Simulation en combustion diphasique turbulente: codes, formation, diffusion chez les industriels, calculs HPC (GENCI, PRACE, INCITE)

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T. Poinsot[2]

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[2] IMFT, Toulouse

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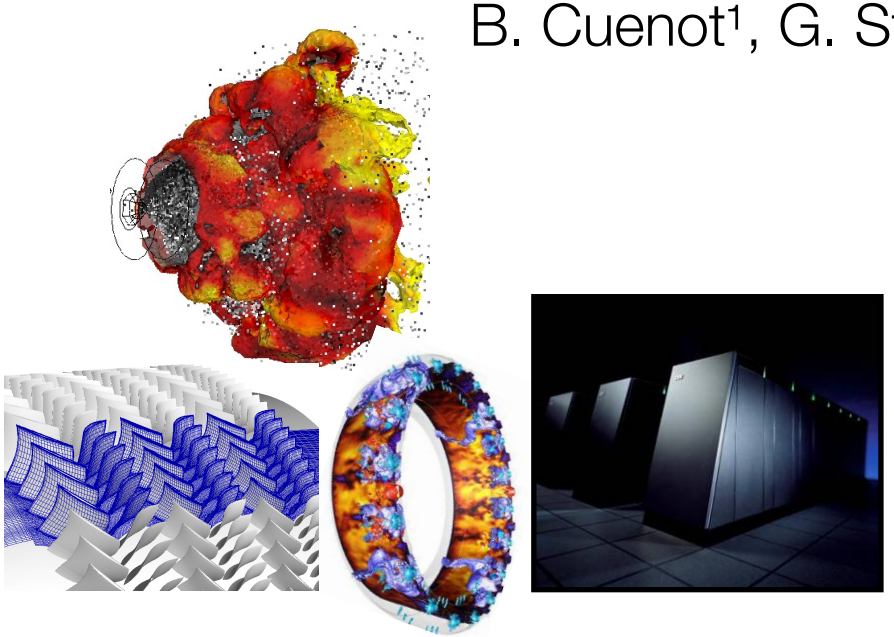
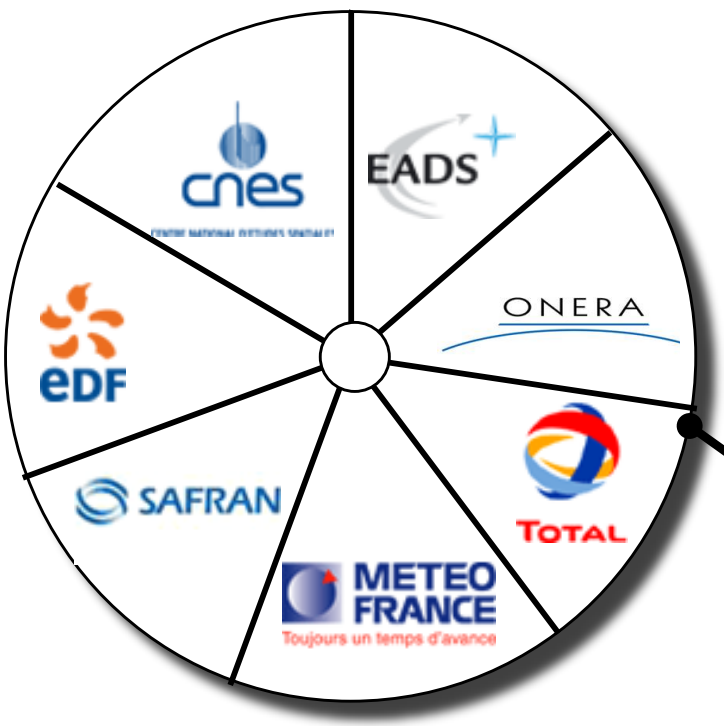
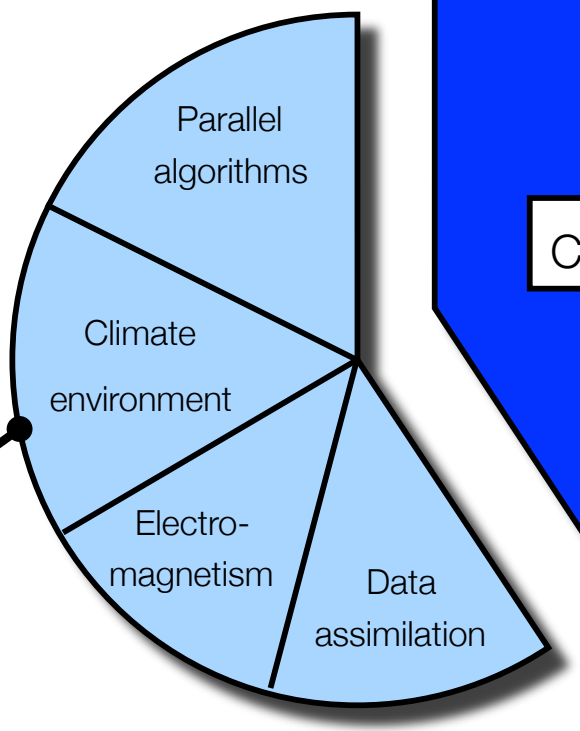
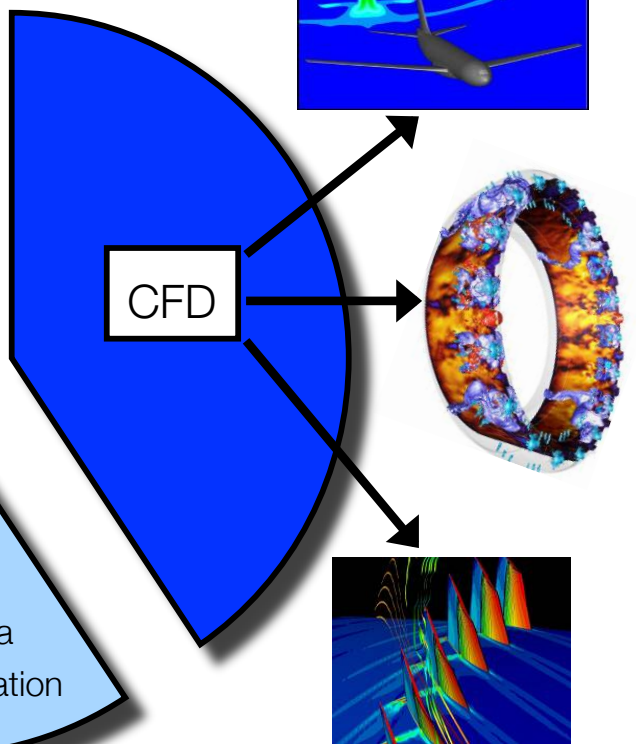


CERFACS is a private research center

7 shareholders, ~120 people in 5 teams







- **Expertise in scientific computation**
- **Access to large computational resources**

http://www.cerfacs.fr

INTRODUCTION: The overall context

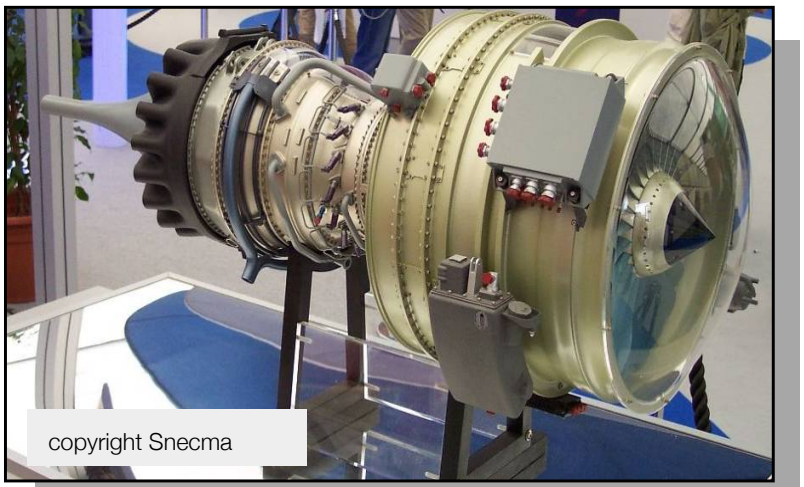
- CO_2 emissions from 1990 to 2025[a]: +100-600% (2008: 2.2% of the total).

