High Performance Computing Serves Aerospace Engineering: Opportunities for Next Generation Product Development

Cord-Christian Rossow, Norbert Kroll

DLR, Institute of Aerodynamics and Flow Technology,

Center for Computer Applications in Aerospace Science and Engineering

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DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Outline

- Motivation
- Challenges + Perspective
- Development Targets
- Approach
- Conclusions

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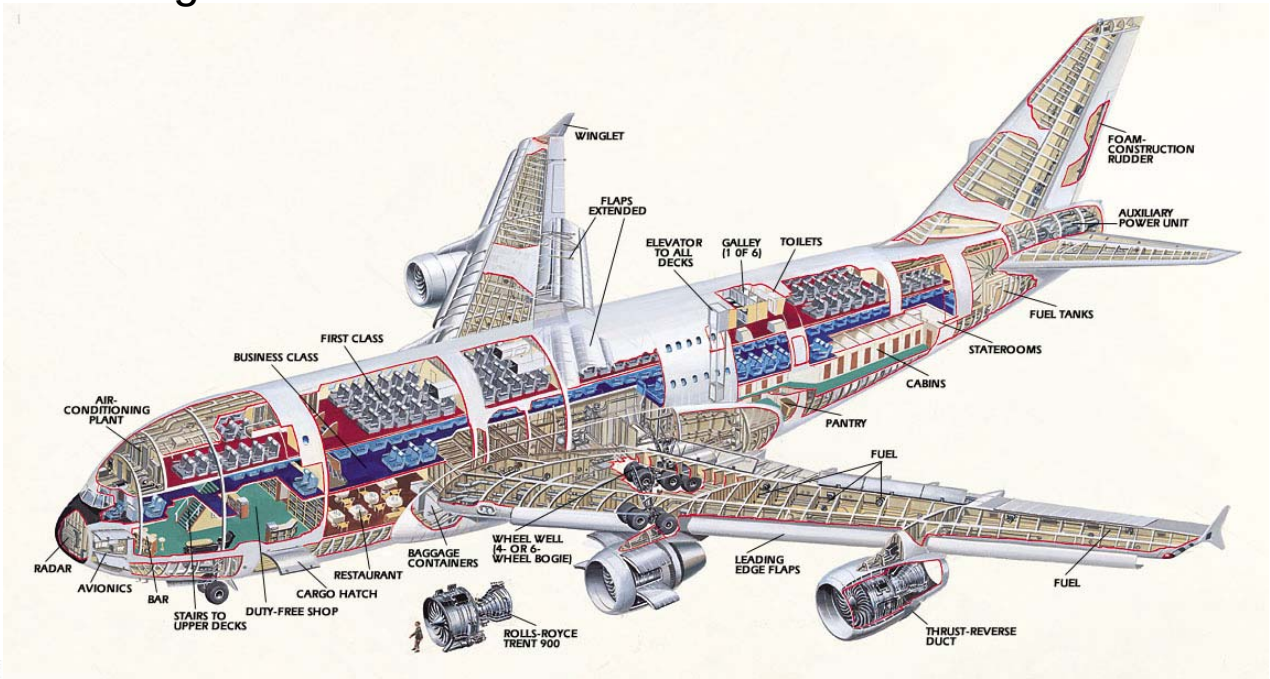
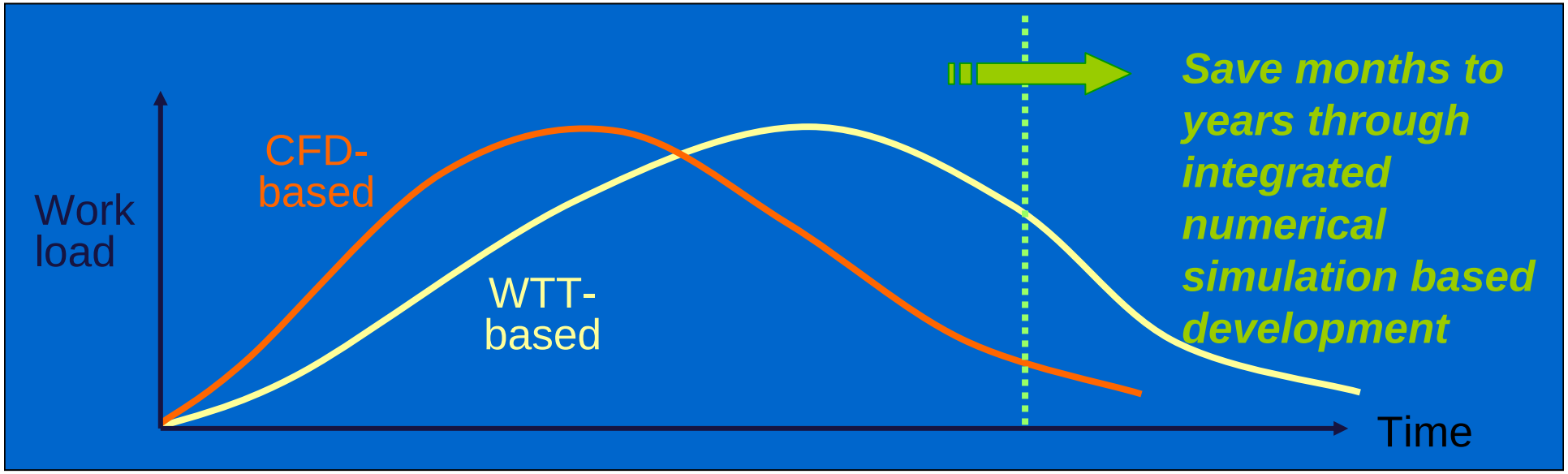
Design Challenges

- Typical challenges for real world engineering design:
  - Large numbers of variables
  - Evaluations, which are expensive
  - Aspects which are difficult to quantify
  - Constraints that are many, complex and interdependent
  - Robust design solutions



