of the compressor directly drives the thermodynamic cycle efficiency**

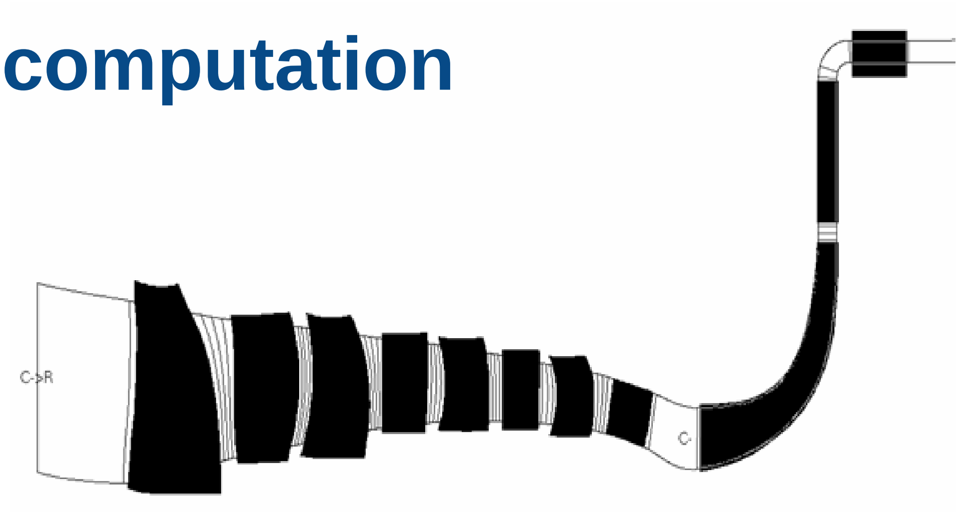
- **When the compressor load (the pressure ratio) increases**
  - **The compressor efficiency become more sensitive to ‘local effects” such as leakages, quality of the surfaces, tip gap, etc …**
  - **The operability become a difficult issue (surge)**
  - **Unsteady behavior can lead to HCF of the compressor (rotating stall, flutter, NSV, …)**

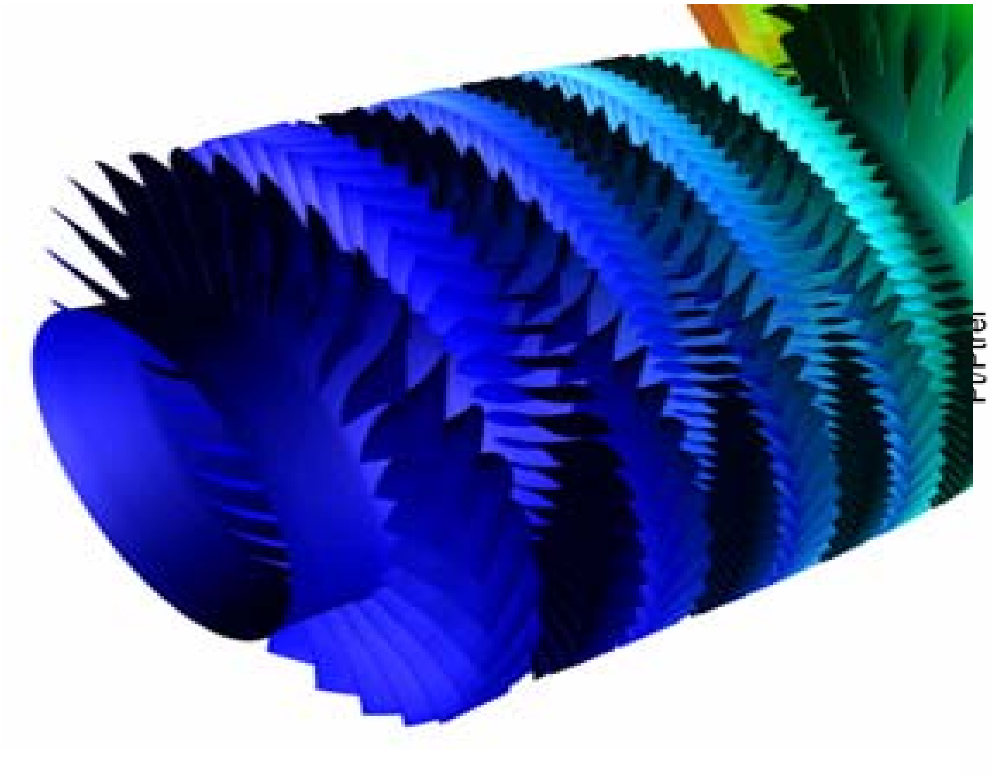
- **High fidelity physics simulation is conducted on**
  - **Full compressor, to take the effects of all the stages integration**
  - **Model of the local technologic effects**
  - **Steady or unsteady computations**

