FP7 Support Action - European Exascale Software Initiative

DG Information Society and the unit e-Infrastructures

IESP-7

Industrial applications

Energy and Transportation

(EESI WG 3.1)

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WG3.1 List of Experts

Henri CALENDRA	(TOTAL, F)	Geophysics, Oil and gas
Keld NIELSEN	(ENI, I)	Multiphase flows, Oil and gas
Thierry POINSOT	(CERFACS, F)	Combustion, CFD
Eric CHAPUT	(EADS/Airbus, F)	Flight physics, Aeronautics
Demetrios PAPAGEORGIOU	(Imp.College, GB)	Applied math., Physics
Ulrich RUDE	(U. Erlangen, D)	HPC, Particle dynamics
Jean-Daniel MATTEI	(EDF, F)	CFD, Hydraulics
Christian HASSE	(BMW, D)	Propulsion and engine flows, Automotive
Heinz PITSCH	(Univ. Aachen, D)	Propulsion, Engine flows
Norbert KROLL	(DLR, D)	CFD, Aeronautics
Tanguy COURAU	(EDF, F)	Neutronics, Nuclear industry
Chuan-yu WU	(U. Birmingham, GB)	Chemical engineering
Mark SAWYER	(Univ. Edimburgh)	Computing
Jacek MARCZYK	(Ontonix)	Computer aided engineering

Outline

- HPC and industry, some general comments based on Top500
- Economical challenges: design and competitivity,
  a few examples from transportation and energy industries
- Roadmaps to exascale for large industries :
  Aeronautics, Oil, Nuclear energy, …
- Societal and environmental challenges
- Outcomes and software needs
- Overall cost of an exascale European program

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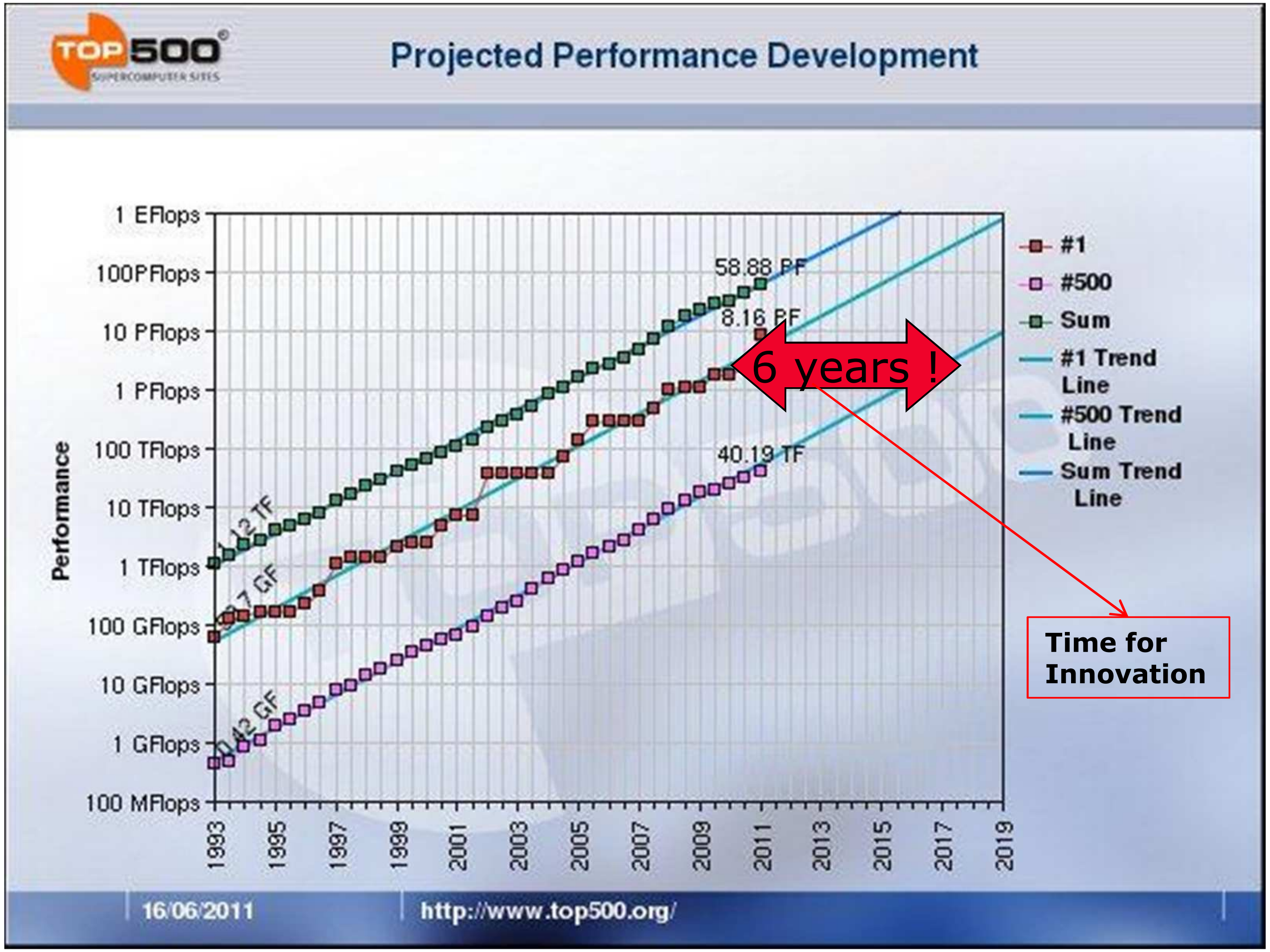
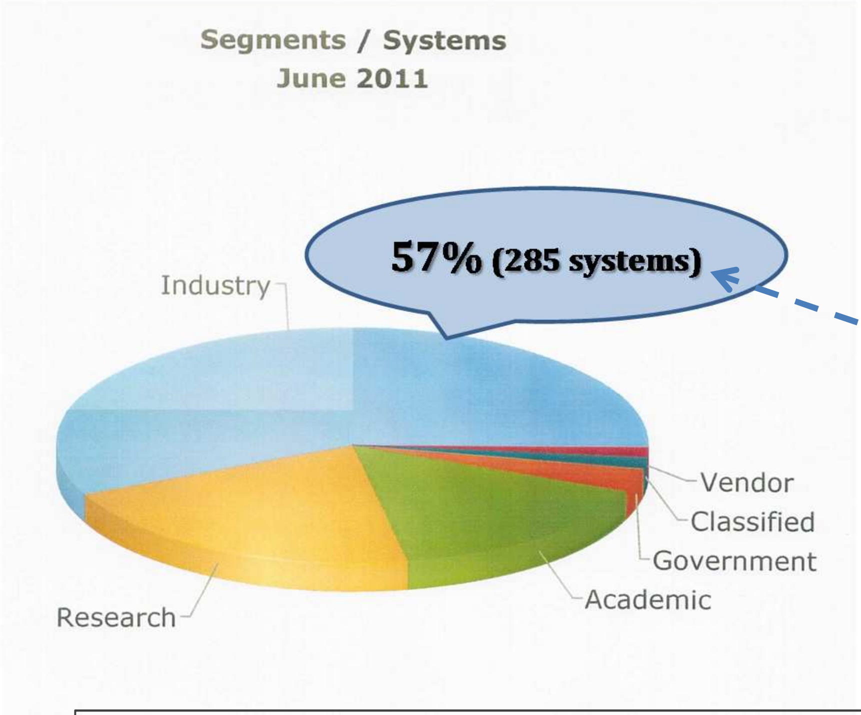
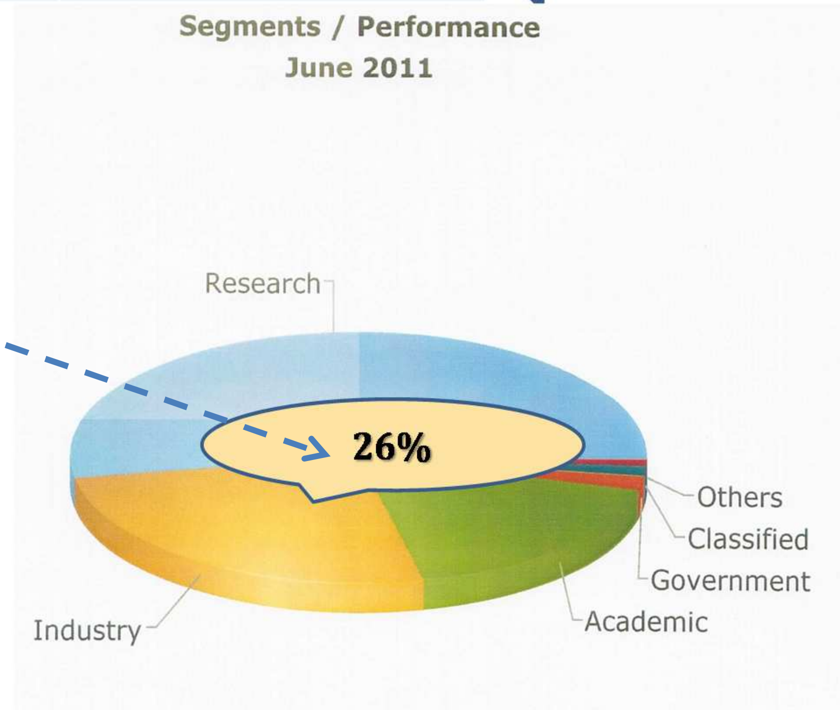
HPC and industrial competitivity



