The Virtual Product

Next Generation Simulation for Future Aircraft Design

Cord Rossow, Norbert Kroll*
Institute of Aerodynamics and Flow Technology
***$C^2A^2S^2E$**
Center for Computer Applications in AeroSpace Science and Engineering

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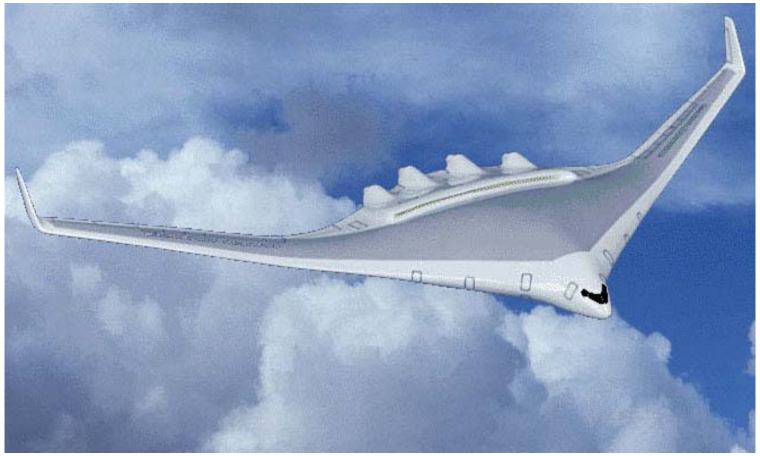
Outline

- Introduction
- Virtual Product
- Simulation Scenarios
  - Performance
  - Flight Envelope
  - Design
- DLR's Research Areas
- Concluding Remarks

Acknowledgement: Thanks to numerous DLR colleagues for providing material for this presentation

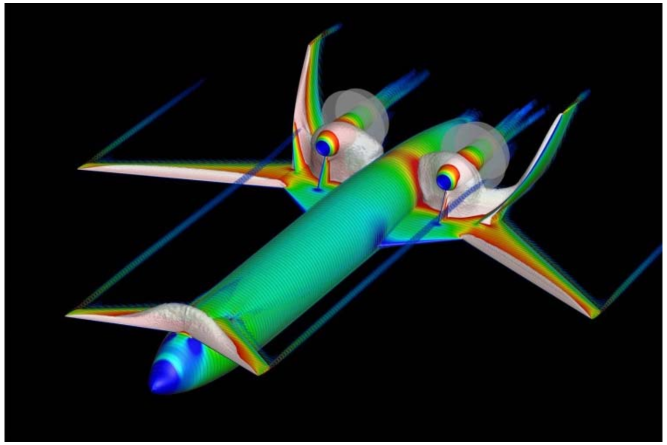
What is the Future ?



What is the Future ?

Today's products highly matured:
Are improvements possible at all?

- Numerical simulation may be the key enabler
- Multidisciplinary optimization will be mandatory
- Future Designs via concept of "Virtual Aircraft"