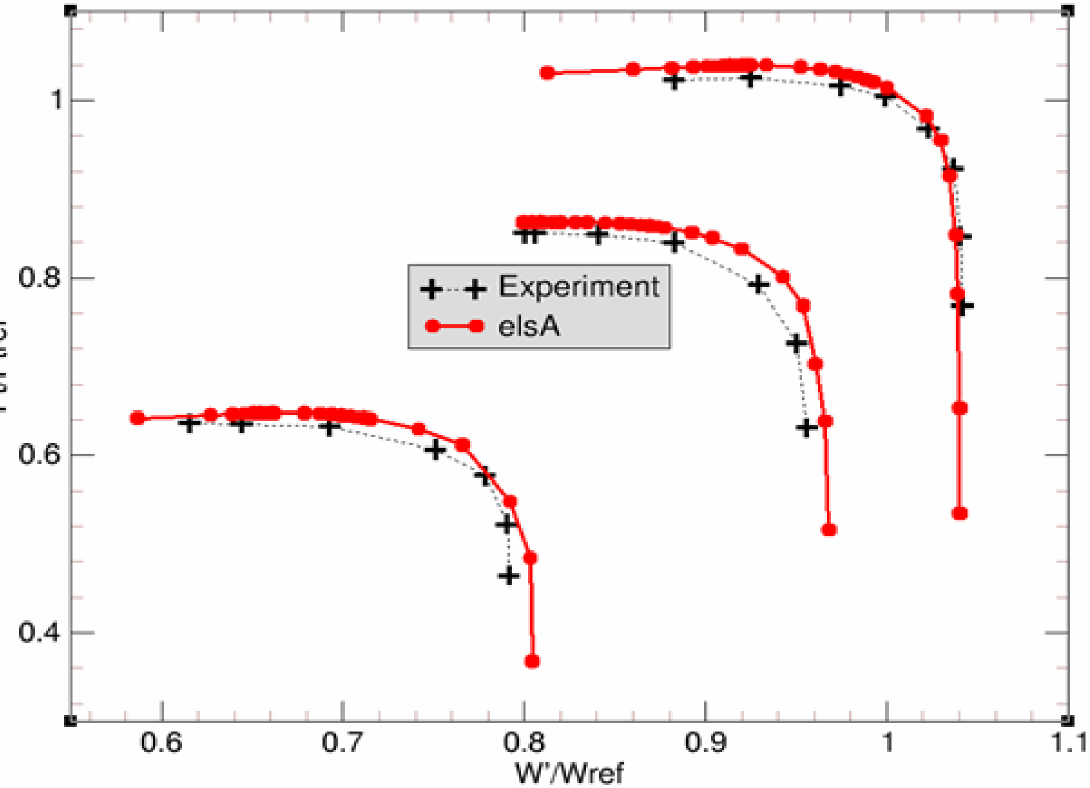
Typical compressor steady computation

- **RANS with a 10 million point mesh**
  - **10 CPU hours on a NEC SX8**

- **Elsa code developed by ONERA**







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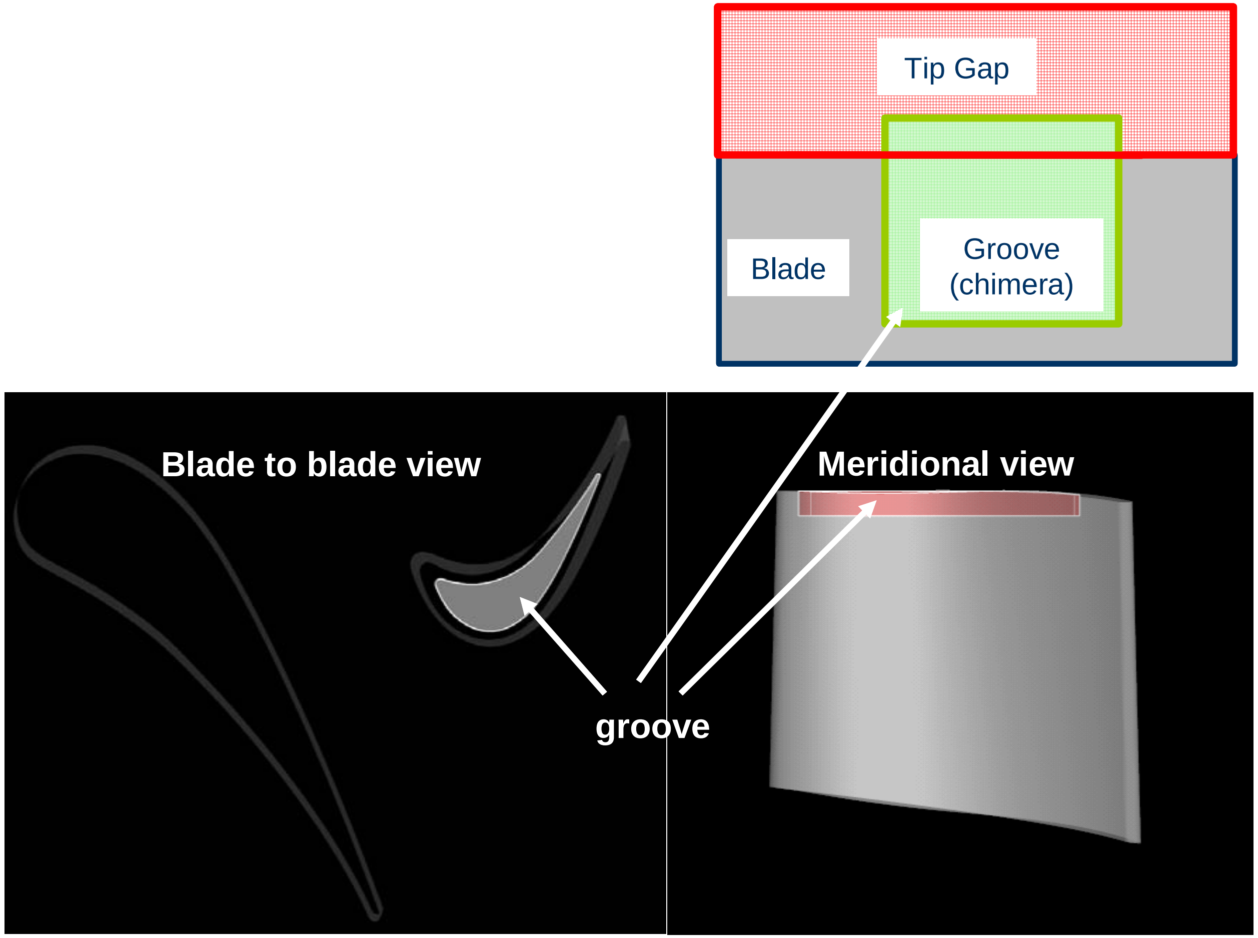
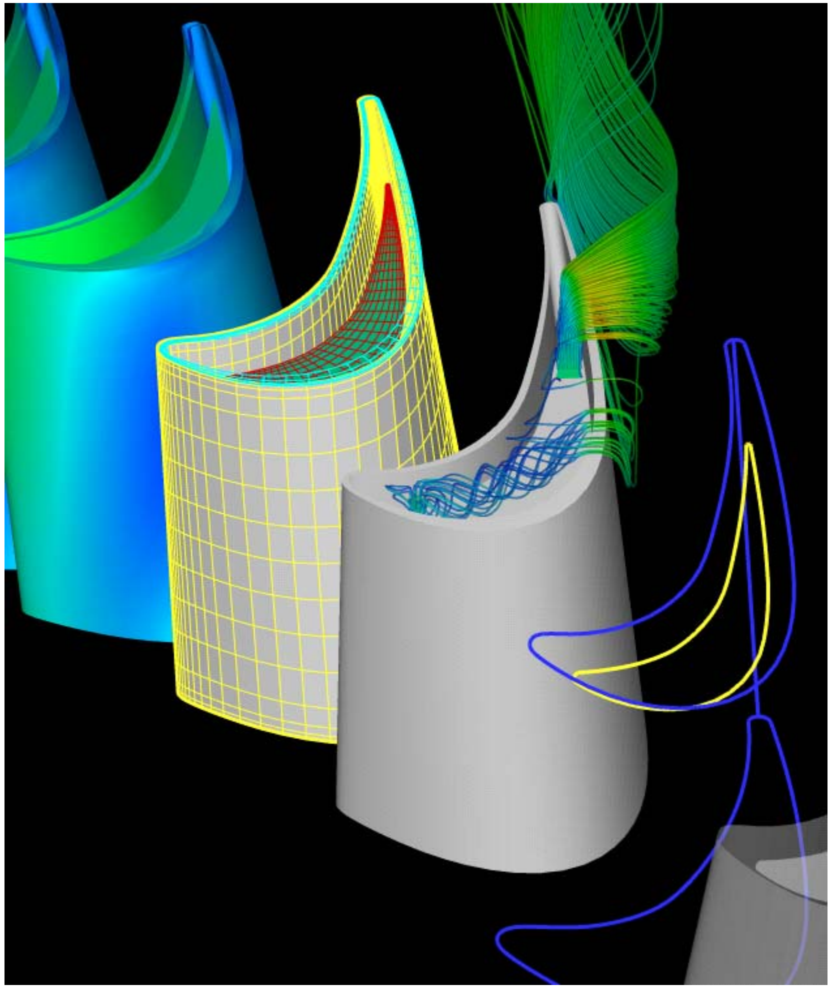
Typical compressor steady simulation