HPC and industrial competitivity

Ranking	Europe	Outside Europe	
1 to 100	7	1	8%
101 to 500	49	228	50%





Challenge for industry: Best coupling between **Architecture / Algorithm / Application**, in order to **address and solve on Exaflop systems crucial issues** in energy & transportation industries, and more generally engineering industries.

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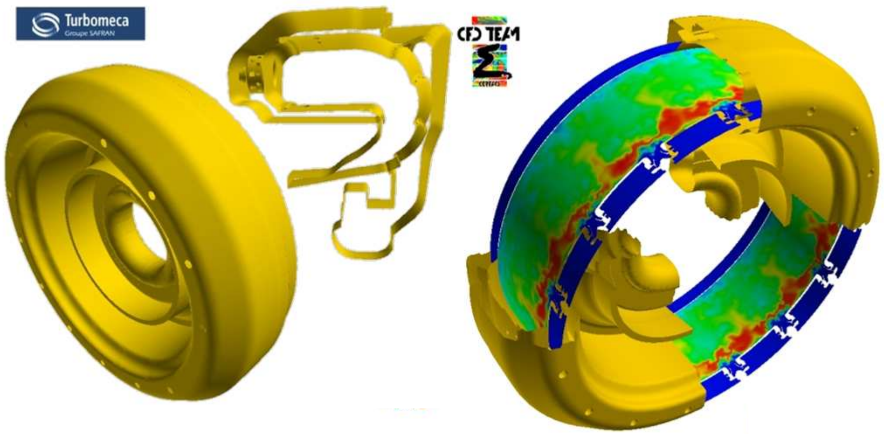
HPC and industrial applications

