Flight-Physics Capability Strategy
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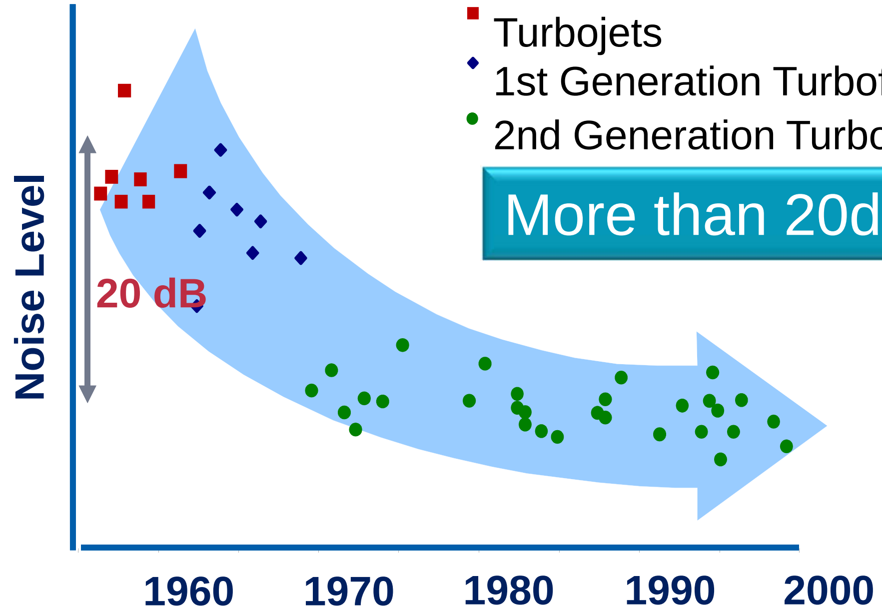
Exascale Needs & Challenges for Aeronautics Industry

PRACEdays15 - Dublin,
May 26th 2015

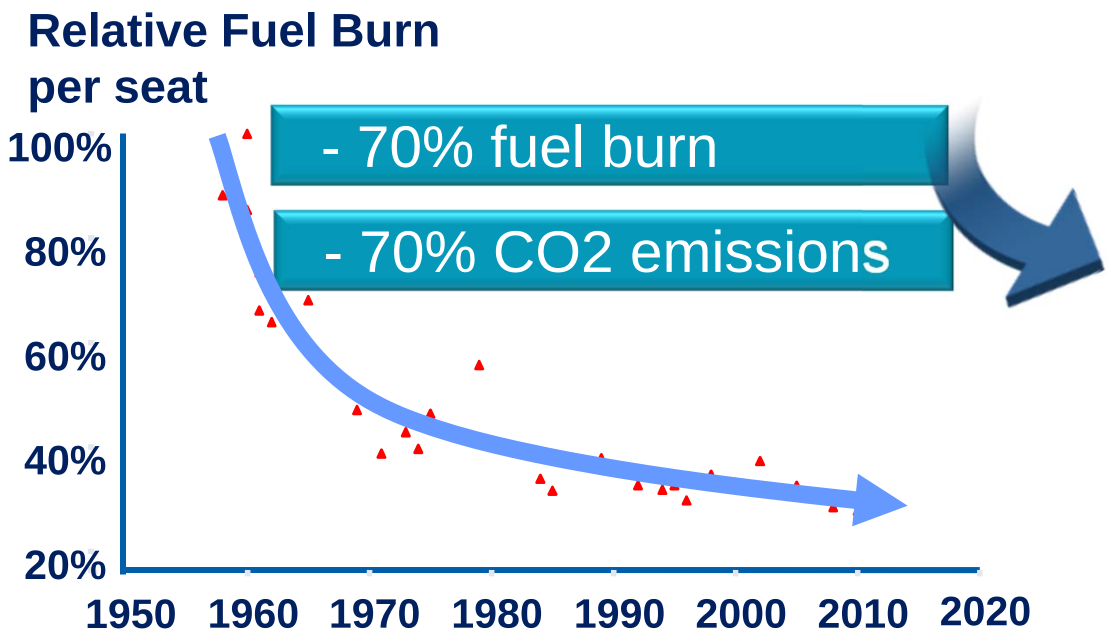
Content

A historical perspective

- In the last 40 years, commercial aviation industry has achieved:



More than 20dB improvement



- 70% fuel burn
- 70% CO2 emissions

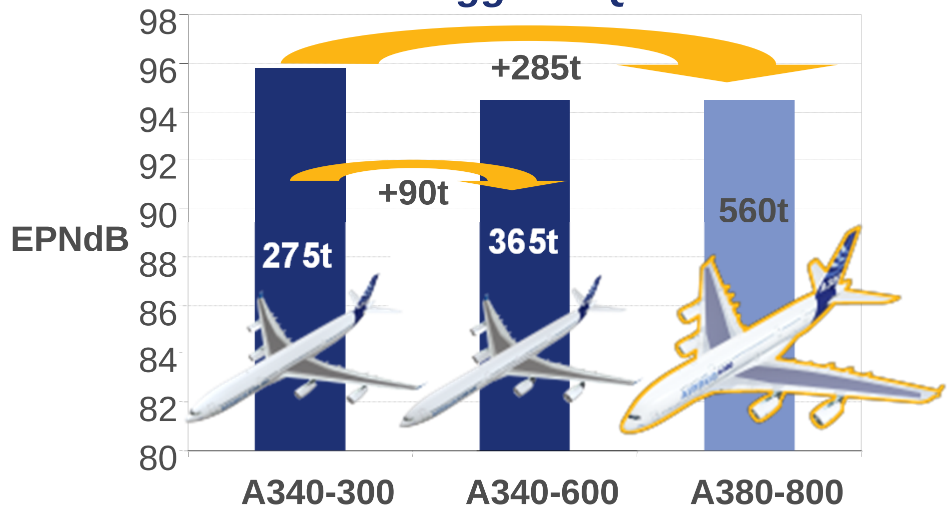
- Within Airbus, we have played a key role in reducing the environmental impact from aviation

AIRBUS

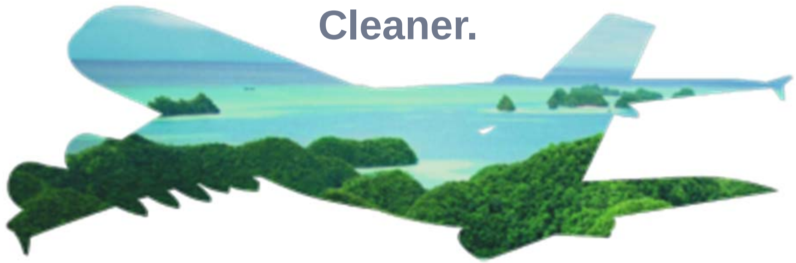
Simulation and HPC in the A380 Design

- The first Airbus aircraft to have exploited aerodynamics simulation & HPC

A380 Bigger & Quieter



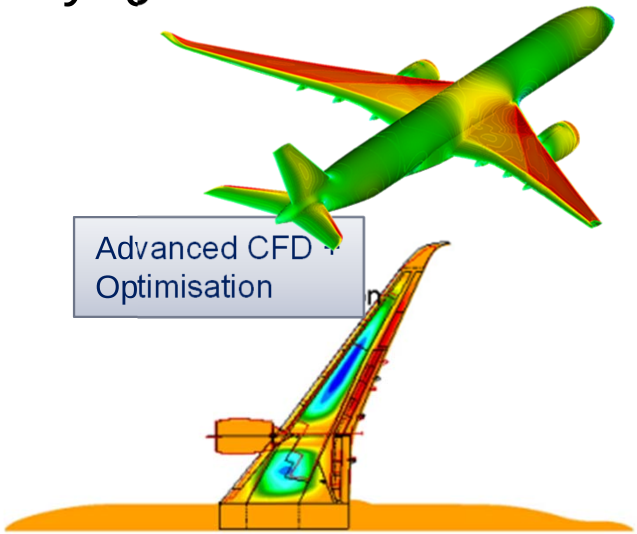
Twice as many passengers flown for the same noise level



- Less than 3 litres of fuel per pax per 100 km
- Less than 75g of CO2 per pax per km

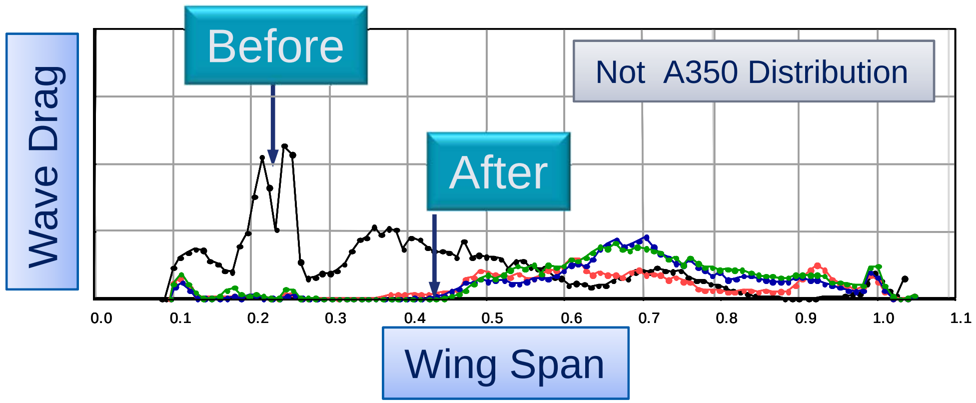
Pushing the Boundaries through the A350

- An evolution of the aerodynamics design: Heavy use of simulation and HPC – around 5000 data sets
- Cryogenic Wind Tunnel Testing replicating flight conditions