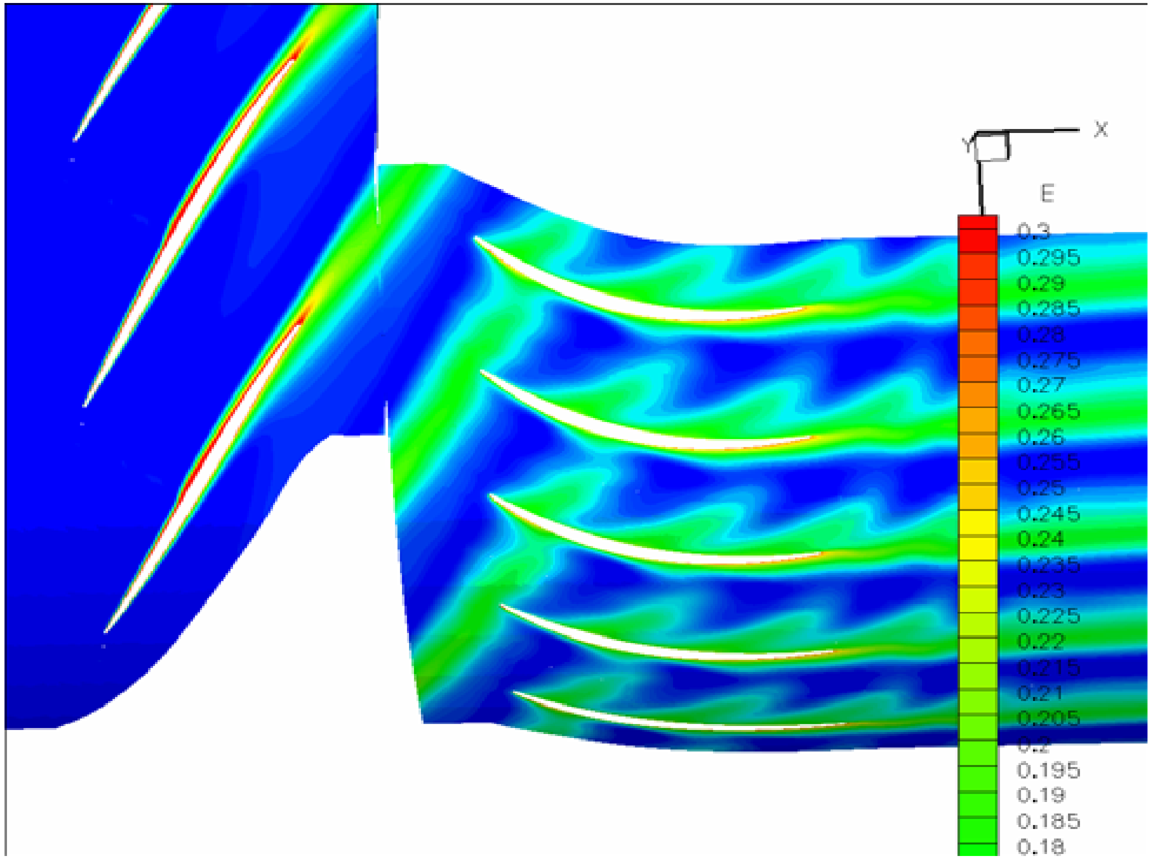
Model of the tip gap by chimera technique