1. Solving instability in a gas turbine engine

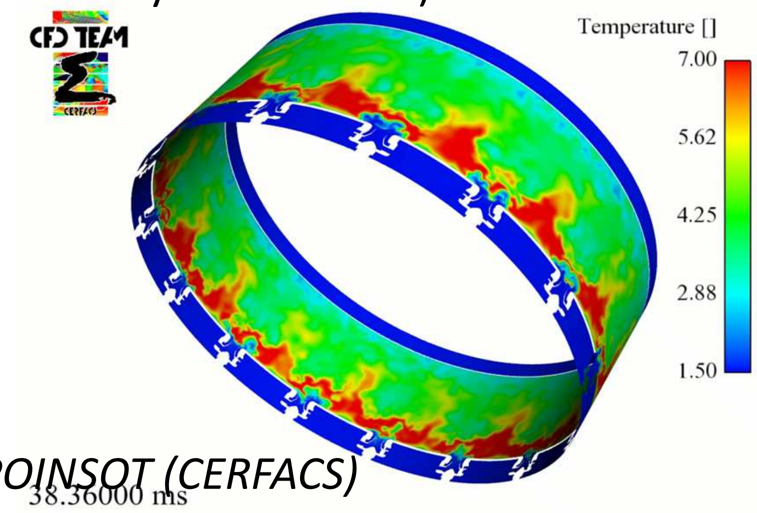


Gas turbine engine combustor

Unstable combustion at high operating condition leading to vibrations and making it inadequate for certification

HPC identification of the source of the unstable modes and verification of the stability of the planned modification:
AVBP code (CERFACS and IFP), B/G and SGI machines up to 330 M cells, 16,000 cores.
Cost: 1000 CPU years ca. **1M€**)

Industrial gain per engine development :
- **engineering work value reduced by 6M€,**
- **world leading combustor design,**
- **no potential loss of business opportunities.**



Acknowledgements: C. BERAT (TURBOMECA) and Th. POINSOT (CERFACS)

HPC and industrial applications

2. To faster airplane design

Boeing: Number of wing prototypes prepared for wind-tunnel testing

Date	1980	1995	2005
Airplane	B757/B767	B777	B787
# wing prototypes	77	11	11

Plateau due to RANS limitations.Further decrease expected from LES with ExaFlop

HPC and industrial applications

2. To faster airplane design

Airbus: "**More simulation, less tests**“

From 

to 

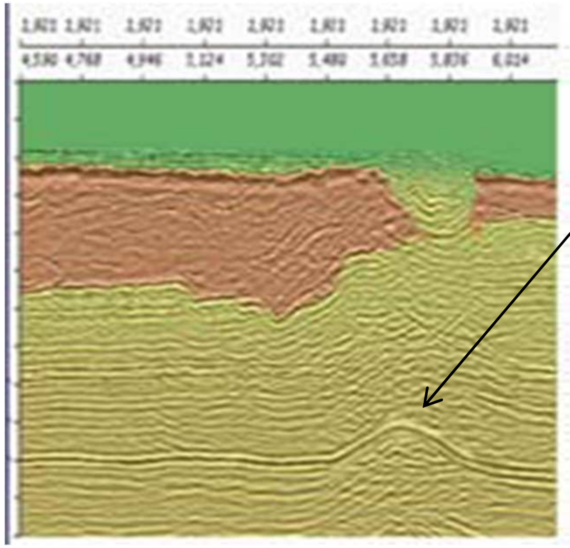
- **40%** less **wind-tunnel days**
- **25%** saving in aerodynamics **development time**
- **20%** saving on wind-tunnel **tests cost**

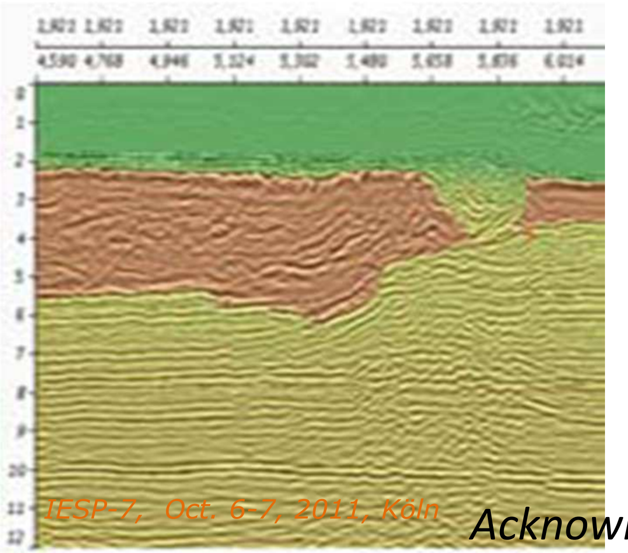
thanks to HPC-enabled CFD runs, especially in high-speed regime, providing even better representation of aerodynamics phenomenon turned into better design choices.

Acknowledgements: E. CHAPUT (AIRBUS)

HPC and industrial applications

3. Increasing efficiçency in Oil & Gas





Seismic profiles of a region of the Gulf of Mexico.

The top image, in 2003 , on **64 processors,**
At the bottom right-hand side , a structure shaped like a bowler hat, typical of a petroleum zone.

Based on this image, ready to install boring equipment on this site.

Fresh data analysis, on a **13 000 cores** supercomputer revealed that the structure was an artefact.

Thanks to HPC, 80 M$ saved

In the **mid-90's, only 40%** of deposits fulfilled their promises. Numerical simulations that analyse data obtained by seismic echography have radically changed the playing field. Armed with the new supercomputer … , the Total engineers are **now** hitting the bull's eye **in 60-70% of cases."**

Journal La Recherche, special HPC, July 2009,

Acknowledgements: H. Calandra, Ph. Ricoux (TOTAL)

HPC and industrial applications
4. Increasing design and lifetime of nuclear power plants

Nuclear electricity

Extending the lifetime of a nuclear power plant by **10 years** represents a gain of **25% in investment**.