- European objectives for 2020[b]:

  - ➢ reduce pollutant emissions (NO_x: -80%, CO_2: -50%),
  - ➢ reduce the noise emissions (-10dB).

- Economical constraints:
  - ➢ cut the engine costs (today it represents 30% of the aircraft cost).

copyright Airbus


copyright Snecma

Economical and environmental constraints impose technical and technological changes!

[a] *INRETS, 2004*

[b] *ACARE recommendations*

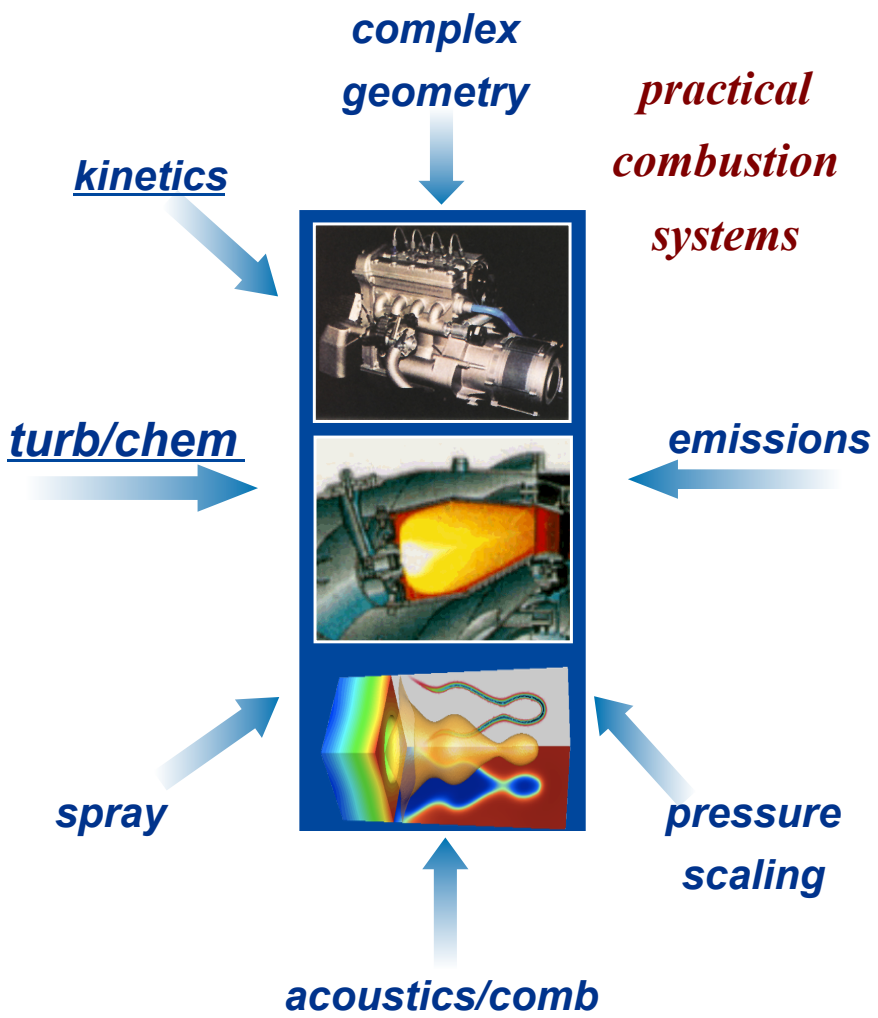
TECHNICAL CHALLENGES IN AERONAUTICAL BURNERS

Performances

- Temperature field ⟹ Turbine life cycle
- Efficiency & Emissions ⟹ Nox, CHx, CO2,CO
- Wall temperature ⟹ Chamber life cycle
- Stability & ignition

Technical challenges

- Aerodynamics & mixing
  ⟹ swirl, jets in cross-flow, multiperf.
- Turbulent combustion
  ⟹ kerosene kinetics, pollutants
- Two-phase flow
  ⟹ fuel flow physics & dynamics
- Heat transfer
  ⟹ cooling, thermal radiation



Advanced CFD and ***Massively parallel*** computer architectures offer a clear potential for time and cost reductions of the design chain while providing ***more accurate predictions***

Performances

- Temperature field ⟹ Turbine life cycle
- Efficiency & Emissions ⟹ Nox, CHx, CO2,CO
- Wall temperature ⟹ Chamber life cycle

complex geometry

practical combustion

kinetics

Orientations and actions that are now well accepted by the turbulent combustion research community...

QUESTION: How to transform such findings into a differentiating research and development tool ?

Advanced CFD and ***Massively parallel*** computer architectures offer a clear potential for time and cost reductions of the design chain while providing ***more accurate predictions***

1/ The AVBP Code

=> Code characteristics and models

=> HPC capabilities

2/ The Community and Development model

=> French combustion community and CERFACS / AVBP

=> CERFACS team

- Team actions and orientations: Formation, GUI, code maintenance (relation with HPC centers)
- Transfer towards the industrial partners

=> Outcome of this organization

3/ Conclusions and perspectives

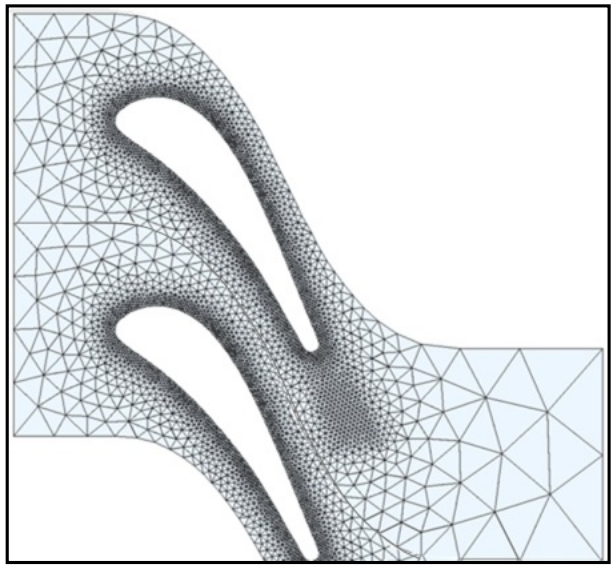
AVBP - An unstructured LES flow solver:

- Developed by CERFACS and IFP-EN,

- External/internal flows,
- Fully compressible turbulent reacting flows (ideal & real gases),
- DNS/LES approaches,

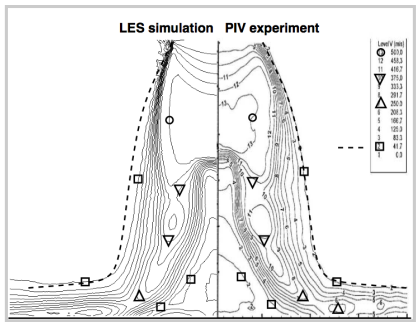
- Unstructured hexaedral, tetraedral, prisms & hybrid meshes,
- Massively parallel,
- C/Fortran languages,
- SPMD approach.

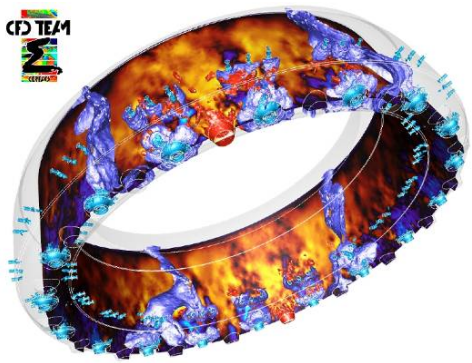
- Multi-phase solvers (Lagrangian & Eulerian)

