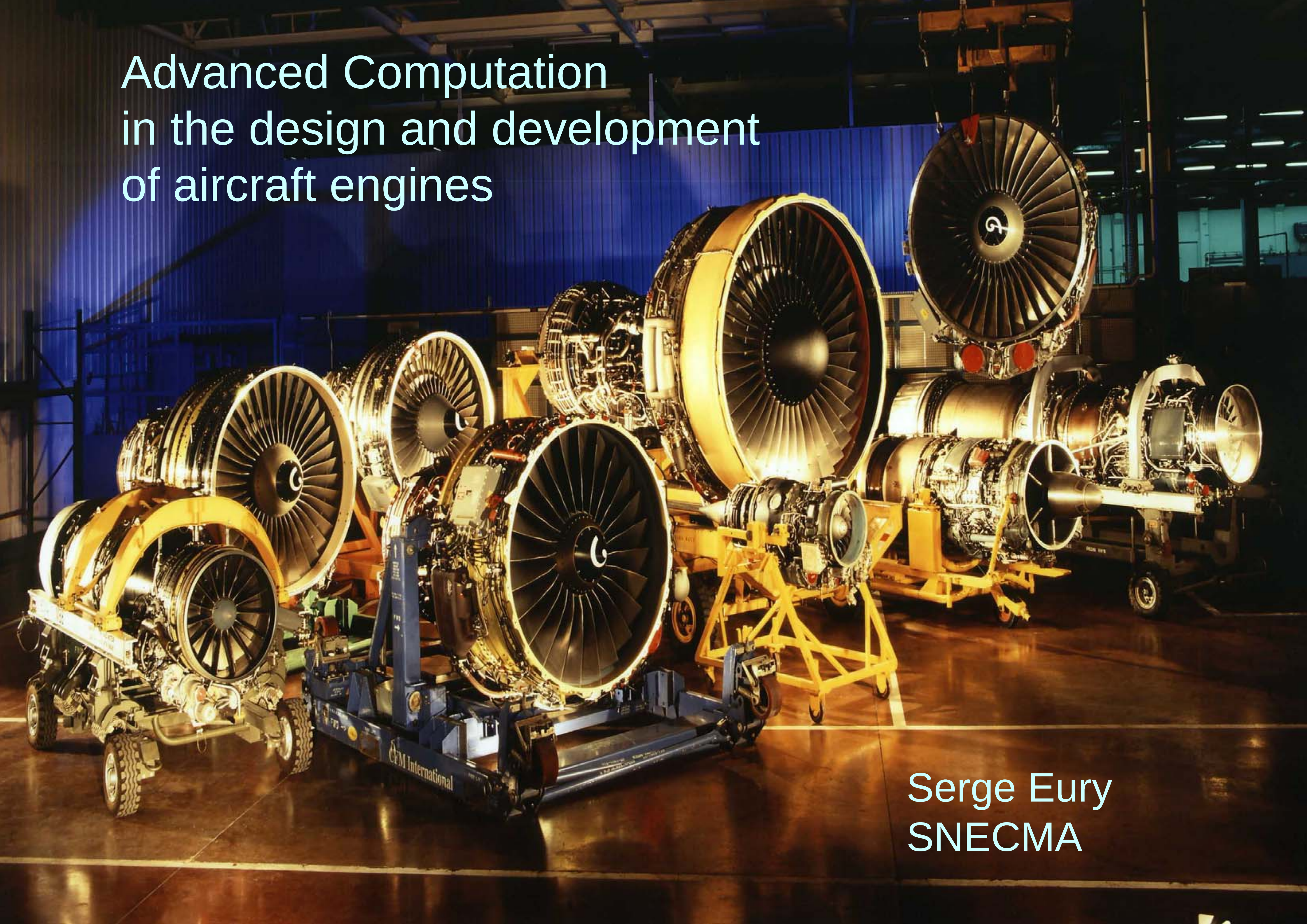
Advanced Computation in the design and development of aircraft engines

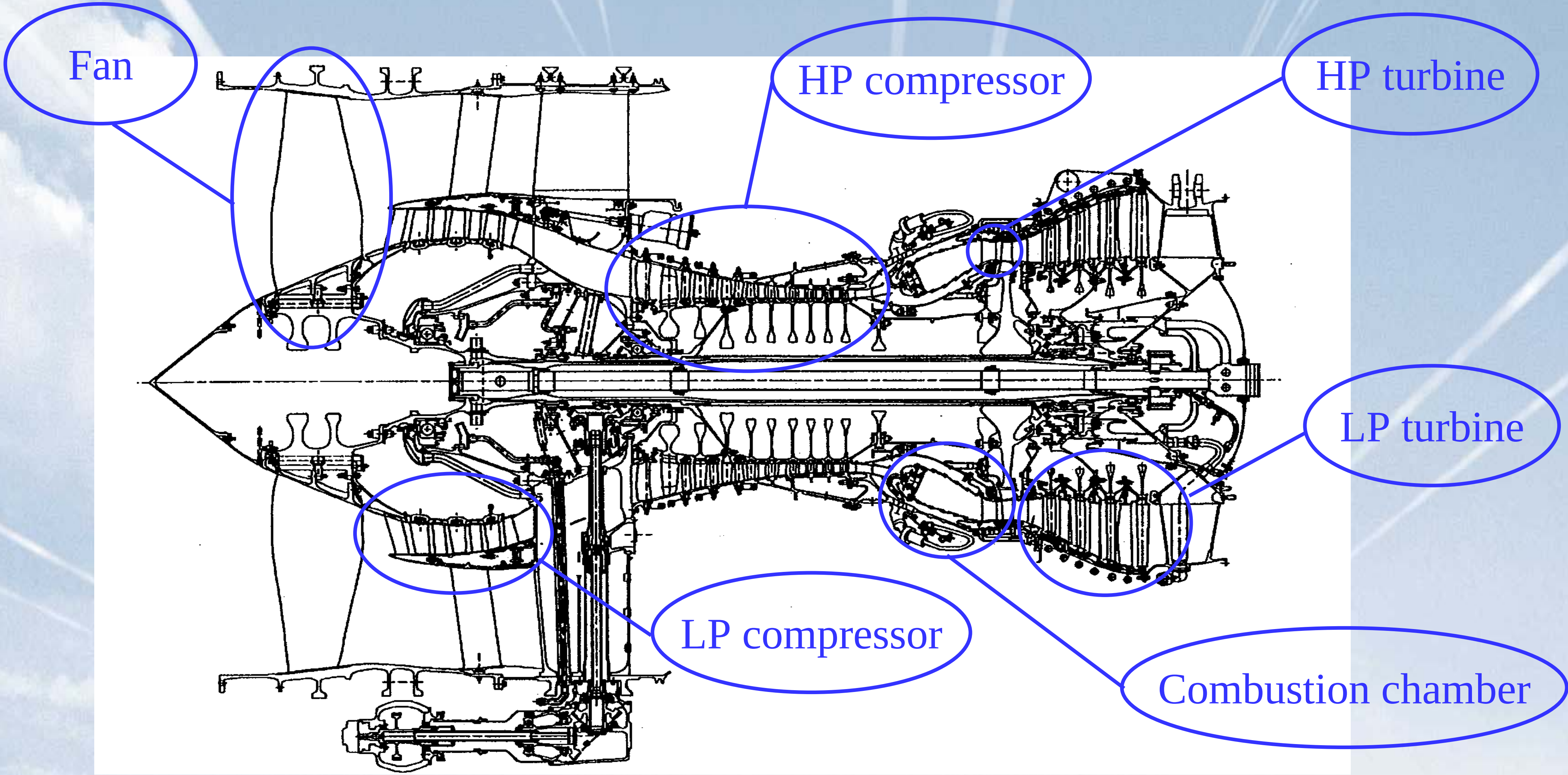


Serge Eury
SNECMA

Advanced Computation in the design and development of aircraft engines

- Introduction
- Some examples
- Conclusions

An engine is a complex multi-component system



Numerical computations are key processes in the design and development of aircraft engines for very various kind of problems

Snecma
SAFRAN Group

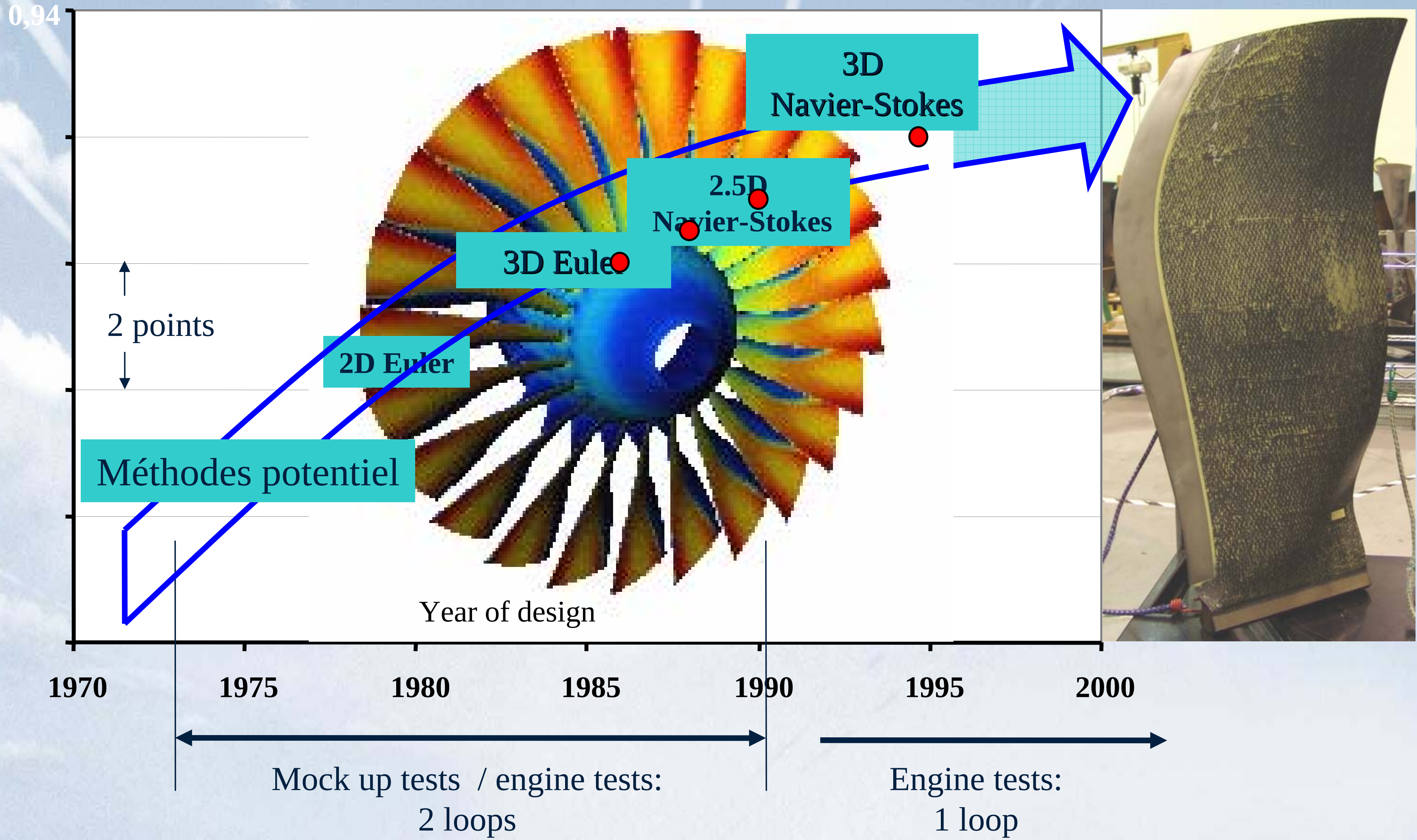
Improved performances thanks to computations e.g.. FAN aerodynamic efficiency

<u>In 25 years</u>

+ 8 % in efficiency

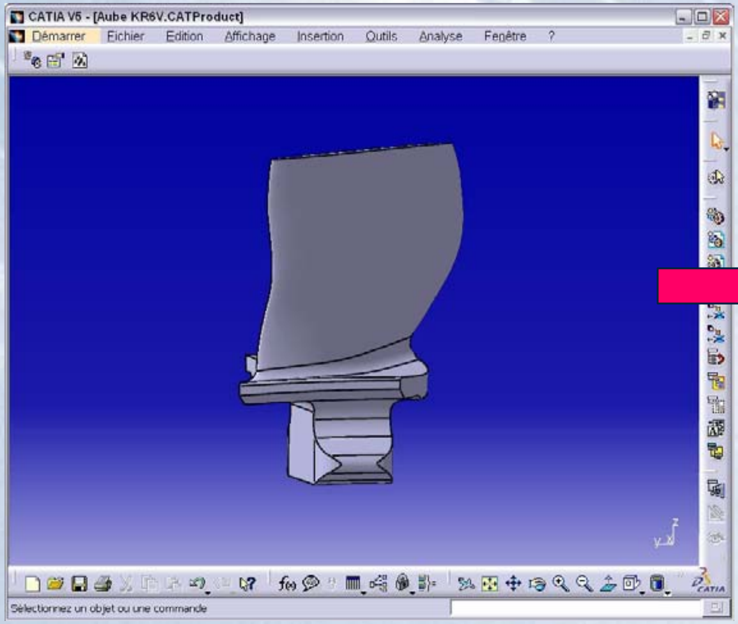
+ 9 % in specific mass flow

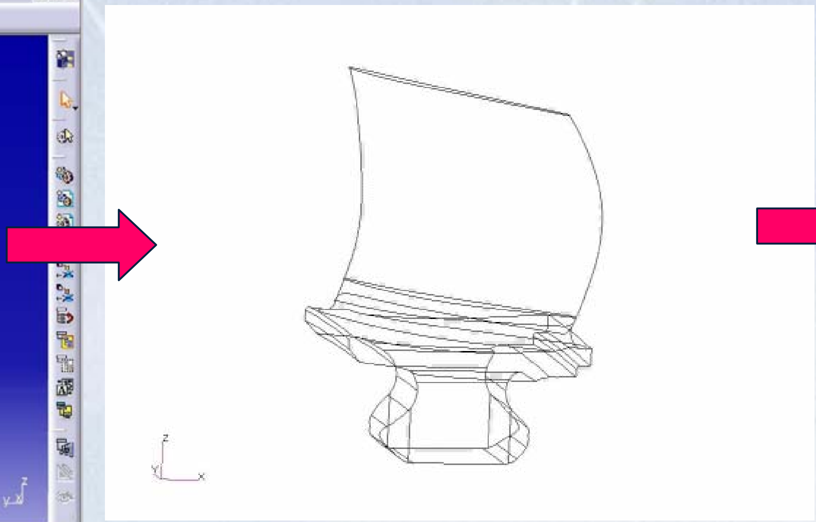
Increased stability

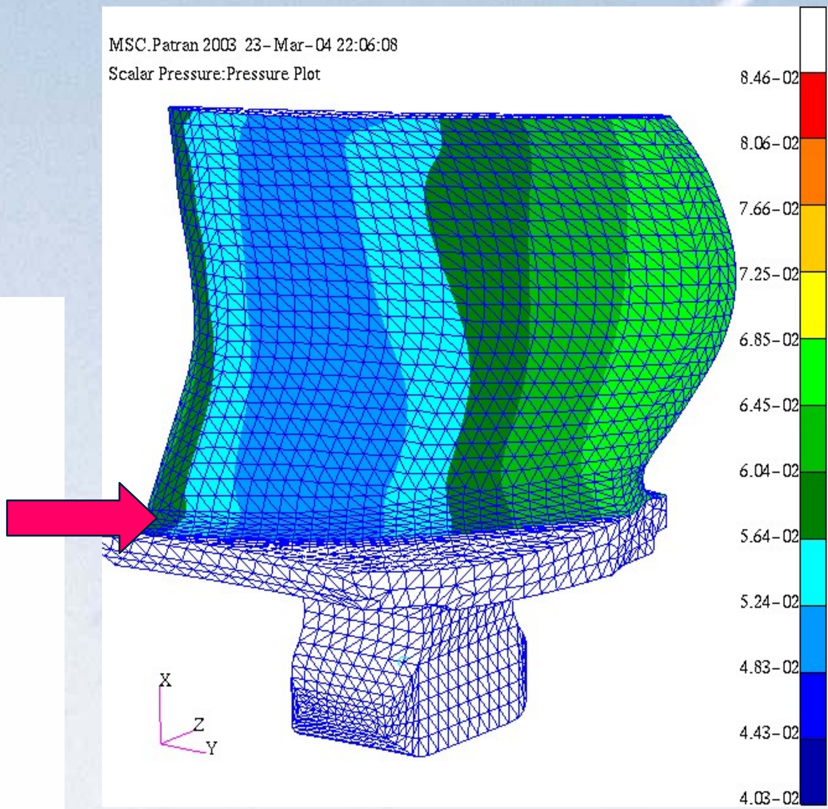


Optimisation of design by chain and loop of computations

- Catia V5 parametric model
- Meshing
- Standard automatic computations
- Parametric sensibility
- Optimisation