- Concept of **Virtual Product** extends simulation to complete a/c lifecycle

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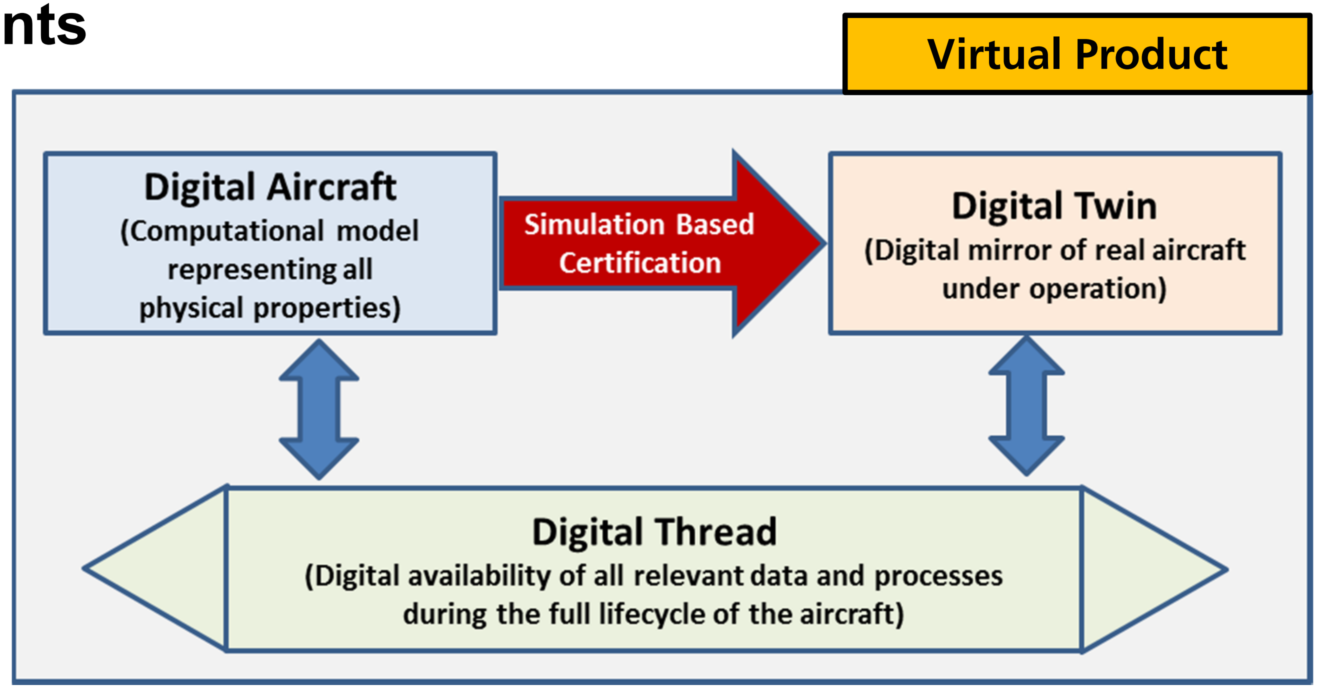
Virtual Product in Aeronautics
Components



Digital Aircraft: Encompasses design, testing, manufacturing & certification process

Digital Twin: Reflects the use of a particular series-production aircraft to predict the impact on its operational capability, maintenance & overhaul requirements

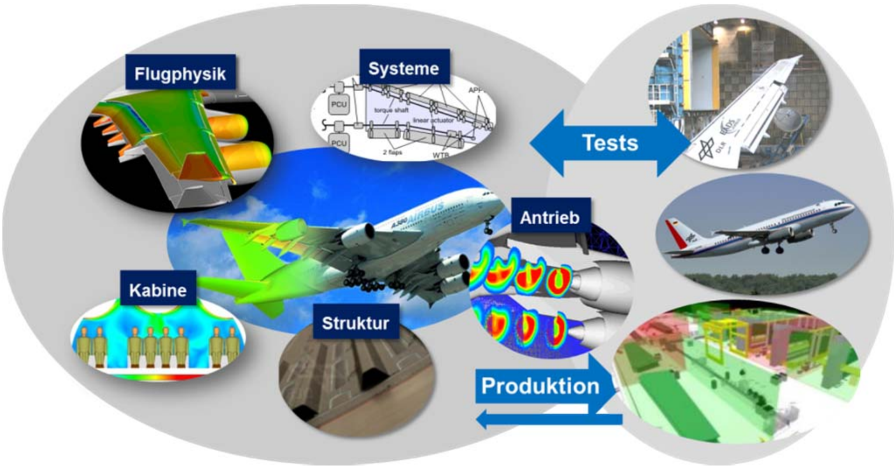
Digital Thread: Addresses complete data flow from early concept phase to final decommissioning, including feed back from the Digital Twin into upgrades of the current Digital Aircraft or improvements of future designs

The Virtual Product – DLR Guiding Concept in Aeronautics

Digital description of an aircraft with all its properties and components **based on highly accurate physical and mathematical models**