Aerodynamic Design: Use of Computational Fluid Dynamics



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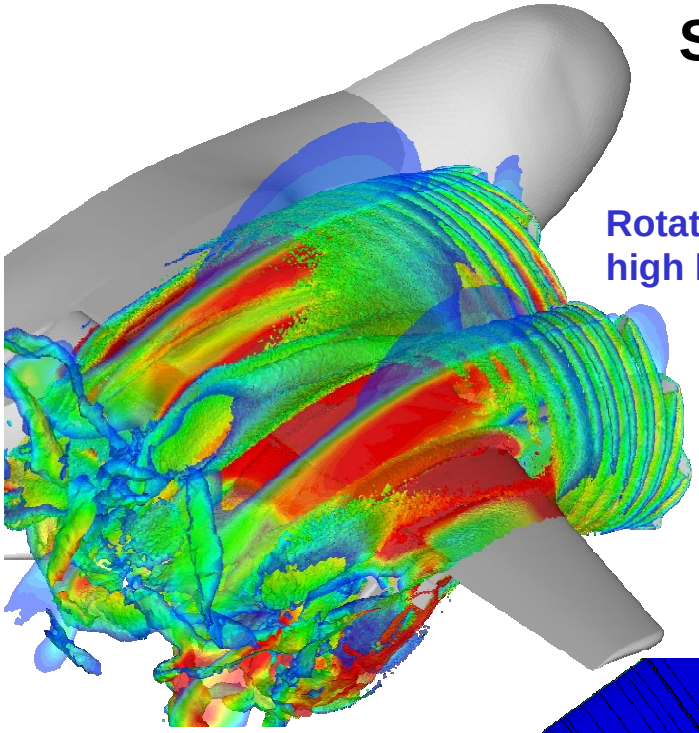
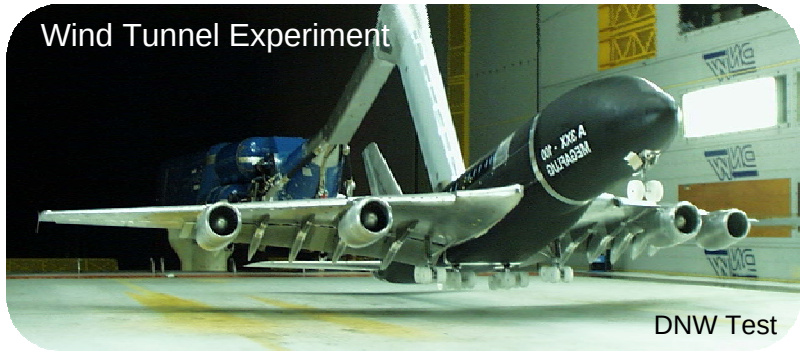
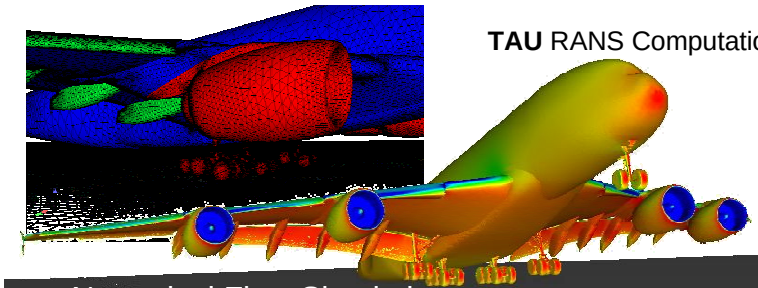
Some Applications of Advanced CFD

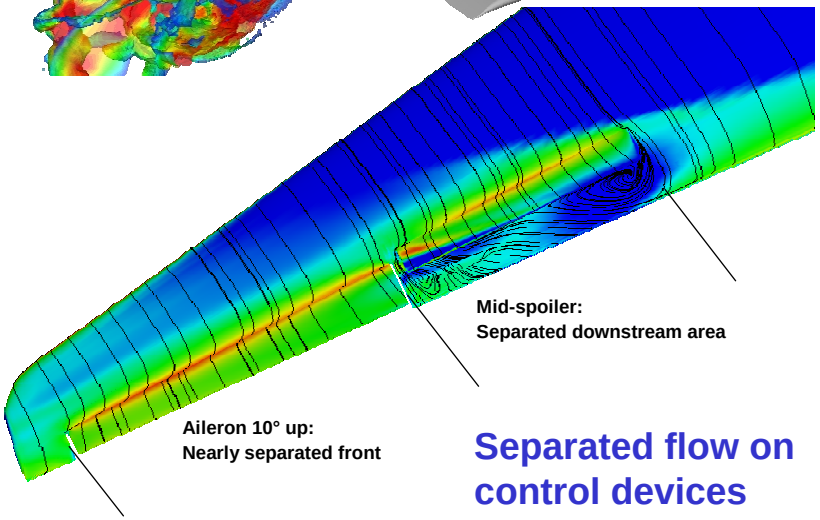


Rotating propellers on high lift configuration





Numerical Flow Simulation



Separated flow on control devices

Ground Effect Investigation

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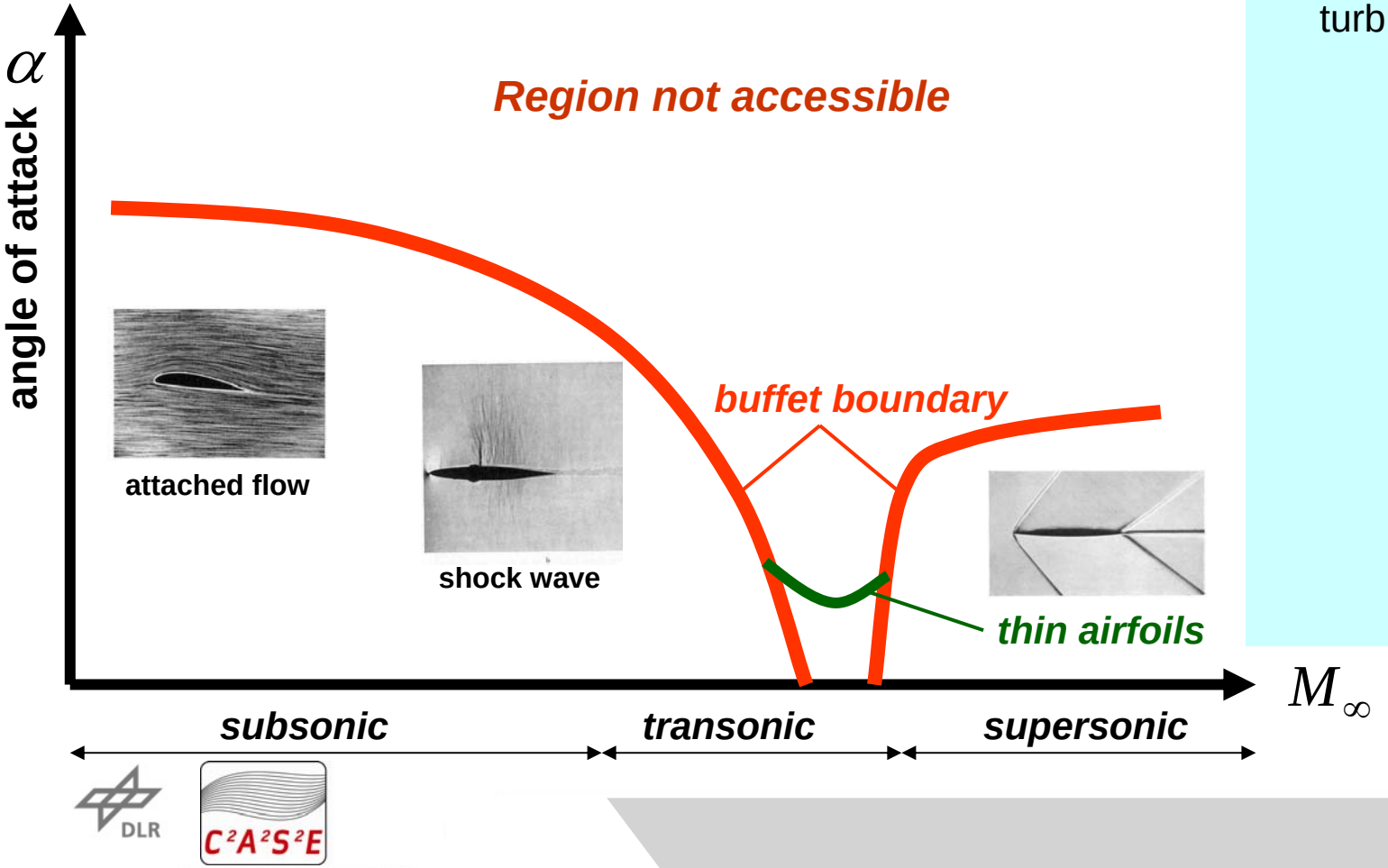
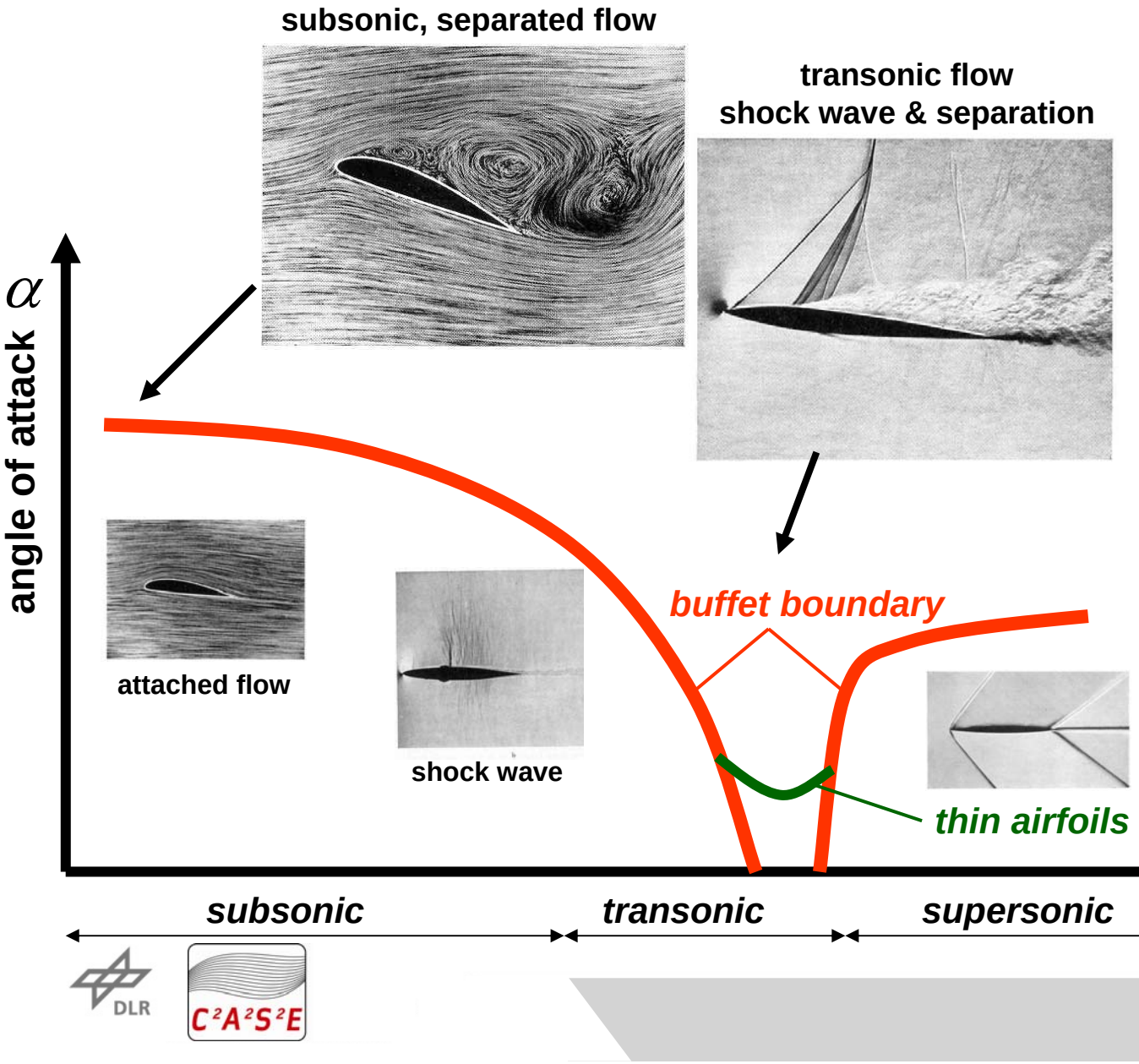
Challenge: Border of Flight Envelope