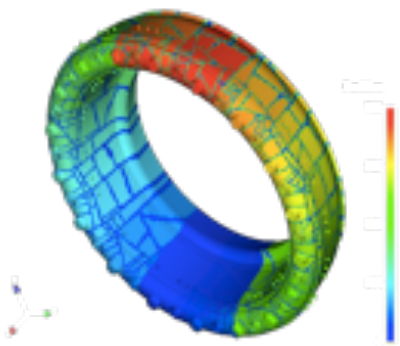


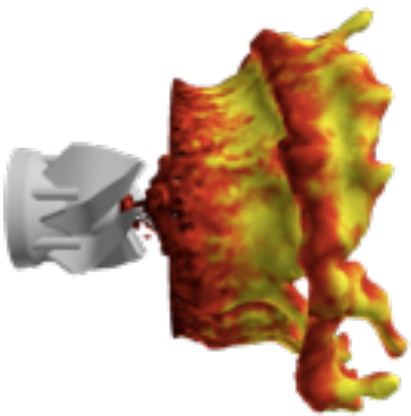
Unstructured grid

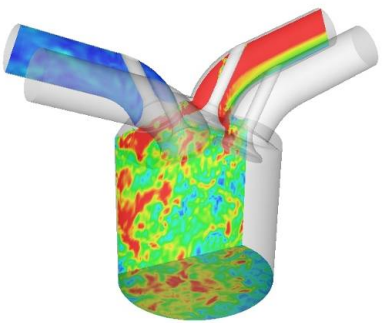
(Coincident interfaces)

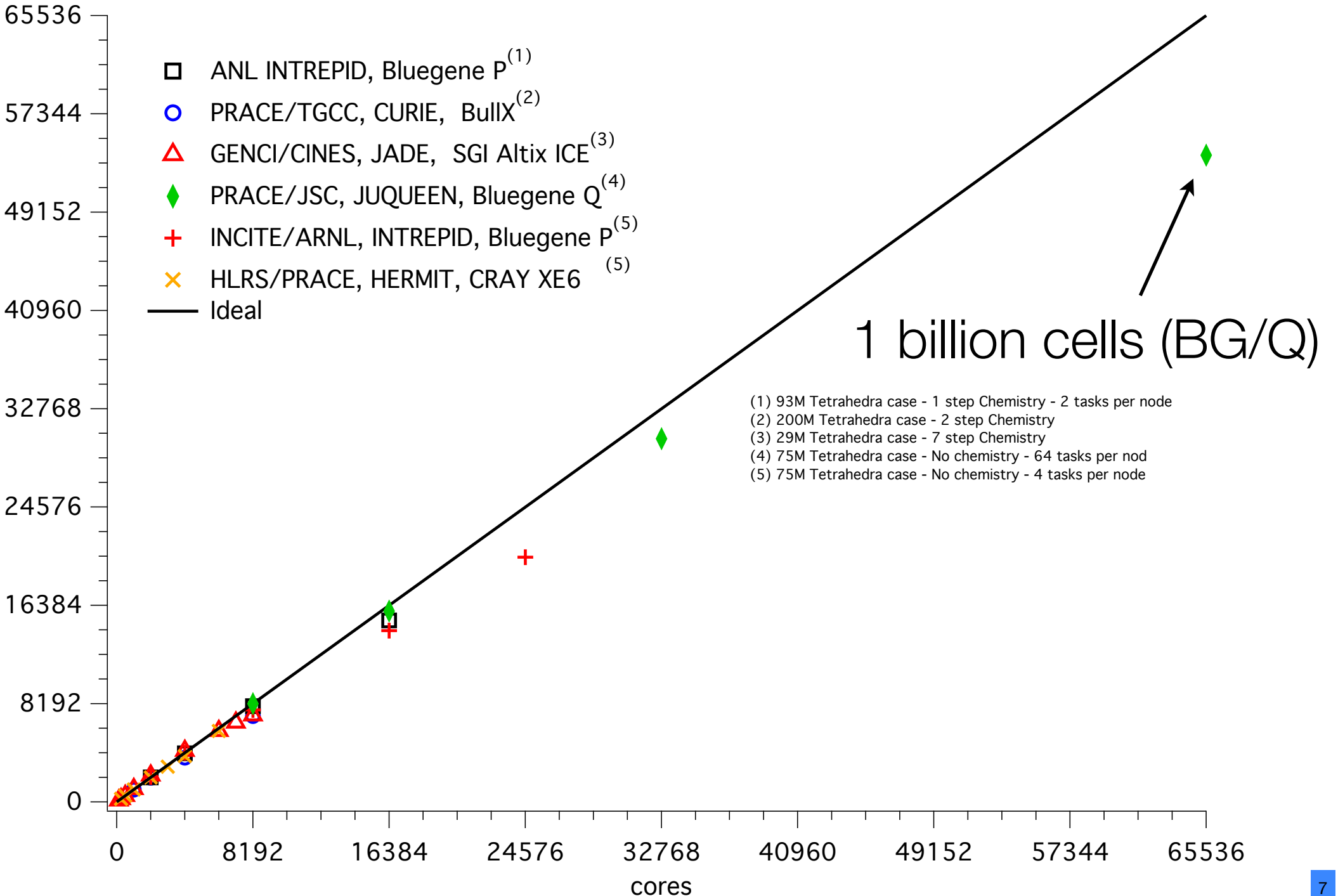








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40960
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57344
65536
cores
ANL INTREPID, Bluegene P(1)
PRACE/TGCC, CURIE, BullX(2)
GENCI/CINES, JADE, SGI Altix ICE(3)
PRACE/JSC, JUQUEEN, Bluegene Q(4)
INCITE/ARNL, INTREPID, Bluegene P(5)
HLRS/PRACE, HERMIT, CRAY XE6 (5)
Ideal
1 billion cells (BG/Q)
(1) 93M Tetrahedra case - 1 step Chemistry - 2 tasks per node
(2) 200M Tetrahedra case - 2 step Chemistry
(3) 29M Tetrahedra case - 7 step Chemistry
(4) 75M Tetrahedra case - No chemistry - 64 tasks per nod
(5) 75M Tetrahedra case - No chemistry - 4 tasks per node

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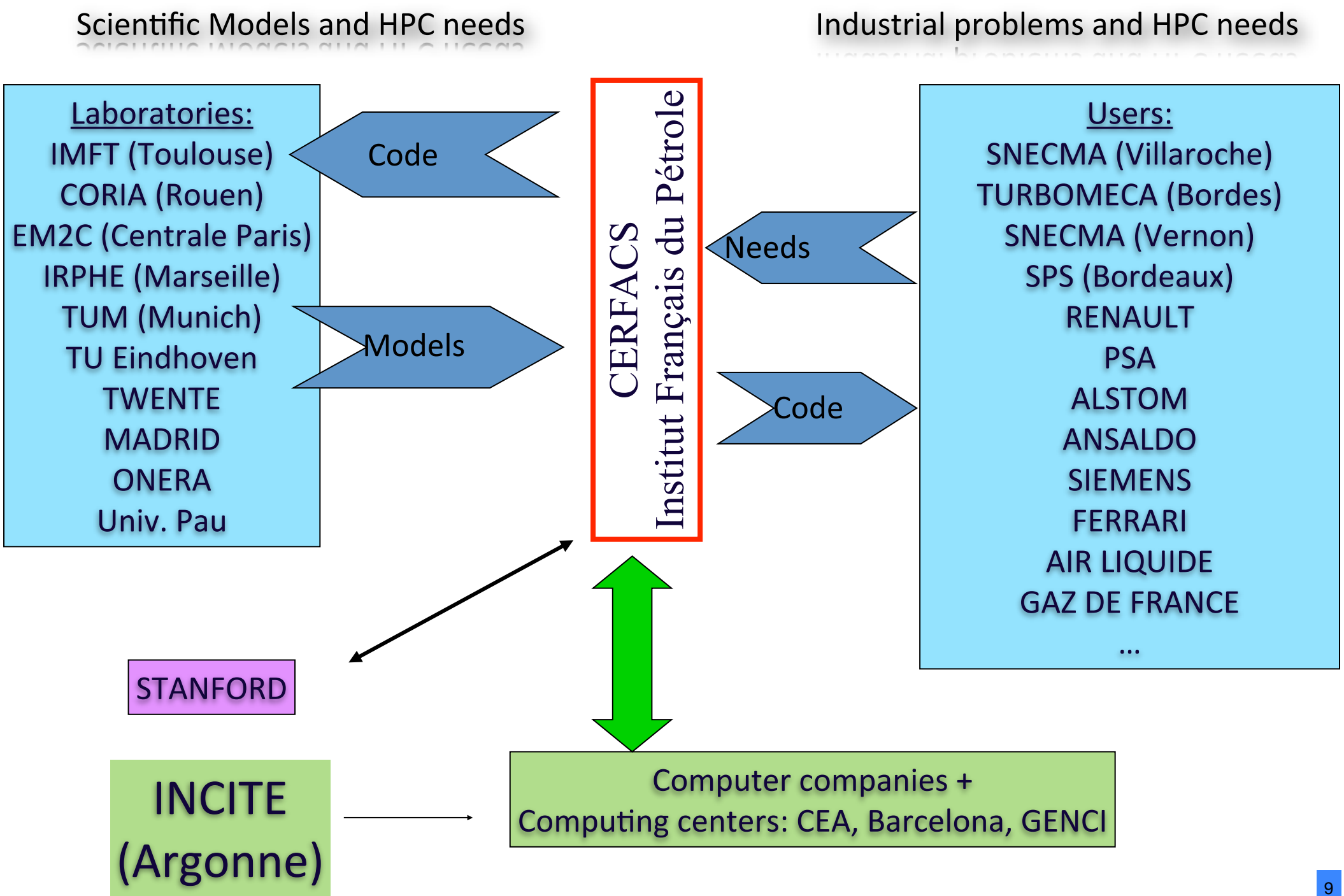
AVBP Working Model