The cost of an individual nuclear power plant is of the order of **4 G€** => **1G€ per plant**

HPC 3D-simulations are on the **critical path**, are **absolutely necessary**, for assessing the 10-year extension of this lifetime

Difficult to give precise figures, but the numbers at stake are enormous

Acknowledgements: J.-Y. BERTHOU (EDF)

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Roadmaps to exascale for large industries
(Aeronautics, Oil, Nuclear energy, …)

Roadmaps are different depending upon particular industries but *for a number of domains Exascale* ***capability/capacities*** *are needed to solve the industrial problems*

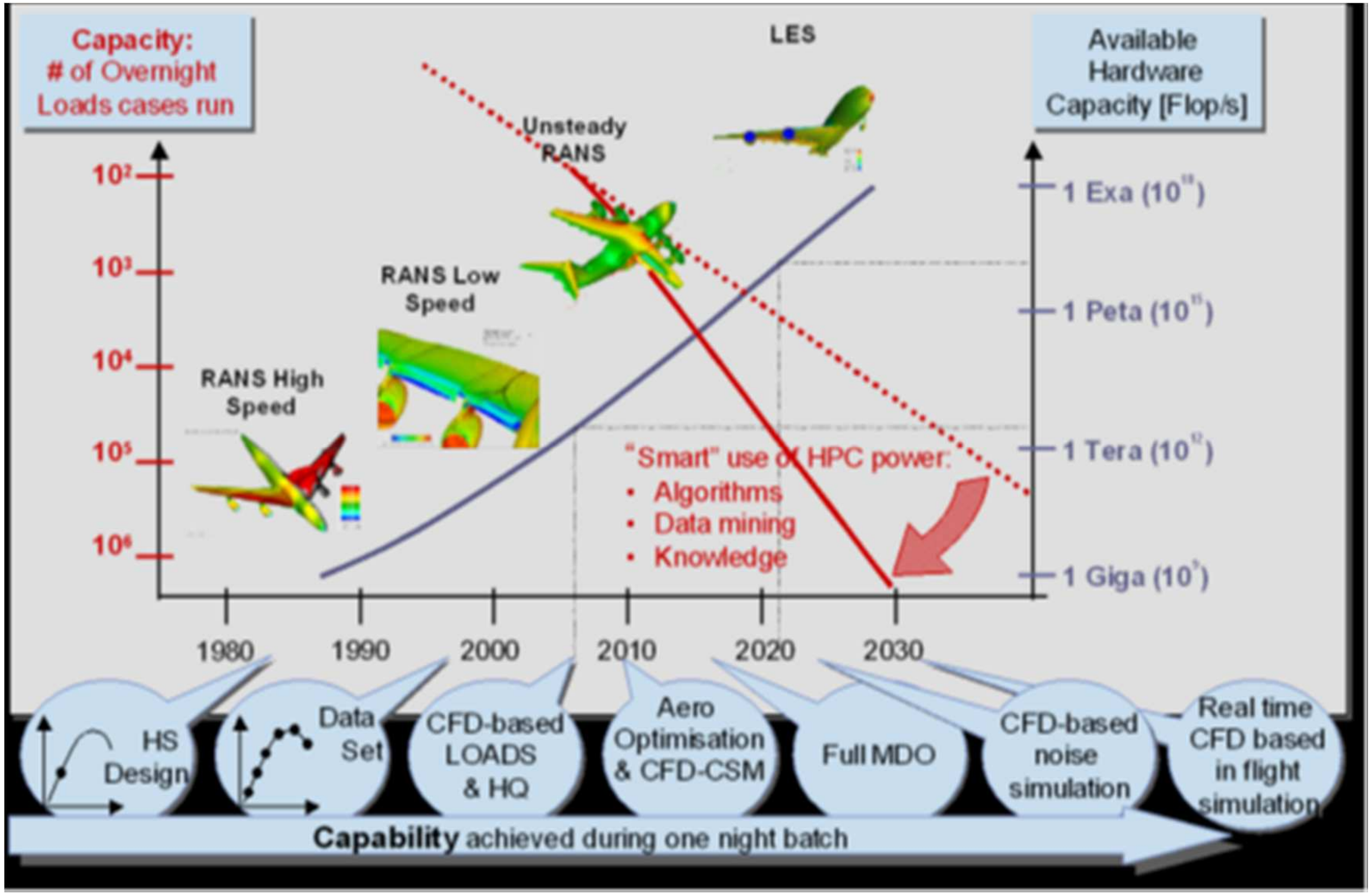
Industrial roadmaps: 1, Aeronautics

Improved predictions of complex flow phenomena around full aircraft configurations with advanced physical modeling and increased resolution, multi-disciplinary analysis and design