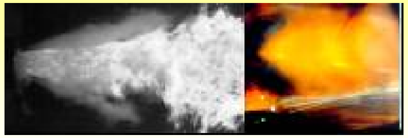


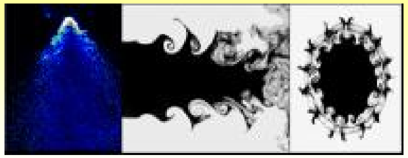
Snecma SAFRAN Group

Computations must be based on simulations of the real physics

Research

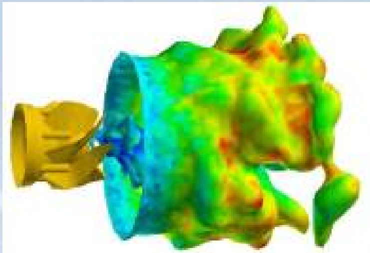

Emission and Environment


Dynamics Combustion

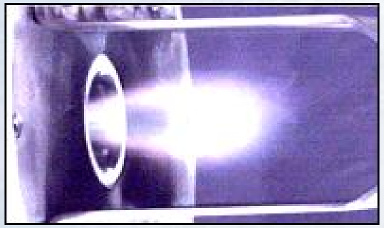

Injection and mixing


Wall interaction

Development of simulation codes



Experimental validation

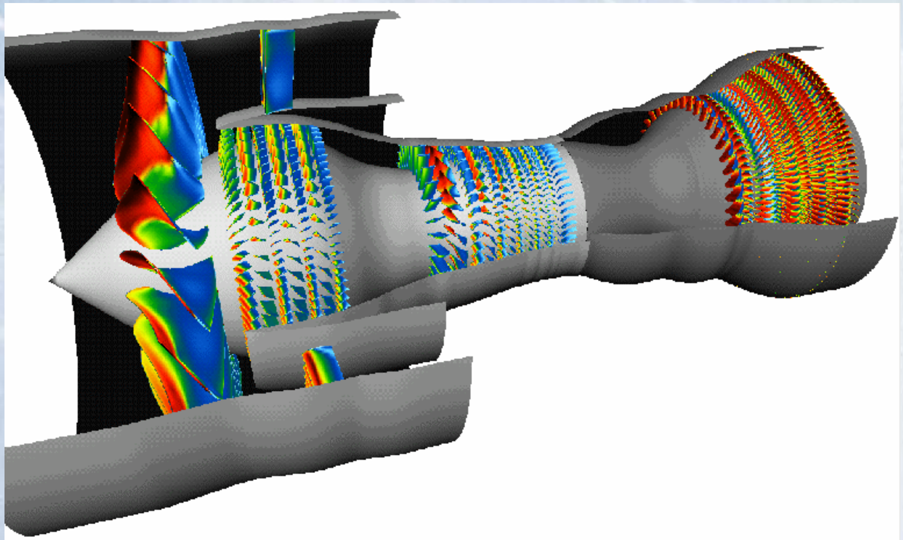


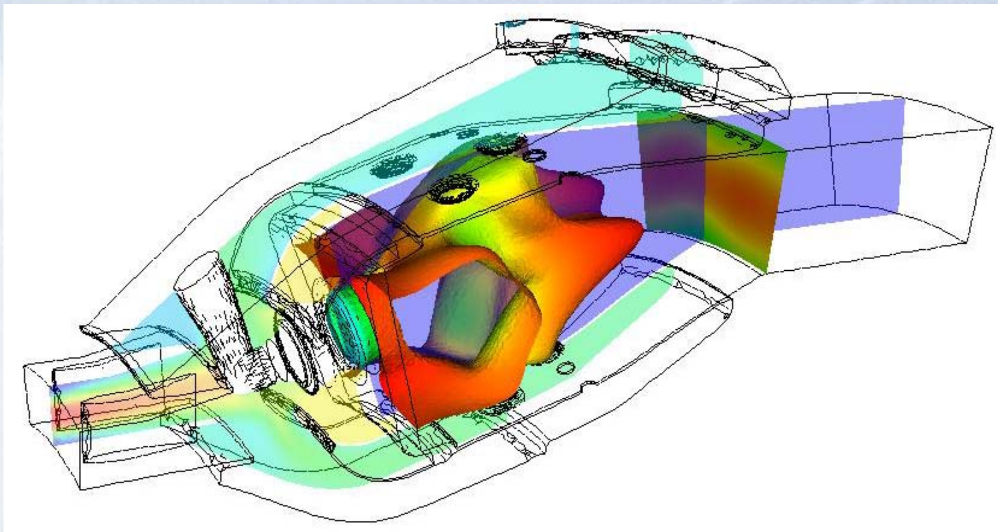
Maturation of technologies

Used in development for new engine

Numerical computations in development process

- They are of different kinds with different objectives with durations compatible with the design cycle :
  - Optimisation of design < 1 day
  - Check of design < 1 week
  - Simulation of test < 1 week
  - Analyse of special point < 1 month
  - Exploratory computation < 3 months





Snecma SAFRAN Group

Some examples

Aerodynamic
Aero thermo mechanic
Combustion
Mechanic
Dynamic
Acoustic

For various modules of engines

or various kind of problems

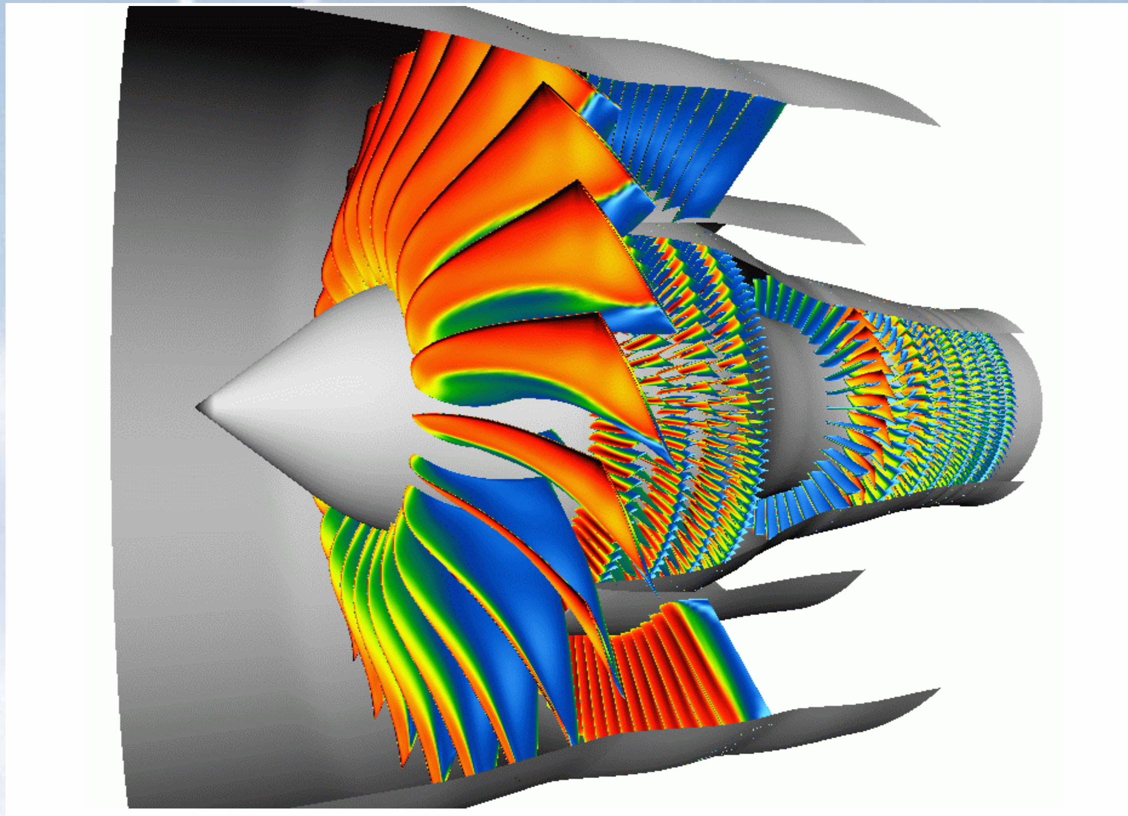
or various kind of interactions

Snecma
SAFRAN Group

CFD applications on FAN design

Efficiency ↗

- Single and multiple stages simulation
  - Aerodynamic and aeromechanic
  - steady and unsteady



- **Today:** Steady RANS k-ε bypass
  OGV and IGV analysis
  - 5 millions of nodes
  - 10h CPU time using NEC SX6

- Target in 3 years :
  - To include unsteady analysis
    to perform aero acoustic prediction
  - More than 1200h CPU
  - Expected restitution delay < 1 week
  - Need of About 200 scalar processors
    (cluster linux itanium/opteron)

Snecma SAFRAN Group

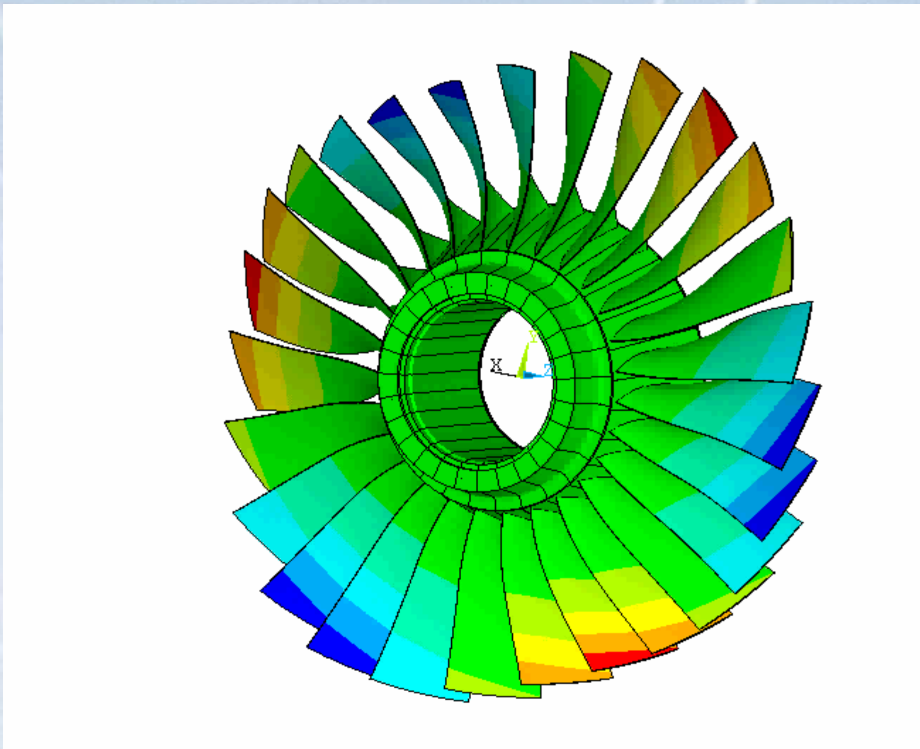
Unsteady analysis of fan blade Flutter

Stability ↗

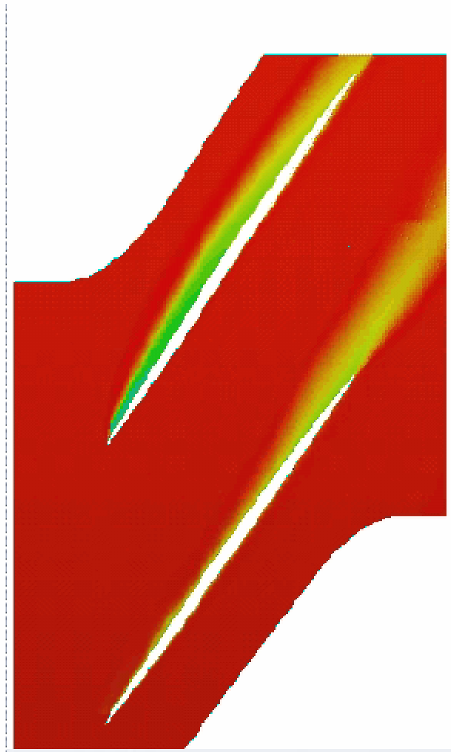
- **Today :**
  - 1 million of nodes
  - 2 equations turbulence modelling
  - More than 100 calculations carried out
  - 1 computation : 10h CPU time using NEC SX6

- **Target in 3 years :**
  - To complete a flutter analysis over 1 week
  - Including mistuning effect (more than 500 calculations)
  - About 1500h CPU time using NEC SX6

Critical areas



Blade motion



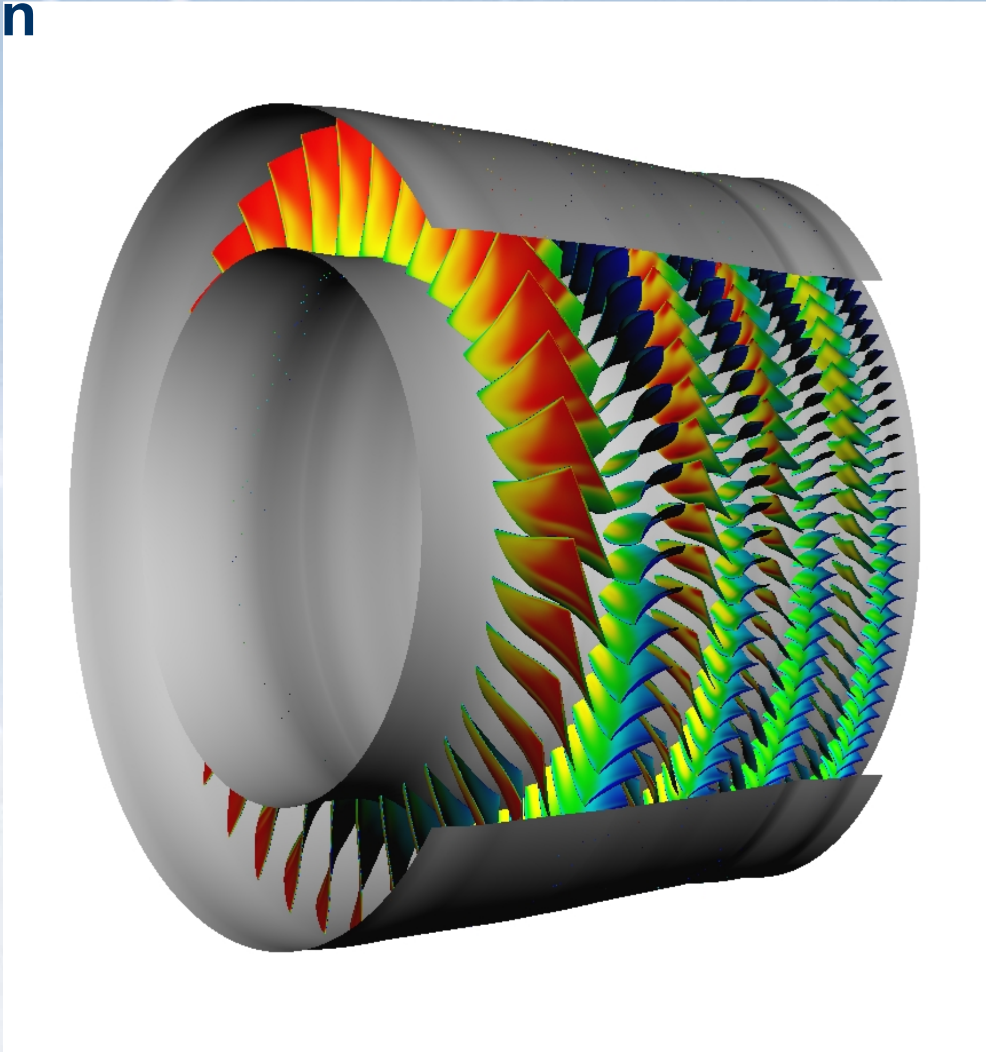
Aerodynamic forces

CFD applications on HP compressor design

- **Single and multiple stages simulation**
  - Aerodynamic and aeromechanic
  - steady and unsteady