Typical compressor unsteady simulation result

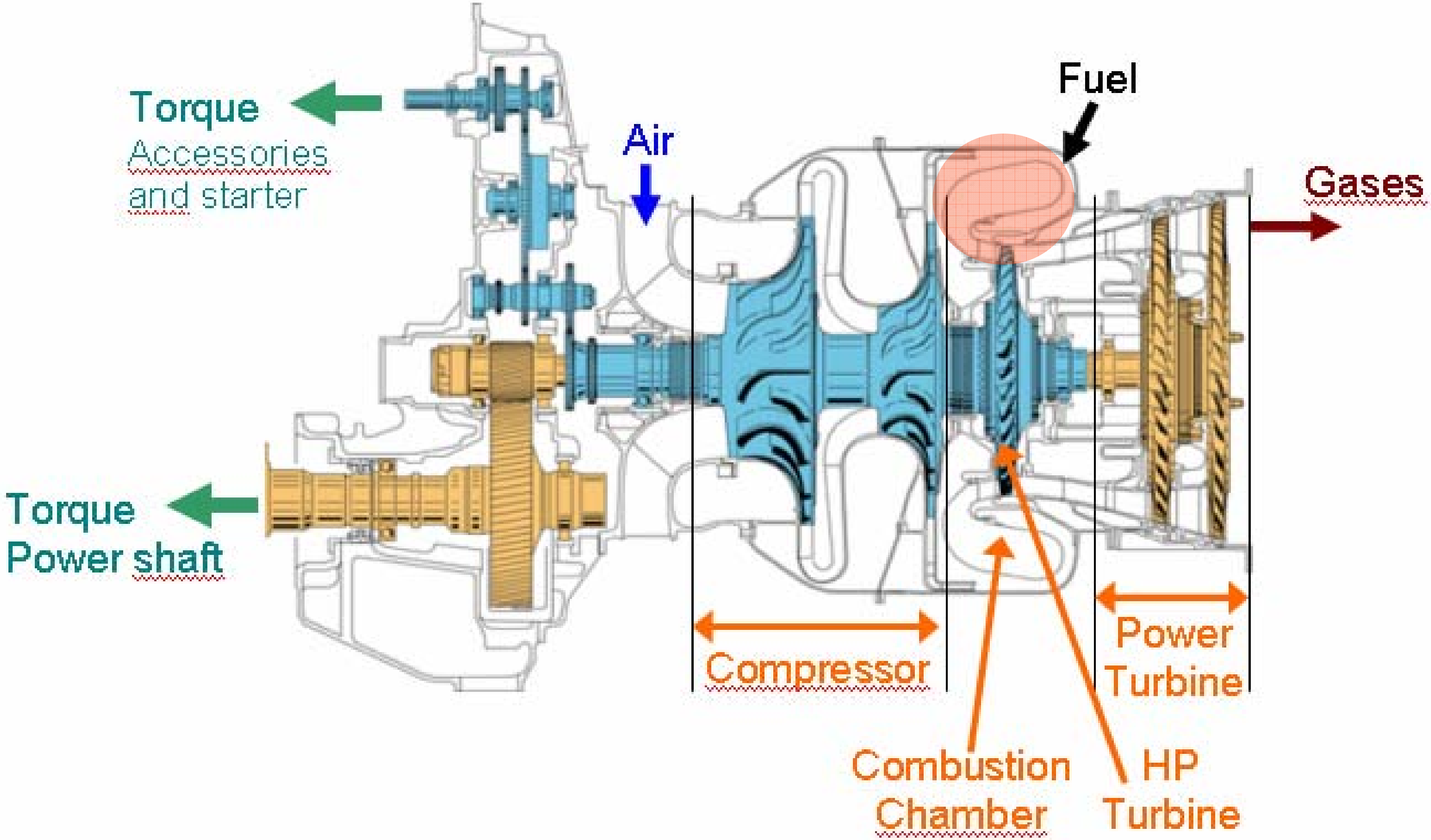
- **Interest of the unsteady computation**
  - Accurate performance assessment
  - Simulation of particular operating points
  - Physical understanding
  - Vibration assessment (multiphysic approach)



- **CPU time x10 compared to steady computation**
  - Alternative numerical approaches under development

- **Instantaneous entropy field**

Simulation challenges for gaz turbines



Combustion simulation issues

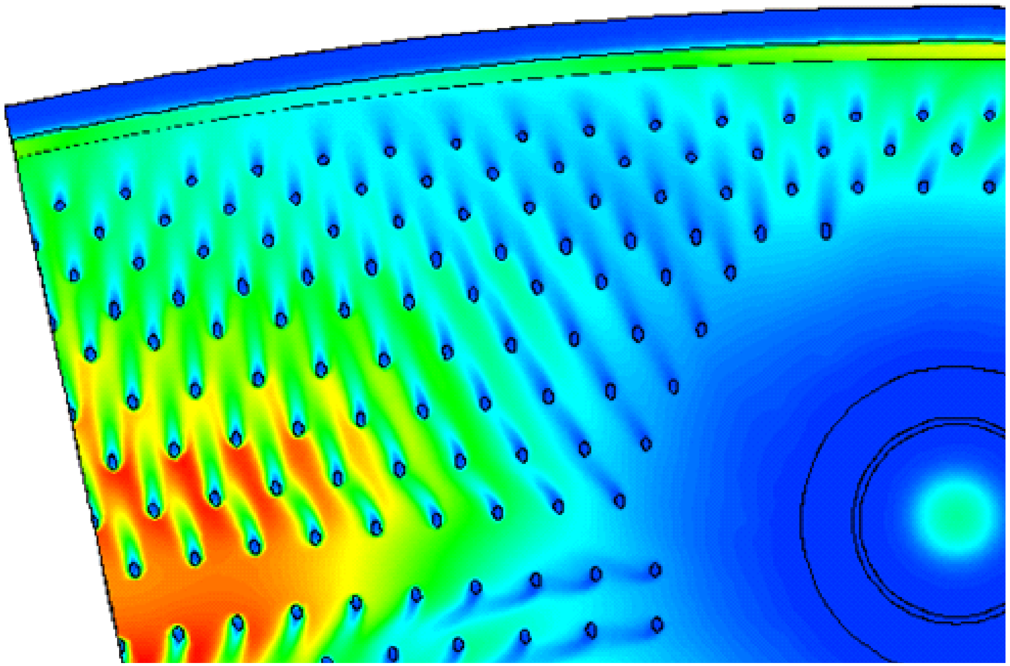
- **The combustion chamber design drives**
  - **The temperature field for the downstream HP turbine (>1500°C)**
  - **The emission levels (CO_2, NOx, UHC, particles, …)**
  - **Low SFC engines are based on high pressure ratio: negative effect on NOx**