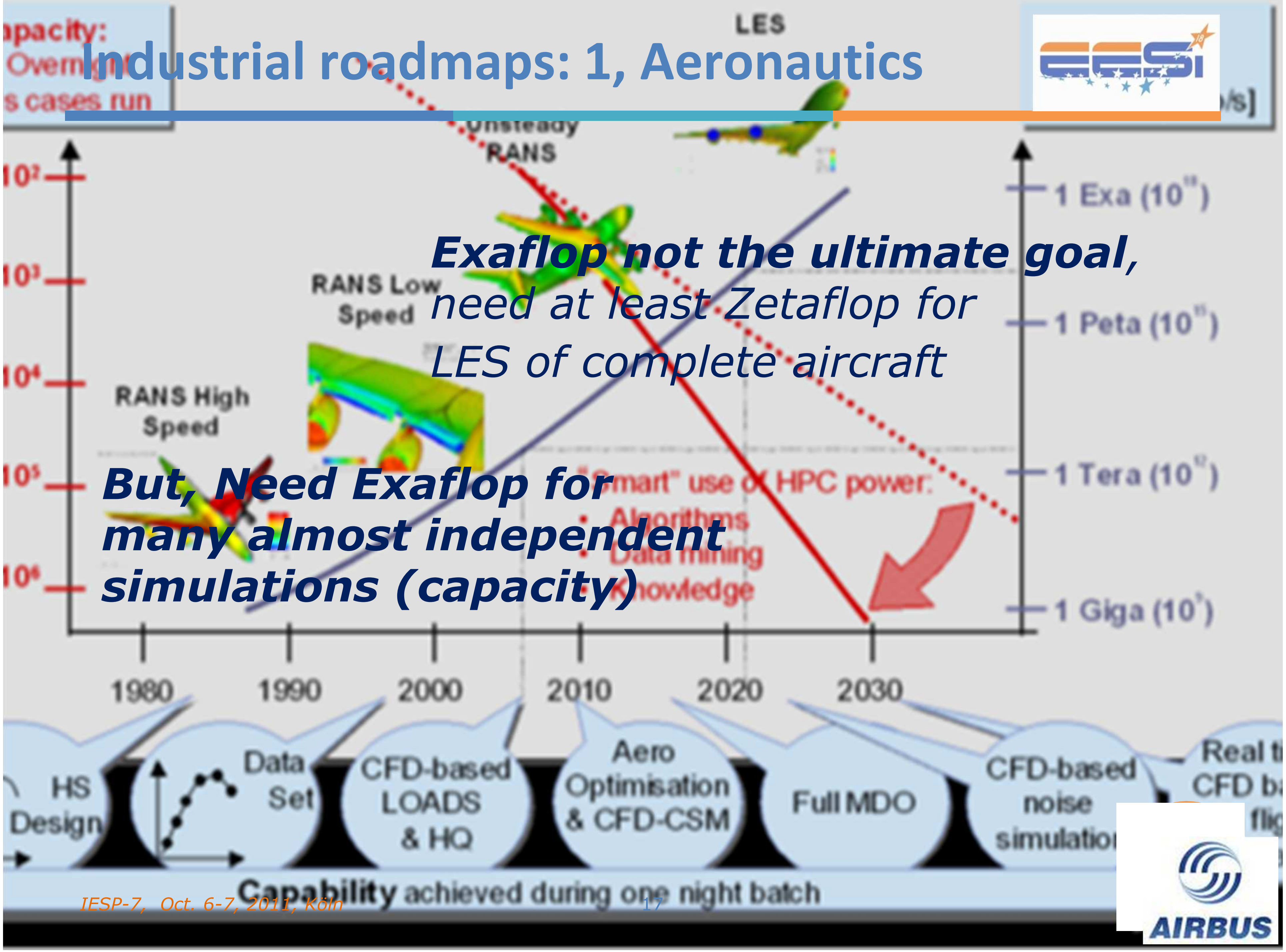
Aerodynamic and aeroelastic data prediction

Real-time simulation of maneuvering aircraft

Industrial roadmaps: 1, Aeronautics



Industrial roadmaps: 1, Aeronautics



Exaflop not the ultimate goal, *need at least Zetaflop for LES of complete aircraft*

But, Need Exaflop for many almost independent simulations (capacity)