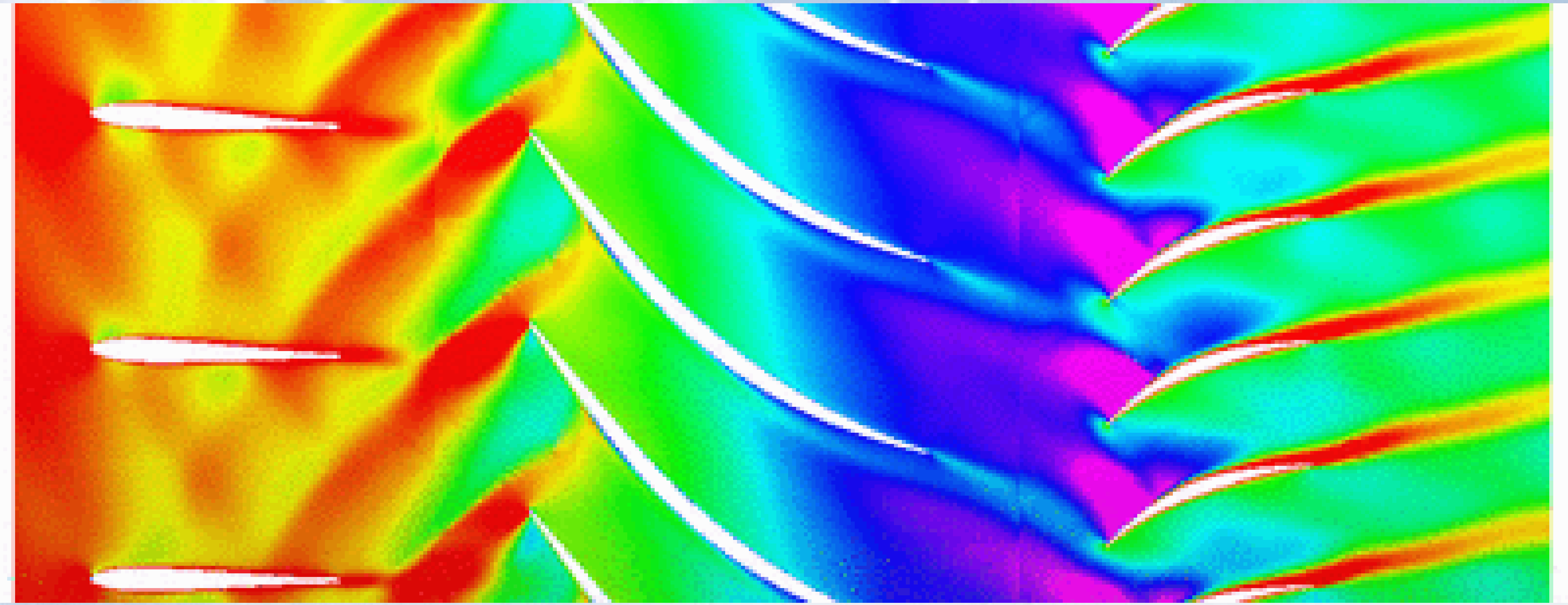
- **Today : Multi stages steady RANS k-ε**
  - 10 millions of nodes
  - 20h CPU time using NEC SX6
    (4 stages HP compressor)

- **Target in 3 years :**
  - Multi stages (8) unsteady analysis
  - About 200h CPU NEC SX6
  - Expected restitution delay = overnight
  - Need of About 150 scalar processors
    (cluster linux itanium/opteron)



Unsteady analysis of HP compressor Forced response

Mechanical vibrations



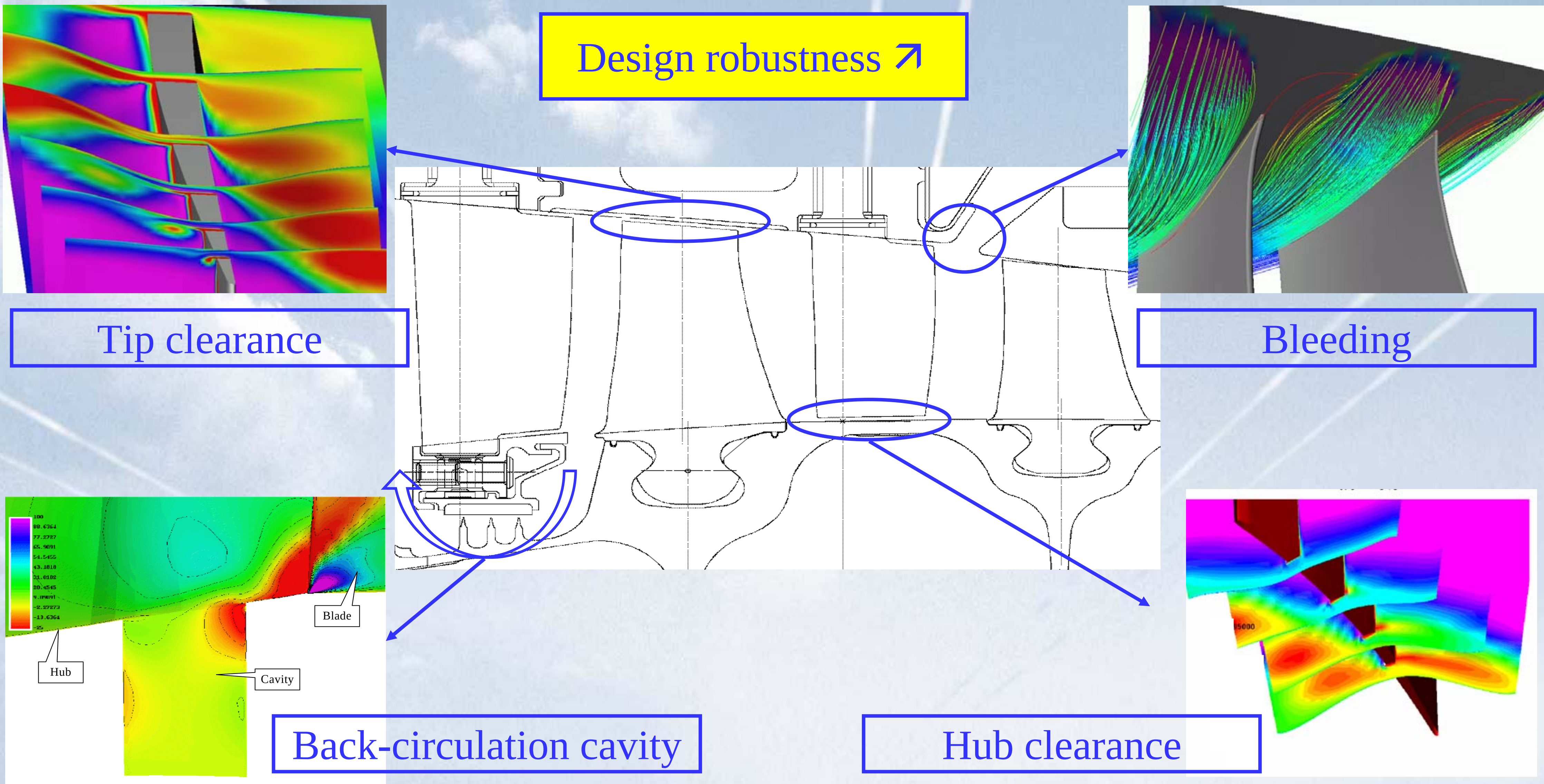
Inlet guide vane

Rotor blade

Stator

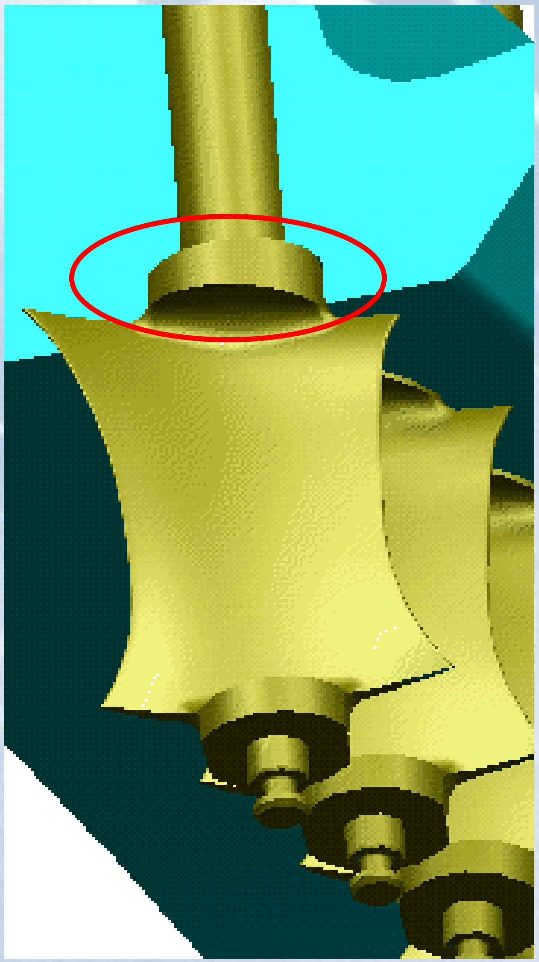
Snecma
SAFRAN Group

Steady analysis of compressor blade
Technological effects



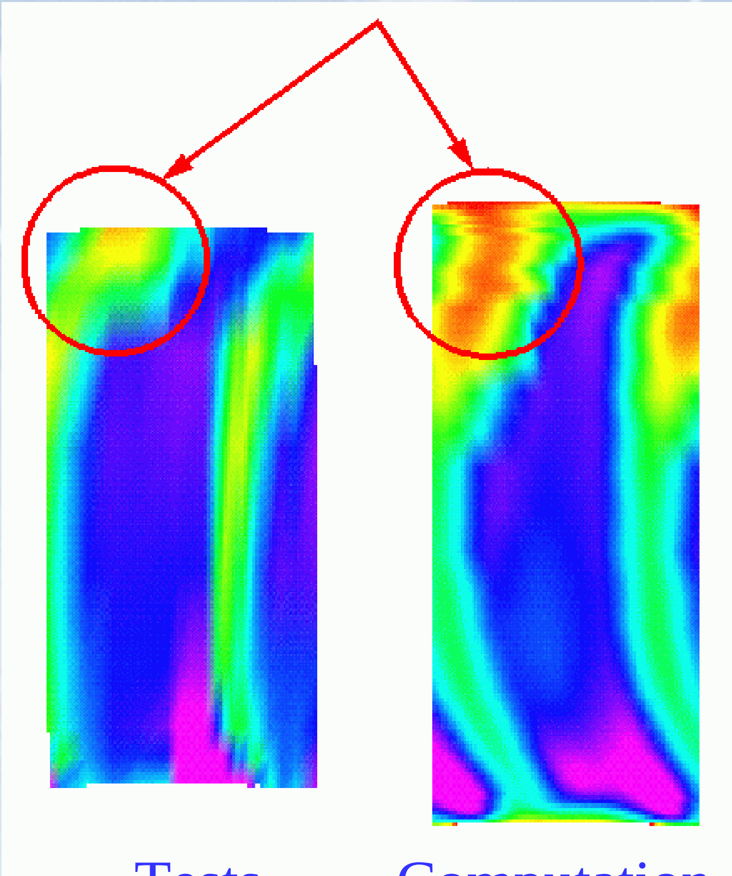
Steady analysis of variable stagger vane
Technological effects