The last ten years AVBP has been essentially used at CERFACS and research labs. With the explosive development of AVBP and YALES at *SAFRAN*, the last two years have shown that building an efficient HPC CFD team in combustion requires multiple experts:

CERFACS

Combustion experts	***HPC experts***
- know the physics - write the models - use the code but do not address HPC	- develop the code - port it on new machines - do the first demos

CERFACS Combustion team organization

CERFACS

Combustion experts
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HPC experts
- develop the code
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Combustion labs:
- know theory and experiments
- don’t know the code details or HPC

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Industry experts:
- know combustors
- know 'old style' CFD and learn HPC

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***Sous traitants*:**
- know a little bit on CFD and the combustors

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***Students*:**
- know nothing

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Increasing demands on both sides
!! Everybody wants its share of the cake !!

Combustion labs:
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- don't know the code details or HPC

***Students*:**
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CERFACS today

Combustion experts
- know the physics
- write the models
- use the code but do not address HPC

HPC experts
- develop the code
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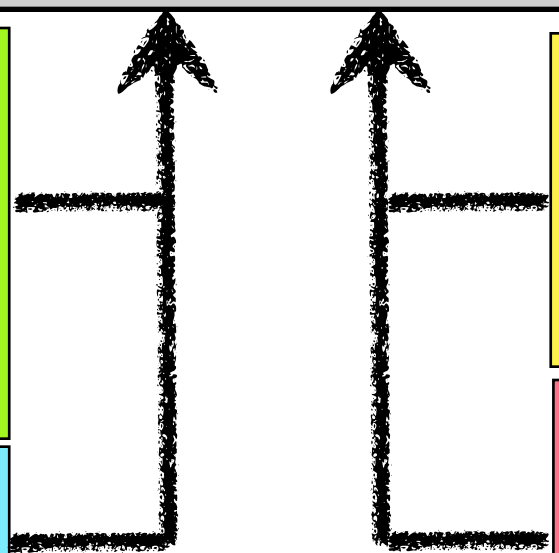
Interface / formation
- interfaces to access the code
- formation to learn the basics



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TRAINING SESSIONS AT CERFACS

http://www.cerfacs.fr/training

@ training@cerfacs.fr

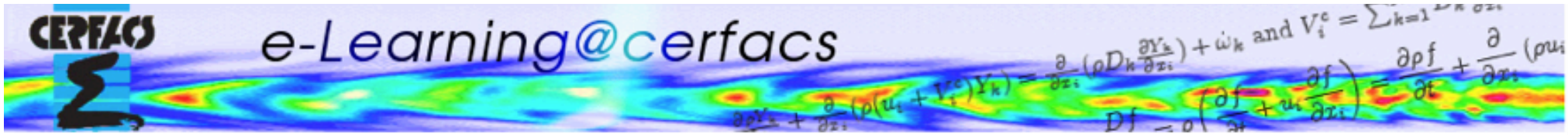
In 2011, CERFACS initiates a training program for computer science targeting students, PhDs, engineers and researchers, in academic and applied research.

The training sessions are taught by CERFACS researchers and engineers.

Practical training sessions dedicated to the codes developed or co-developed by CERFACS are part of the program. CERFACS is authorized to give training sessions within the Individual right to training (DIF).

PROGRAMME 2011/2012

Numerical methods for Large Eddy Simulation using AVBP	10-14 october 2011 2-6 april 2012
Code coupling using OpenPALM	17-19 october 2011 18-20 january 2012 13-15 june 2012
Advanced mesh generation using CENTAUR	26-27 january 2012
Data assimilation using OpenPALM	30 january-1st february 2012
Programming in Fortran 90	13-14 march 2012
Computer architectures and optimisation	22 march 2012
Parallel programming tools	23- 24 april 2012
Downscaling climate scenarios with the weather-typing based methodology DSCLIM	25-26 april 2012
Solution methods for optimisation problems	9-11 may 2012
Fundamentals to understand and analyze high fidelity CFD simulations	21-25 may 2012
Code coupling using OASIS	30-31 may-1st june 2012
Numerical methods for the electromagnetic problem using CESC	6-8 june 2012
Solution methods for linear systems	11-12 june 2012
Introduction to data assimilation	18-19 june 2012
Solutions of partial differential equations: applications to the wave propagation problem	25 - 26 june 2012
Advanced algorithms for data assimilation	27-29 june 2012



eLearning @ Cerfacs - Online Courses

Contents

CERFACS members collaborate to formation in multiple places (engineering schools and universities in Toulouse, Bordeaux and Paris, and specialized schools for PhDs and engineers such as Von Karmann Institut, College de Polytechnique, etc) and on many topics (numerical methods, high-performance computing, fortran, optimization, tutorial for Large Eddy Simulation of reacting flows, theoretical and numerical combustion, Computation Fluid Dynamics on massively parallel architectures, etc).

To ensure that students can have the best access to teaching materials (courses, hands-on exercices, links to various external sources, examples of exams), CERFACS has gathered data on this website where you can download all data related to the course they are following. You are welcome to use this site.