Attached flow

- steady flow
- classical eddy viscosity turbulence models



Challenge: Border of Flight Envelope



Separated flow

- unsteady flow
- RANS / URANS may be not sufficient

LES

- more turbulence scales resolved
- not possible for high Re flow due to enormous computational effort

Hybrid RANS/LES

- suitable for high Re flow
- limited in application

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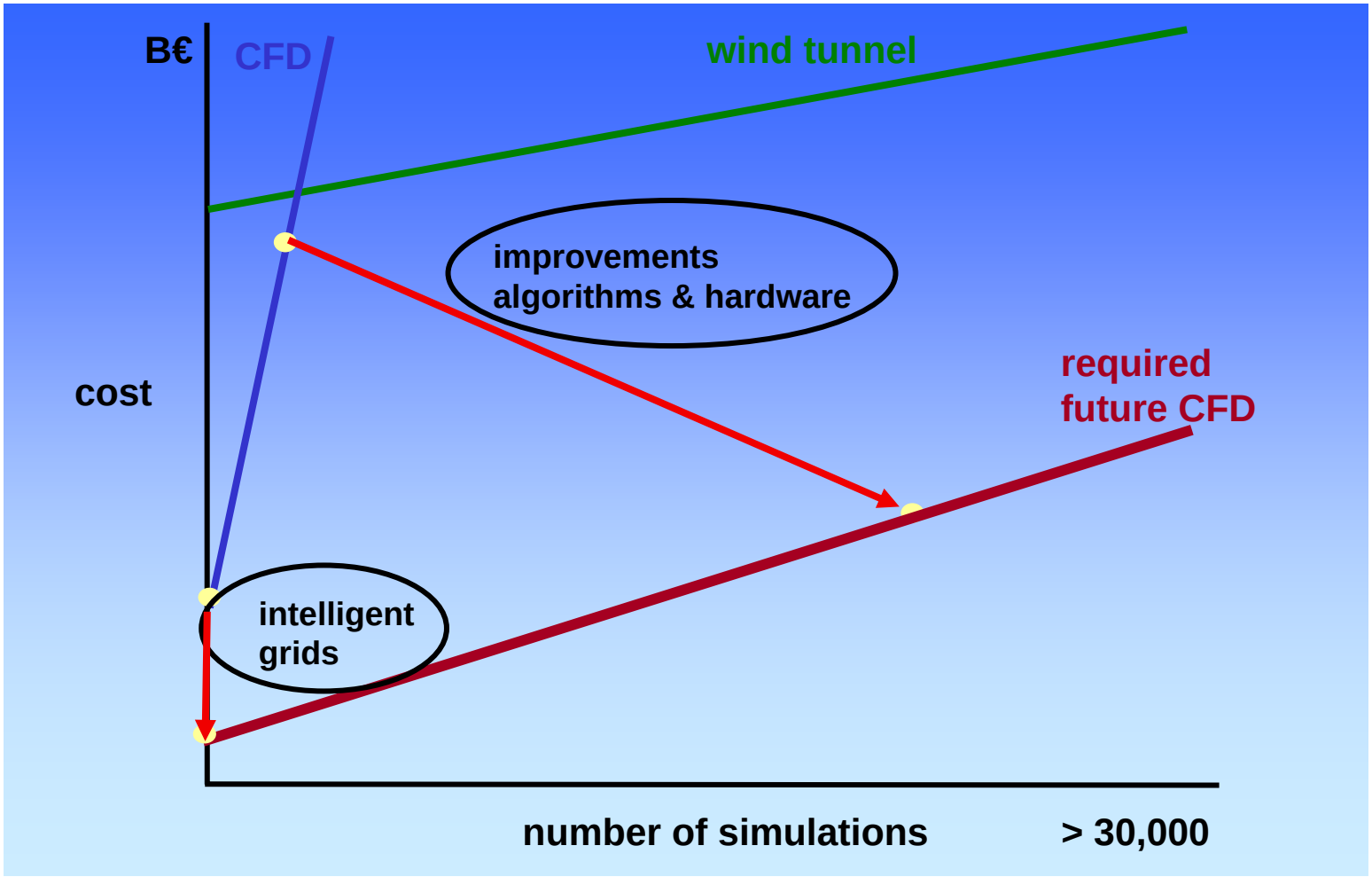
Challenge: Cost of Repetitive Computations