Design robustness ↗

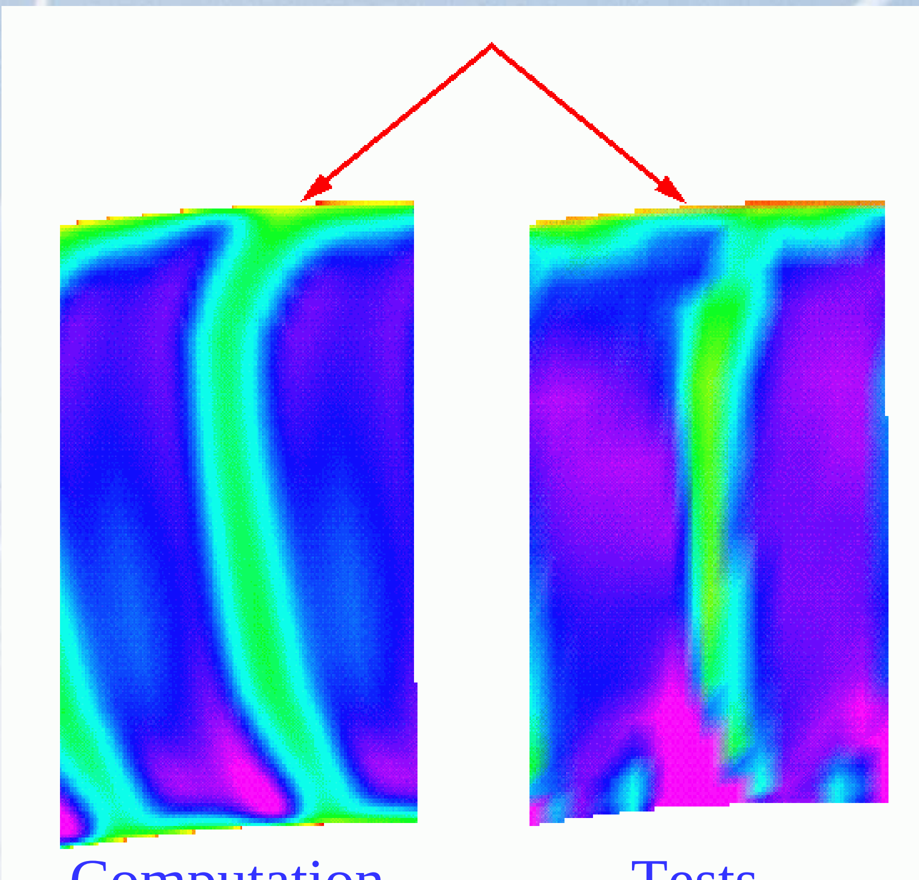


Button protruding in flow path

Smooth flow path



Tests Computation

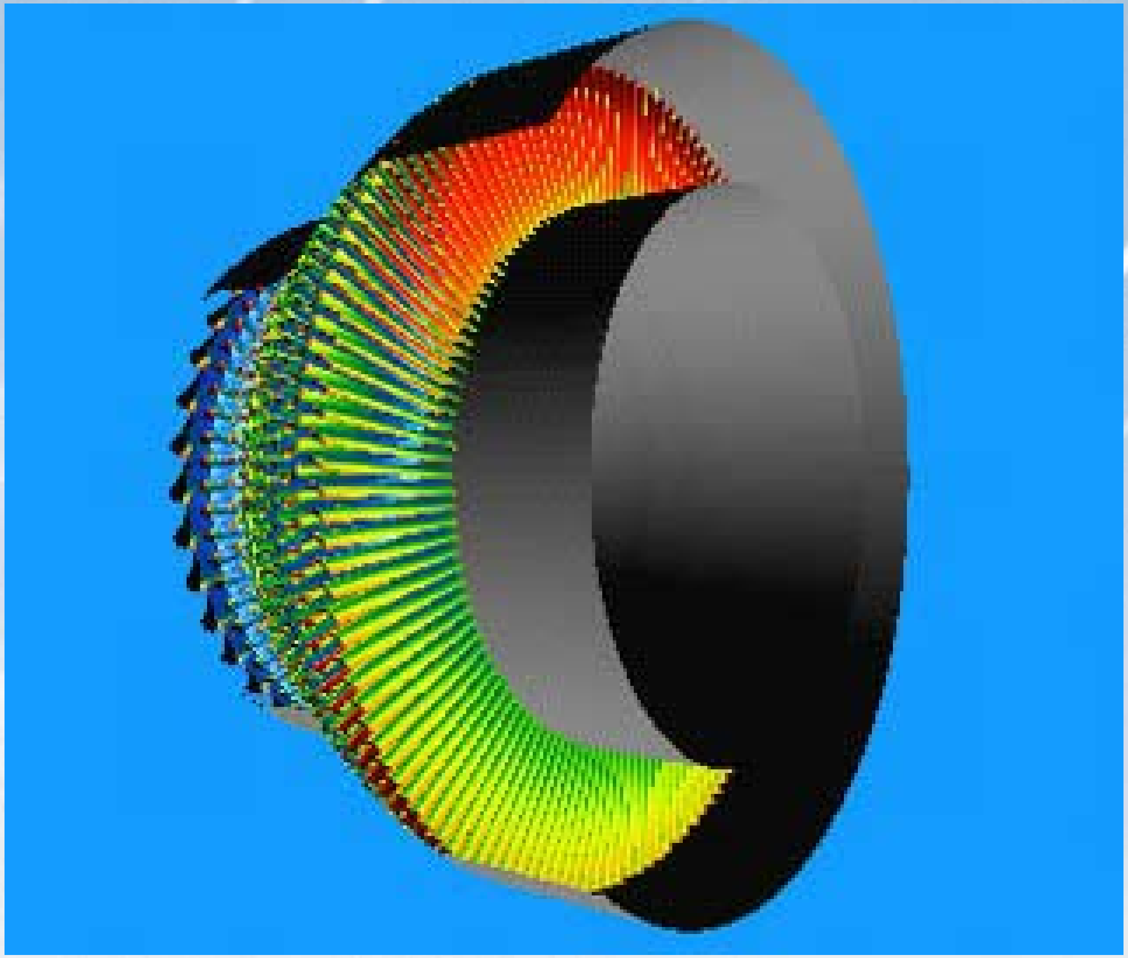


Computation Tests

Snecma SAFRAN Group

CFD applications on turbine design

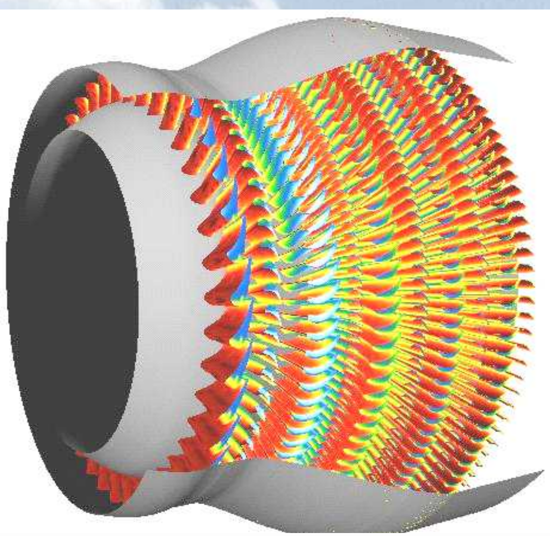
- **Single blade simulation**
  - aerodynamic
  - Aeromechanical
  - Aero thermal
  - steady and unsteady
- **Multiple blade simulation**
  - aerodynamic
  - steady and unsteady

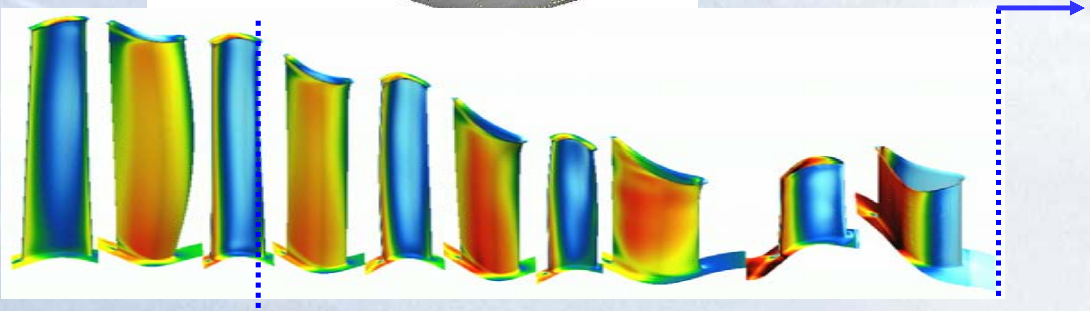


Snecma SAFRAN Group

Steady analysis of HP turbine + LP turbine Components matching

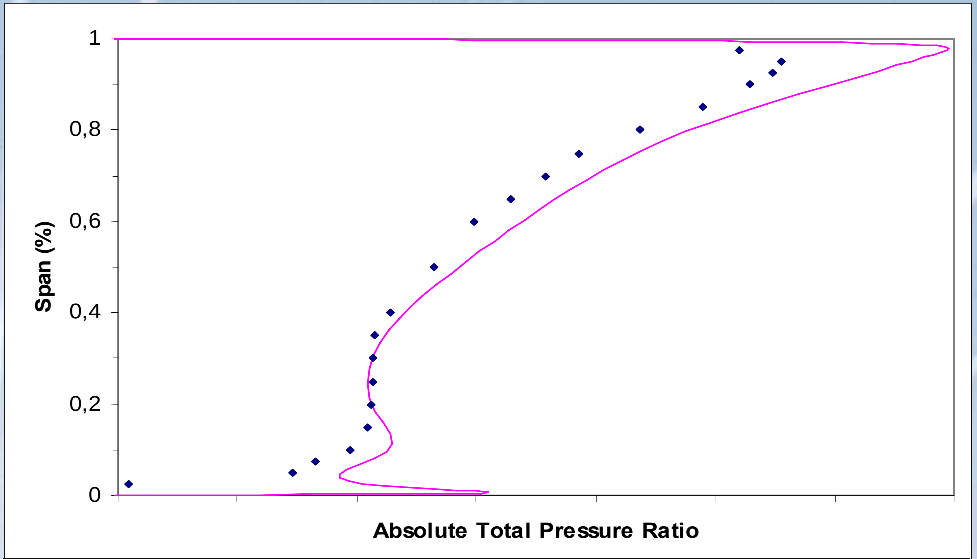
Efficiency ↗
Stage and Blade count

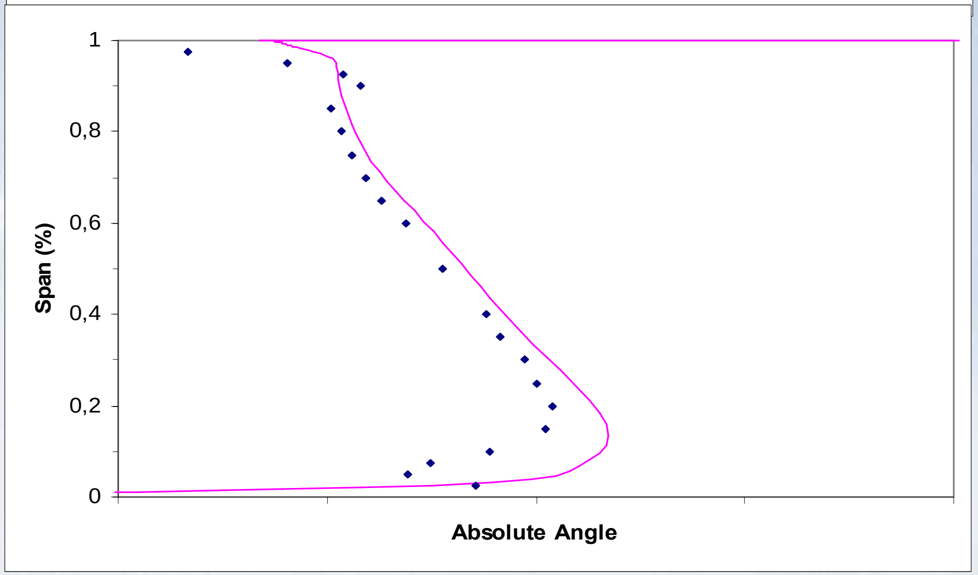




HP turbine

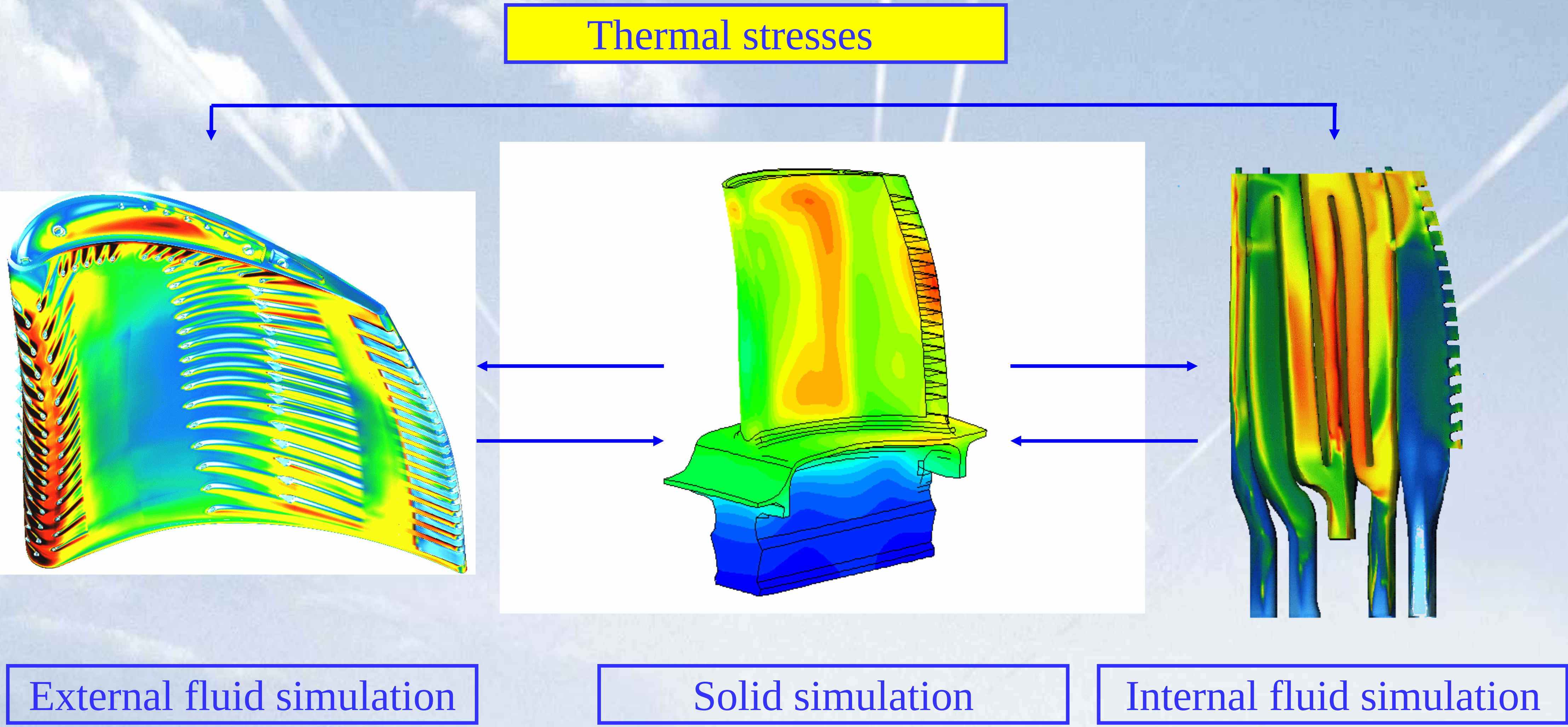
LP turbine





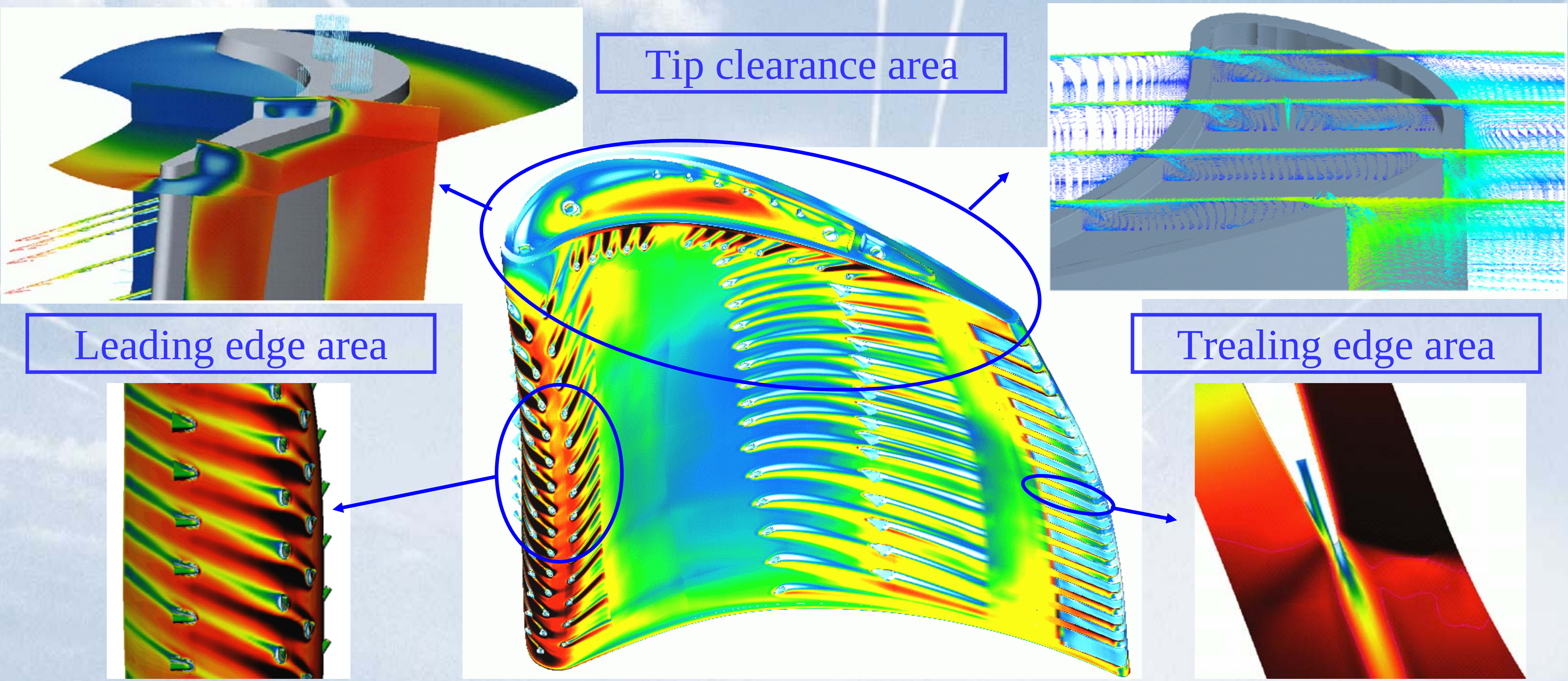
Snecma SAFRAN Group

Aero thermo mechanical steady analysis of HP turbine rotor blade: fluid / solid heat transfer