- 40 % less test than in A380

- Optimised aircraft design, finest aerodynamics and lowest fuel burn

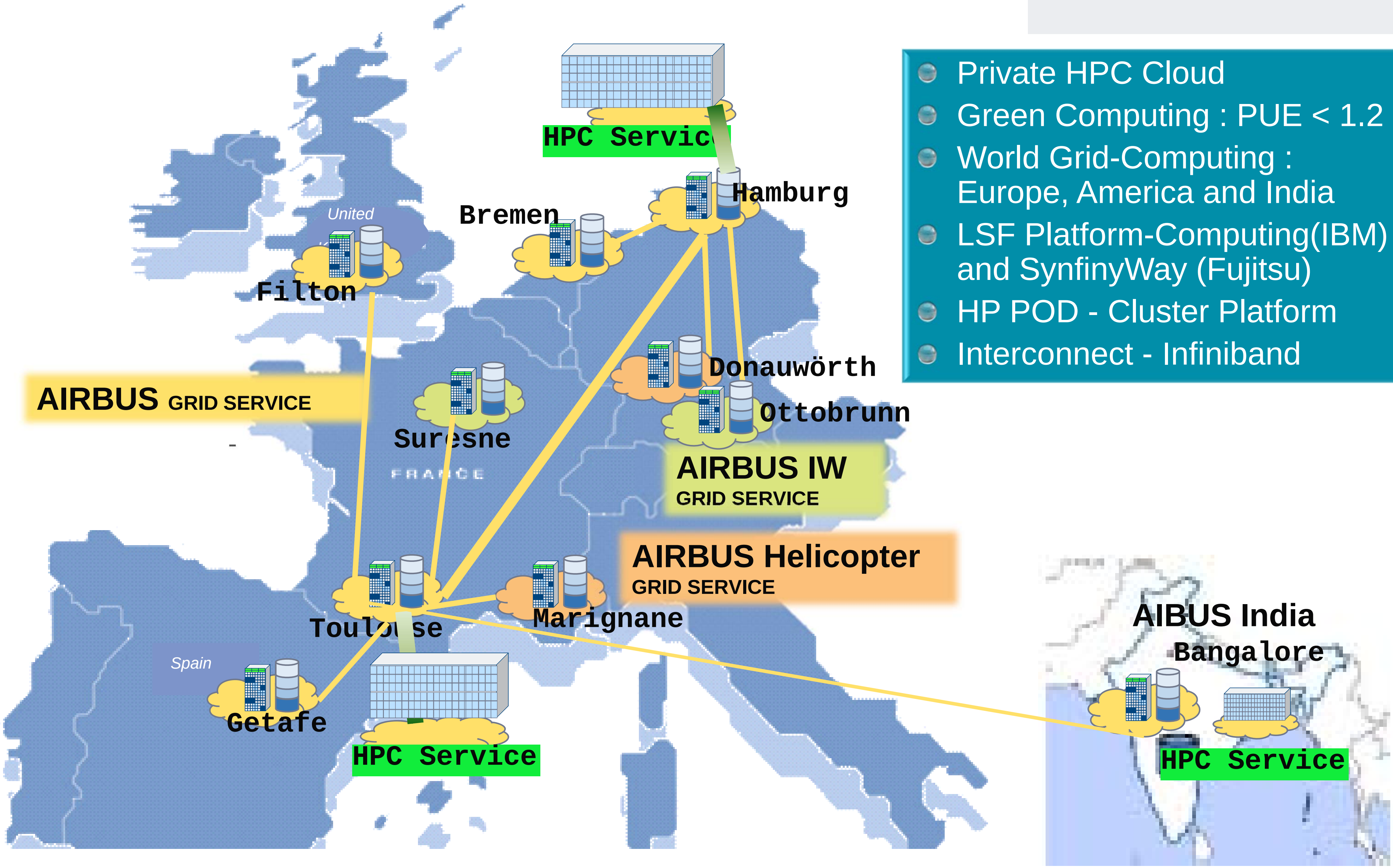


Airbus HPC patterns

- **Simulation frameworks**
  - Higher process level (e.g. D.O.E./sensitivity analysis, optimization, trade-off studies…)
  - Massive data production in single process (e.g. aero-data direct production geometry using HPC)
  - Complex processes (e.g. multi-level, multi-disciplinary optimization) ➔ Advanced execution & data management
- **Grid services / LSF profiles**
  - Virtualization of HPC resources (e.g. separate & *global* optimization of HPC activities)
  - Meta-scheduling ➔ global virtualization of HPC resources through grid, local queues management through LSF
- **FlowSimulator / Open-PALM**
  - FlowSimulator modular approach (e.g. share mesh parallel services , coupling strategies parallel scripted at solver time loop level)
  - Capability to use FlowSimulator brick as a server being one of the component of a distributed simulation

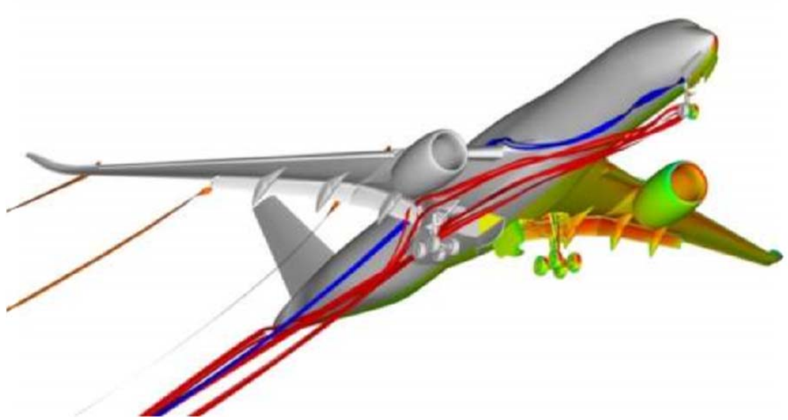
AIRBUS Cloud & Grid Architecture

- Private HPC Cloud
- Green Computing : PUE < 1.2
- World Grid-Computing : Europe, America and India
- LSF Platform-Computing(IBM) and SynfinyWay (Fujitsu)
- HP POD - Cluster Platform
- Interconnect - Infiniband



AIRBUS HPC4 - Key Characteristics

- Location : Toulouse, Hamburg
- Containers : 3 POD‘s
- Servers : 2 320
- Cores : 55 680
- RMAX : 1 to 2 Pflops (Ivy Bridge, Broadwell)
- Memory : 270 TB
- Local Storage : 1 500 TB
- Shared Midterm Storage : 750 TB
- Shared Computing Storage : 1 800 TB
- Outsourced service
- Energy Efficiency (PUE < 1.2)
- Access / Scheduler Resource Management : LSF / Synfiniway
- Interconnect : Infiniband

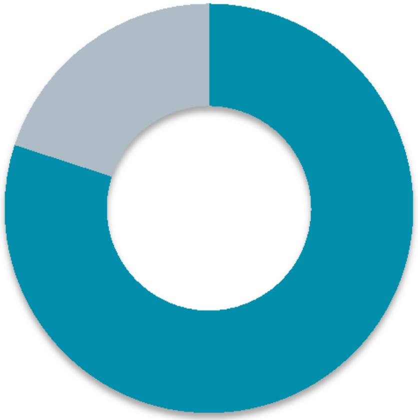


Flight Physics current major HPC customer

Flight-Physics

Computational Fluid Dynamics

- Design & Optimize External Aircraft Shapes
- Design Sensitivities & Trades
- High Speed an Low Speed Performance
- Unsteady Aerodynamic/Aeroelastic Effects
- Structural Flexibility Effects
- Aircraft Data Model for the whole Envelope
- Loads and Aeroelastic Data
- Multiphysics : Aeroacoustics, Aerothermics…



80%

of HPC Capacity

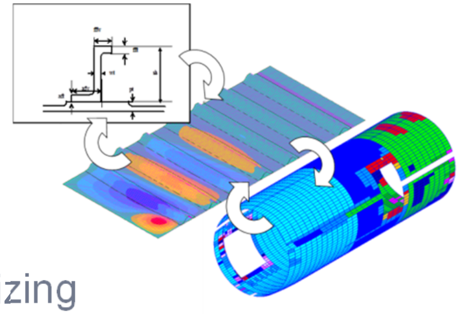
2013

Aerodynamics

Loads & Aeroelastics

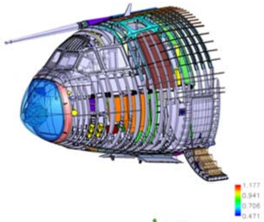
Systems, Structure, PowerPlant future big customers

Structure



Major Component Optimisation

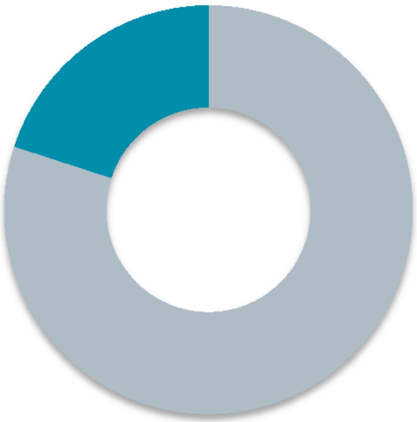
- Box sizing (covers)
- Composite fuselage preliminary sizing (covers thickness)
- Hundreds of variables and thousands of constraints



Virtual testing - Non Linear FE

- Generalization of NLFE models with contact and complex material

Strength analysis

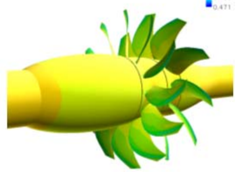


20%

of HPC Capacity

2013

Powerplant



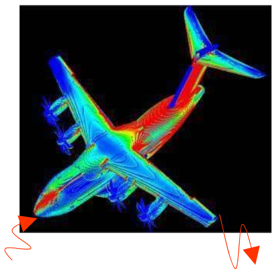
Noise prediction

- Integration of noise constraints in the A/C design process
- Robustness of noise assessment along development cycle

Propellers / contra propellers noise

- Assessment of noise radiated by SRP and CRP.
- Optimisation of engines installations (MDO)
- Extensive use of coupled CFD/CAA numerical tools