CFD still has large potential for further improvements
Rigorous exploitation to drastically reduce base as well as cost of repetitive simulations

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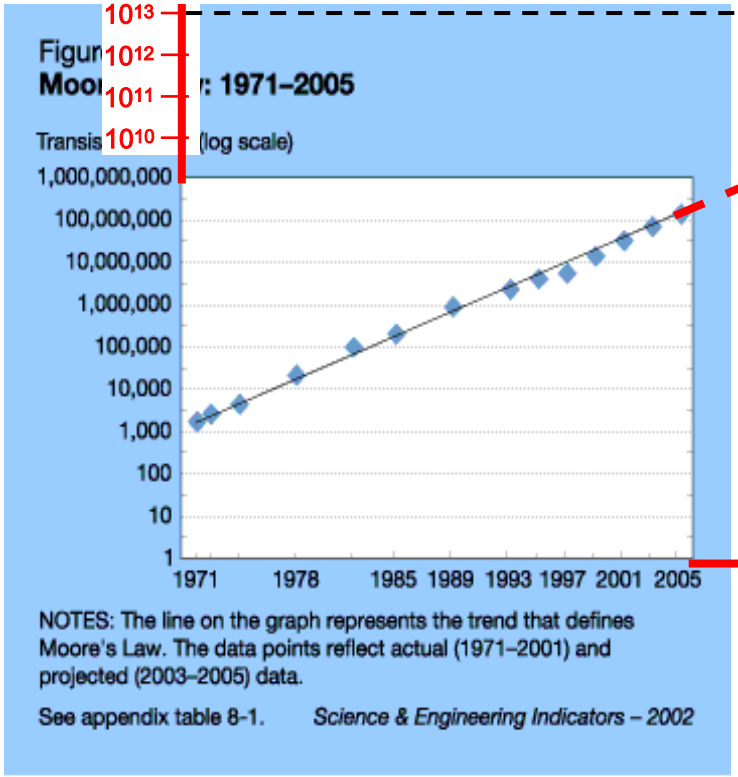
Based on Rubberts, 1994

Perspective: Advances in Computer Hardware

Moore‘s Law



10^{13}
10^{12}
10^{11}
10^{10}

2035

Development of simulation time

Year	Factor	Time (t=0)
t=0	1	8 h
10	32	11 days
15	150	50 days
20	1,000	11 month
30	33,000	30 years

Increase in computer power
by factor of 2 every 2 years

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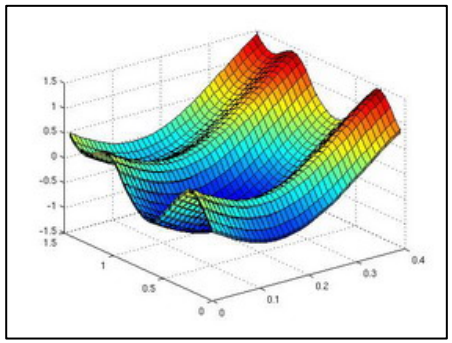
Target: Full Flight Simulation - Digital Flight

High-fidelity simulation of maneuvering A/C in the computer

- Governing flow equations
- 6-DOF flight mechanics equations
- Aeroelastic phenomena
- Propulsion system
- Flight control system



Possible approaches

- Generation of static & dynamic aerodynamic data-base using high-fidelity simulations

  "Flying through the database"

- Time dependent multidisciplinary maneuvering aircraft simulations

  "Flying by the equations"

see also [M.D. Salas, 2006], [M. Mavripilis, 2007]

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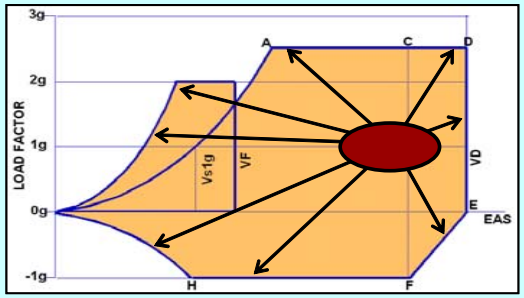
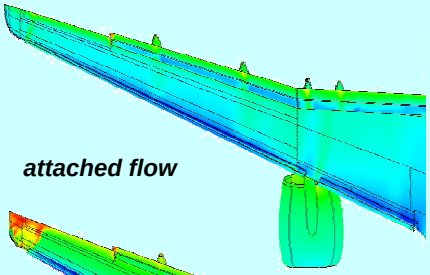
"Flying through the database"

Aero Data Production

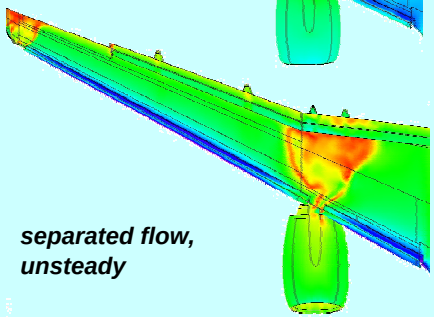
Full design envelope coverage:

CFD mostly done near cruise point





attached flow



separated flow, unsteady

configurations:

clean

airbrakes deployed

high lift

50 flight points
100 mass cases
10 a/c configurations
5 maneuvers
20 gusts (gradient lengths)
4 control laws

~ 20,000,000 simulations

Engineering experience for **current** configurations and technologies

~ 100,000 simulations

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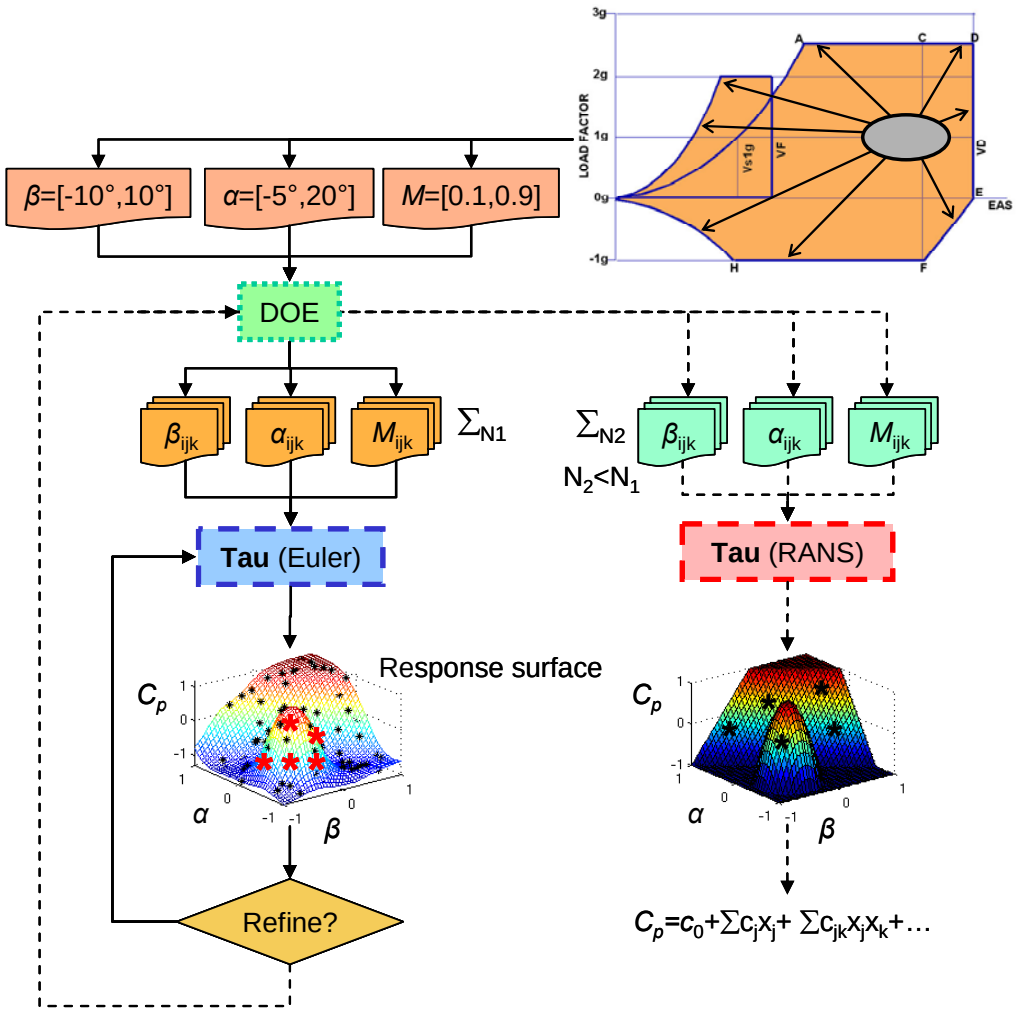
Variable-Fidelity Methods