Steady analysis of HP turbine rotor blade
Technological effects

Efficiency - Cooling effectiveness ↗
Stage and Blade count ↘

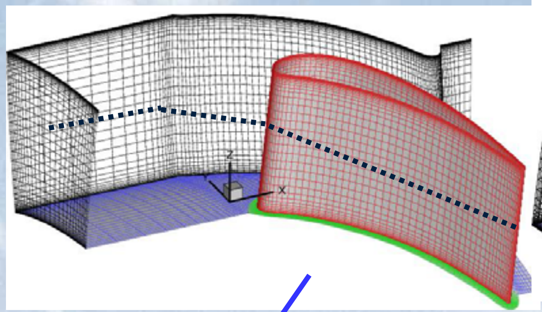


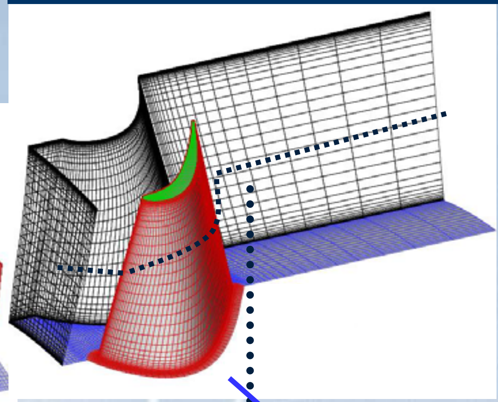
Snecma
SAFRAN Group

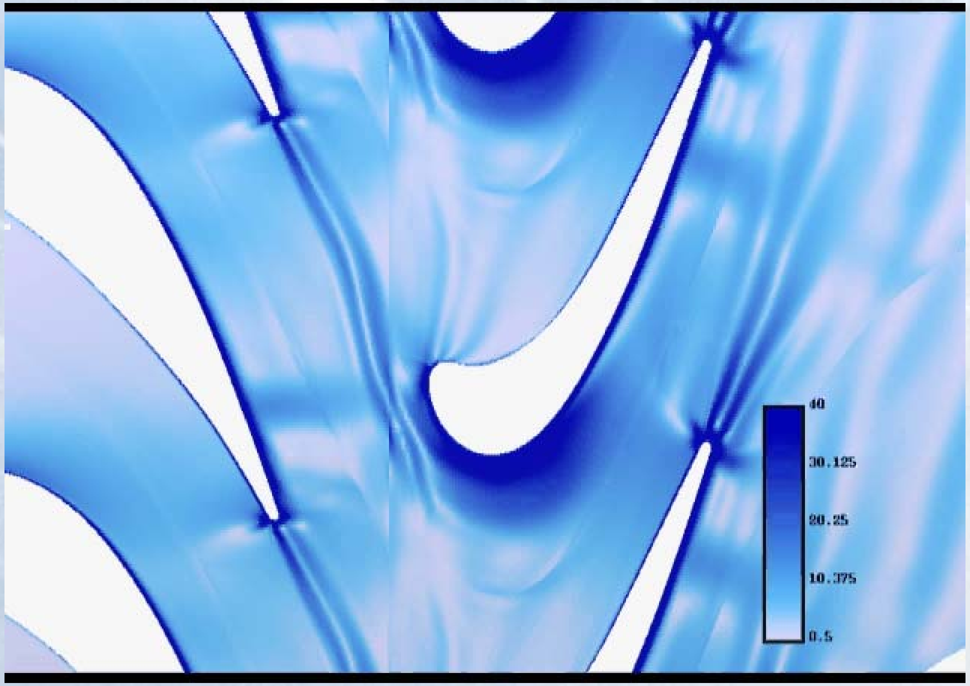
Unsteady analysis of HP turbine Unsteady phenomena

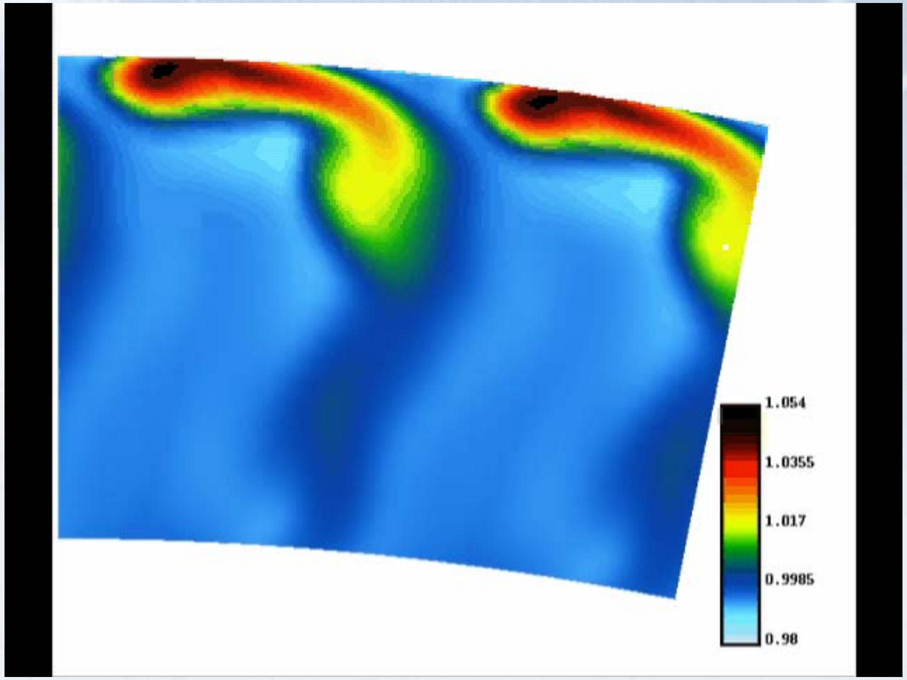
Nozzle guide vane

Rotor blade



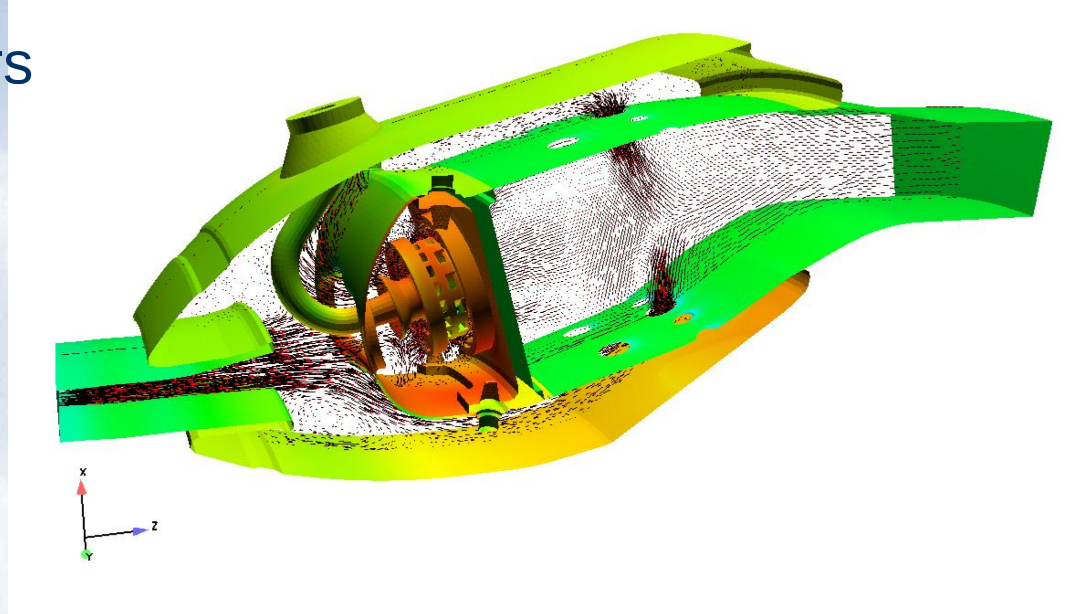






Aero thermo mechanical steady analysis with combustion in the design of a chamber

- **Today: steady reactive two phases flows analysis of one sector of combustion chamber**
  - 1 millions of nodes
  - 48h CPU time using 64 processors (cluster linux itanium/opteron)

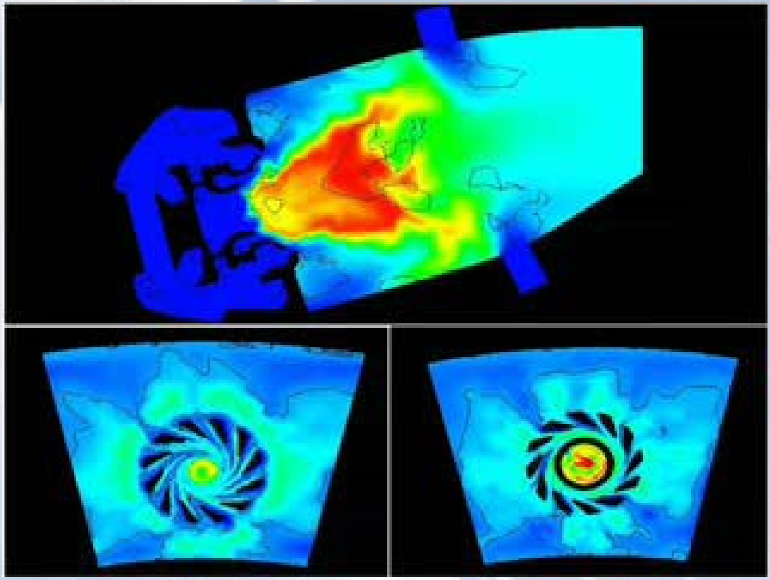


- **Target in 3 years :**
  - 3-5 millions of nodes
  - Detailed tabulated chemistry
  - Restitution delay = overnight (RANS calculation)

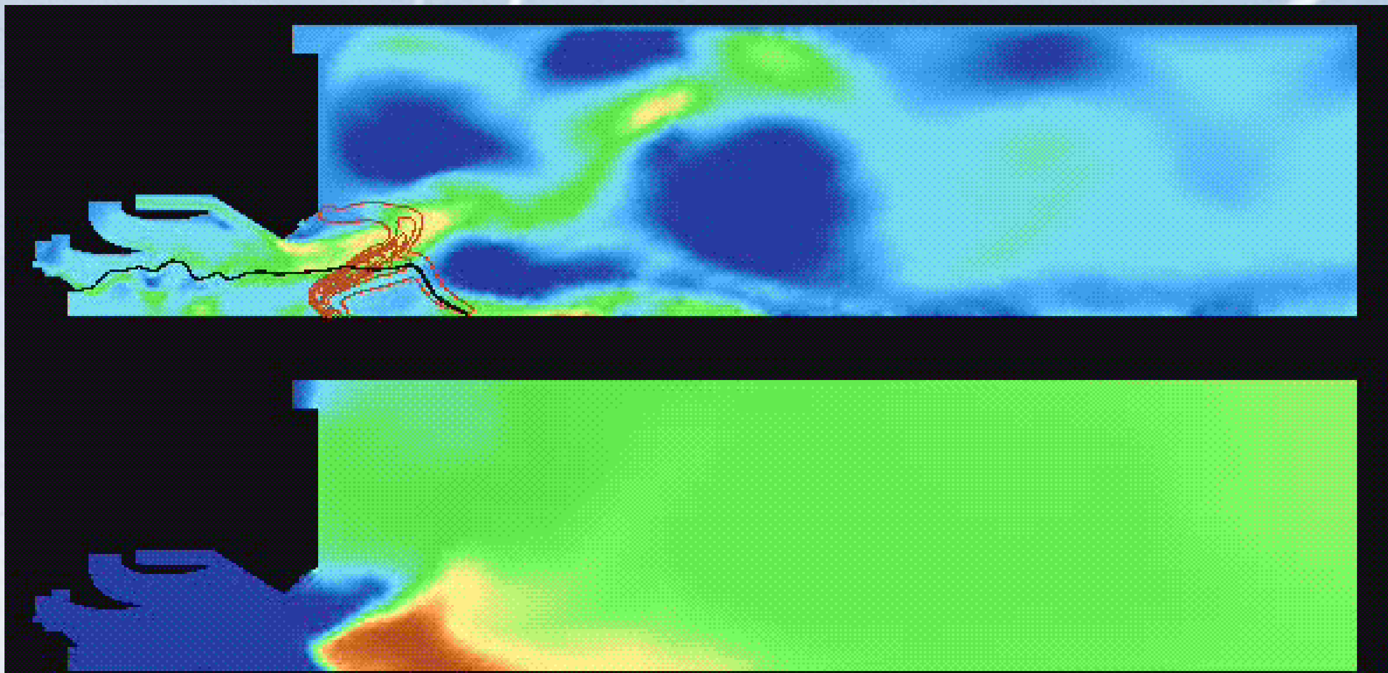
  - **LES calculation** (combustion chamber sector) < 1 month

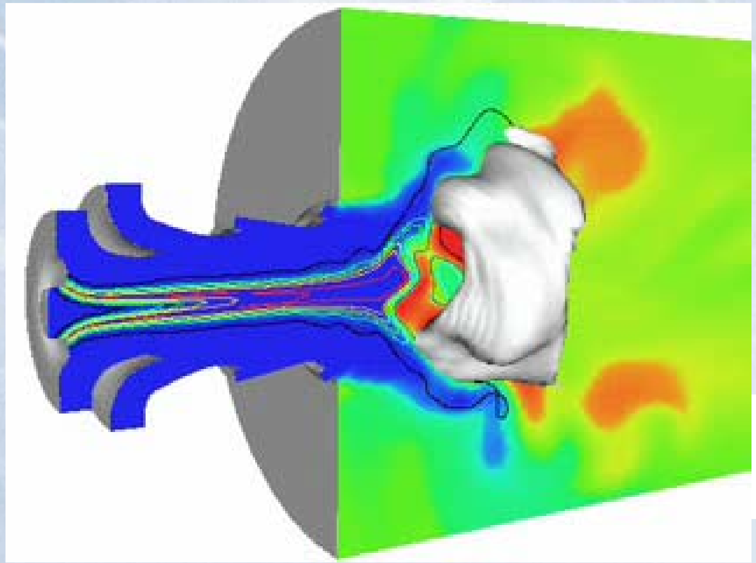
Snecma
SAFRAN Group

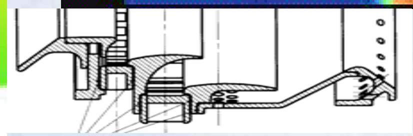
Unsteady LES analysis of combustion chamber dynamics and instability