Industrial roadmaps: 2, Oil industry

Seismics, Oil and Gas

Hero application to push the limit,
"farming" applications to follow

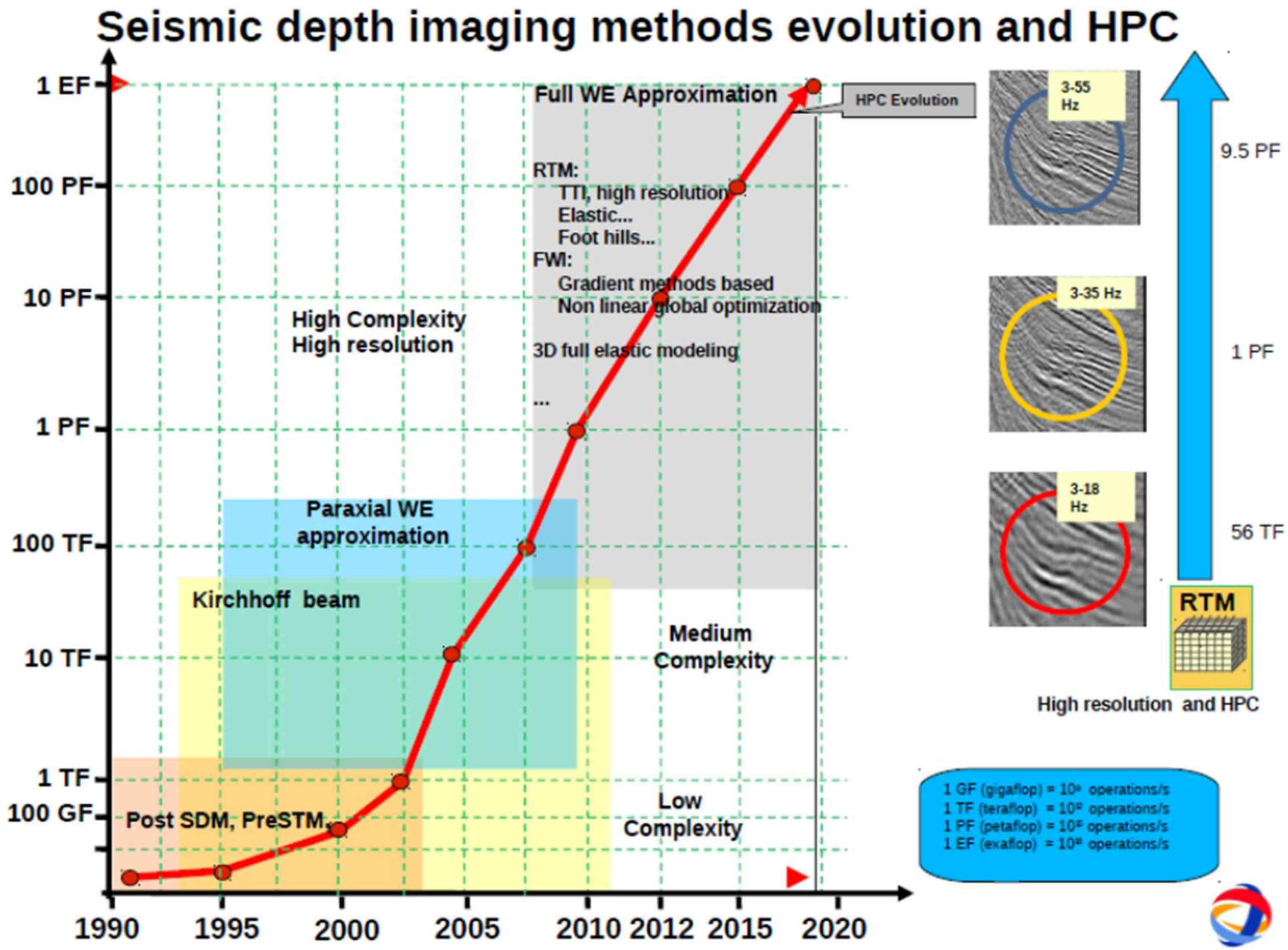
Largely embarrassingly parallel

Major problems are programming model, memory access and data management,

Need Zetaflop for full inverse problem

Uncertainty qualification (UQ) in numerical simulation

Industrial roadmaps: 2, Oil industry



Industrial roadmap: 3, Nuclear energy

Nuclear Energy:

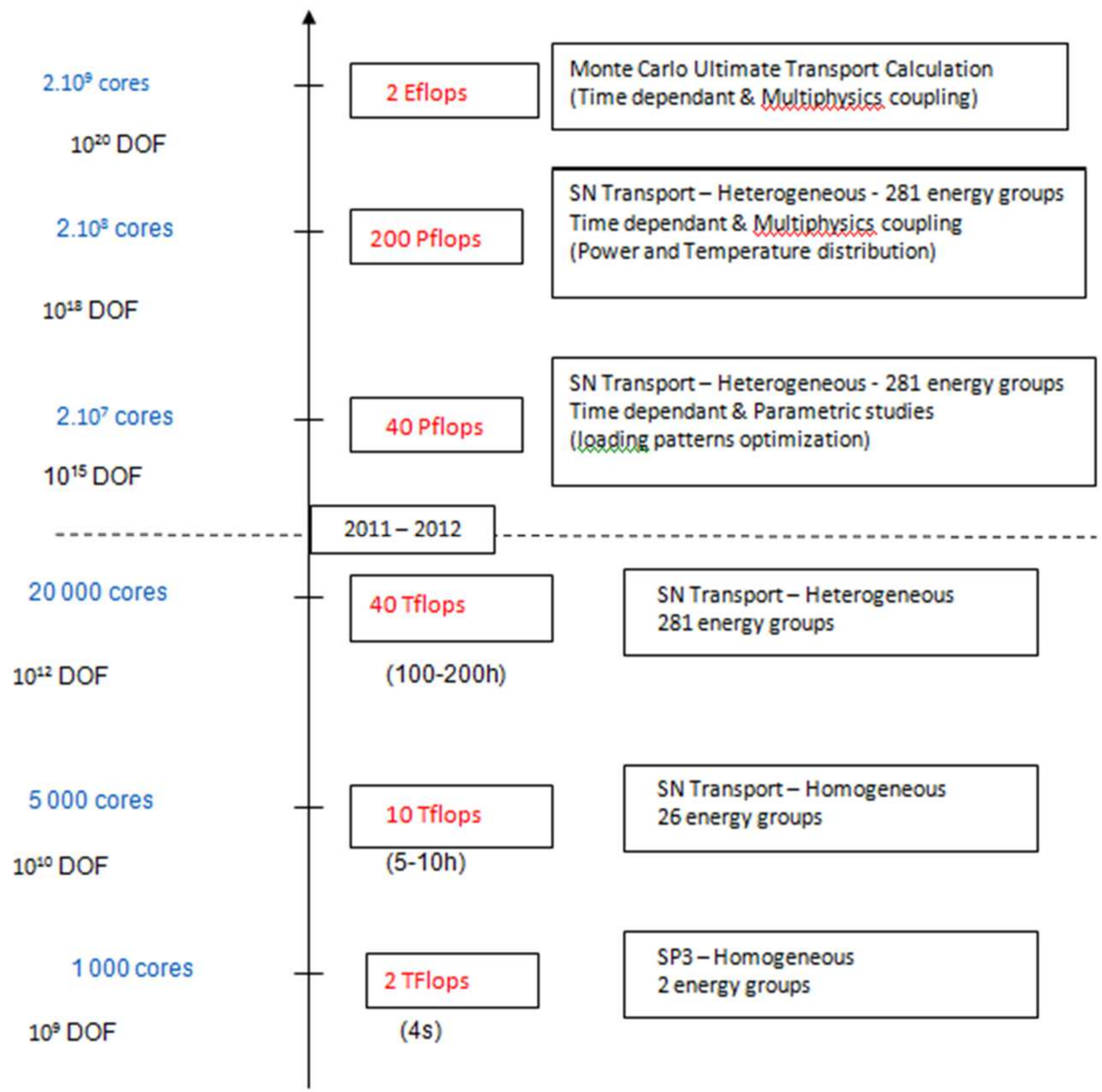
Steady CFD calculations on complex geometries

*RANS, LES and quasi-DNS type calculations under uncertainties (**UQ**),*

Monte Carlo ultimate neutronic transport calculations

Time-dependant & multi-physics coupling

Industrial roadmap: 3, Nuclear energy



Industrial roadmap: 4, Combustion & reactors

Combustion and Gasification:

Hero applications in multi-scales, multi-physics

Turbulent combustion/gasification modeling

Exaflop for combustion at the right scale,

LES in large scale reactors

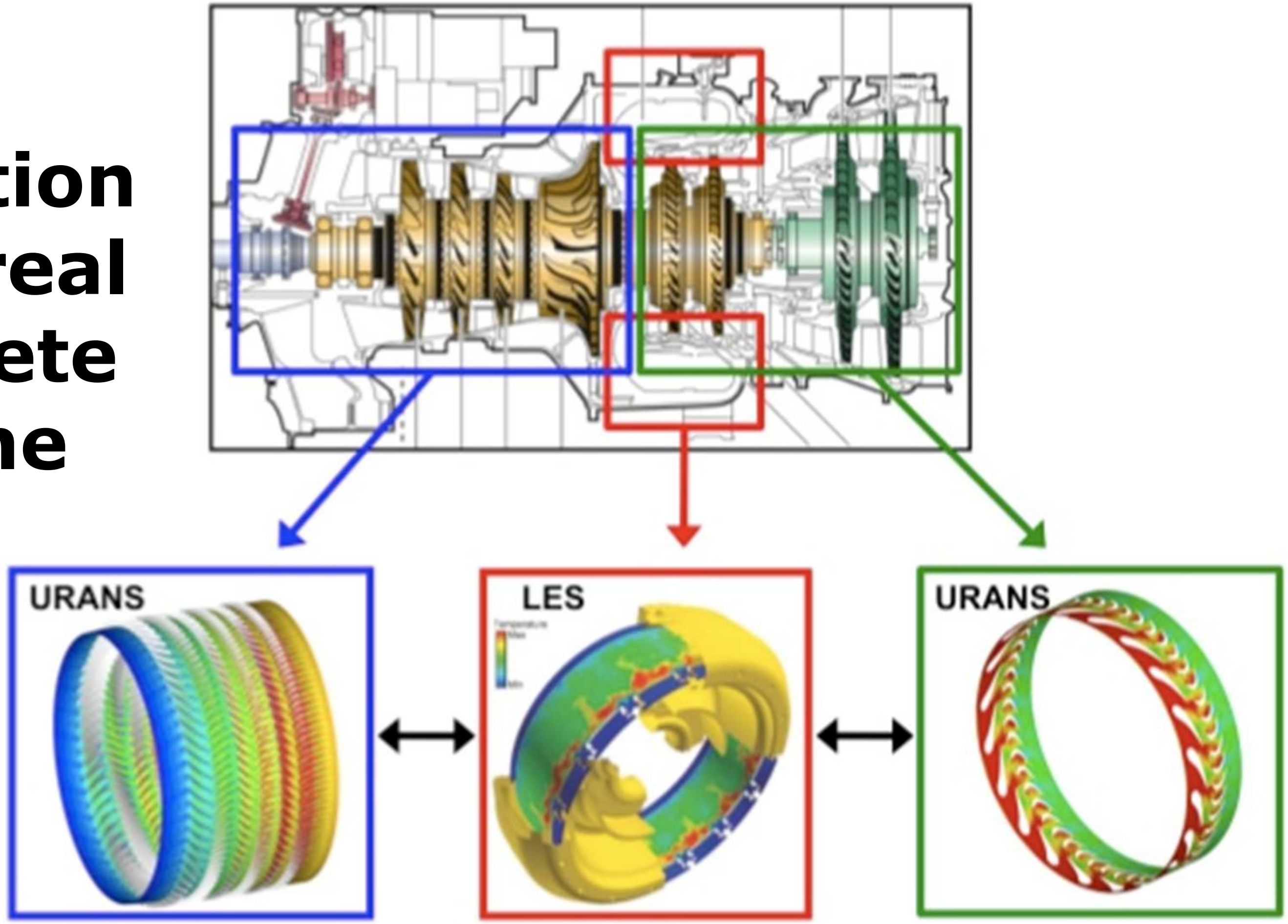
Coupling, multi-physics

Multi-cycle engine (weak scalability)

UQ in combustion/explosion

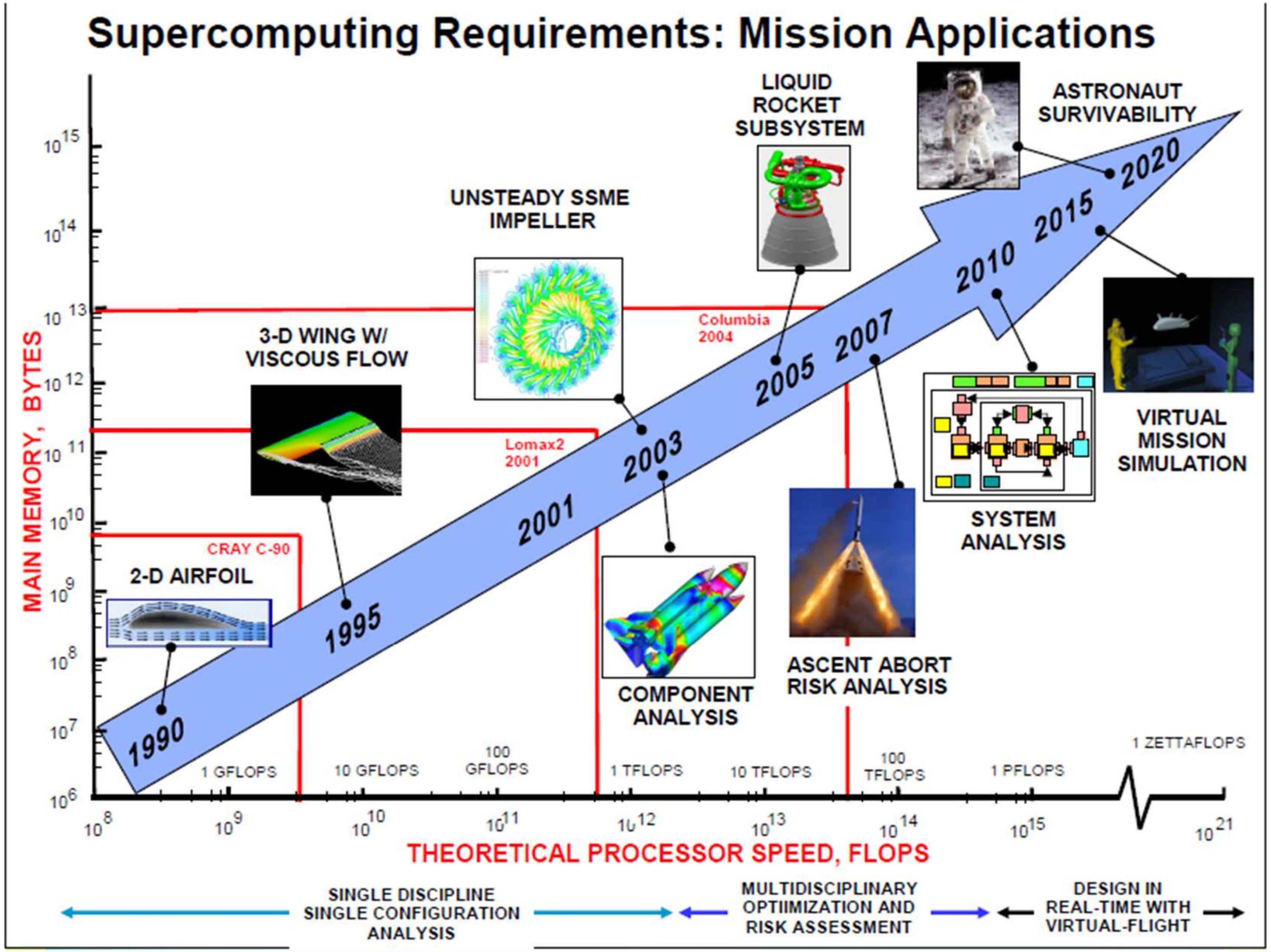
Industrial roadmap: 4, Combustion & reactors