Systems



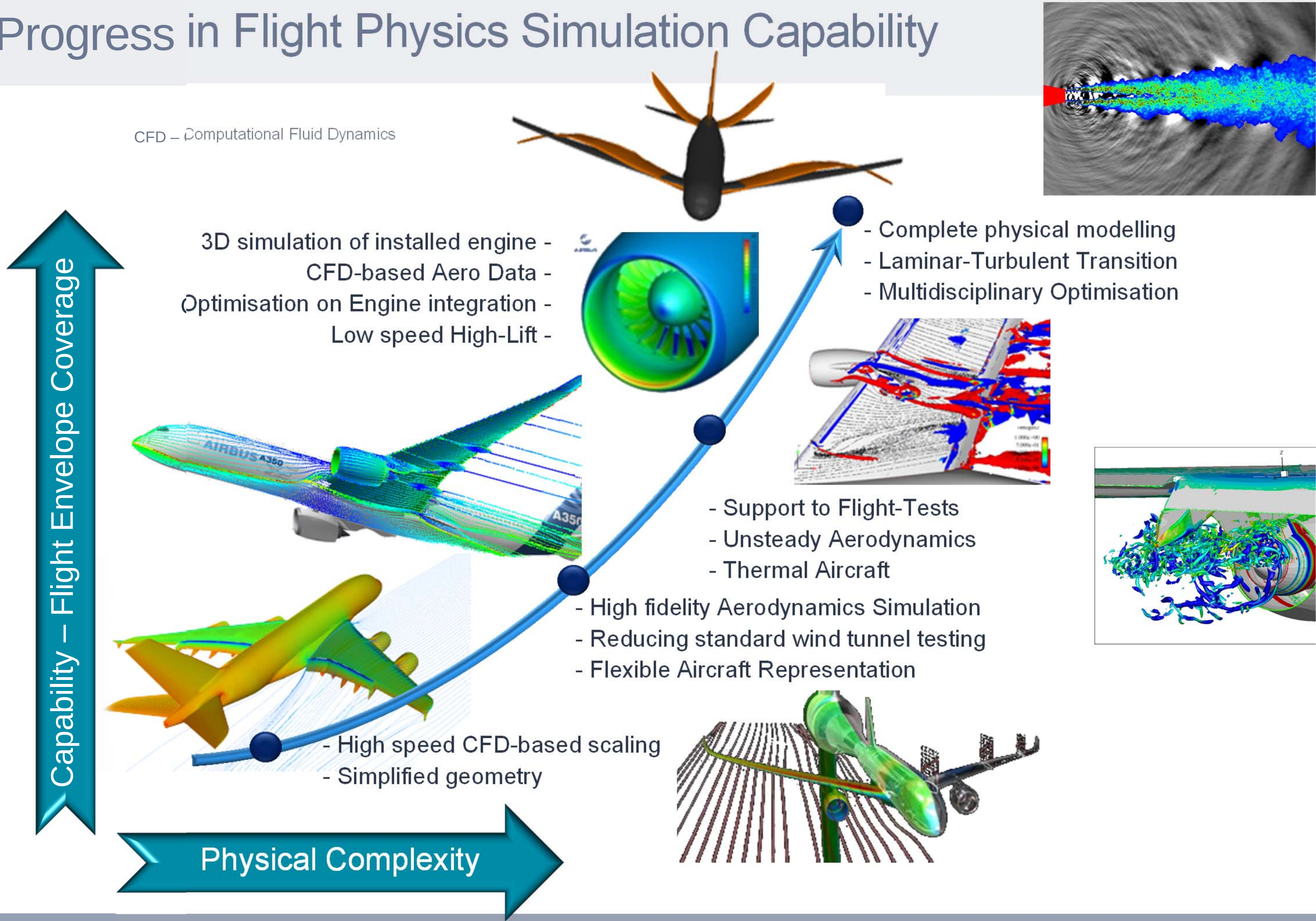
Safety & Certification contribution

- Electromagnetic compatibility in nominal and hazardous conditions (EMH)

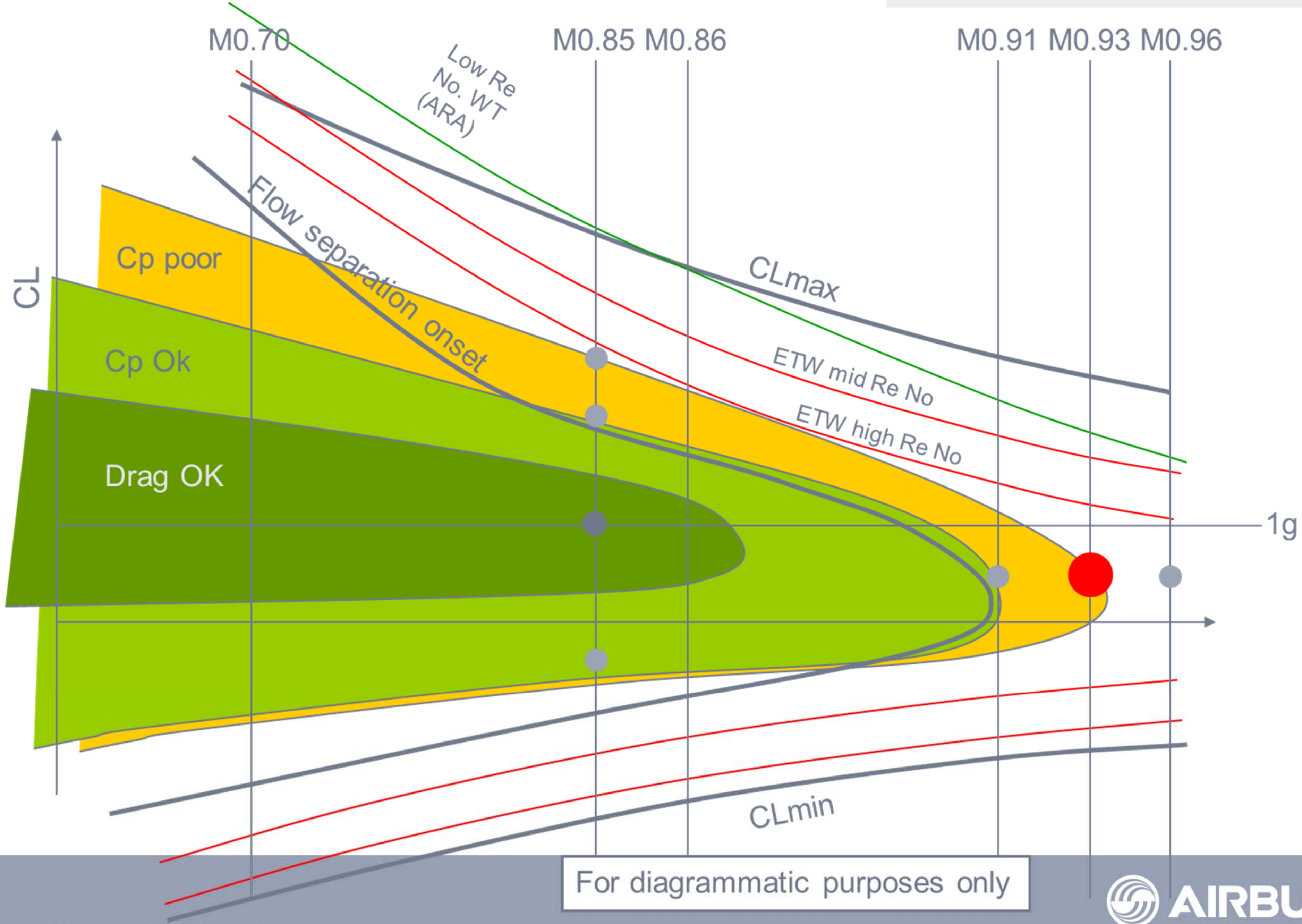
Fuel Tanks: thermal fluid modelling

- Thermal fluid modelling for Fuel tanks is used throughout the whole A/C development lifecycle

Progress in Flight Physics Simulation Capability

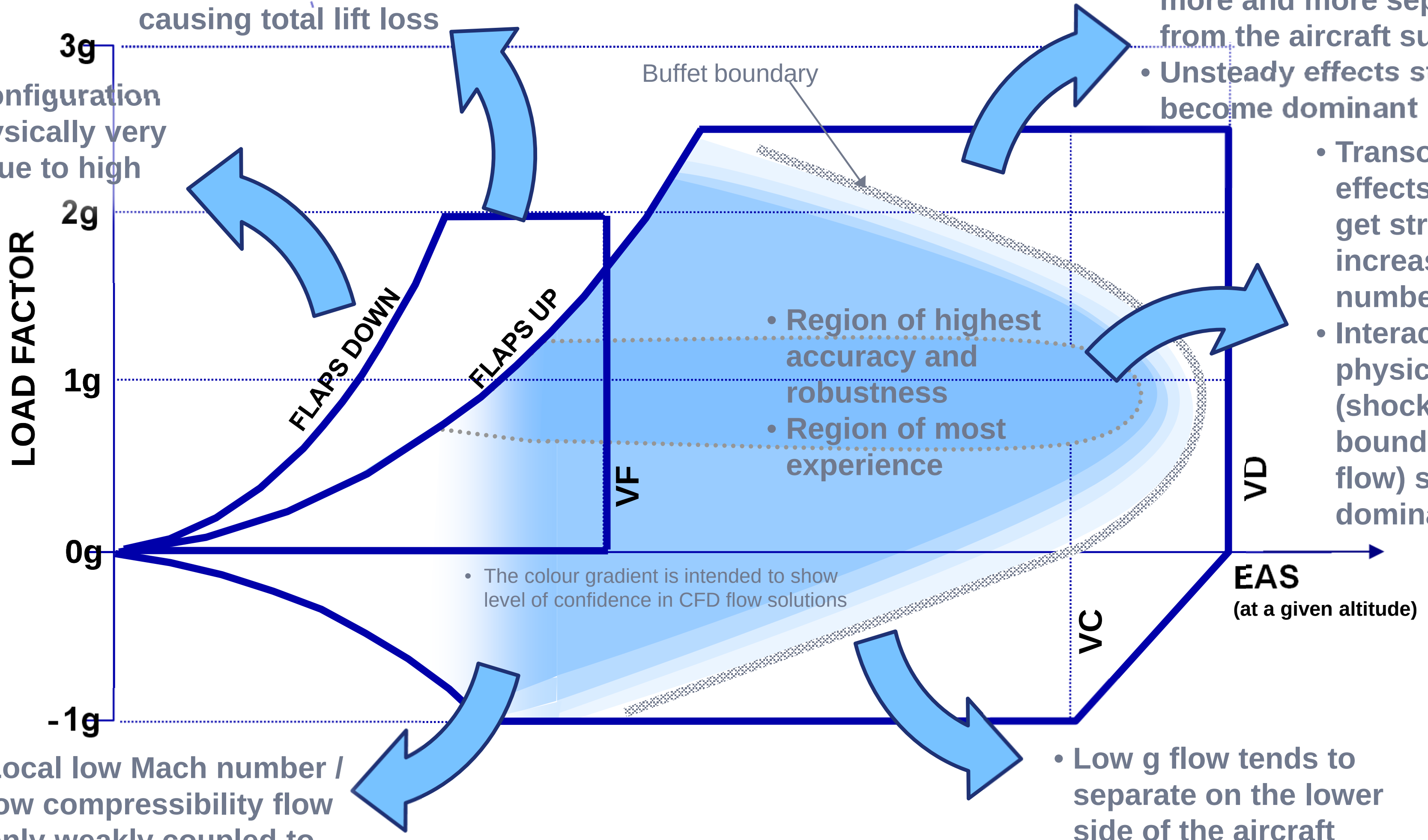


Simulation Envelope



Aerodynamic Flow Predictions vs. Flight Envelope

- Maximum lift borders are determined by onset of massive separation causing total lift loss
- High lift configuration flow is physically very complex due to high loading
- Beyond buffet boundary flow tends to become more and more separated from the aircraft surface
- Unsteady effects start to become dominant
- Transonic flow effects (shocks) get stronger with increasing Mach number and load
- Interaction of physical effects (shock flow, boundary layer flow) start to dominate



- Local low Mach number / low compressibility flow only weakly coupled to main flow
- Low g flow tends to separate on the lower side of the aircraft