Operability ↗
NOx emissions

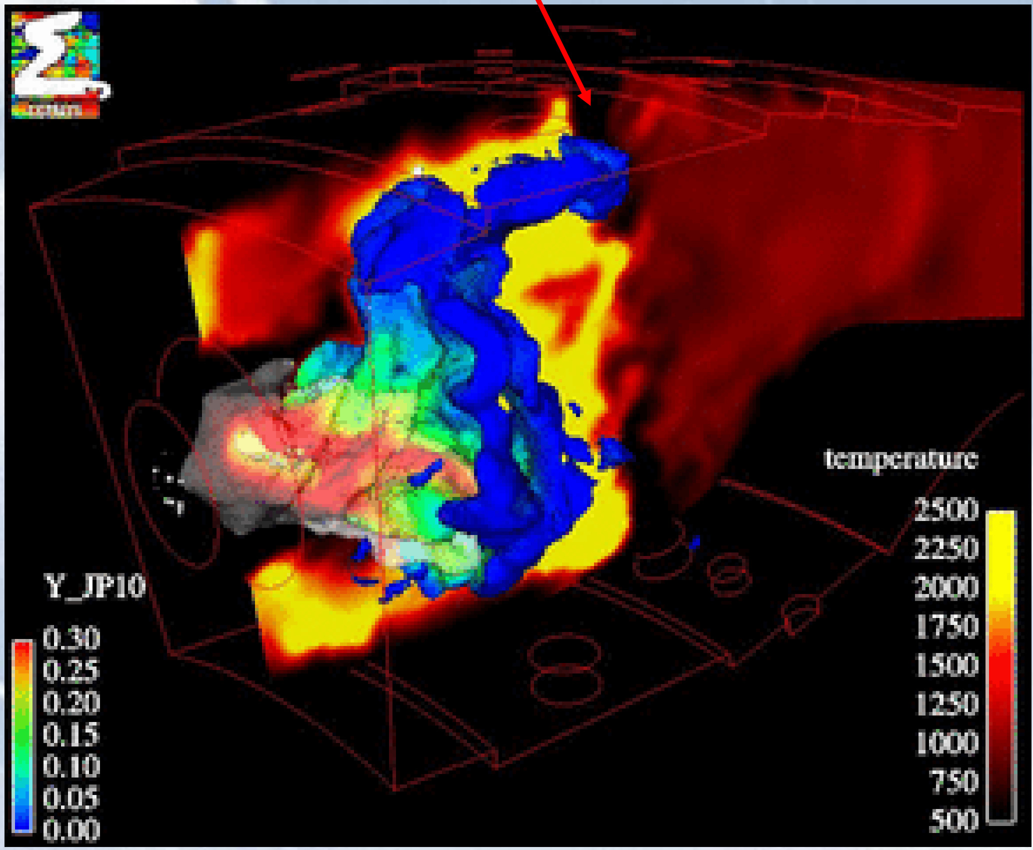


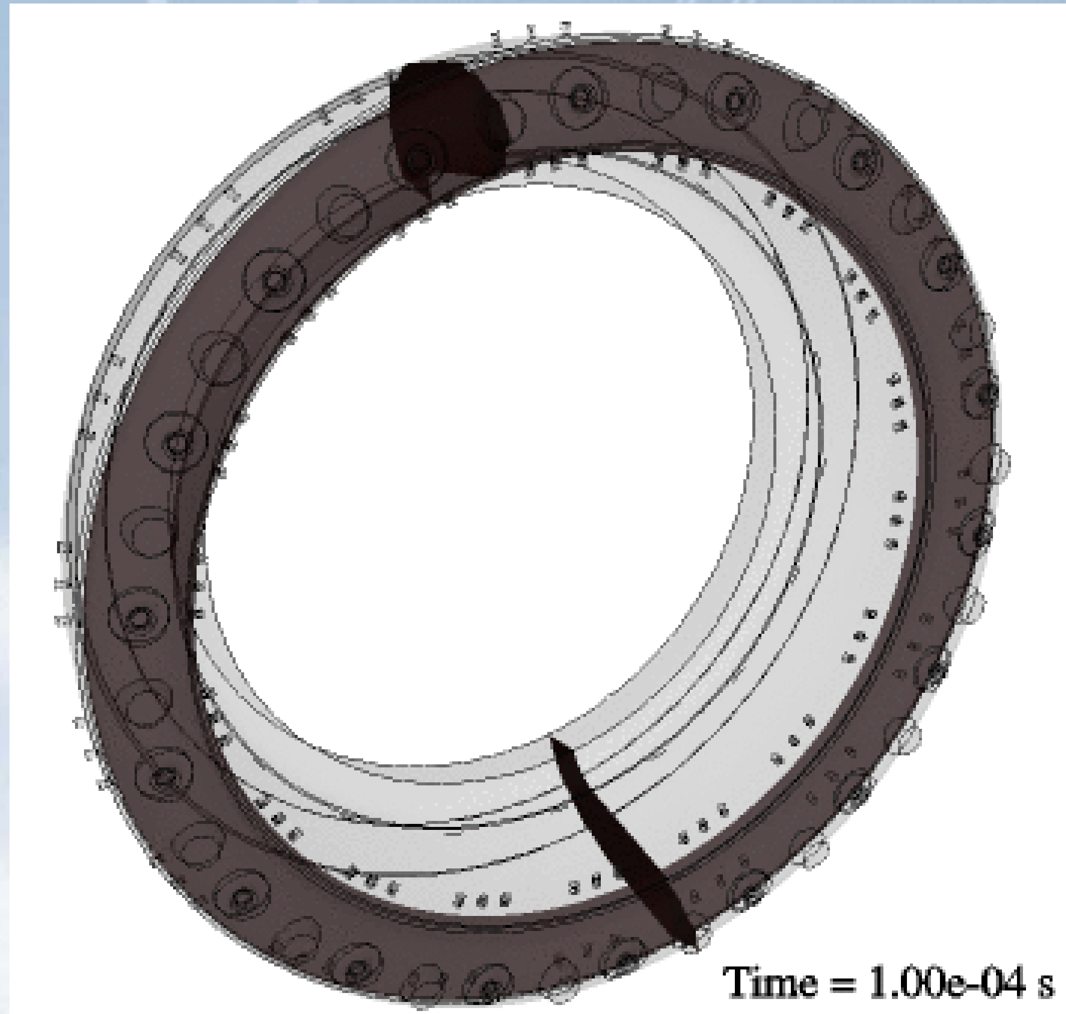




Snecma
SAFRAN Group

Numerical igniters





Thanks to CERFACS
Powerful evolution of LES
in combustion inside the network

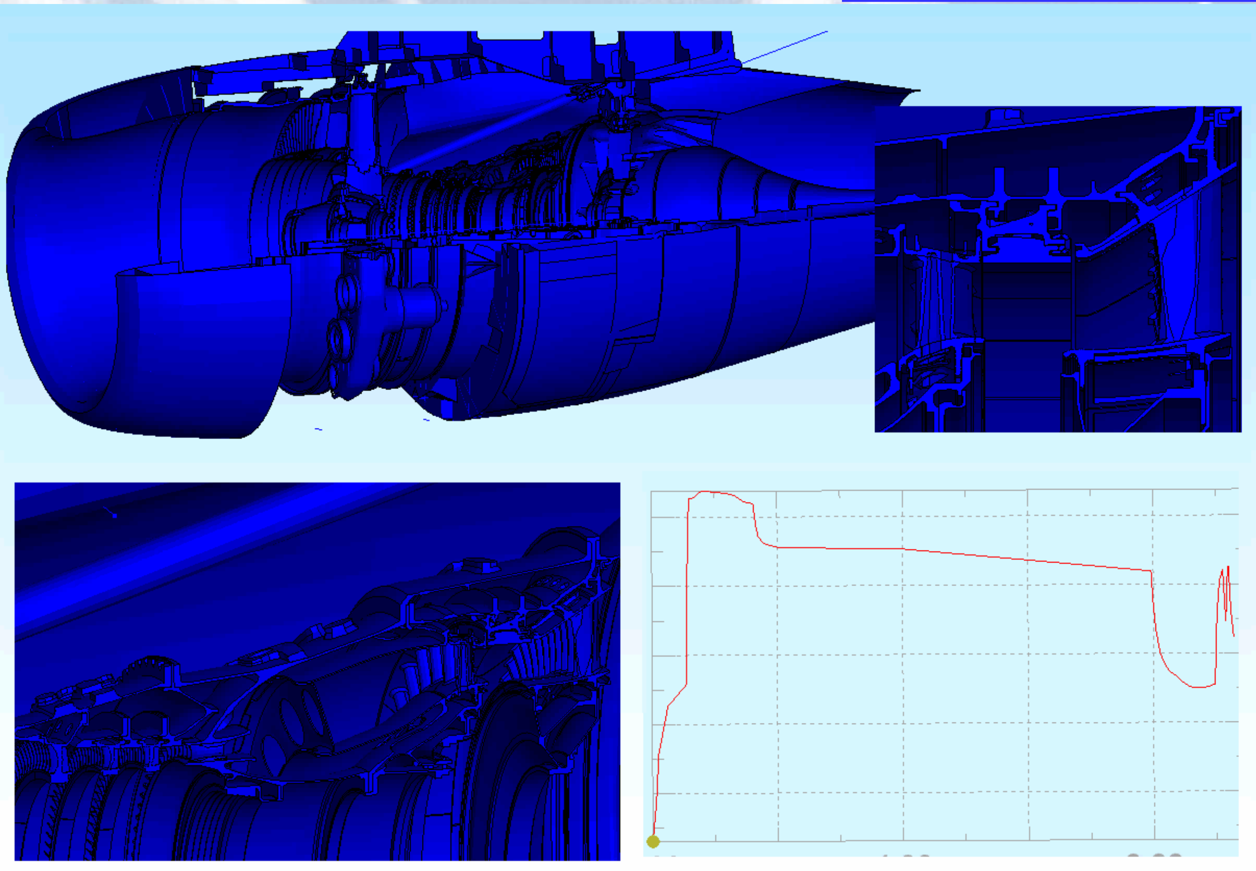
INCA

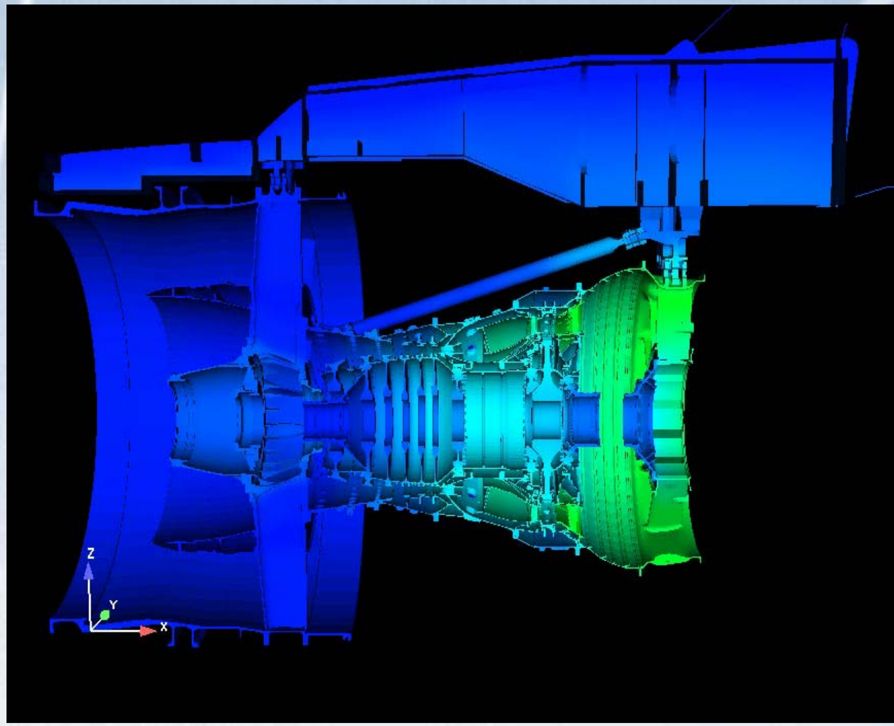
20 millions of nodes
2000 processors

Snecma
SAFRAN Group

Thermo-mechanical behaviour of the all engine during a mission: tip clearance above blades