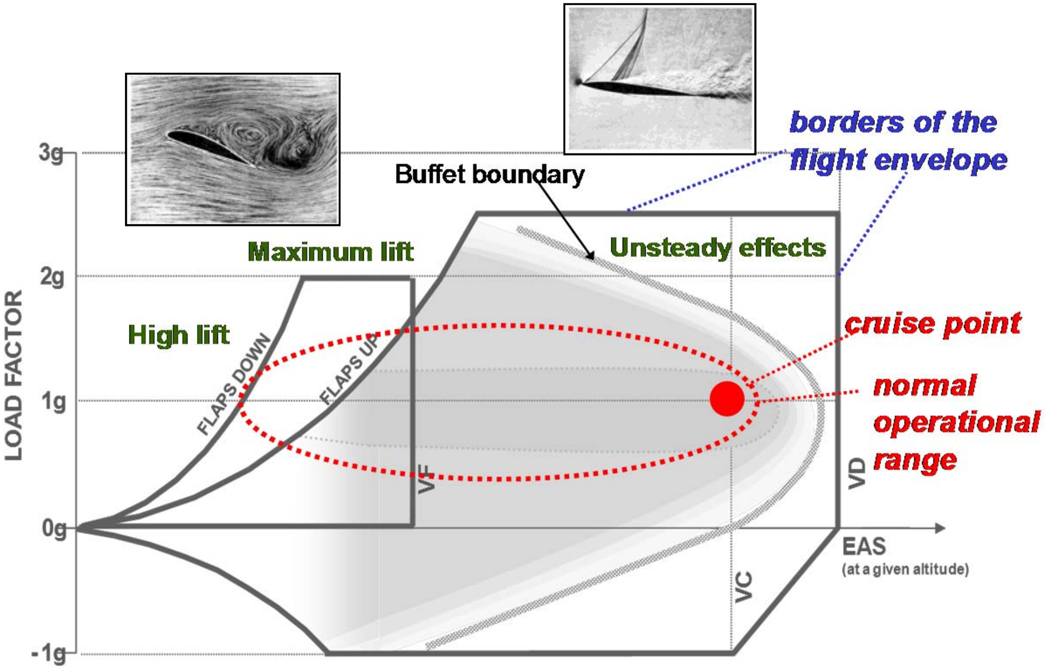
- Across all disciplines
- In every phase of the development phase
- Across entire aircraft lifecycle

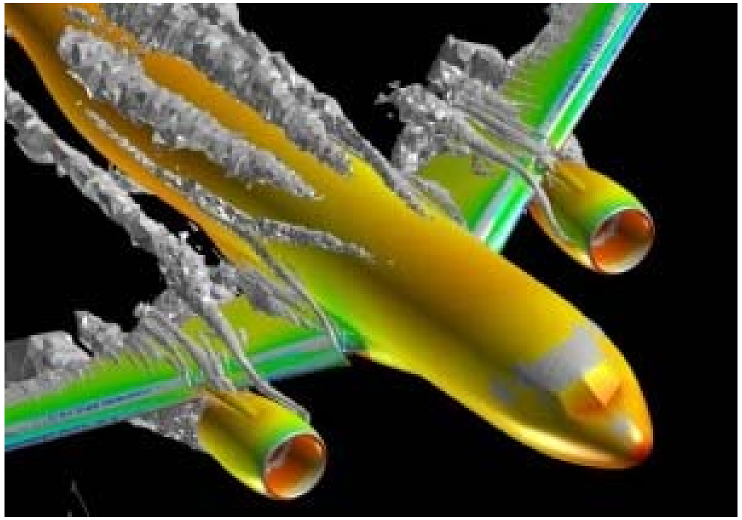
Concept allows DLR research to scientifically track all phases of aircraft development including aircraft design & testing, manufacturing, certification, operations & impact on environment



⟶ **Virtual Overall System Capability**

Which Simulations are Required?