Topics

- Combustion
- Turbomachines

Home

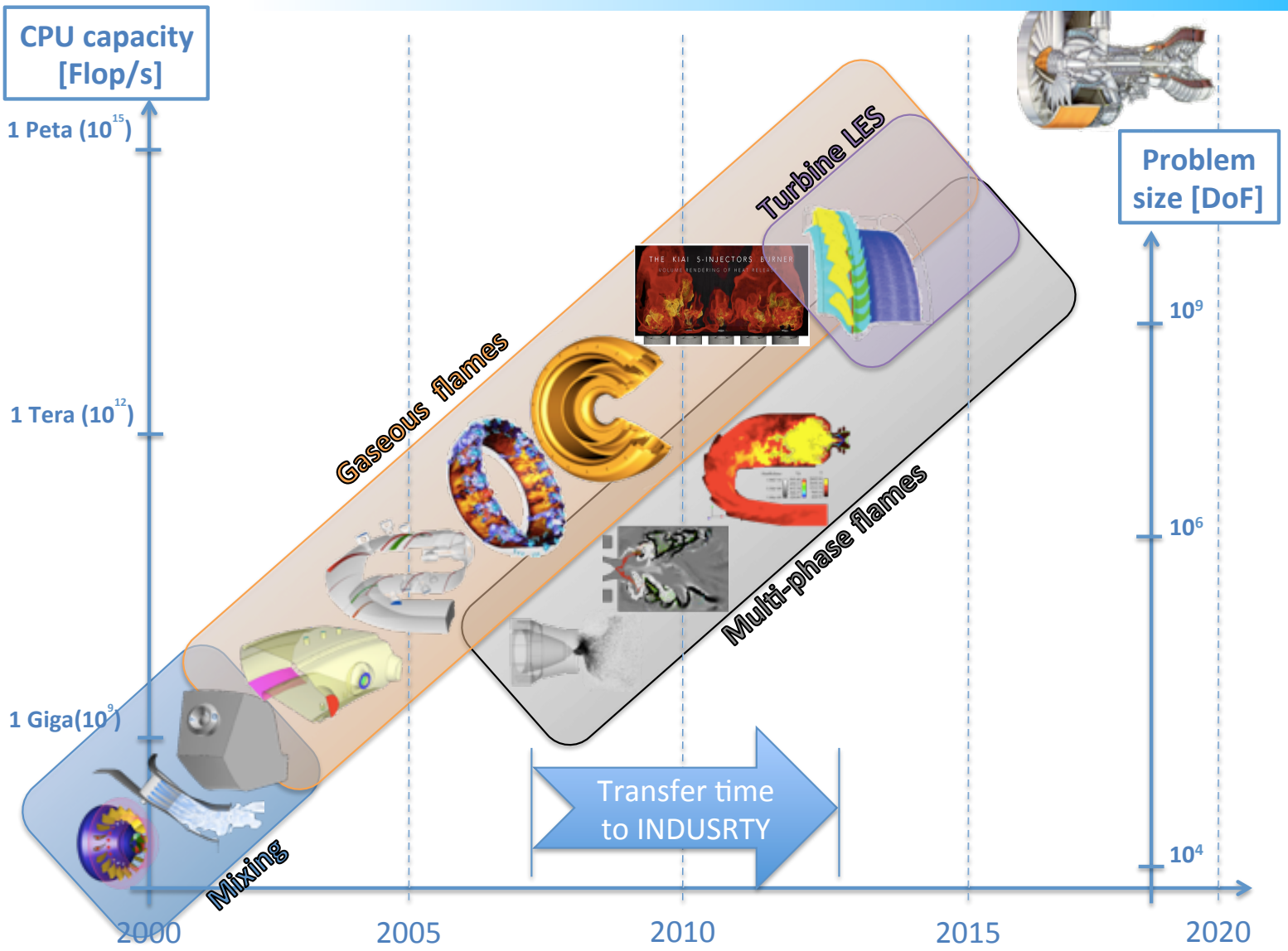
Topics

- Combustion
- Turbomachines
- Environmental science
- Numerical methods for CFD
- Advices for phD students
- Miscellaneous
- Coupling

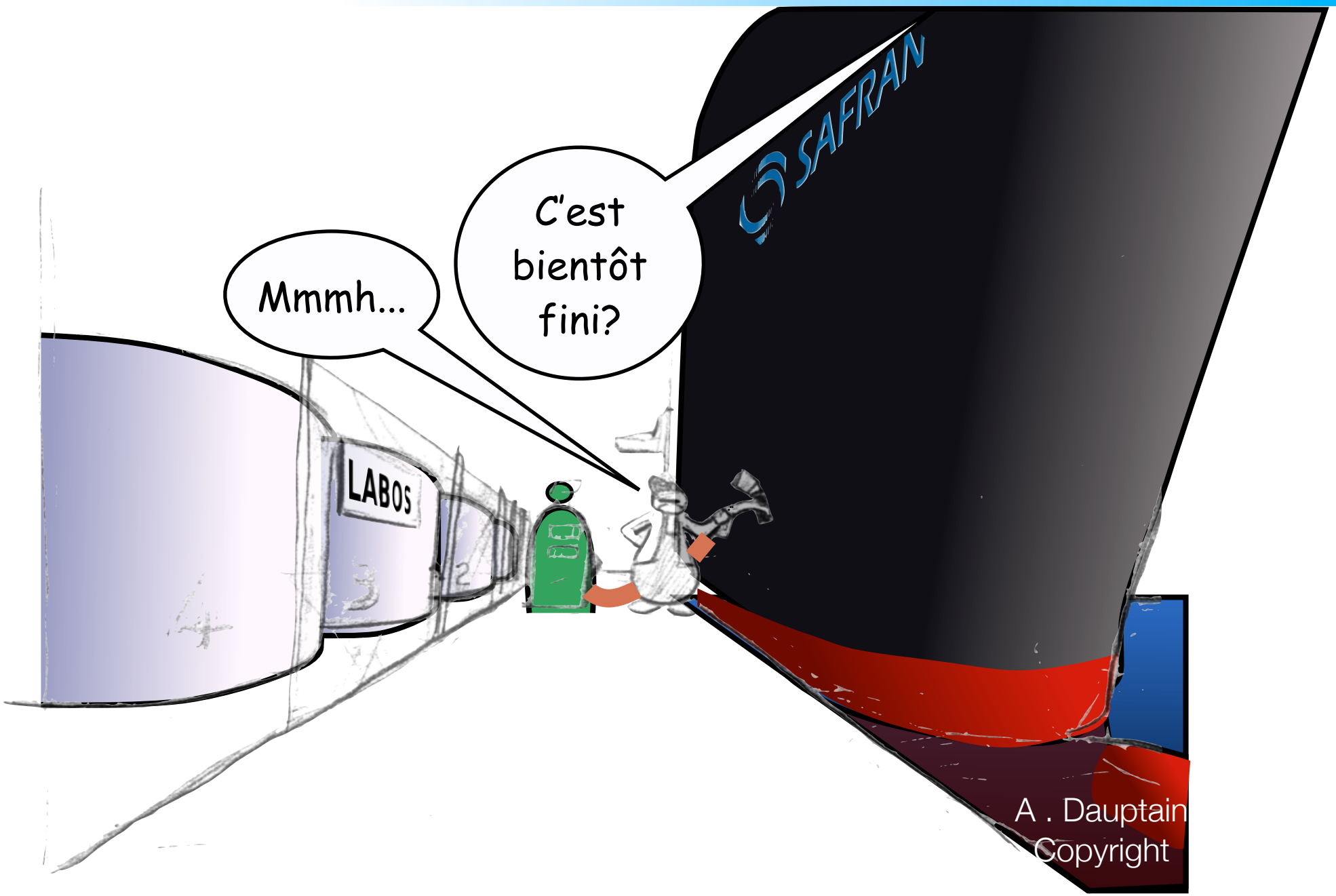
Multiple deported lectures from CERFACS' teams:

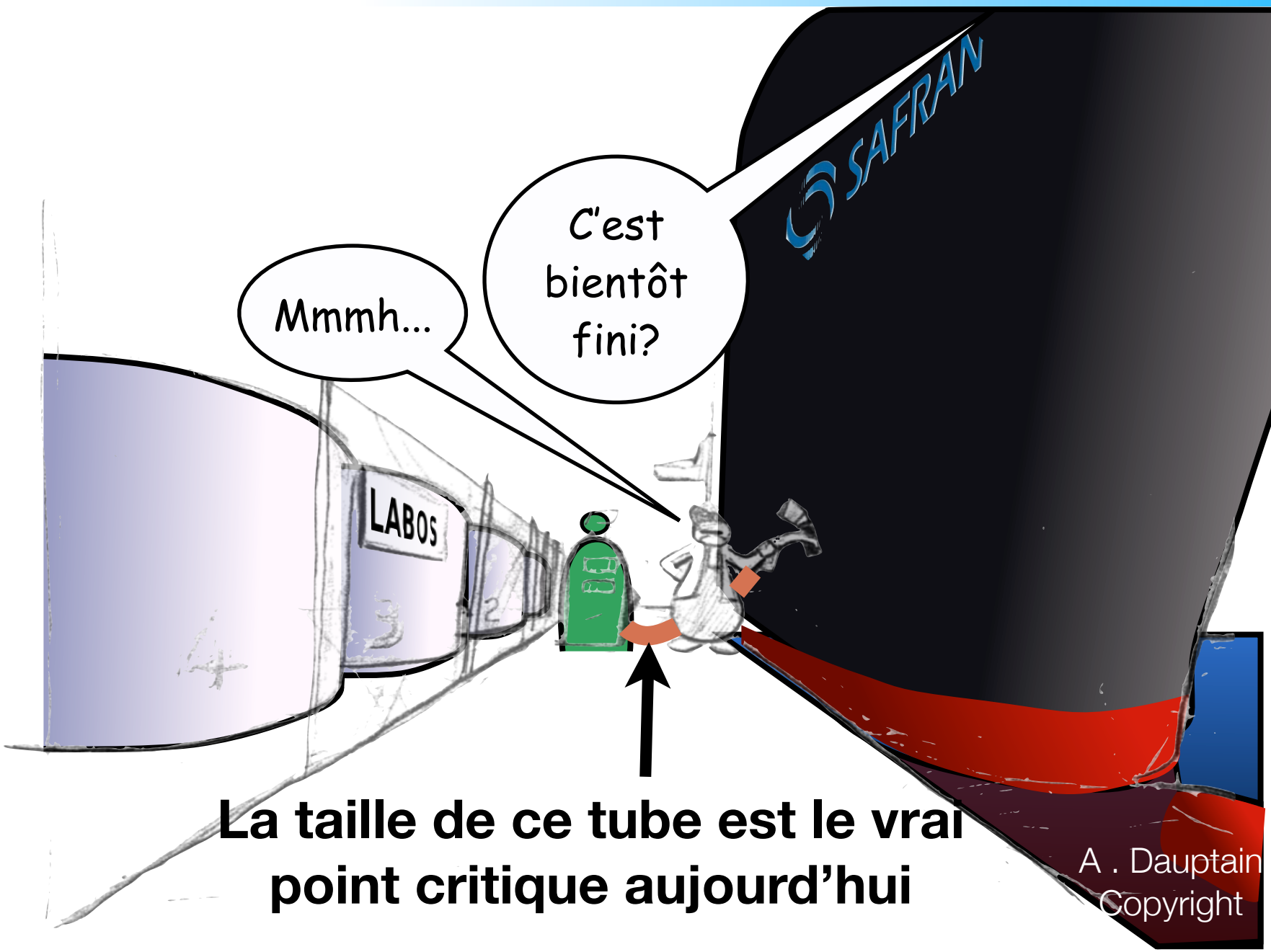
- Princeton Combustion Week: Turbulent Combustion Simulations, T. Poinsot - June 2013
- Open Palm Formation @ CINES by F. Duchaine, May 2013
- VKI Lecture Series: LES for Aero Acoustic Flow Predictions by L. Gicquel - March 2013
- .....