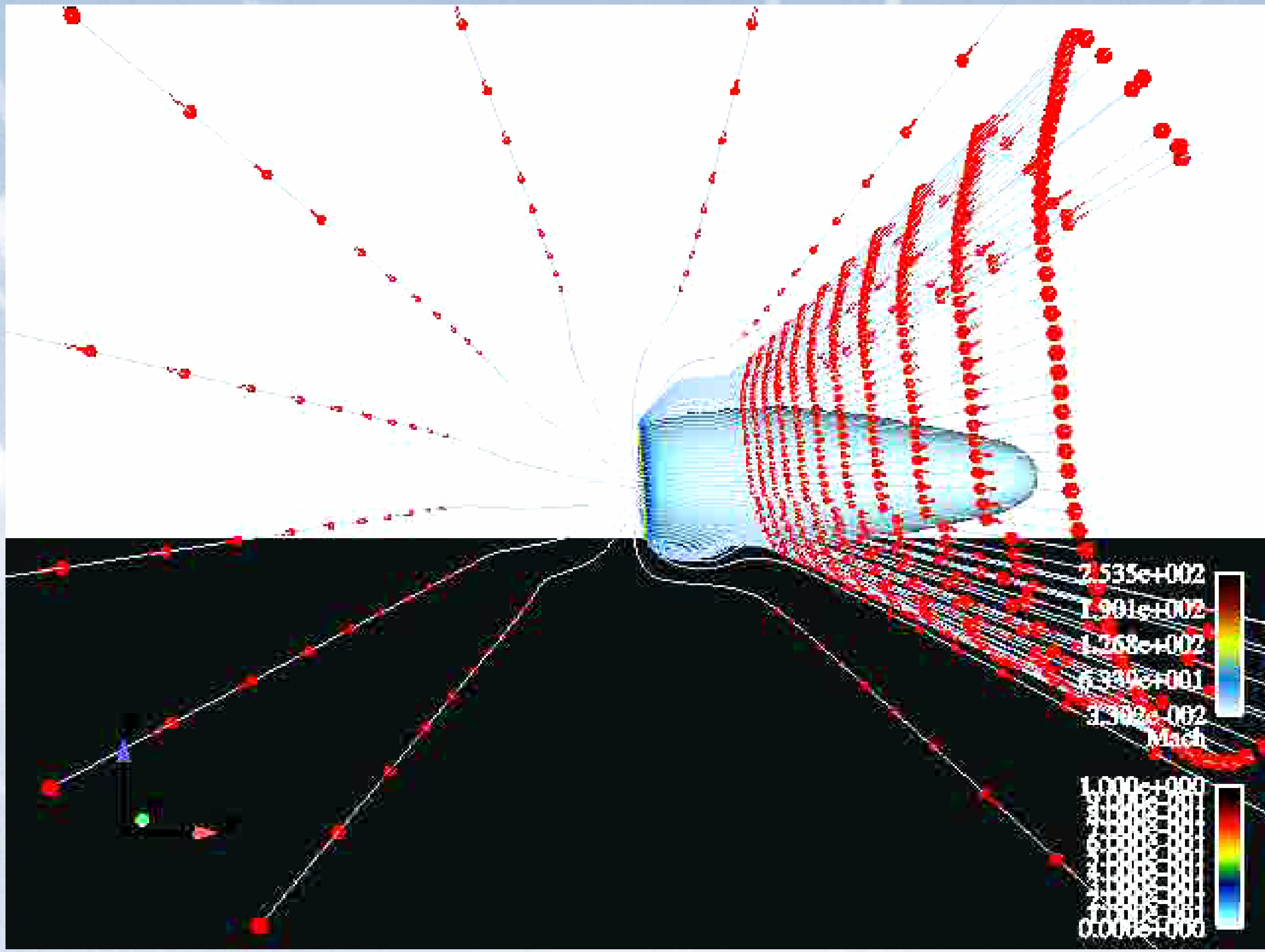
Operability ↗
Efficiency ↗





Snecma SAFRAN Group

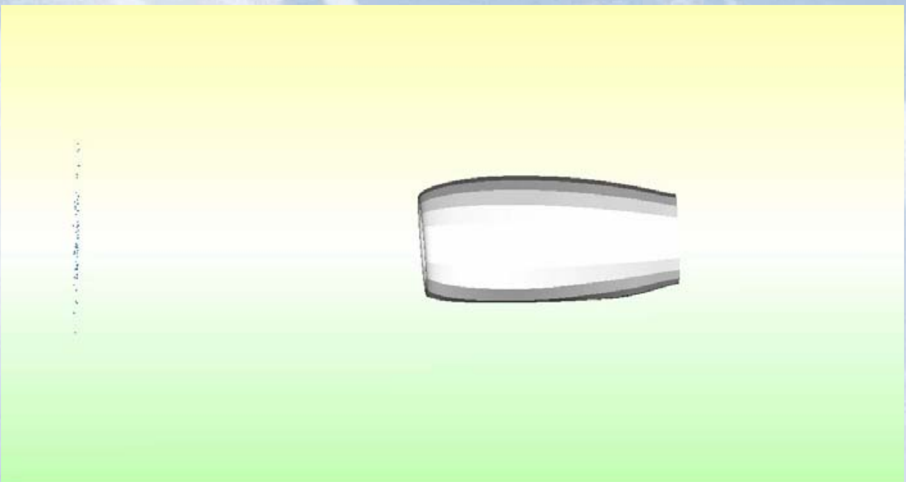
Nacelle feeding with transversal wind



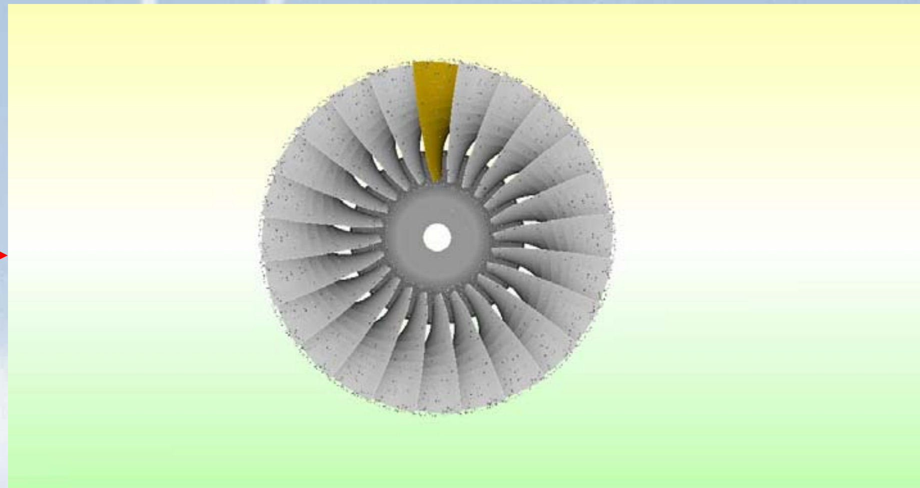
Water and hail ingestion

Start of computation

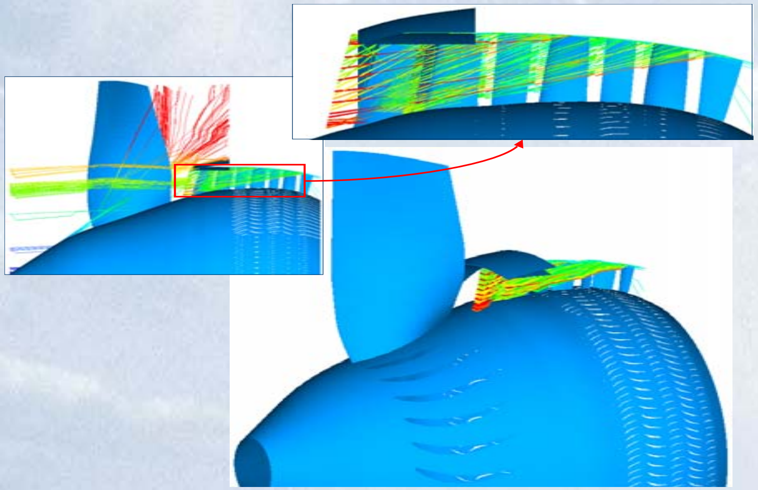
hail ingestion in air inlet



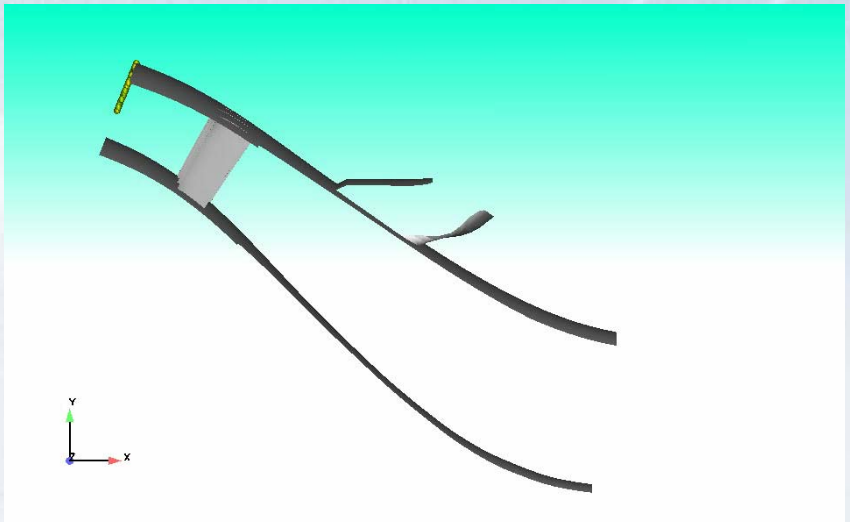
Hail through the Fan



Hail through the booster



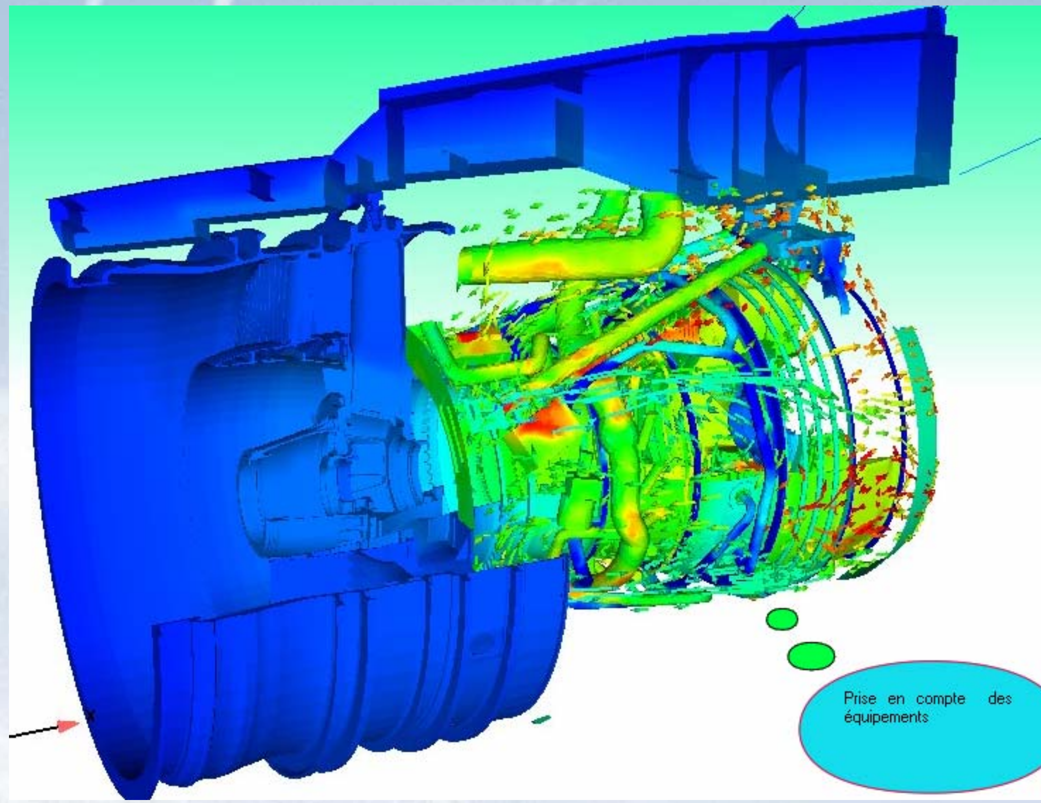
Exhaust of the hail through the VBV



Aero thermal nacelle venting

- **Today: steady analysis**
  - 3 millions of nodes
  - 10h CPU time using 64 processors
    (cluster linux itanium/opteron)

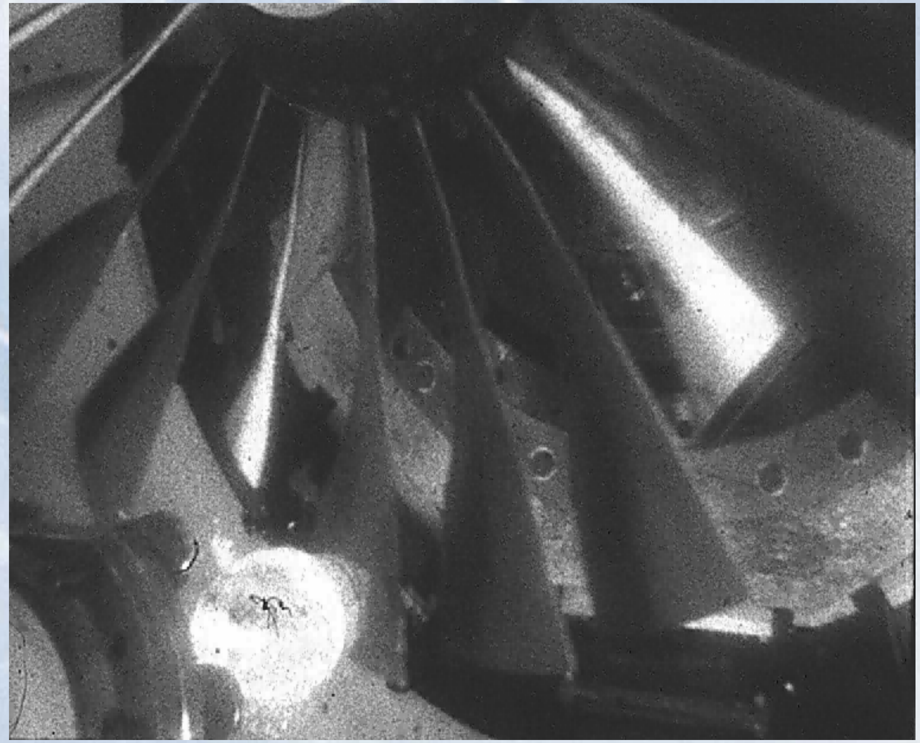
- **Target in 3 years : steady analysis**
  - Over 20 millions of nodes
  - Including more detailed geometry
  - Expected restitution delay
    = overnight



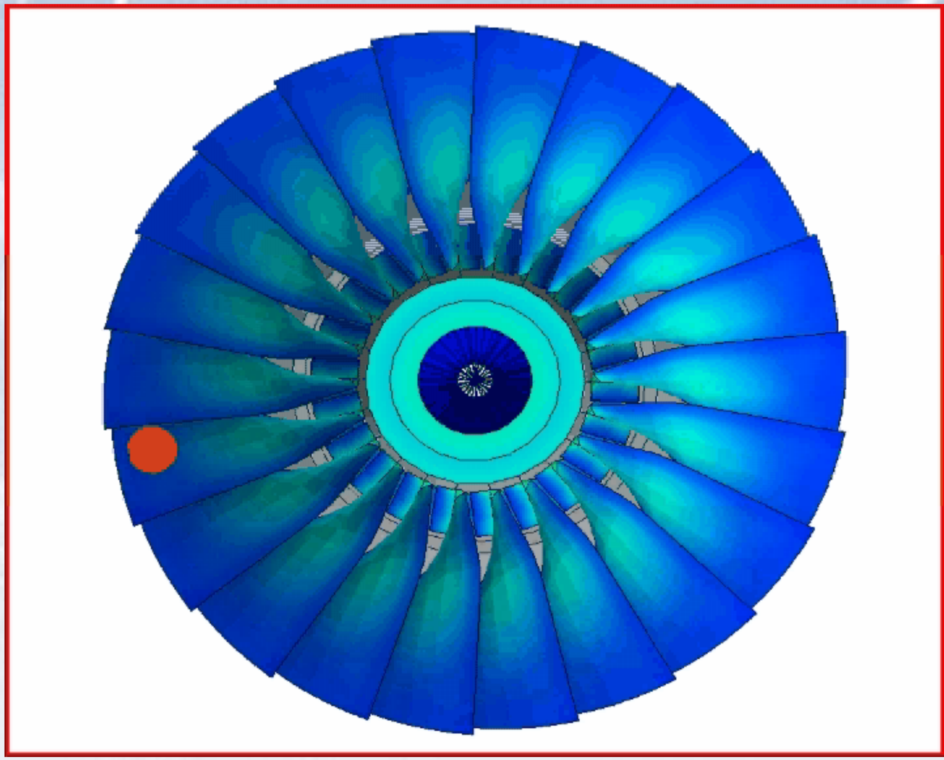
Snecma SAFRAN Group

Test simulation to reduce cost and duration of development

- Around 250K elements (blades + bird)
- CPUT 3 days for 10 ms



CFM56 -7 Bird ingestion test

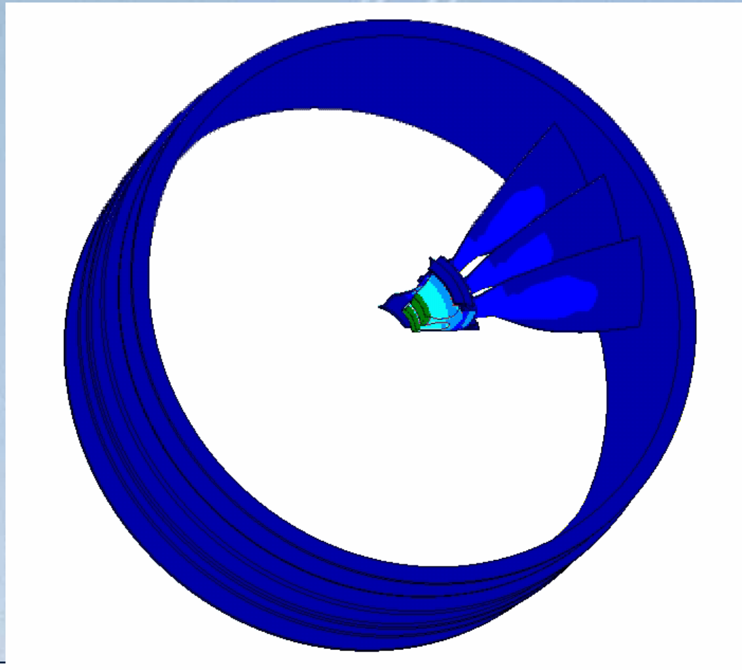


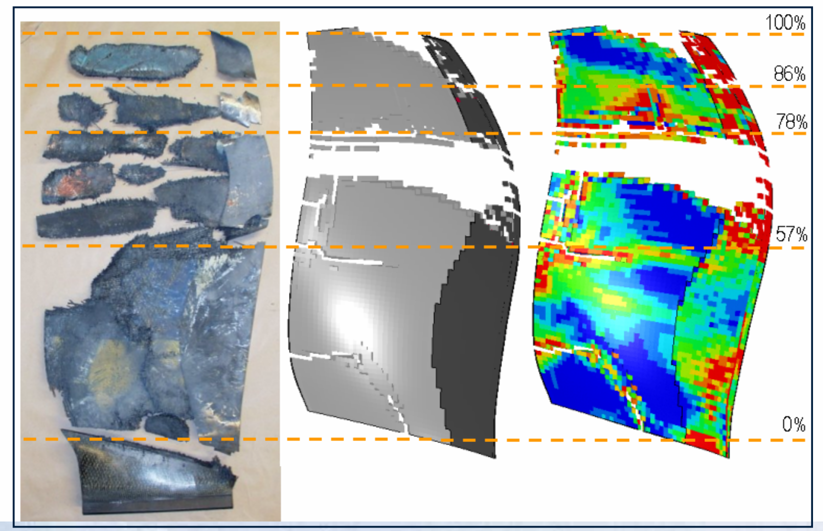
Simulation

Snecma SAFRAN Group

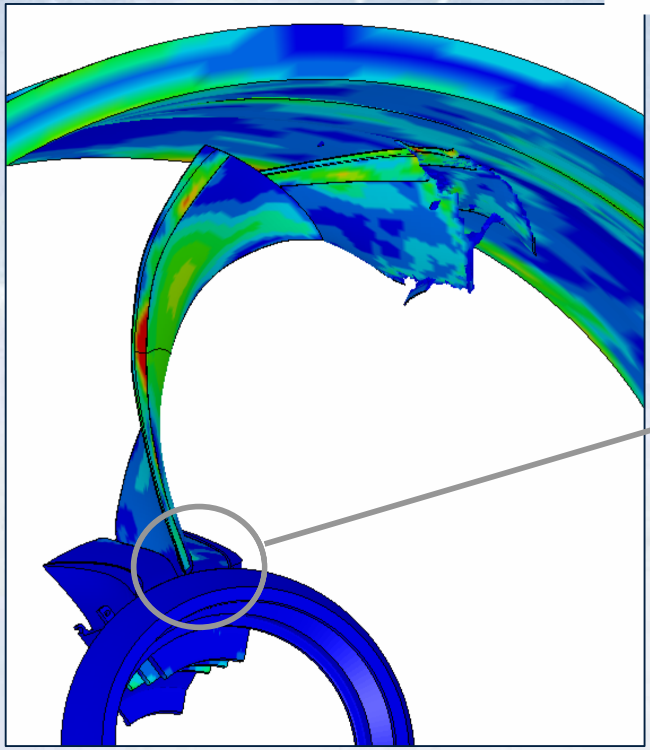
Fast transient dynamics Fan blade release

- Simulation of test until rupture (> 10ms)
- From 250K to 1M elements
- CPUT 6 days for 15 ms
- Comparison of results between simulation and tests
- Understanding of events
- New way to redesign and improve the blade

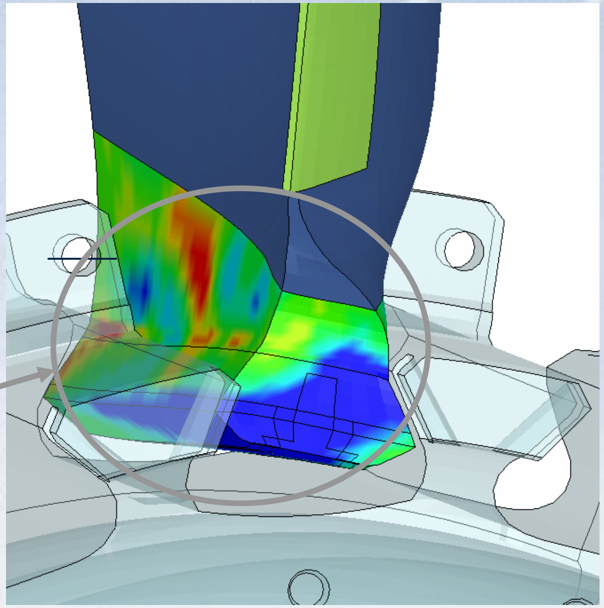




Fragmentation (test versus simulation)