AIRBUS

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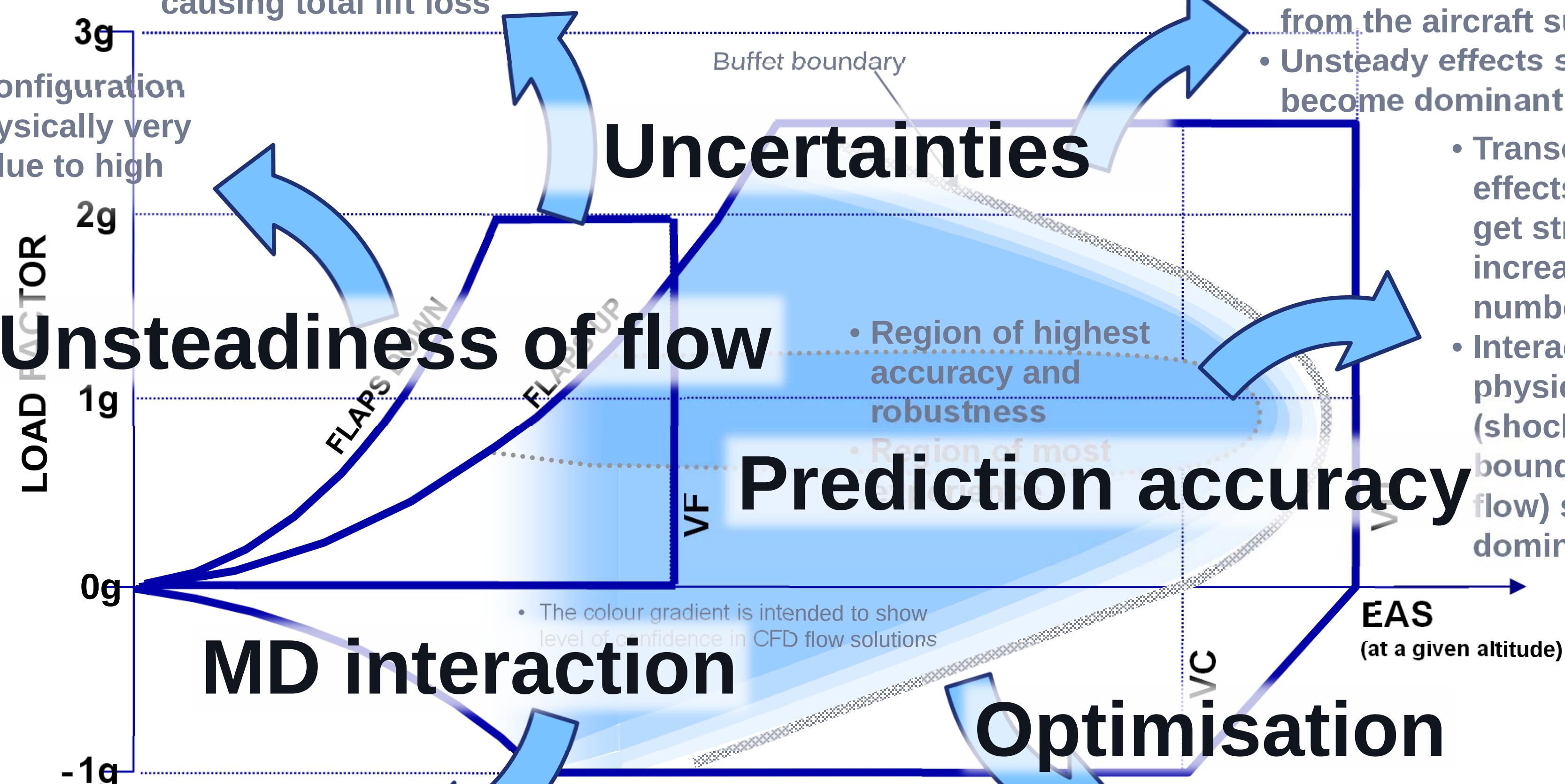


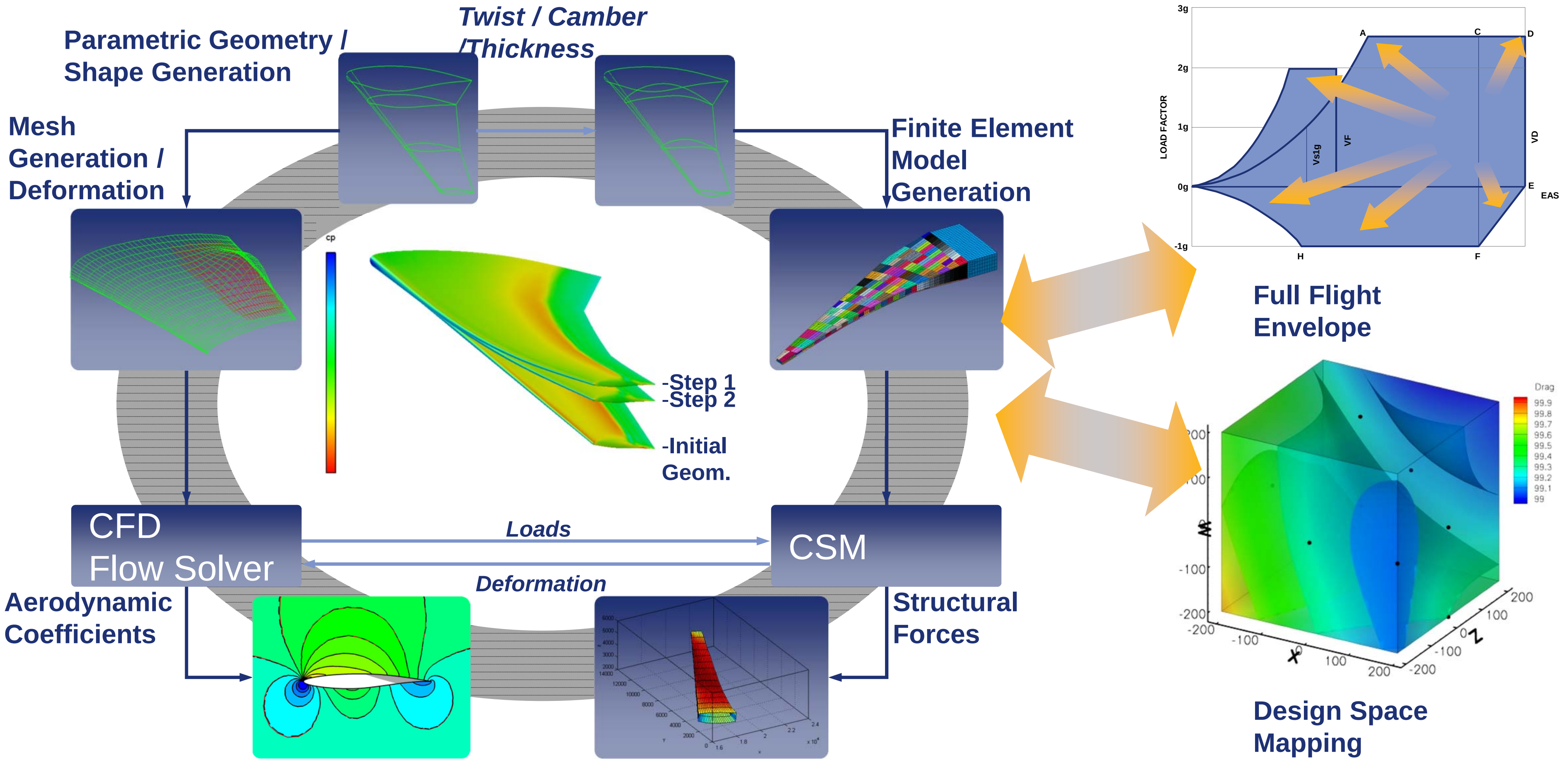
- Local low Mach number / low compressibility flow only weakly cou... main flow
- Low g flow tends to separate on the lower ... raft

Exascale Vision

- Exascale computing key enabling technology for future aircraft design
- Fully multi-disciplinary development and optimization process
- Wide use of integrated MDA/MDO capabilities
- Real-time/interactive way of working fostering innovation

Multidisciplinary Design Capability

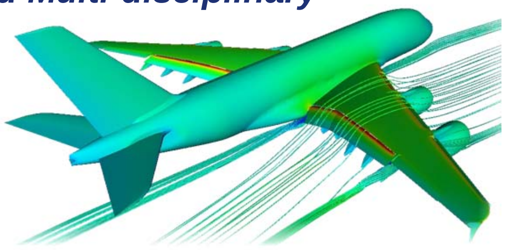
- Multi-disciplinary analysis and design, supported by affordable CFD-based aerodynamic and aero elastic data prediction will be a significant change of paradigm in aeronautics industry.



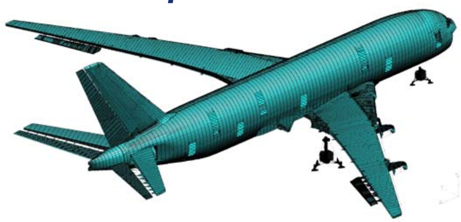
Exascale Challenges: Fly the Virtual Aircraft