- Select points in parameter space using Design of Experiments (DOE) techniques
- Automatically compute O(100) or O(1000) solutions at these points using low-fidelity methods
- Fill-in remainder of parameter space using interpolation, response surfaces, neural networks, SID, ….
- Compute a few points selected with DOE using high-fidelity CFD
- Use Bridging functions to correct low fidelity model with high-fidelity results

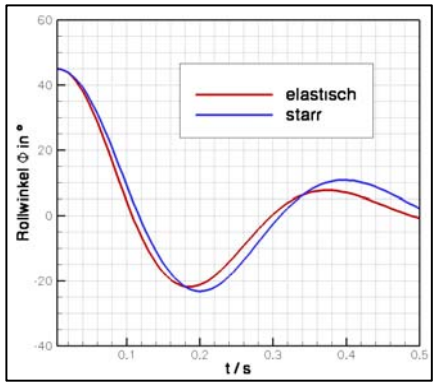


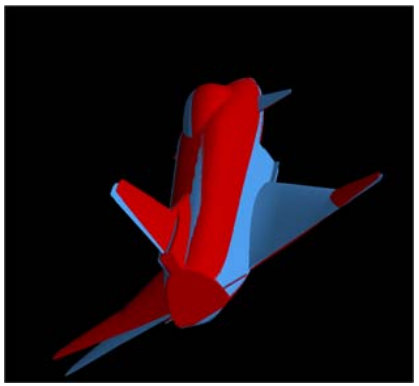
“Flying by the equations”

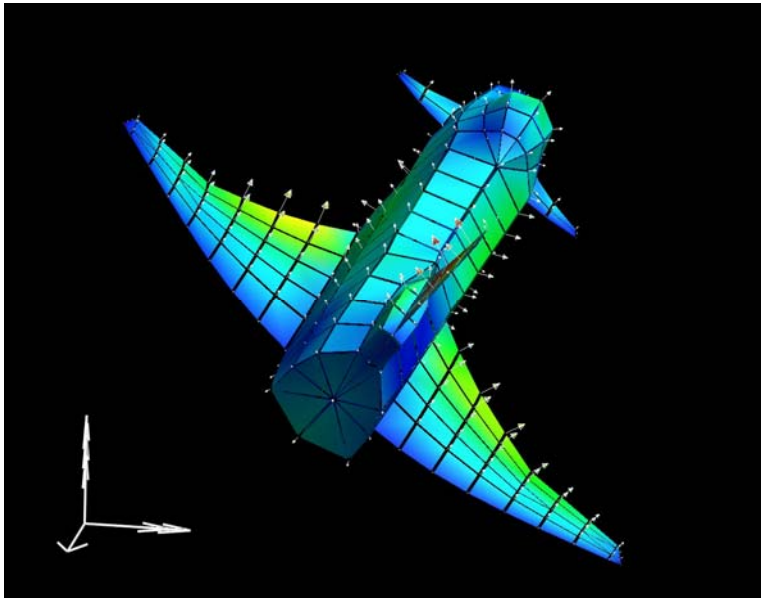
Multidisciplinary Maneuver Simulation

Challenges

- Multidisciplinary simulation
  - fluid dynamics
  - structural mechanics
  - flight mechanics
  - control laws
- Full aircraft with moving control surfaces
- Time accurate simulation
- Advanced physical modeling







Fluid:	Euler
Structure:	FE
FM:	1Dof

Free-to-roll simulation

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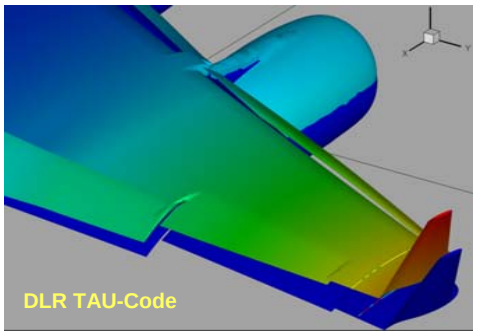
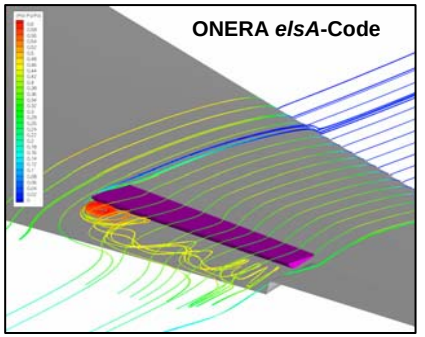
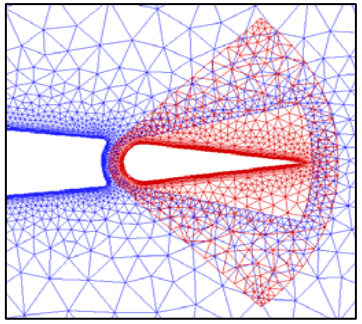
Multidisciplinary Maneuver Simulation

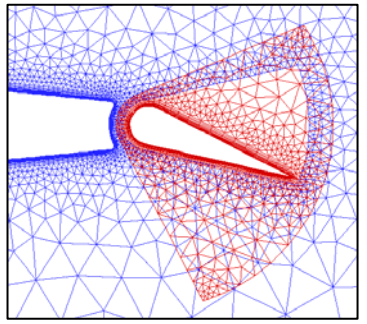


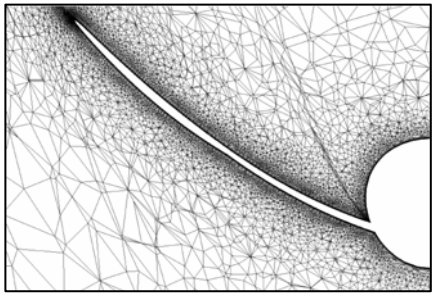


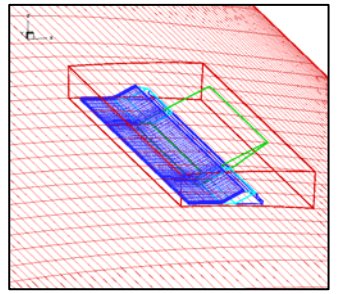
Developments required

- Efficient flow solver (fast, accurate, robust)
- Interpolation tools for aero-loads and geometry deformations for complex geometries
- Trimming procedures
- Automatic overset methods for movable control surfaces
- Robust grid deformation tools for complex geometries
- Mixed low/high-fidelity methods & reduced order modeling for efficient aeroelastic simulations
- Flexible coupling environment