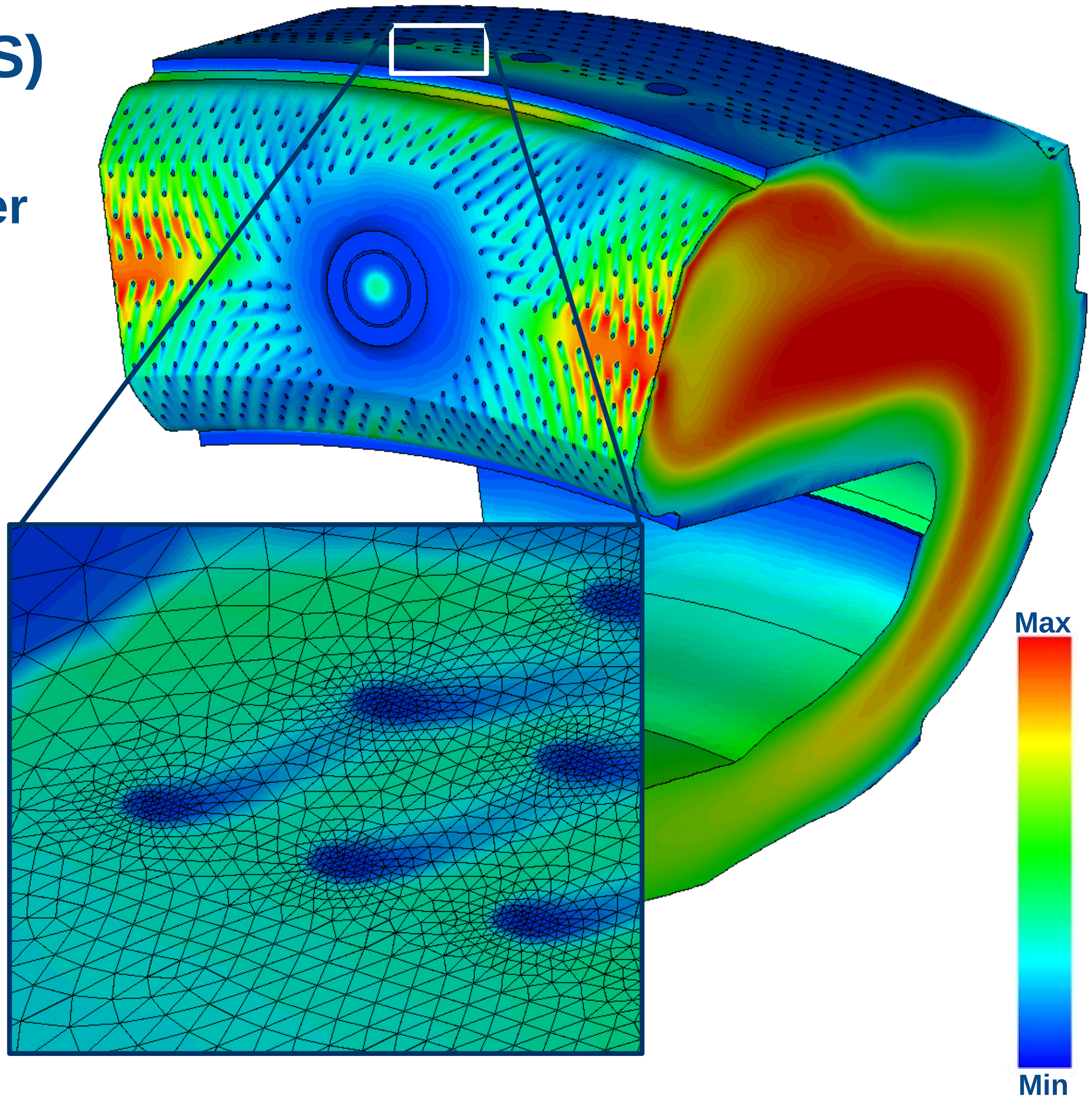
- **A fully coupled component with complex flows**
  - **Aerodynamic / Thermal / Chemical / Stress behavior must be taken into account, with various coupling levels**
  - **Dysphasic analyses required for the fuel injection**

- **At the design point, the combustion is optimized to be stable**
  - **The combustion chamber must remain lighted in all the flight envelope, up to 6000m and -50°C**
  - **The ability to relight must be demonstrated for airworthiness purpose**
  - **In these extreme conditions, the combustion may be significantly unsteady**

Typical combustion steady computation

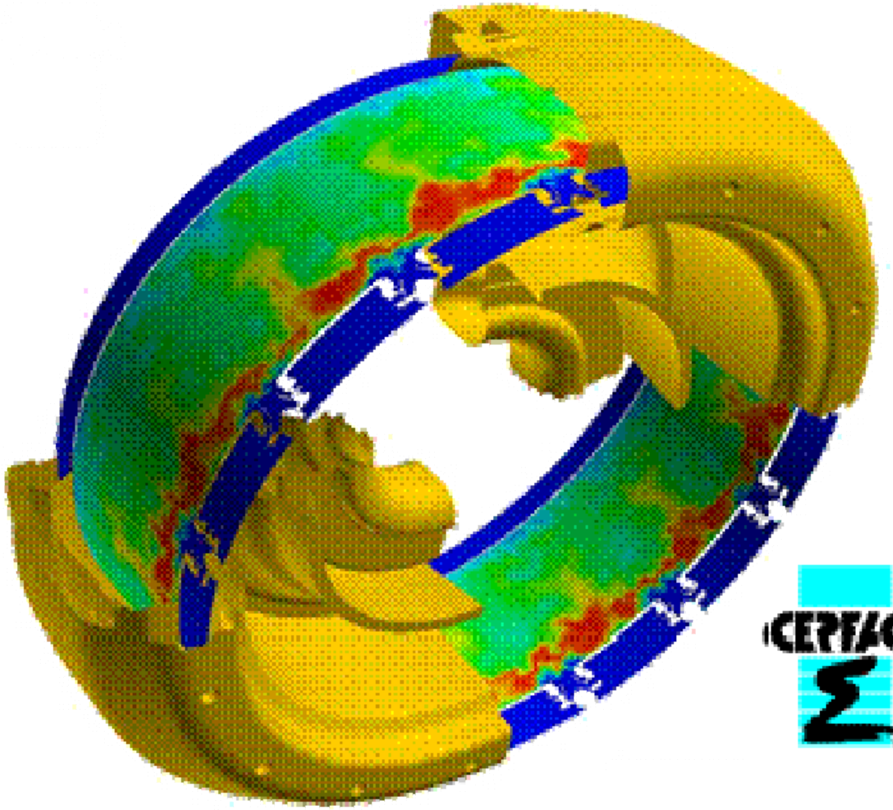
- **RANS aerothermal simulation (N3S)**
  - **100 processors / 72 CPU hours**
  - **1/12 portion of the combustion chamber**
  - **8 200 cores French CEA-CCRT (Atomic Energy Commission R&T Computing Centre)**

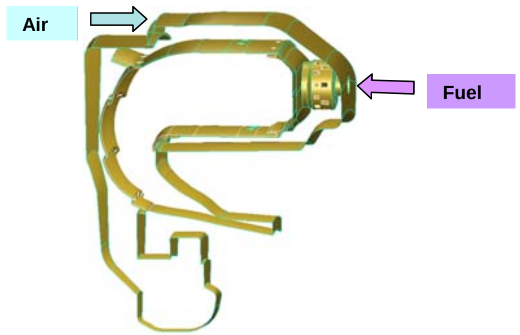


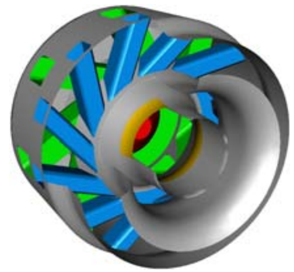


Typical combustion unsteady computation

- Large Eddy Simulation to better capture the turbulence (LES)
- AVBP code (CERFACS): 42 Millions tetrahedral cells
- 10 CPU days on 256 processors @ MareNostrum in Barcelona
  - 200Gb of Data