- Real-time Simulation of Manoeuvre Flight of a Complete Aircraft

Full Unsteady aerodynamics simulation and Multi-disciplinary interactions



Full Finite Element Modelling of the Airplane



Virtual Certification Prior to Production

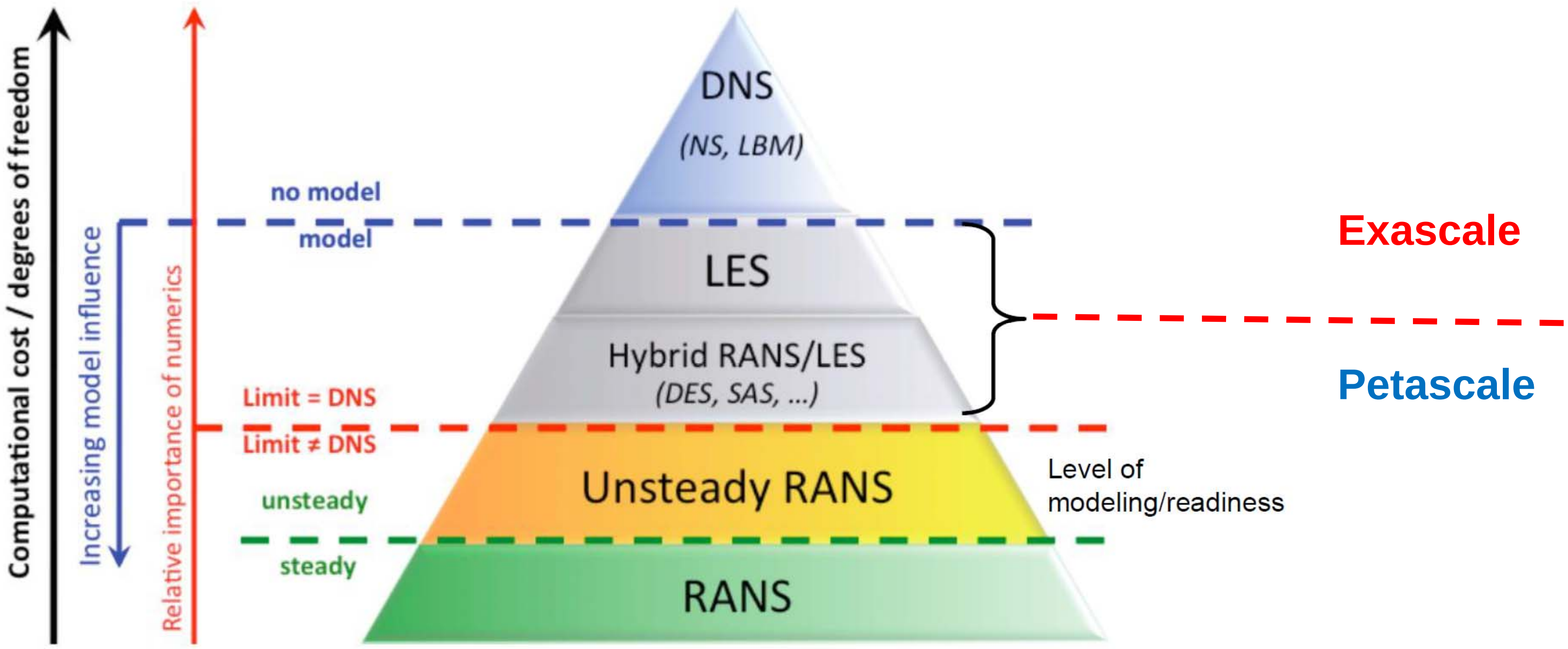
Full Simulation of Manoeuvre Flight

- Loads and Stress for the Airplane in the Whole Envelope

- Digital Prediction of “Flight Performance” and “Handling” Prior to First Flight

RANS to LES

- Move from RANS to unsteady Navier-Stokes simulation, (ranging from current RANS-LES to full LES) and/or Lattice Boltzmann method
- Significantly improve predictions of complex flow phenomena around full aircraft configurations with advanced physical modelling.



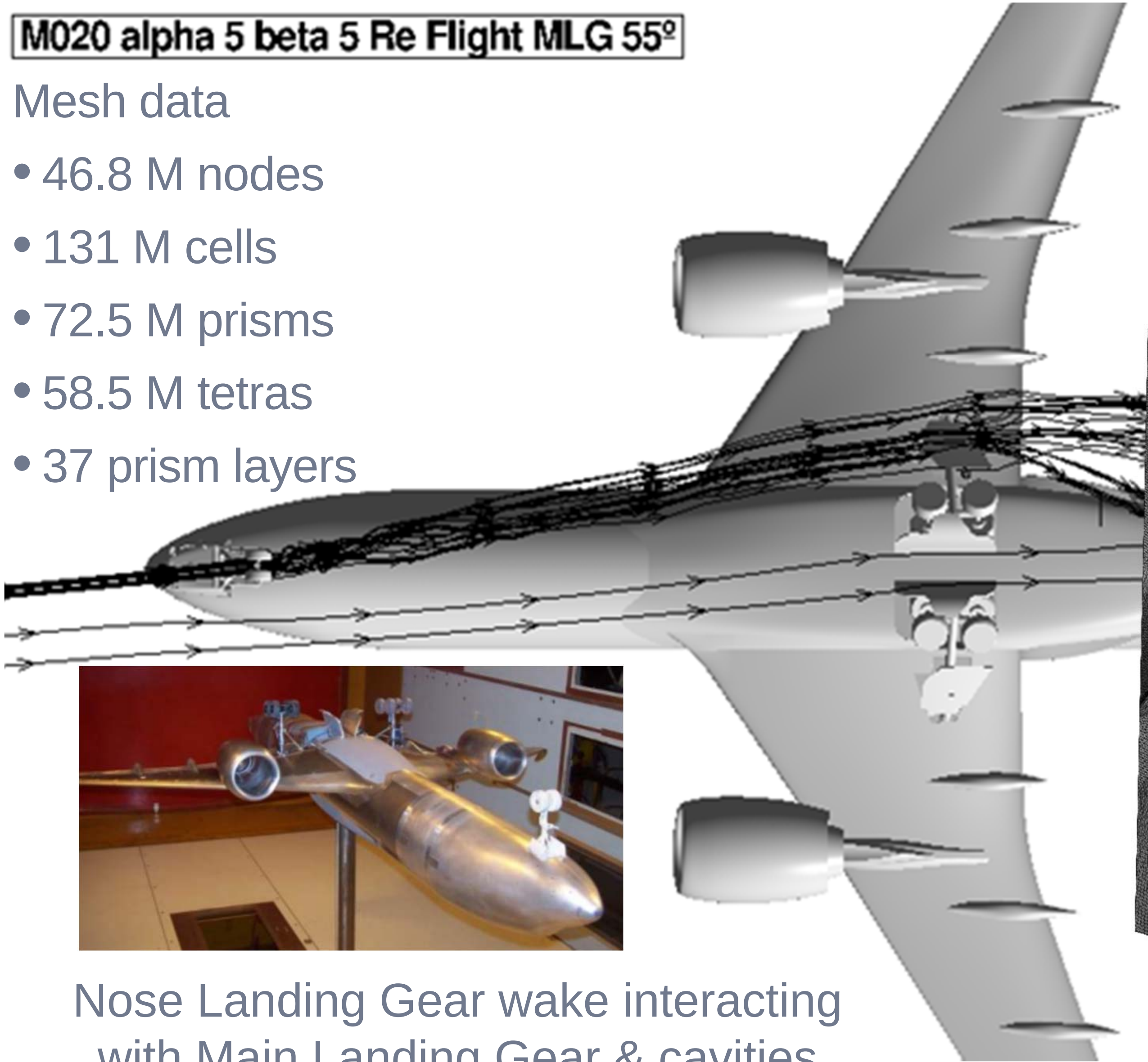
From *Sagaut P., Deck S., Terracol, M. (2006) Multiscale and Multiresolution Approaches in Turbulence. Imperial College Press, UK, 356 pp*