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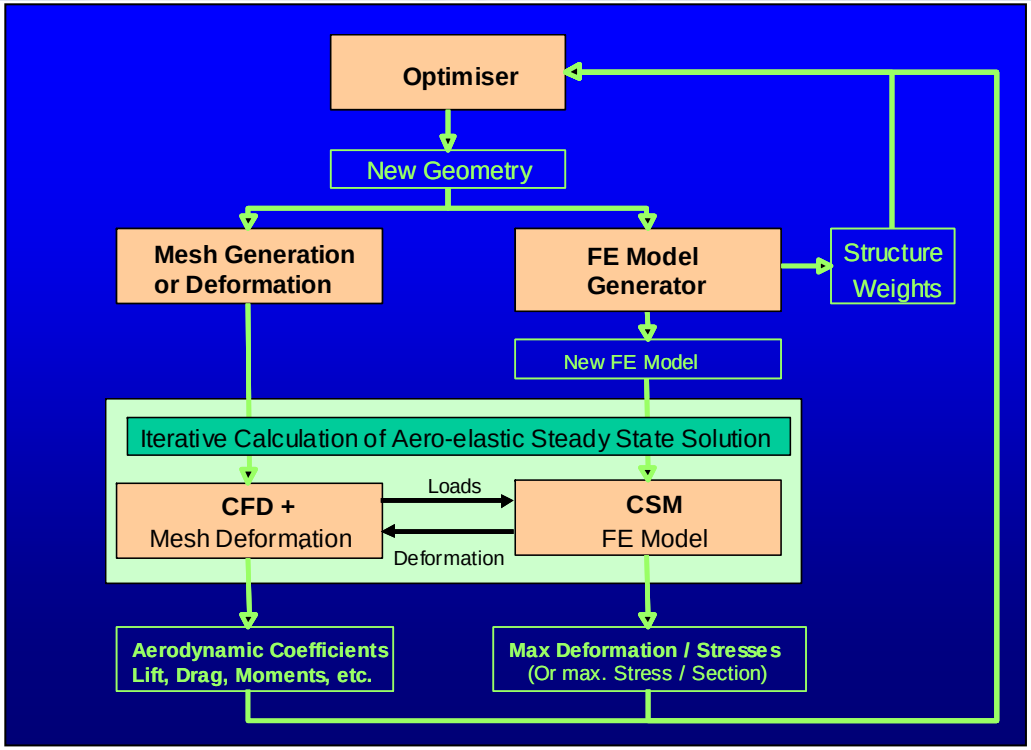
Target:

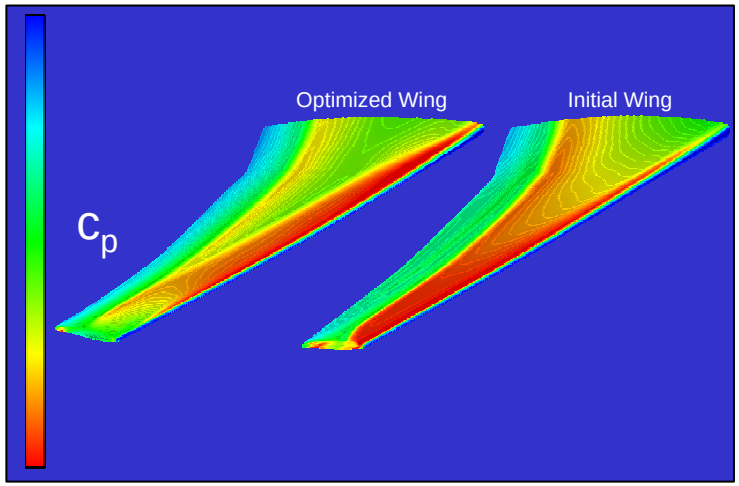
Multi-Disciplinary Optimization

- **Cost function composition from relevant disciplines**
- **Parametric model set-up with parameters from different disciplines**

- **First step**
  (no routine application yet):

  Full CFD/CSM optimisation
  - Parametric geometry/shape generation
  - Mesh generation / deformation
  - Parametric FE model generation
  - Aerodynamic coefficients
  - Structural loads and stresses
  - Aerodynamic wing deformation





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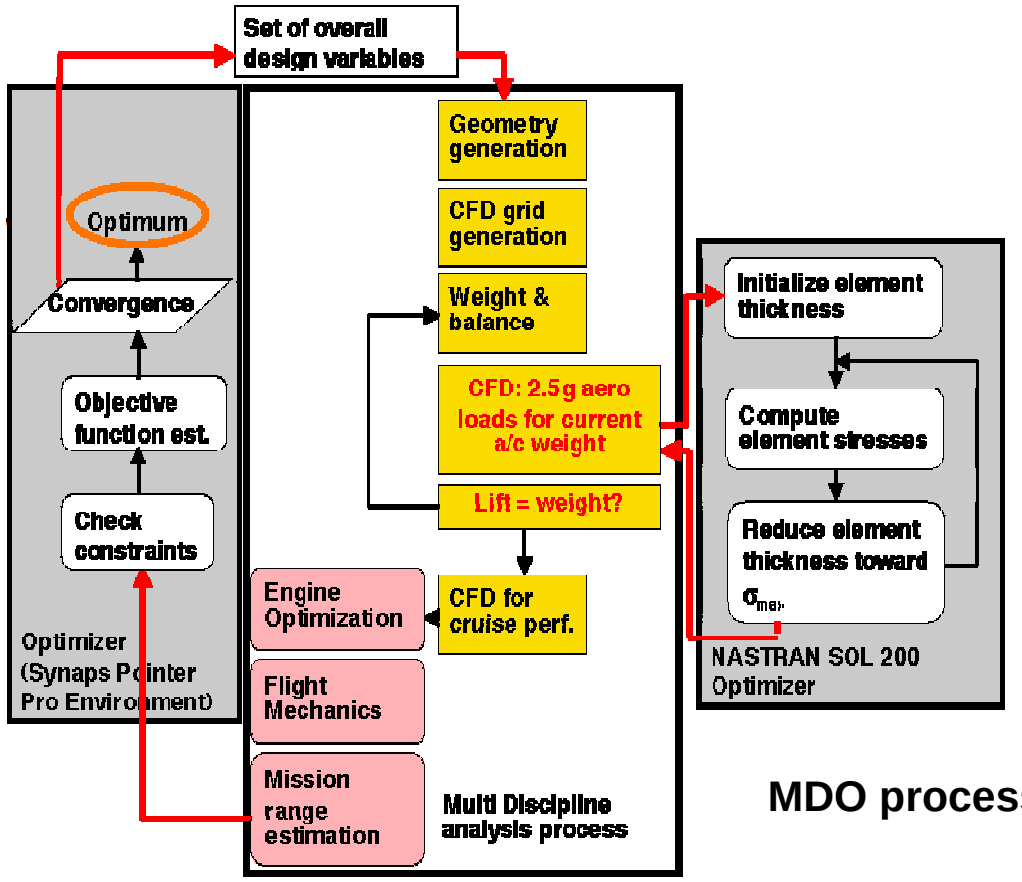
Target:

Multi-Disciplinary Optimization

- **Integration of mission requirements**
- **Hierarchical modeling**

- **Synthesis of conceptual and preliminary design**
  - Risk reduction in A/C development by incorporation of repercussions from late design changes:

    closure of the design loop



MDO process

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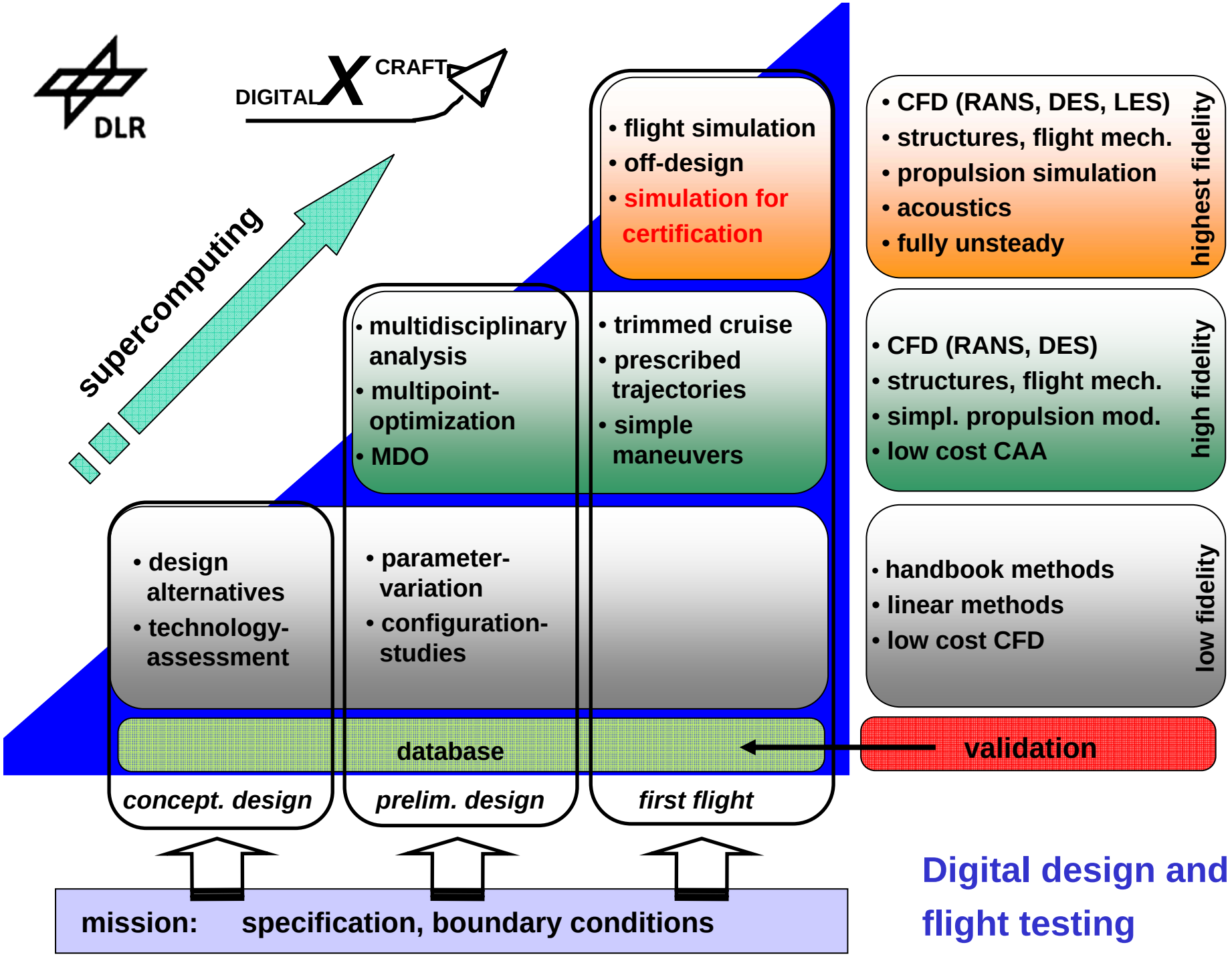

Digital design and flight testing

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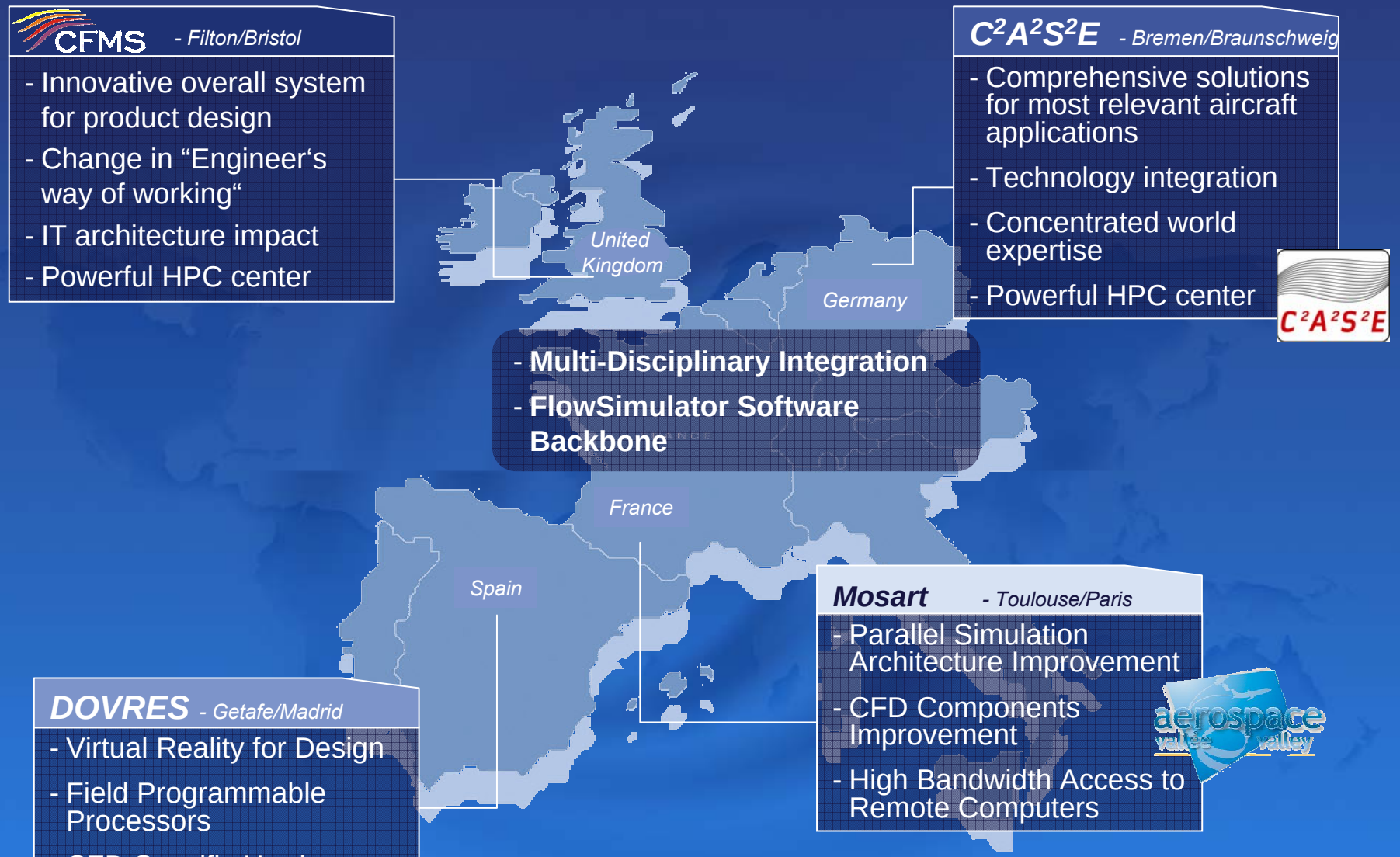
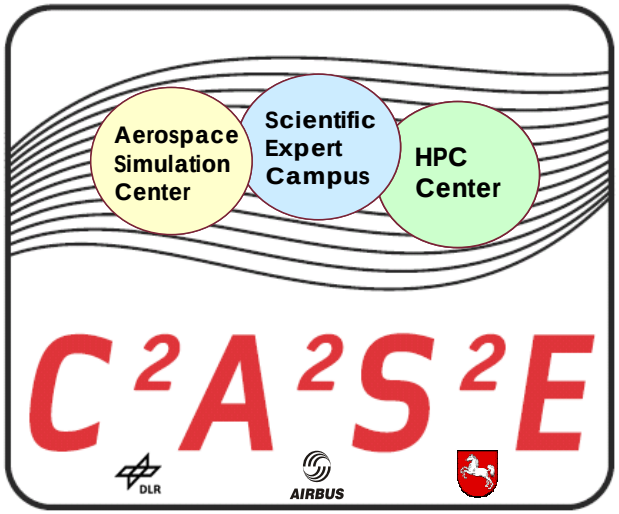
FuSim – Complementary Actions for the Whole