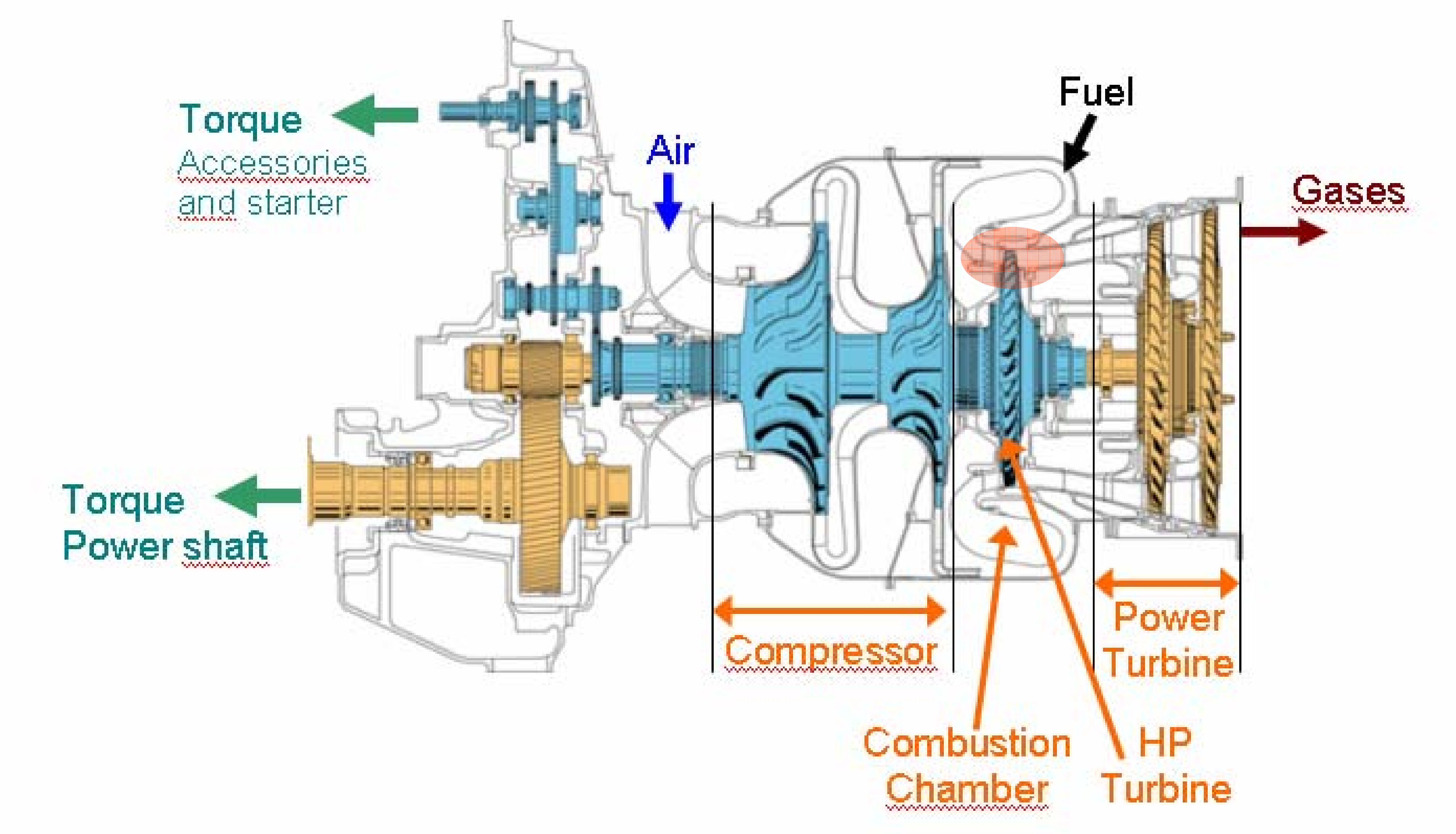






Instantaneous temperature field in the combustion chamber

Simulation challenges for gaz turbines



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Simulation challenges for turbines

- **The turbine inlet temperature increase allows to reduce the air flow necessary to achieve the required power**
  - **The size of the compressor is minimized and the engine mass can be decreased significantly, which has a positive impact on emission**

- **Turbine components are subjected to extremely high temperature and loads**
  - **More than 1200°C mass temperature on the blades requires single crystal heat resisting alloys with ceramic thermal coatings**
  - **A 20°C error on the component temperature leads to a factor or 2 on its life**
  - **Measurement are very complex and expensive**

- **Extremely accurate simulation**
  - **Aerothermal + mechanical coupling**
  - **Complex flows, including cooling must be accounted for**