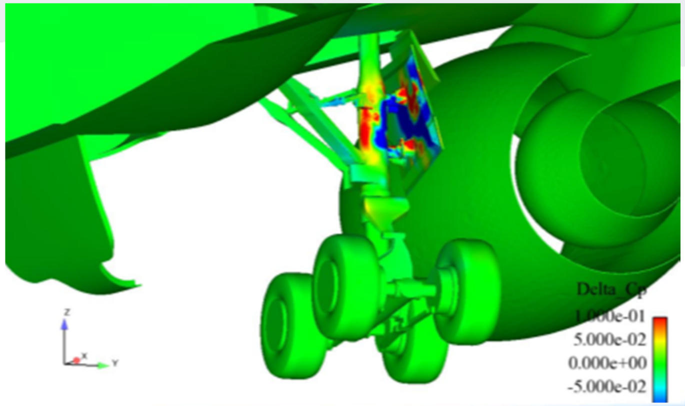
Complex high lift case: RANS-LES vs LBM

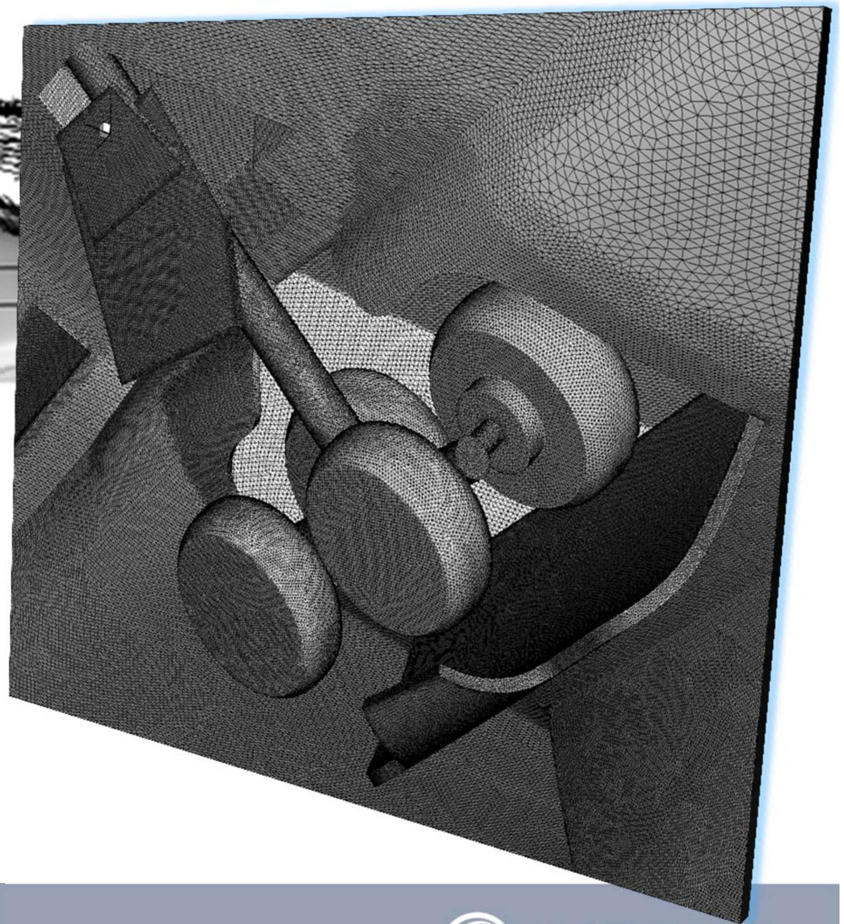
M020 alpha 5 beta 5 Re Flight MLG 55º

Mesh data

- 46.8 M nodes
- 131 M cells
- 72.5 M prisms
- 58.5 M tetras
- 37 prism layers

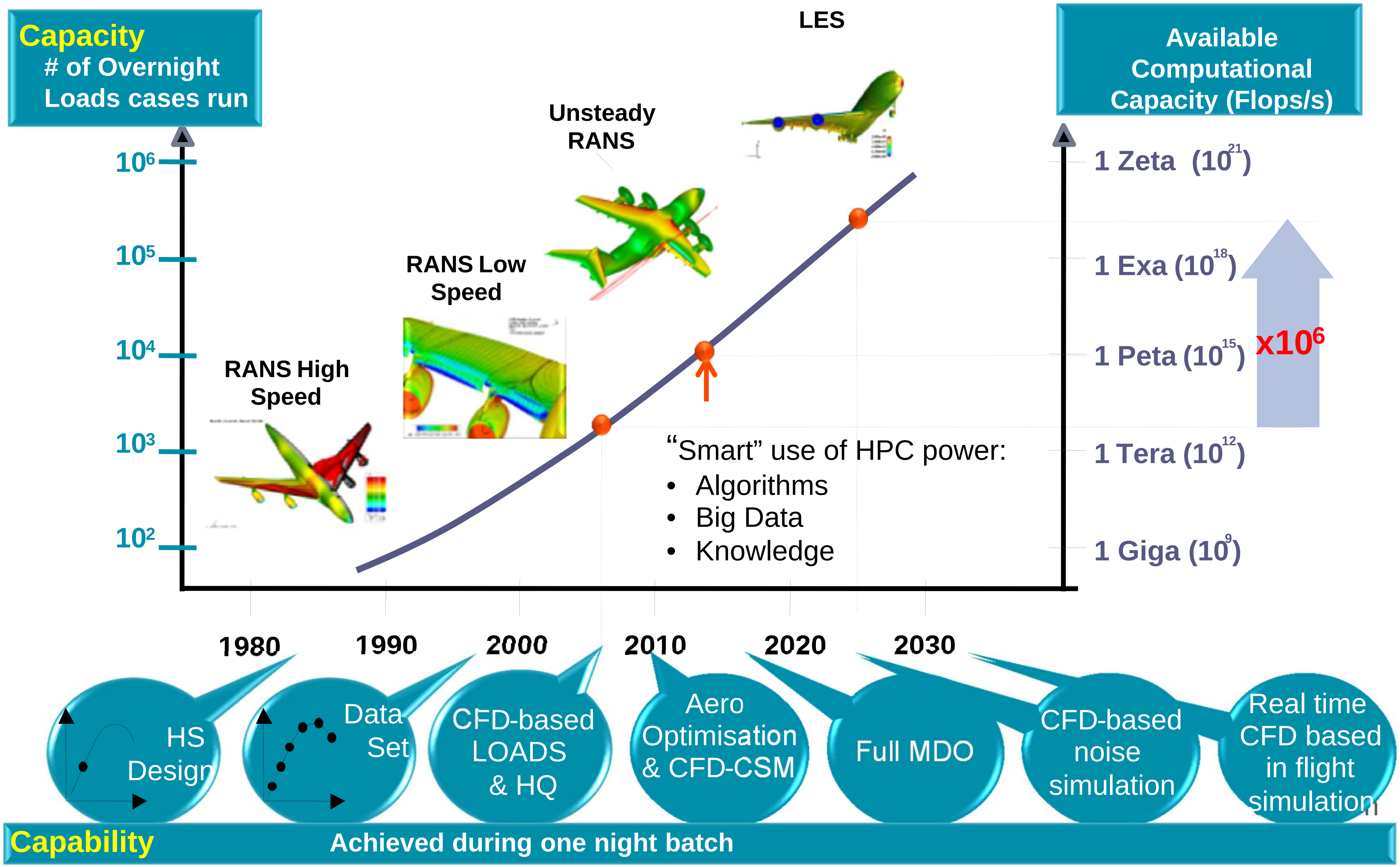






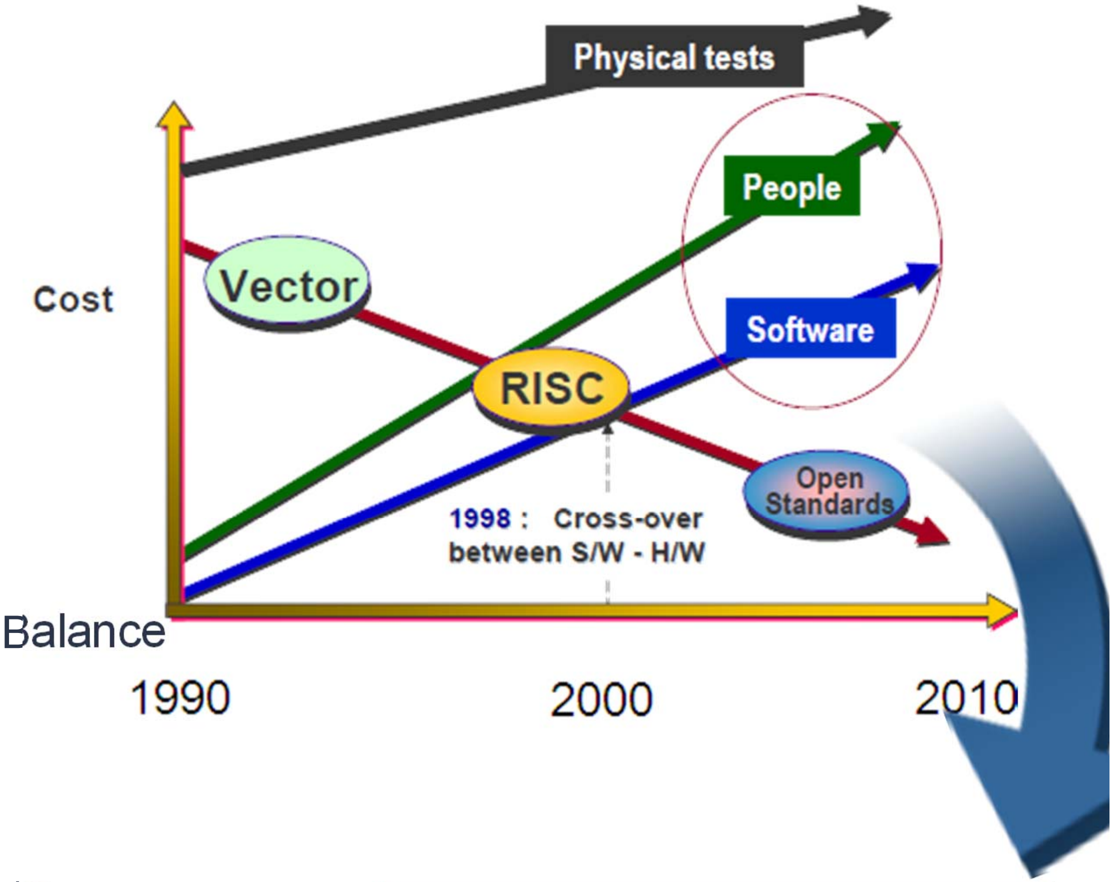
Nose Landing Gear wake interacting with Main Landing Gear & cavities

Petaflops to Exaflops Challenges



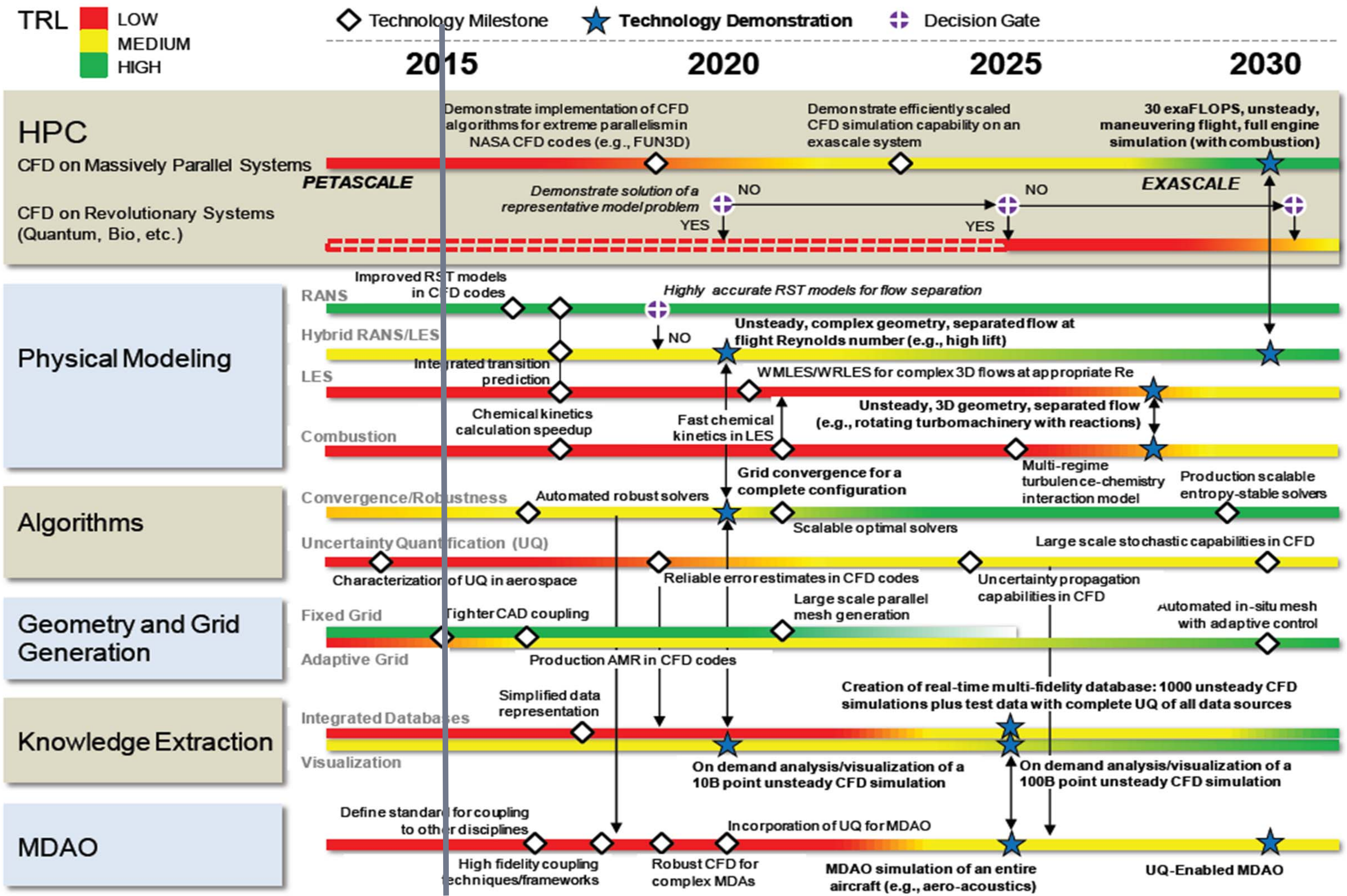
Exaflops Challenges

- Hardware challenges:
  - Billion of components
  - Energy consumption
  - Size of system memory
  - System resilience
  - Energy Efficiency
  - System resilience
- Software Co-design challenges:
  - Extreme Parallelism
  - Compute, I/O & Storage Performance Balance
  - Simple rule of thumb design
  - Middleware aware of failure resilience
- Optimize trade-off among
  - Supporting new workloads, e.g. Big Data
  - New HPC Delivery models, e.g. Cloud
  - applied mathematics, algorithms, computing challenges
- Educational challenge