Source: J. Klenner, Future Simulation Concept; CEAS-Conference 2007

$C^2A^2S^2E$ – the German Initiative

Center for Computer Applications in AeroSpace Science and Engineering



Objective

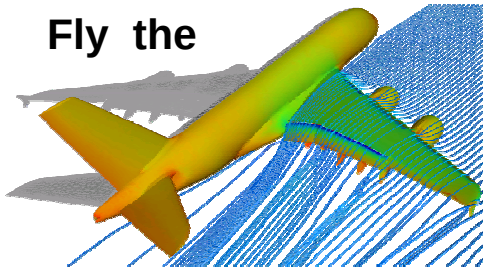
To provide a validated industrialized simulation capability for application challenges from aircraft development, based on latest technology

Current Partners

- **Airbus, DLR**
- **Envisaged to extend to larger contributing community**

Framework

- **3 pillars: Simulation, Expert & HPC centres**
- **Long-lasting research environment (15 years +)**
- **5-year Lower Saxony Government co-funding**
- **Centre is located at DLR / Braunschweig Research Airport**



$C^2A^2S^2E$ - Application Targets

Maneuver Simulation

- Fully integrated interaction of major relevant disciplines

Aero Data Production for the full aircraft

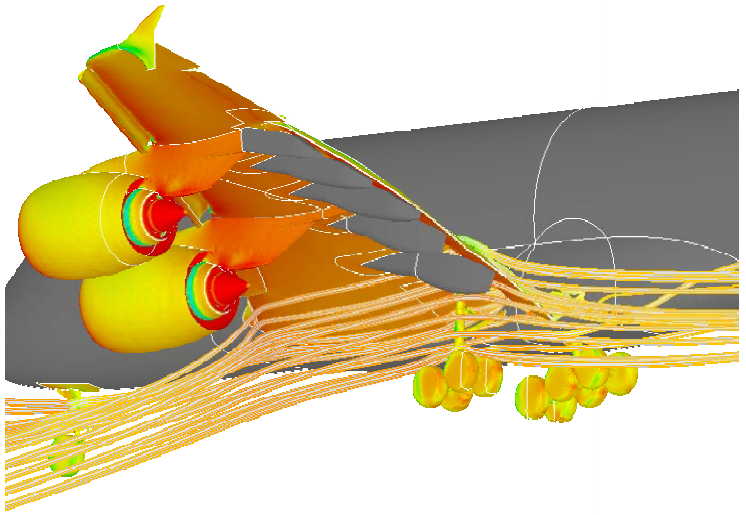
- Intelligent analysis of the flight envelope
- Full knowledge about aircraft behavior in flight

Multi-Disciplinary Optimization of complex A/C

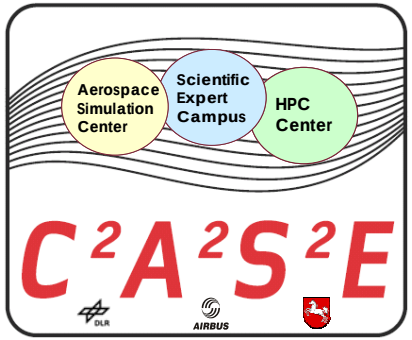
- With respect to loads, performance, HQ, noise …
- Design space elaboration, sensitivities

Establish Pre-Requisites for Virtual Certification

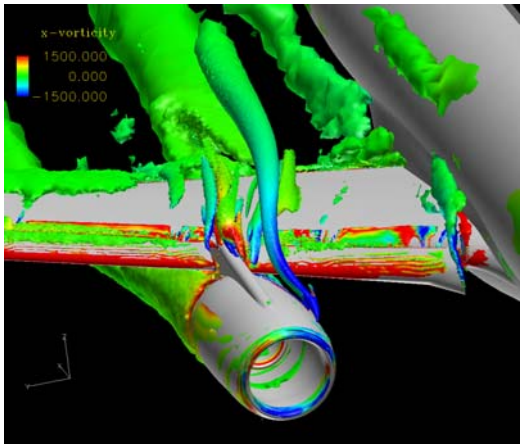
- Knowledge of product characteristics
- Reliable, quantified prediction accuracy

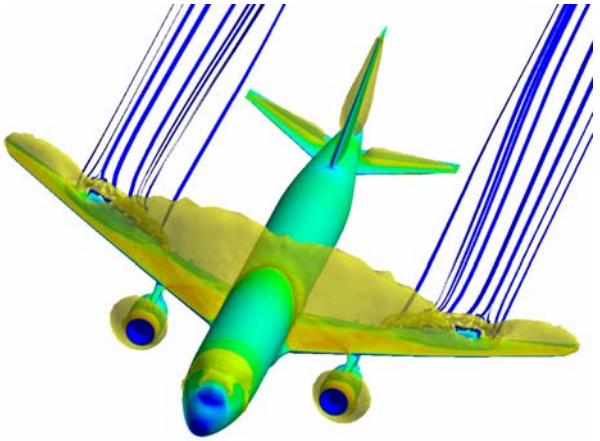


$C^2A^2S^2E$ – Associated Infrastructure



- **Simulation center offices ~**
  30 researchers & developers
- **HPC center (*6080 cores*)**
- **Expert campus ~ *10 guest researchers per year (3 months+)***
- ***Website: http://www.case.aero***
- ***e-mail: norbert.kroll@dlr.de; cord.rossow@dlr.de***





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Conclusions

- Numerical Simulation is key technology for aircraft improvement and reduction in development cost and time
- Digital Flight is one of the grand challenges for numerical simulation
  - “Flying through the database”
  - “Flying by the equations”
- The reliable, hierarchical MDO process for complete A/C is the other
- Significant investment required in
  - Computer hardware
  - All aspects of numerical simulation
  - Carefully designed validation experiments (WT + FT)
  - Education
- Establishment of Simulation Centers ($C^2A^2S^2E$) major step towards realization of ***The Digital X-Craft***

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$C^2A^2S^2E$

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  Norbert Kroll, DLR
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  Murray Cross, Airbus

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ICASE

Institute for Computer Applications in Science and Engineering

1972 - 2002