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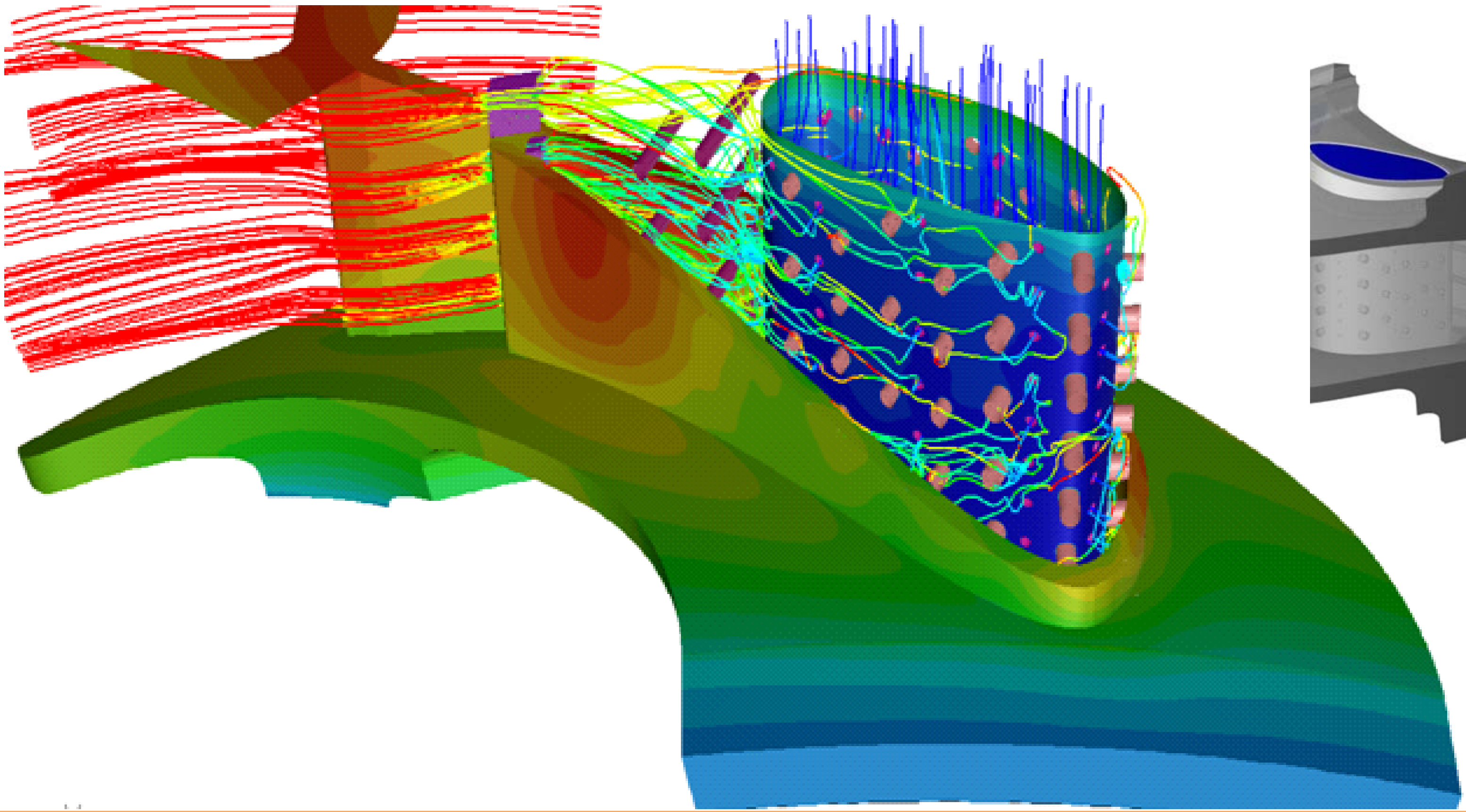
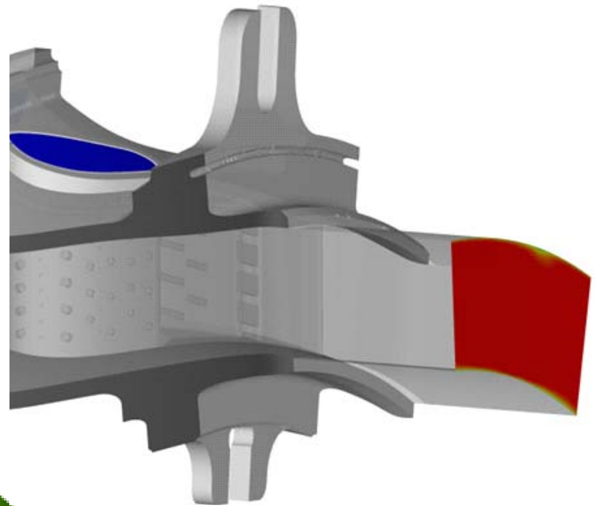
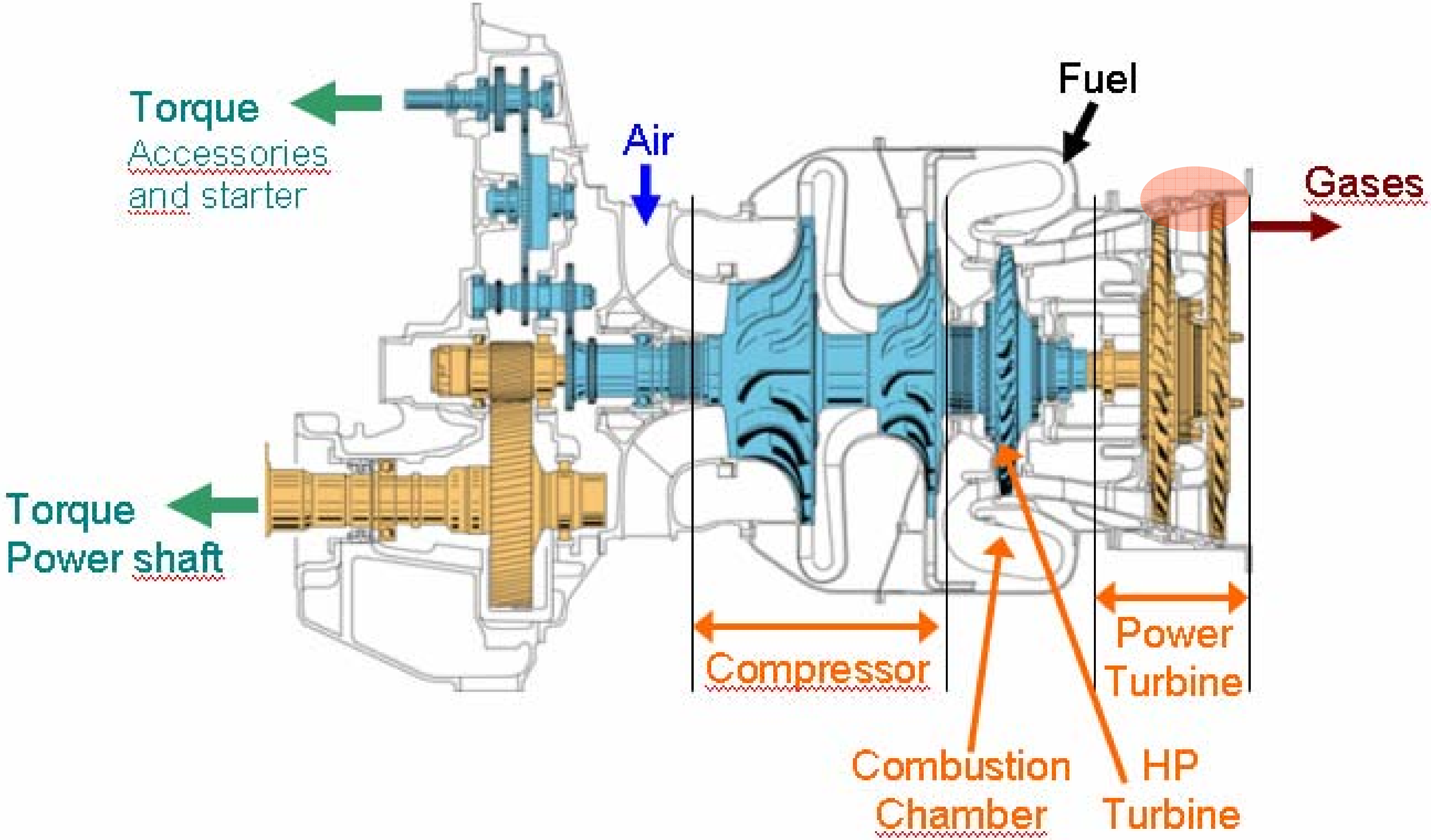
Typical aerothermal analysis on turbines