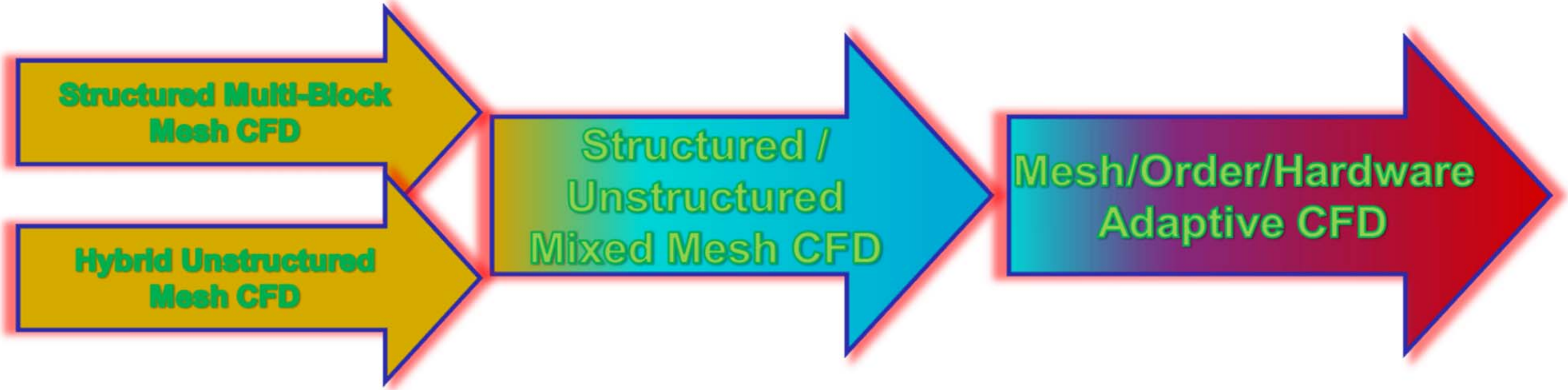
- 2018-2020 - CFD New Generation

CFD Technology Roadmap : NASA Vision 2030 CFD Code



High Fidelity CFD Strategy

Converge the current solutions



Standard CFD

- **… - 2014**
  - State-of-the-art solvers, meshing & post-processing tools
  - Processing & handling for more complex configurations
  - Short term customer needs on operations, maintenance & support

Converged CFD

- **2013 - 2019**
  - Fully complex configurations
  - Locally best fitting meshing approaches
  - State-of-the-art turbulence & transition models
  - Unsteady & coupled CFD solutions
  - Mesh adapted solutions
  - Widely automatic CFD processing
  - Robust & efficient computations

HyperFlex CFD

- **2018 - …**
  - Locally best fitting physical models
  - Higher order discretisations & mesh
  - Mesh/order adapted solutions
  - Fully modular software architecture
  - Flexible adaptation to latest hardware technology
  - Overall CFD capability system

Evolution of CFD towards Exascale

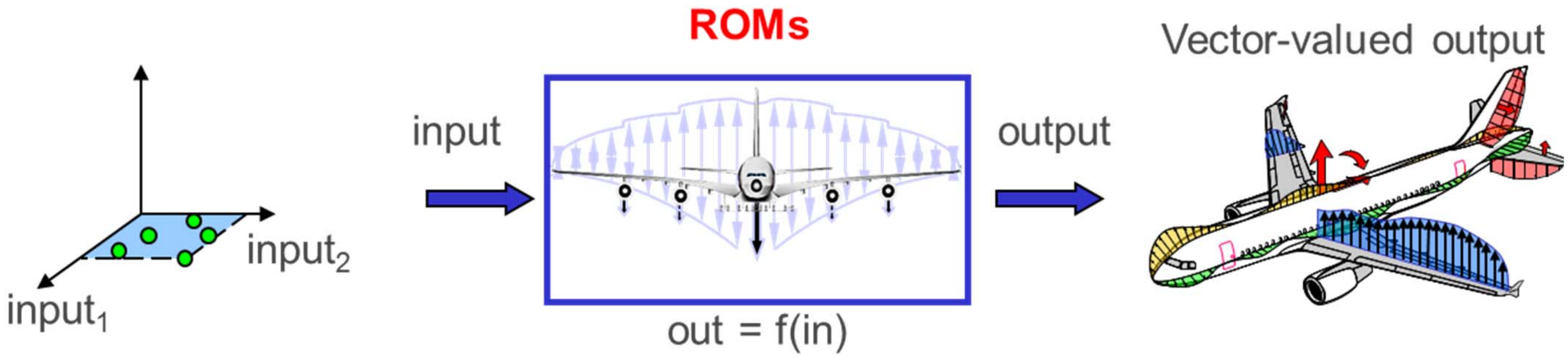
- Multi-Disciplinary / Multiphysics: Parametric Shape, Adjoint-based Optimisation → Coupling Validation & Verification → MDA/MDO
- Knowledge & Visualization: *POD RACER* *GappyPOD* → *Unsteady Data extract.*
- Process Automation: *CFD Manager, FlowSimulator* → *Rapid CFD for MDO*
- Mesh Generation & Adaptation: *MB, Hybrid* → *Chimera, AMR* → *Automatic Hyperflex, Uncertainty*
- Solver Algorithms: *RANS 2nd Order* → *// effectiveness* → *Uncertainty* → *High-Order (DG, SDM, IGA), LBM ; massively //*
- Physical Modelling: *RANS* (*SA, SST* → *RSM*) → *Unsteady RANS-LES, LBM* → *LES*
- Hardware: *TeraFlop/s 2004* → *PetaFlop/s 2014* → *ExaFlop/s 2024*

// – parallel computing
AMR – Automatic Mesh Refinement
CFD – Computational Fluid Dynamics
DG – Discontinuous Galerkin method
IGA – Iso-Geometric Analysis
LBM – Lattice Boltzmann Method
LES – Large-Eddy Simulation
MB – Multi-Block
MDA/MDO – Multi-Disciplinary Analysis / Optimisation
POD – Proper Orthogonal Decomposition
RANS –Reynolds Averaged Navier-Stokes
RSM – Reynolds Stress turbulence Model
SA – Spalart-Almarass turbulence model
SDM – Spectral Difference Method
SST – Shear Stress Transport turbulence model

Challenge #1 – Visualization/Identification of aircraft shape in flight

- Design of Experiment of CFD-CSM computations
- POD of surface pressure
- Visualization of sensitivity to flight conditions

CFD – Computational Fluid Dynamics
CSM – Computational Structural Mechanics
DOE – Design of Experiments
POD – Proper Orthogonal Decomposition



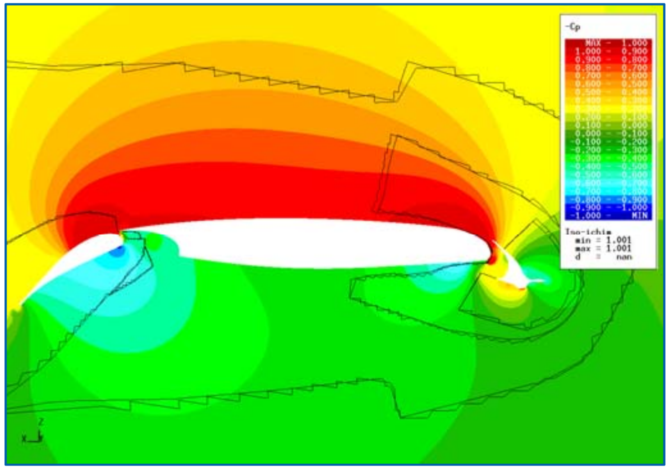
Design of Experiments

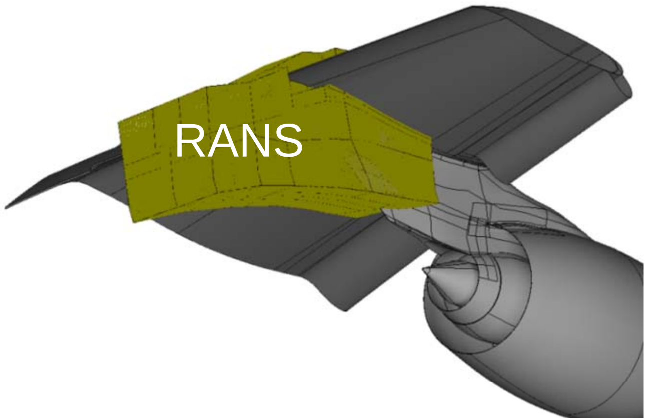
Proper Orthogonal Decomposition

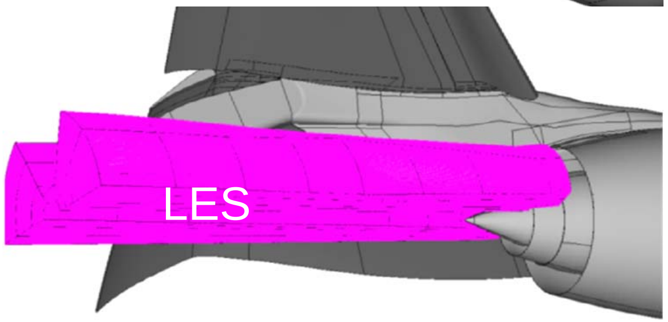
Non-Linear Interpolation

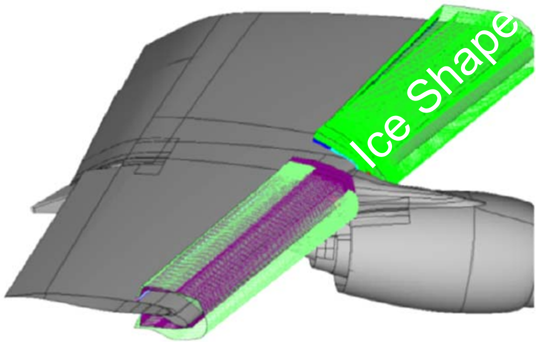
Challenge #2 – From Automated Chimera to Immersed CAD LES

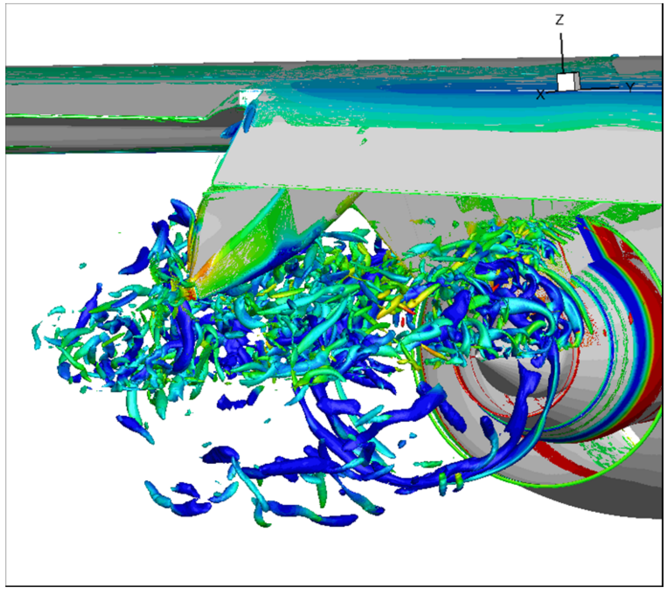
- Derivative A/C design
  - Minimum change in geometry vs legacy
  - Capturing the flow physics (jet, ice shape…)
- New A/C design
  - Immersed boundary in LES