Aerodynamic performance predictions

- Cruise (L/D), high lift (Cl_{max})
- Detailed data at special points of the envelope

Challenges

- Flow separation
- Laminar/turbulent transition
- Flexible aircraft

→ High-fidelity modelling

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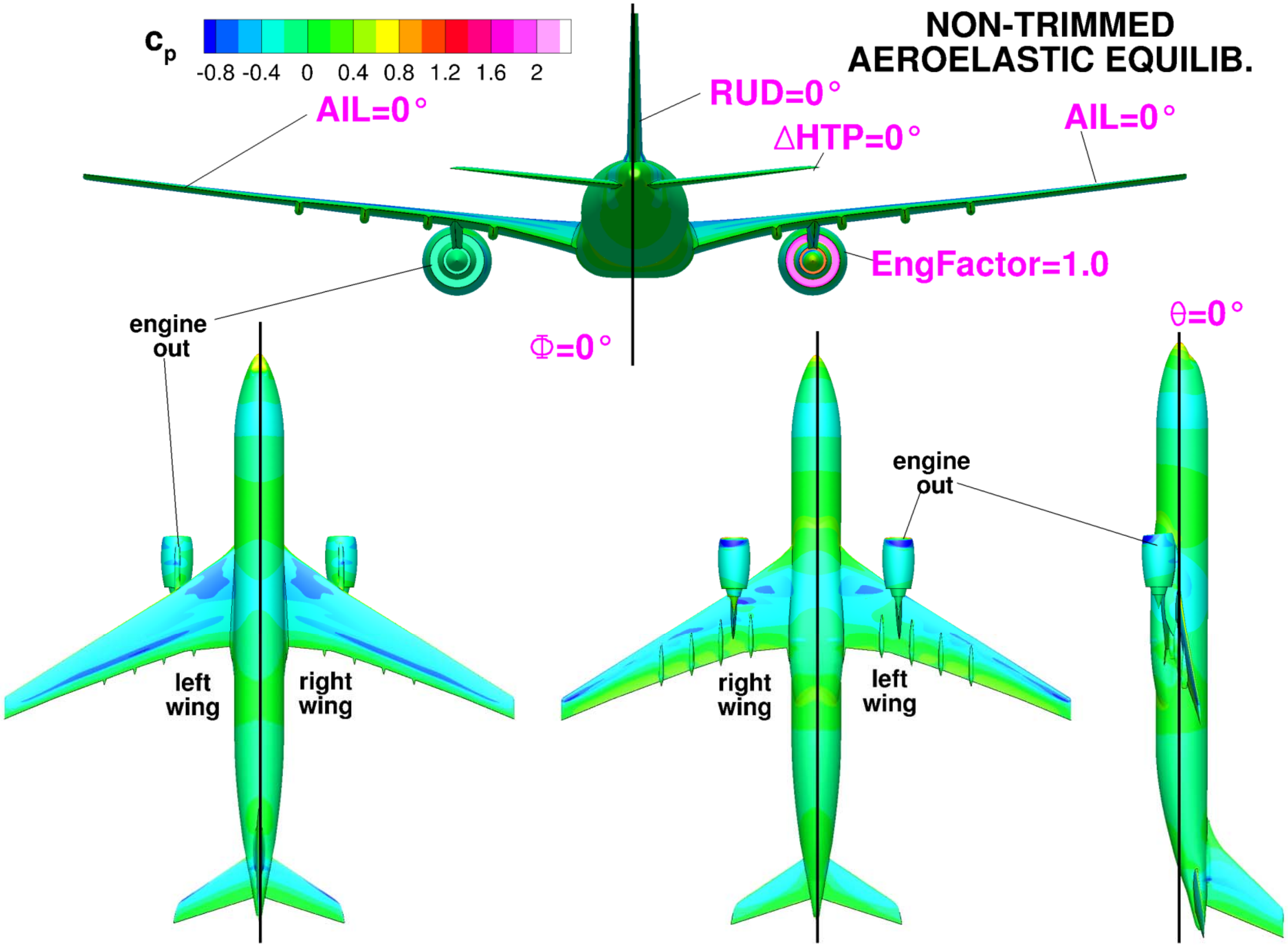
Multi-Disciplinary Aircraft Simulation

Trim of *elastic* transport aircraft, *"One-Engine-Out Case"*

- Horizontal *aeroelastic* trim of XRF1
- Ma = 0.85, Re = 60x10^6, m = 198t, h = 10.7km