Relation with HPC centers



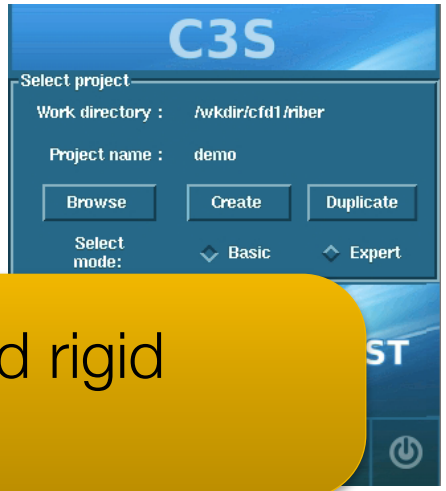
Sustained collaborations and exchanges with HPC computing centers throughout the world allowed the following progresses

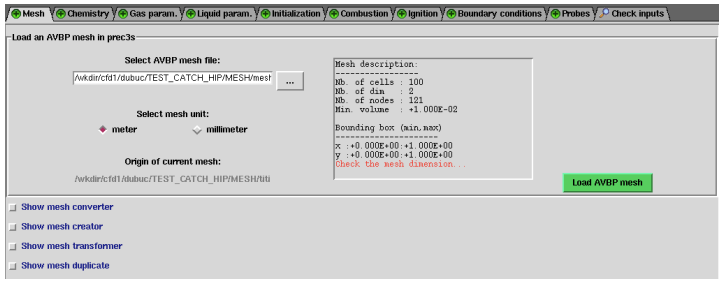

Mmmh...
C'est bientôt fini?
LABOS
SAFRAN
A . Dauptain
Copyright



La taille de ce tube est le vrai point critique aujourd'hui

First generation GUI for AVBP





Rather closed context and rigid framework....

Second generation GUI for AVBP

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        <patchlist value="none"
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    <thermo value="none">
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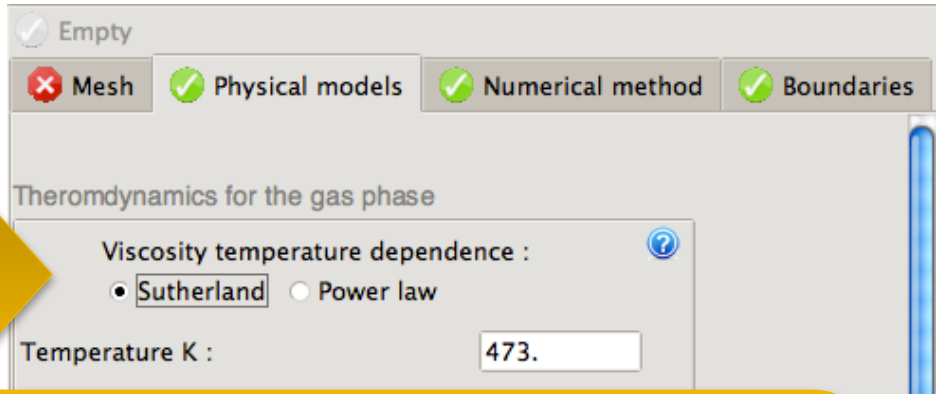
C3S M



New protocol allows the generation
of the GUI by the code developers and tool exportable to other codes

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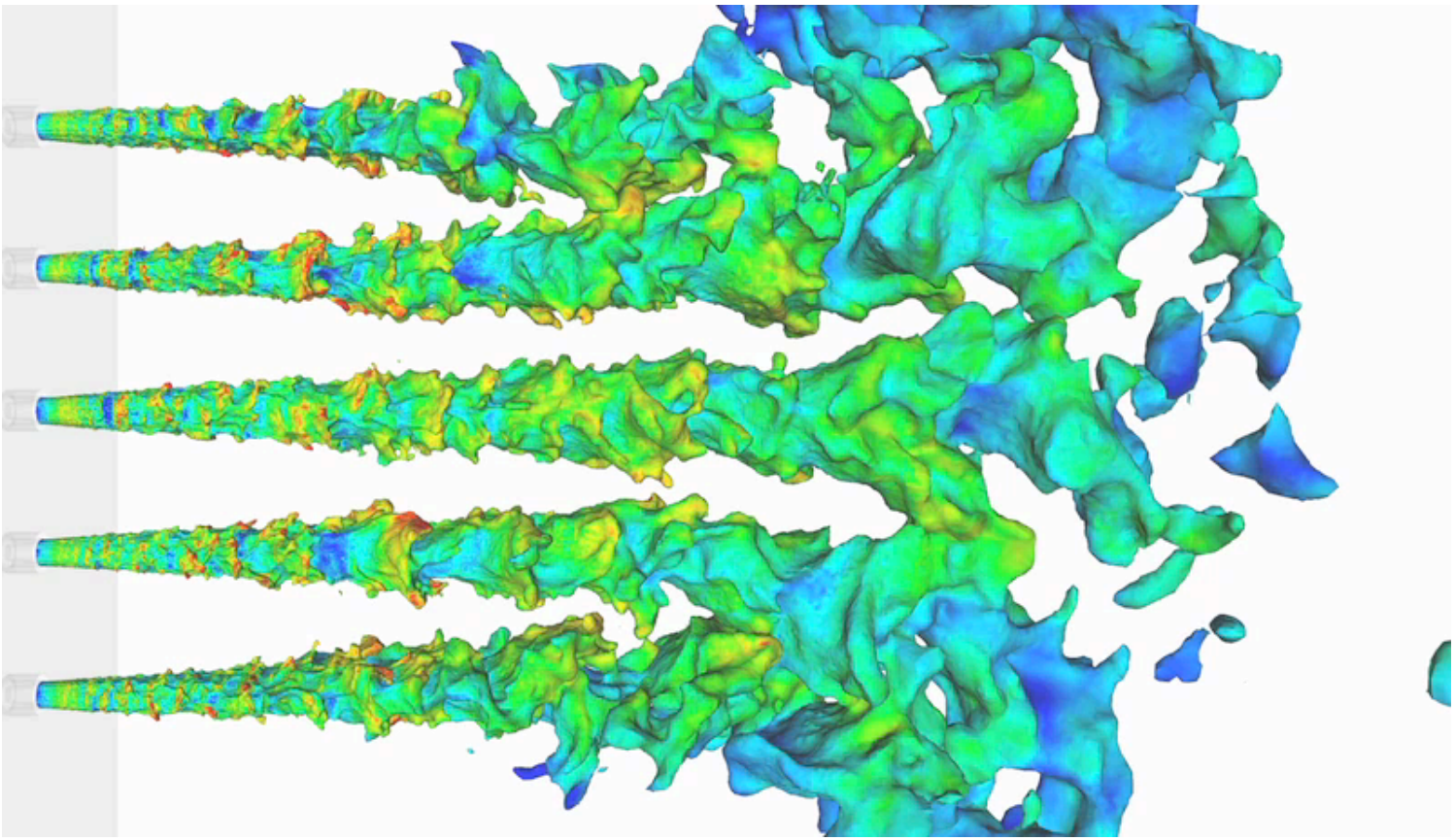
3/ Conclusions and perspectives