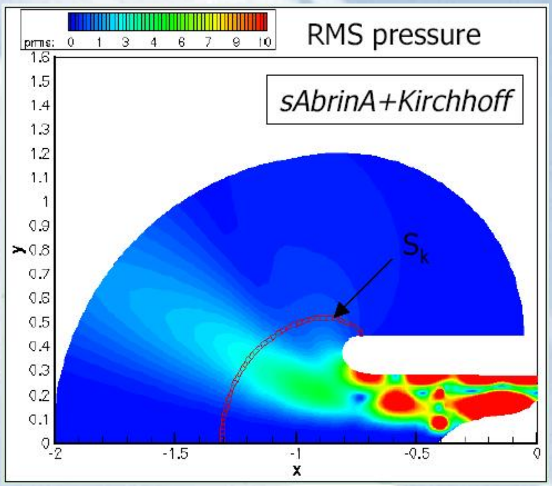
View of the system at 7.5ms

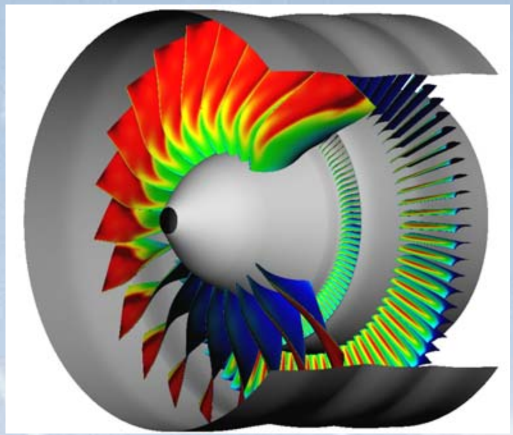


View of the root deformation of the blade at the critical time

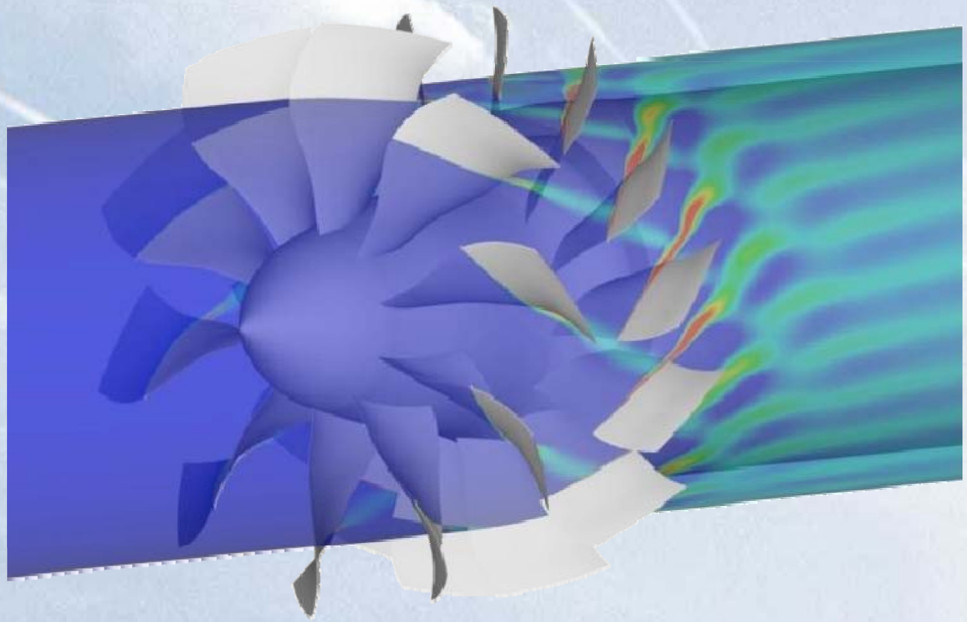
Snecma SAFRAN Group

Fan noise computations





- Steady RANS k-ε, fan+splitter
  - 5 Mpts
  - 10 h CPU (NEC SX6)
  - Acoustic post-processing: 2 mn CPU on PC
- Chorochronic (phase-lagged) RANS k-ε + Acoustic propagation (LEE)
  - 5 to 10 Mpts
  - 6 weeks to 3 months CPU

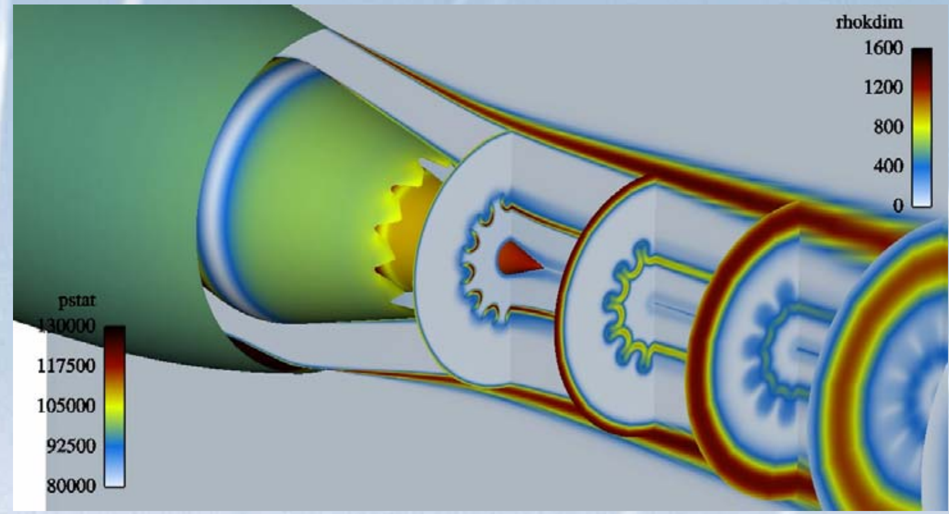


- **Target in 3 Years :**
  - Full-unsteady rotor/rotor computation, on installed Open Rotor configuration
  - 10-15 Mpts
  - Expected restitution delay < 1 month

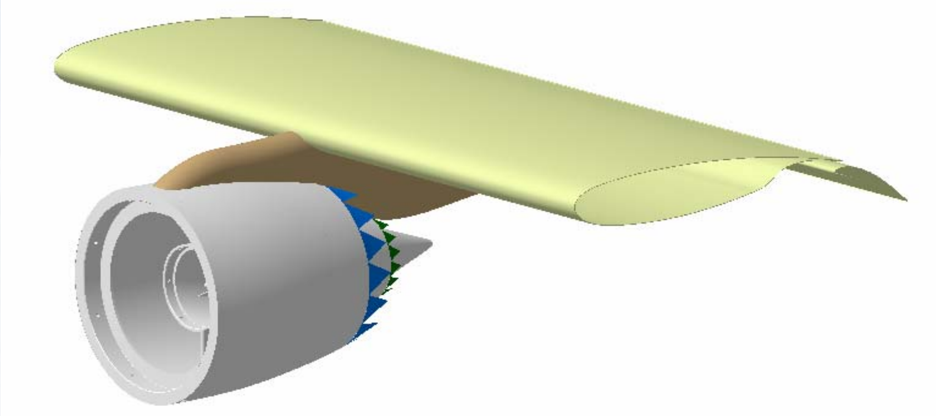
Snecma SAFRAN Group

Jet noise computations

- **Today**: Chevrons / Mixer nozzle without pylon (one sector)
  - Aerodynamics: (RANS k-epsilon)
    - Number of blocks: ~ 25 to 30
    - Number of nodes: ~ 2 millions
    - Number of iterations: ~ 50 000
  - Acoustics: Tam and Auriault theory hybrid with MGB
  - Restitution delay < 1 week



- **Future**: Chevrons / Mixer nozzle with pylon and wing
  - Aerodynamics: (RANS k-epsilon and k-L)
    - Number of blocks: ~ 40
    - Number of nodes: ~ 8 to 10 millions
    - Number of iterations: ~ 100 000
  - Acoustics: Tam and Auriault theory hybrid with MGB
  - Expected restitution delay < 1 week
  - LES calculations for 3D nozzle without pylon

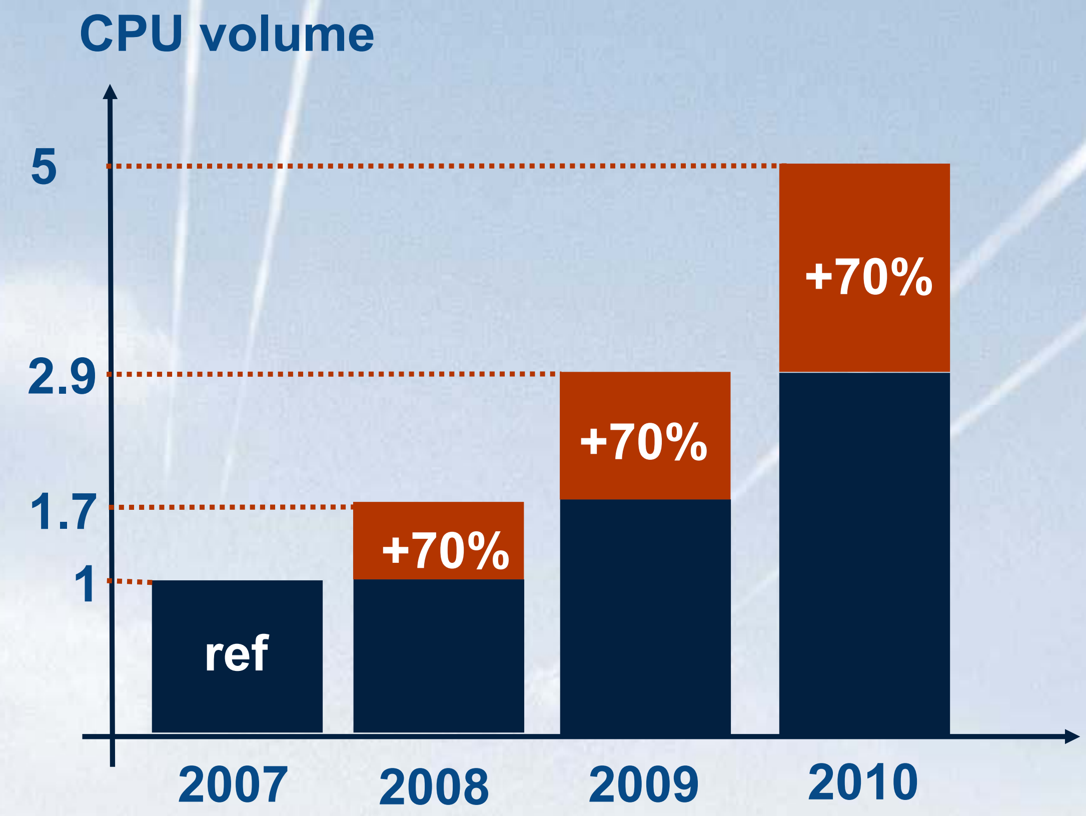


Snecma SAFRAN Group

Evolution of computation

Evolution of quantity of computations

- Evaluation of Snecma's CPU needs for aerodynamic, aero thermo mechanic, combustion, mechanic and dynamic simulations
- 70% of increase forecasted per year for the next three years = Moore's law
- Future prospects in keeping with the evolution observed in the past



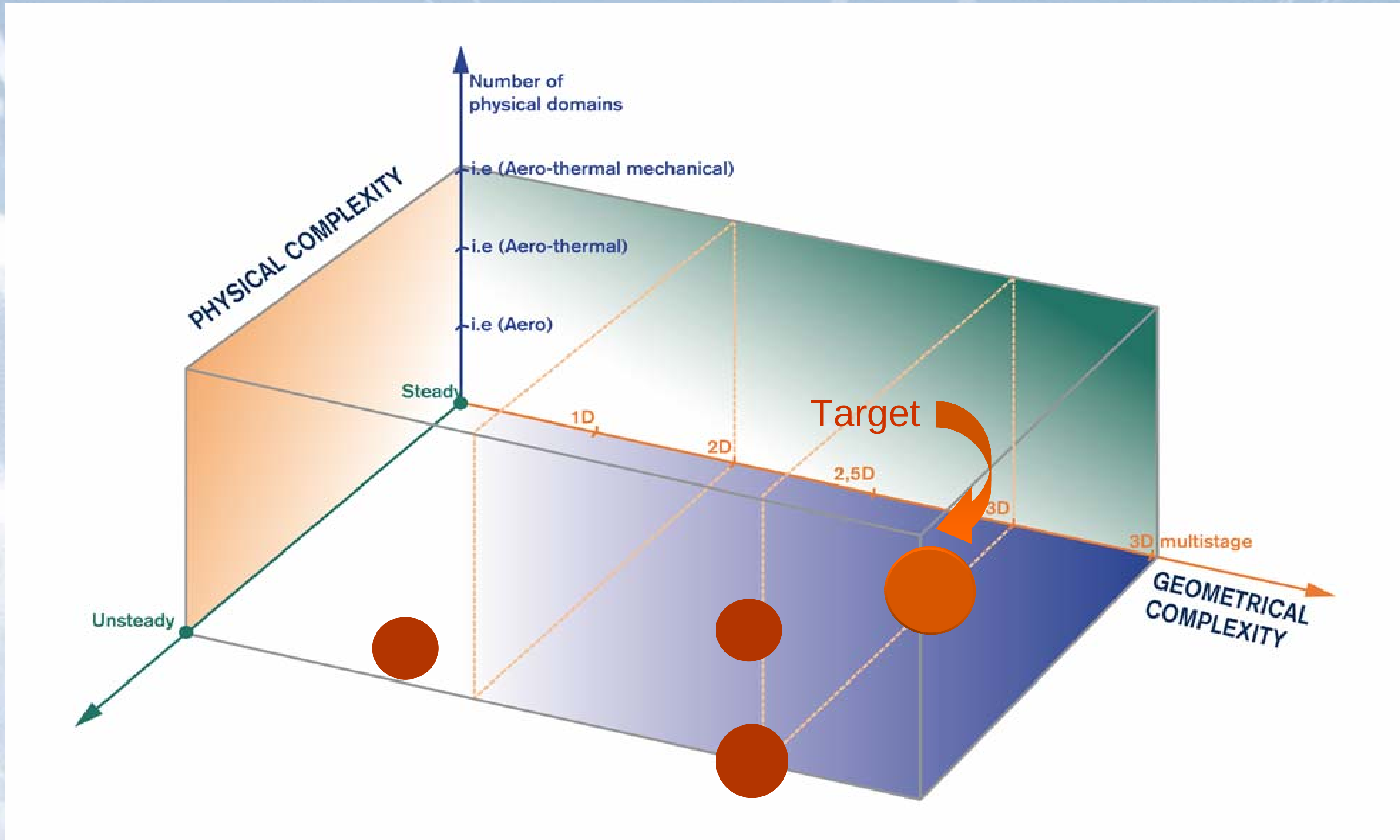
Computations have considerably progressed over the last years, this trend will continue

- Adapting the physical complexity at each step of the design process
- More and more computations organized in chains and loop of optimisation

- Increased geometrical complexity
- Better simulation of the physics
- More and more multi physics
- More and more multi scales
- More and more global

Snecma
SAFRAN Group

On the way to full modelling ?



Target : 3D, multistage, unsteady, multiphysical modelling

Not yet. Due to limitation of power of computation, we have still to choose between priorities

Snecma SAFRAN Group

Some conclusions

- At SNECMA, computations are totally integrated in the design and development process.
- Improvements in the quality and complexity of computations will continue, and improve by the way the design and development process.
- The capacity to simulate complex phenomena, the quality and power of computations give competitive advantages.
- The quality of simulation is the priority, the power of computation cannot compensate for less quality.
- Cost of computation are always too expensive, but always cheaper than test or problem discovered during test.
- Tests are still needed, to check computations or to discovered unforeseen events.
- Power of computation is always insufficient and a limiting factor in the design and development process.

Thank You
for
Your Attention

Snecma
SAFRAN Group