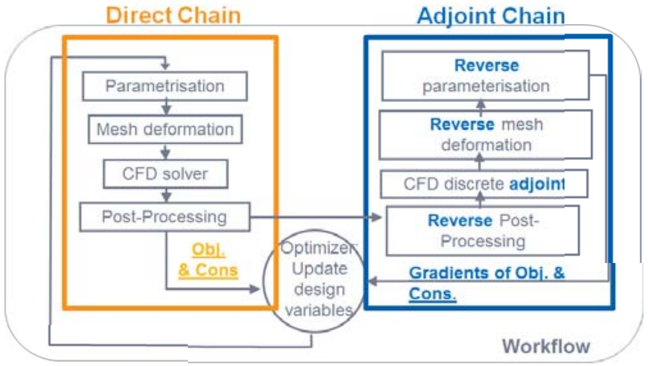


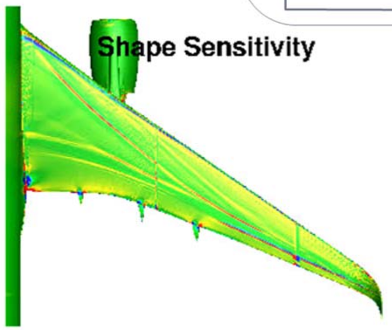


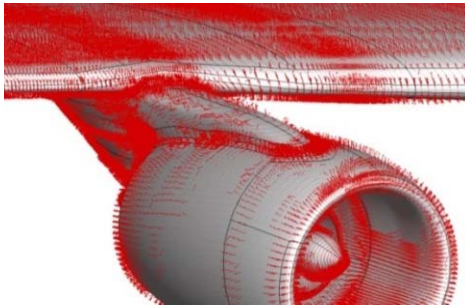


Challenge #3 – Multidisciplinary Design Optimization

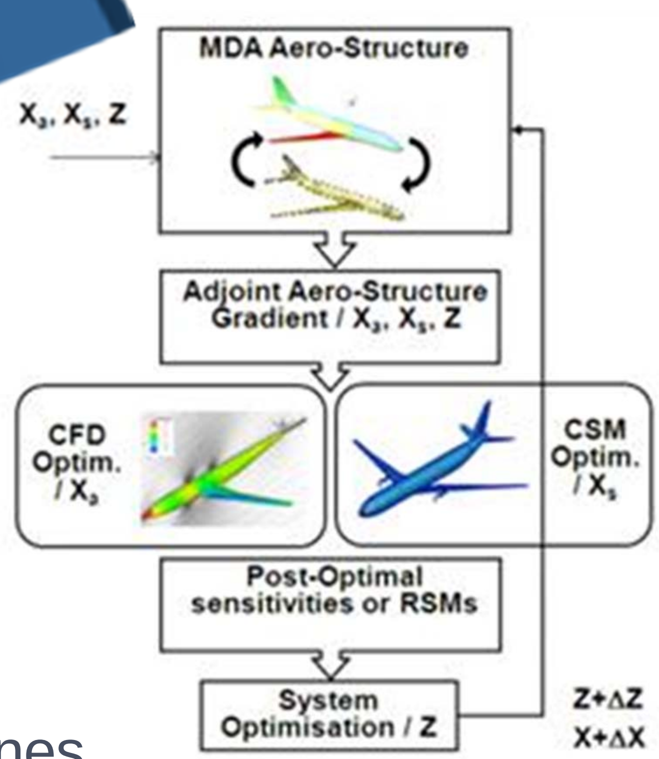
Adjoint-based Aero Optimization







MDO

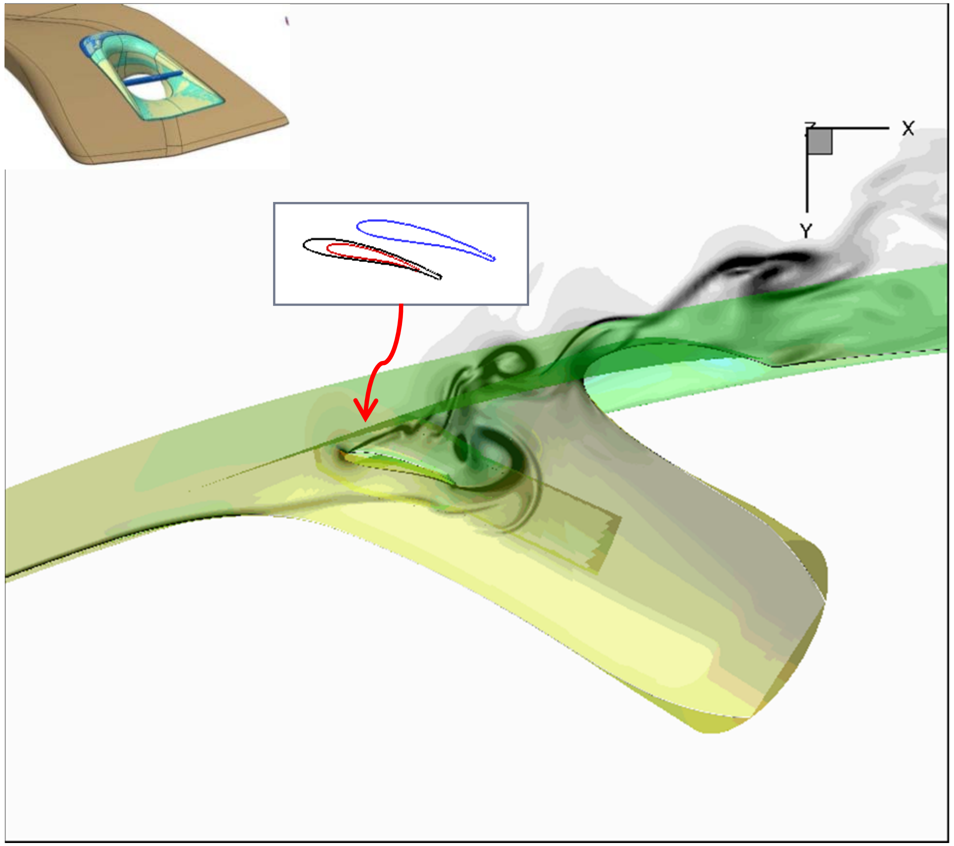


Awareness of design change effect on other disciplines

- Adjoint-based flexible shape Optimization
- Sensitivity of Aero design on Structure Reserve Factor

Challenge #4 – Flow control to reduce noise and vibration

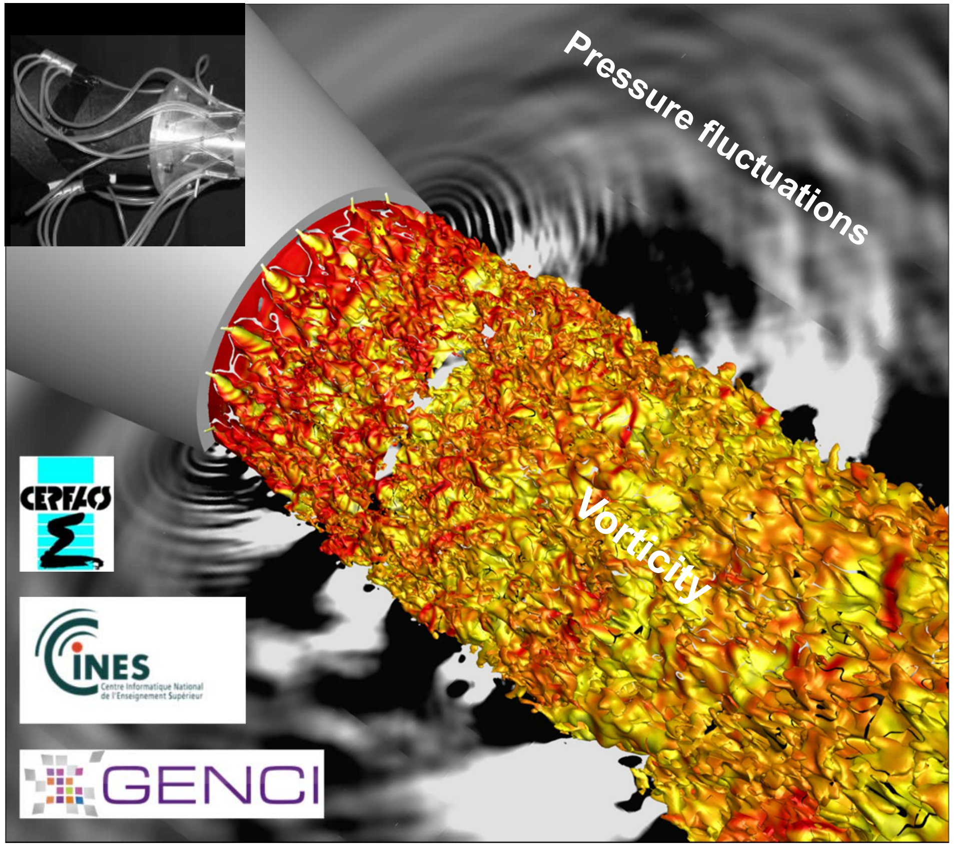
Constrained design



RANS/LES - 7x10[7] cells - HPC 100 CPUcores – 15days

RANS –Reynolds Averaged Navier-Stokes

Direct Noise Computation



LES - 2x10[9] cells - HPC 8000 CPUcores – 20days

LES – Large-Eddy Simulation

Conclusion

- Exascale computing is seen as a key enabling technology for future aircraft design to be developed and optimised in a fully multi-disciplinary way, making a wide use of design systems that provide integrated analysis and optimisation capabilities which allow for a real-time/interactive way of working.
- The move from RANS to unsteady Navier-Stokes simulation, (ranging from current RANS-LES to full LES) and/or Lattice Boltzmann method will significantly improve predictions of complex flow phenomena around full aircraft configurations with advanced physical modelling.
- For instance moving LES capability from Petascale to Exascale computing will accelerate the understanding of noise generation mechanisms and will enable the elaboration of flow control strategy for noise reduction.
- Multi-disciplinary analysis and design, and real time simulation of aircraft manoeuver, supported by affordable CFD-based aerodynamic and aero elastic data prediction will be a significant change of paradigm in aeronautics industry.