Large-Eddy Simulation of high-frequency instabilities under transcritical conditions

T. Schmitt, H. Layal, M. Boileau, S. Ducruix, S.Candel (EM2C),
A. Ruiz, G. Staffelbach, B. Cuenot and T. Poinsot (CERFACS)

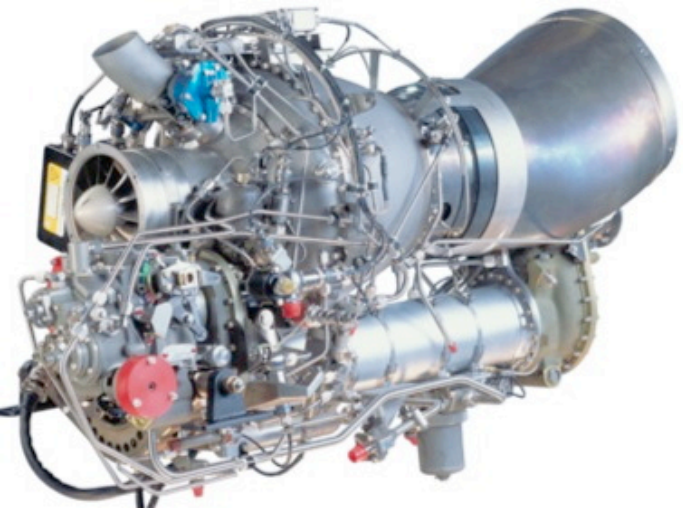
Objective: Observe and understand the flame behavior in transcritical flows of an experimental setup submitted to artificial acoustic transverse perturbation.

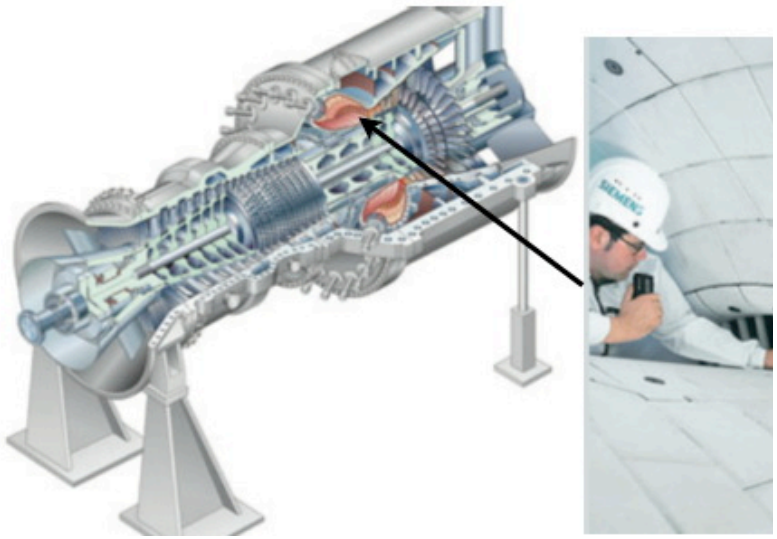


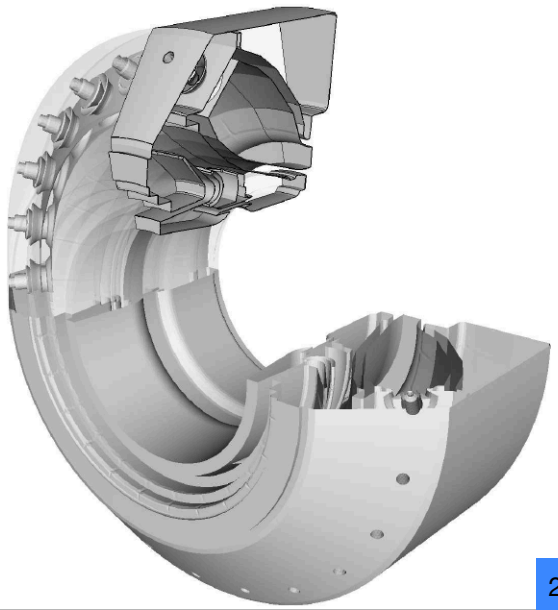
8.5M hours at TGCC

Money: the ERC (European Research Council) INTECOCIS advanced grant at Institut de Mécanique des Fluides and CERFACS 2013-2018 (intecocis.inp-toulouse.fr)

- Five year, 2.5 Meuros project on HPC tools for combustion instabilities. Coordinator: IMFT
- Ten researchers on numerical combustion, 5 years
- Collaboration with GENCI, SAFRAN, ANSALDO, SIEMENS