Simulation of the real complete engine



Acknowledgements: Th. POINSOT (CERFACS)

Industrial roadmap: 5, Space systems



Acknowledgements: R. BISWAS (NASA)

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Societal and environmental challenges

Toward

clean and efficient energy,

ACARE (Advisory Council for Aeronautics Research in Europe)

Vision-2020 sets ambitious goals for the next decades:

*- Decrease of the perceived external noise level by **10-20 dB***

*- Reduction of GHG emissions by **50%***

predicting and mitigating against the effects on climate change

ensuring safe and efficient travel

Societal and environmental challenges

HPC is

- the unique way to study and design, **new processes**

analogic mock-ups getting much too expensive

if not impossible to build !

- the only way to check the real **impact** of these new designs through the use of **advanced climate modelling**

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Common issues for energy applications

•***At the level of the simulation environment:***

➢ ***Unified simulation framework*** *and associated services: CAD, mesh generation, data setting tools, computational scheme editing aids, visualization, etc.*

➢ ***Multi-physics simulation****: establishment of standard coupling interfaces and software tools,* ***mixing legacy and new generation codes***

➢ *Common (jointly developed)* ***mesh-generation tool****, automatic and adaptive meshing, highly parallel*

➢***Standardized efficient parallel IO and data managemen****t (sorting memory for fast access, allocating new memory as needed in smaller chunks, treat parts of memory that are rarely/never needed based on heuristic algorithms, …)*

Common issues for energy applications

•*At the level of application codes:*

- *New numerical methods, algorithms, solvers/libraries, improved efficiency*
- *Coupling between stochastic and deterministic methods*
- *Numerical scheme involving stochastic HPC computing for* ***uncertainty and risk quantification***
- *Meshless methods and particle simulation*

- *Scalable program, strong and weak scalability, load balancing, fault-tolerance techniques, multi-level parallelism (issues identified with multi-core with reduced memory bandwidth per core, collective communications, efficient parallel IO)*
- *Standards programming models (MPI, OpenMP, C++, Fortran, …) handling multi-level parallelism and heterogeneous architecture*

Overall remarks

Experts consider that

Only few "Hero" applications to push the limit, real goal is Zeta and not Exaflop

Large number of applications corresponding to production problems will be "farming" applications

Need some flexibility in architecture: several applications on the same large computer (computer center) and the same application on different architectures (true for farming only)

Need for **training** and increased human resources

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Estimation of resources for solving hurdles

Roadmap issue	Human Resources by year → 2015 High / Low	Integrated (4 years) Provisional Costs 2012 → 2015 High / Low	Human Resources by year 2015 → 2020 High / Low	Integrated (5 years) Provisional Cost 2015 → 2020 High / Low
New Paradigm for programming model	20 / 10	8 000 / 4000	50 / 25	25 000 / 12 500
Common Software Platform, legacy codes	30 / 15	12 000 / 6 000	80 / 40	40 000 / 20 000
Efficient Solvers, Numerical methods	50 / 25	20 000 / 10 000	90 / 45	45 000 / 22 500
Coupling Interfaces	20 / 10	8 000 / 4 000	50 / 25	25 000 / 12 500
Grid generation	30 / 15	8 000 / 4 000	70 / 35	35 000 / 17 500
Data management, Memory access	40 / 20	16 000 / 8 000	70 / 35	35 000 / 17 500
Fault Tolerance	40 / 20	16 000 / 8 000	70 / 35	35 000 / 17 500
Load Balancing	30 / 15	12 000 / 6 000	60 / 30	30 000 / 15 000
Others	20 / 10	8 000 / 4 000	50 / 25	30 000 / 15 000
TOTAL in k€		**108 000 / 54 000**		**300 000 / 150 000**

Estimation of resources for solving hurdles

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Paradigm for ogramming model	20 / 10	8 000 / 4000	50 / 25	25 000 / 12 500
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OTAL in k€		**108 000 / 54 000**		**300 000** [illegible]

2012-2020

400 M€

Thank You