- **RANS simulation with FLUENT code: internal cooling flow, main air throat, coupled with the structure (temperature on the skins)**
  - **72 CPU hours on 12 processors @2GHz - Linux operated Cluster**





Simulation challenges for gaz turbines



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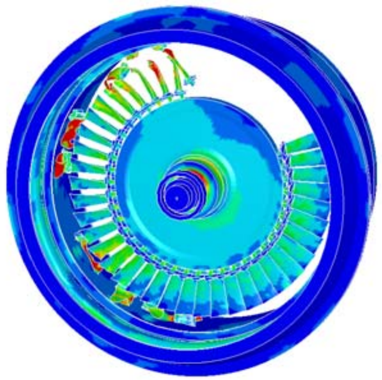
Better performance but no compromise on safety

- Performance improvement to reduce emissions are leading
  - To higher loads on component
  - To higher temperature
  - To mass optimization

- As a consequence, the security margins (safety factors) are reduced to the minimum
  - This is made possible by more accurate simulation to better understand the components / engine behavior close to the limits

- But safety improvement effort MUST go on
  - Simulation is a key contributor
  - Example on the power turbine shield
    200 CPU hours



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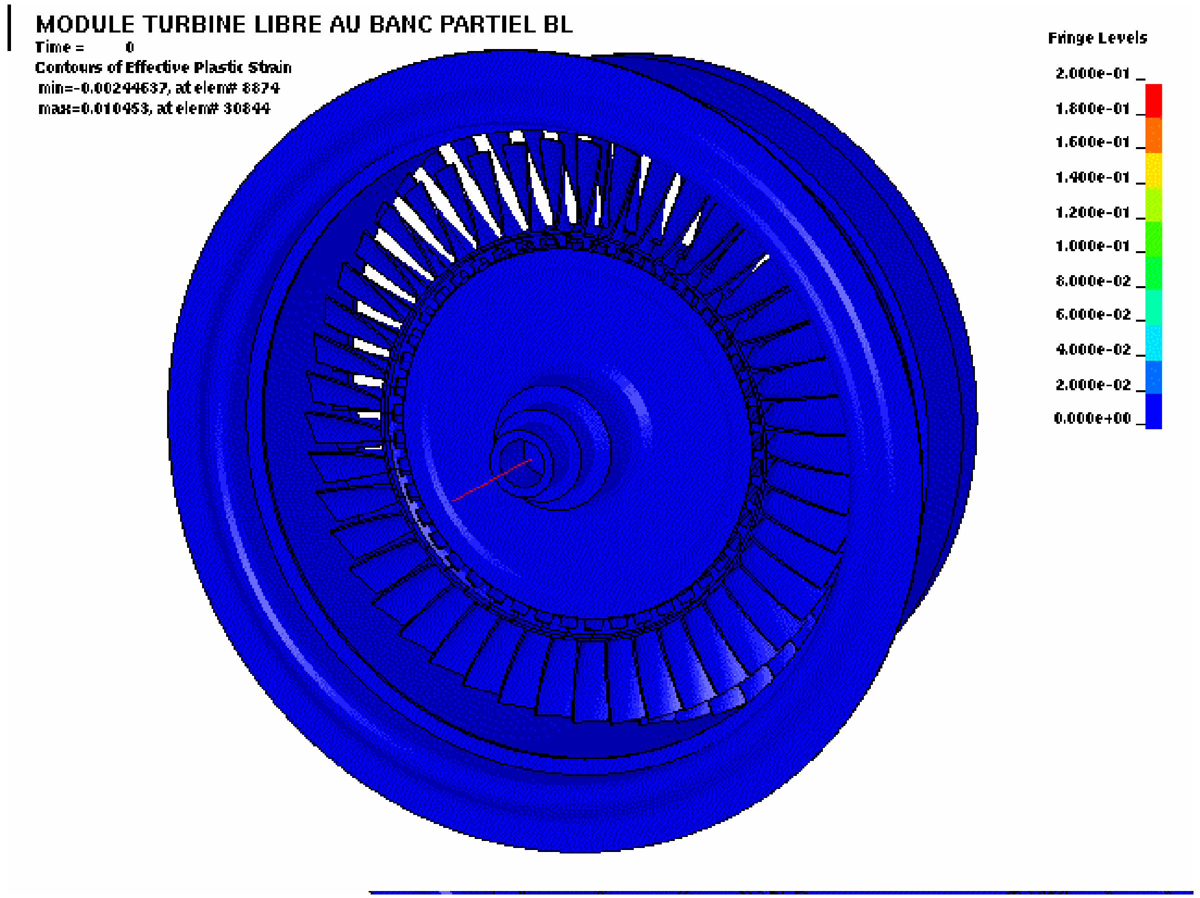
The blade shedding simulation



HPC center typology depends on the design phase

- **Computational power improvement is an opportunity to increase the model size and the physics representation …**
  - **This answers the expectation of the design assessment phase: more power, less collaborative activity (integration is not outsourced)**
  - **Example of SONATE project at FUI9**

- **… but the development risks mitigation is a also priority**
  - **Make more simulation earlier in the design on more simple models (often the geometry is not known) with high fidelity physic representations**
  - **Requires less power but more proximity (local center), more collaborative (access to the supply chain), more flexible (number of software installed)**

- **Need for low cost, local and versatile HPC centers**
  - **Open center to the supply chain, efficient for a wide panel of SW**
  - **Example of MOSART simulation platform initiative (French Aerospace Valley)**