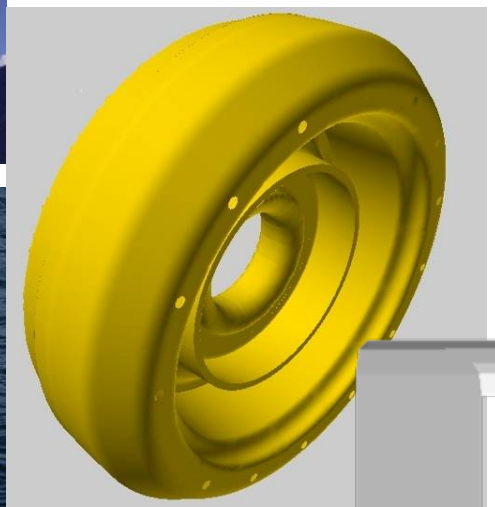


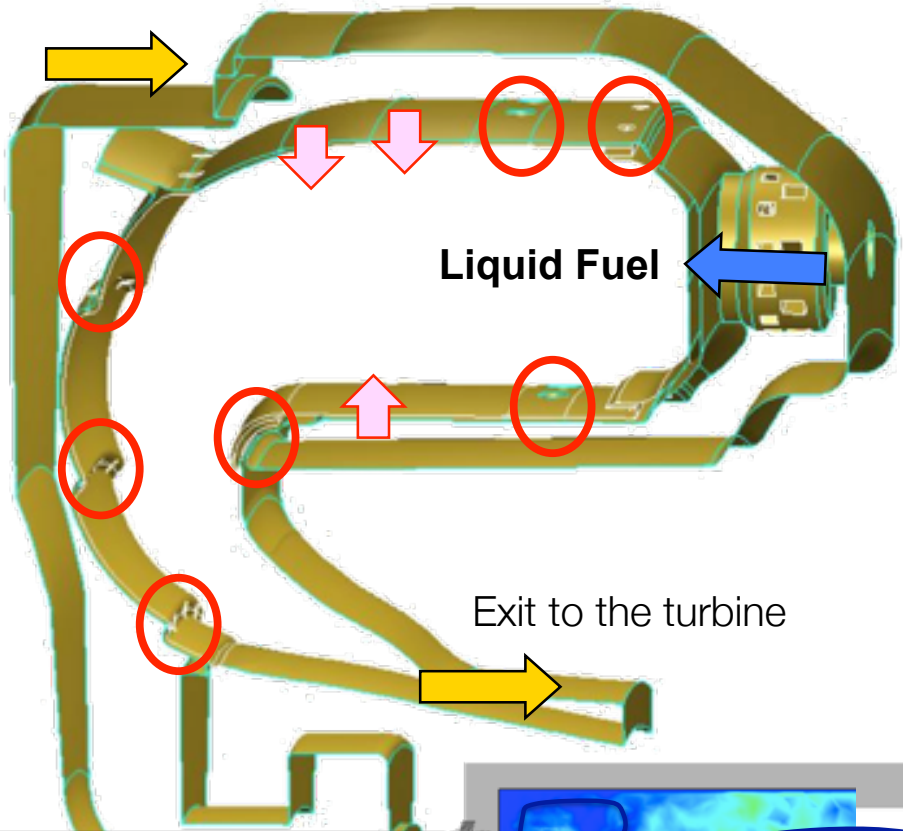


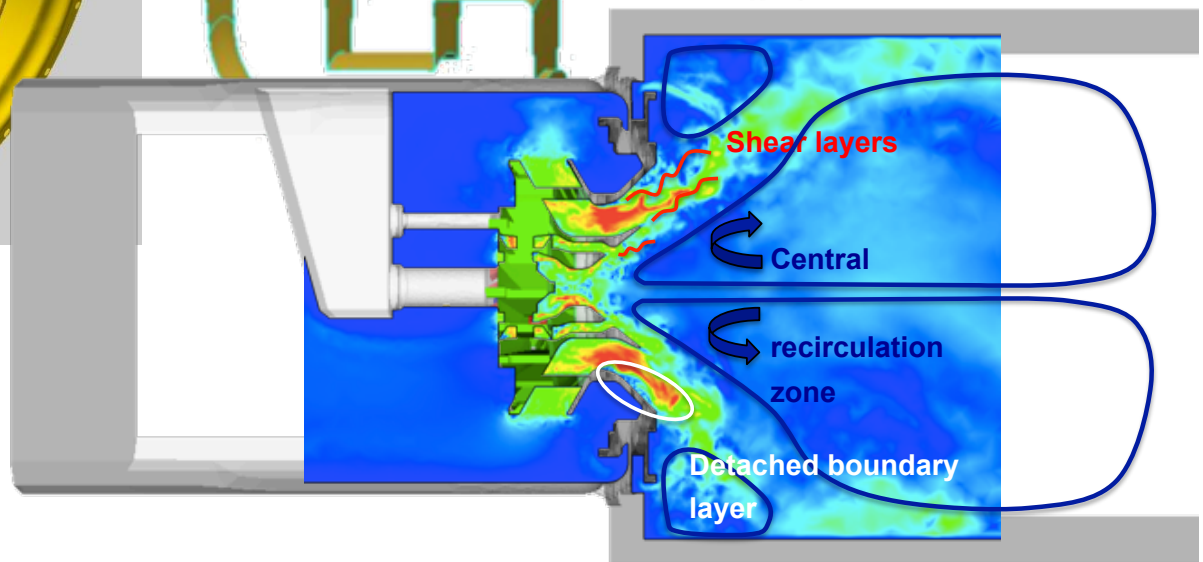
Target configuration: a helicopter combustion chamber – many things differentiate such a problem from the well controlled experimental context

Air coming from the compressor

Annular burner







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sic T. Poinsot at the CEA / GENCI Meeting

- *DANS 10 ANS, LES GROUPES QUI AURONT CONTINUE A DEVELOPPER DES CODES DE PETITE TAILLE EN COMBUSTION, AURONT BEAUCOUP DE MAL A PUBLIER MAIS L'EFFORT POUR CONSTRUIRE DES GRANDS CODES EST ENORME*

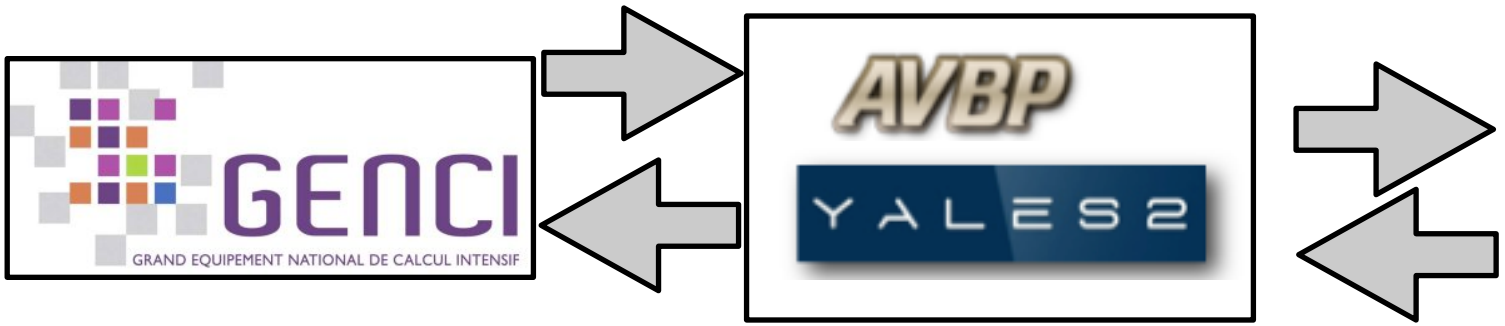
- *SUCCESS: REPONSE 'LOGICIEL' DES COMBUSTIONNISTES FRANCAIS. COUVRE LES LABOS ET LES INDUSTRIELS*

- *L'ARRIVEE DE GENCI A PERMIS A LA COMMUNAUTE 'COMBUSTION NUMERIQUE' DE DISPOSER DES MOYENS NÉCESSAIRES POUR DEMONTRER SON SAVOIR FAIRE*

- *PRACE ET INCITE COMPLETENT CE DISPOSITIF*

- *LA COMBUSTION EST UN EXEMPLE OU CES OUTILS HPC SONT UTILISES AUJOURD'HUI PAR L'INDUSTRIE QUI SUPPORTE LEUR DEVELOPPEMENT DE FACON TRES FORTE*

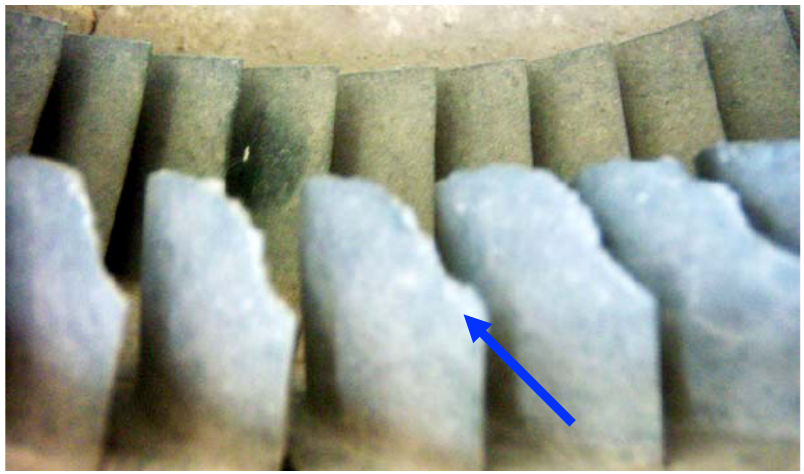
Perspectives

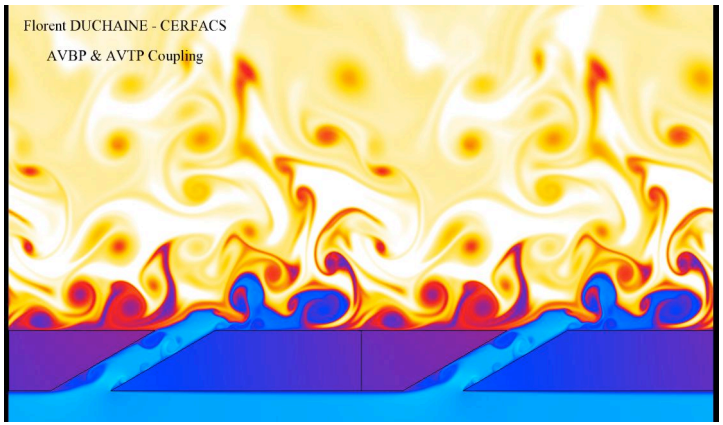


SNECMA
SNECMA DMS
TURBOMECA
RHODIA
ALSTOM
AIR LIQUIDE
HERAKLES
AIRBUS
SIEMENS
ANSALDO

CFD can be coupled to heat transfer to study thermal problems

A 15 K increase at the turbine blade surface decreases the turbine lifetime by 2





Coupling introduces new issues:

- Interfacing massively parallel codes while preserving their respective scalability
- Preserve the overall CPU cost of the new massively parallel application

Co-lateral scientific issues:

- Non-coincident meshes, interpolations schemes, numerical stability…