Multi-Disciplinary Aircraft Simulation

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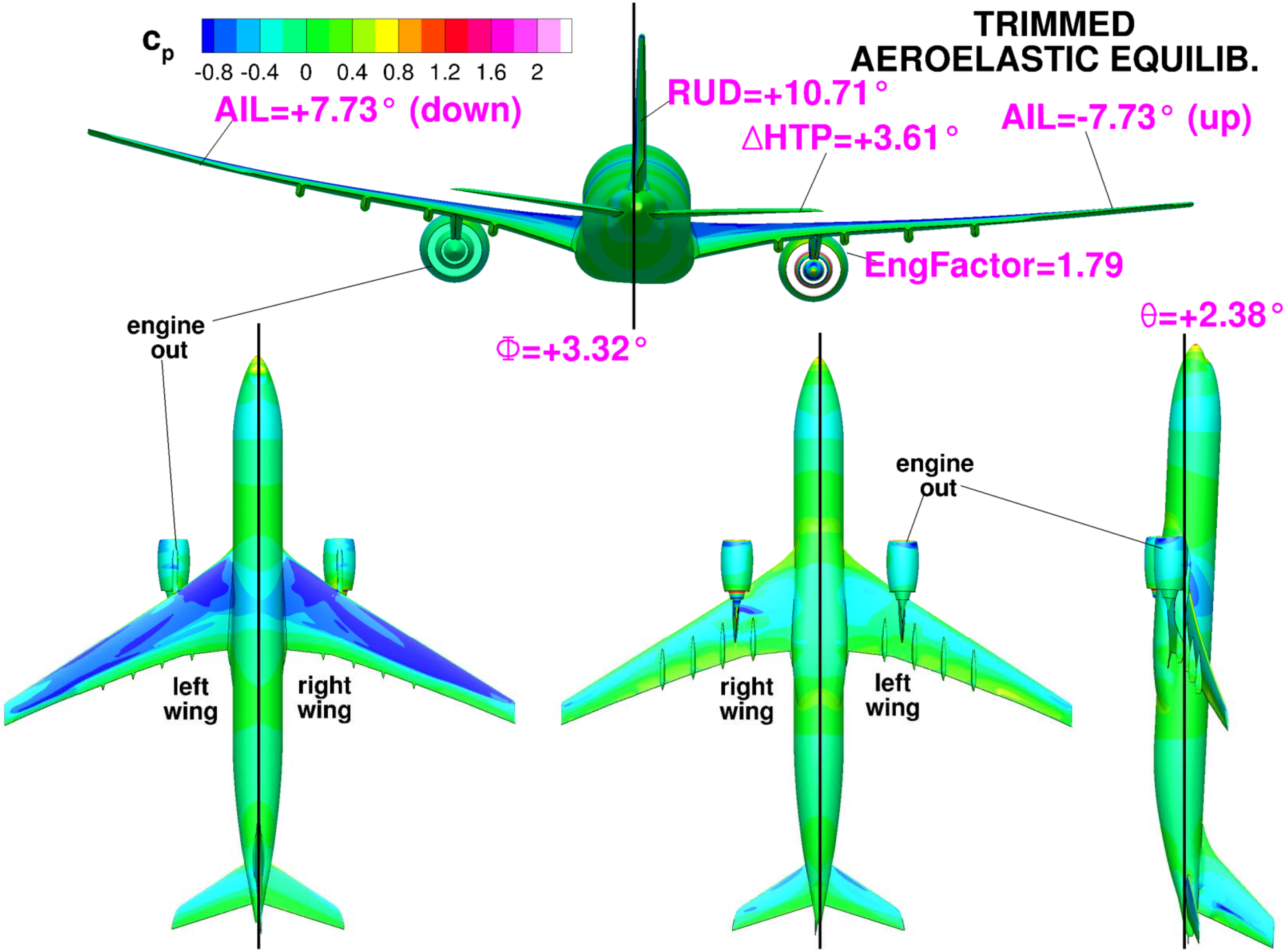

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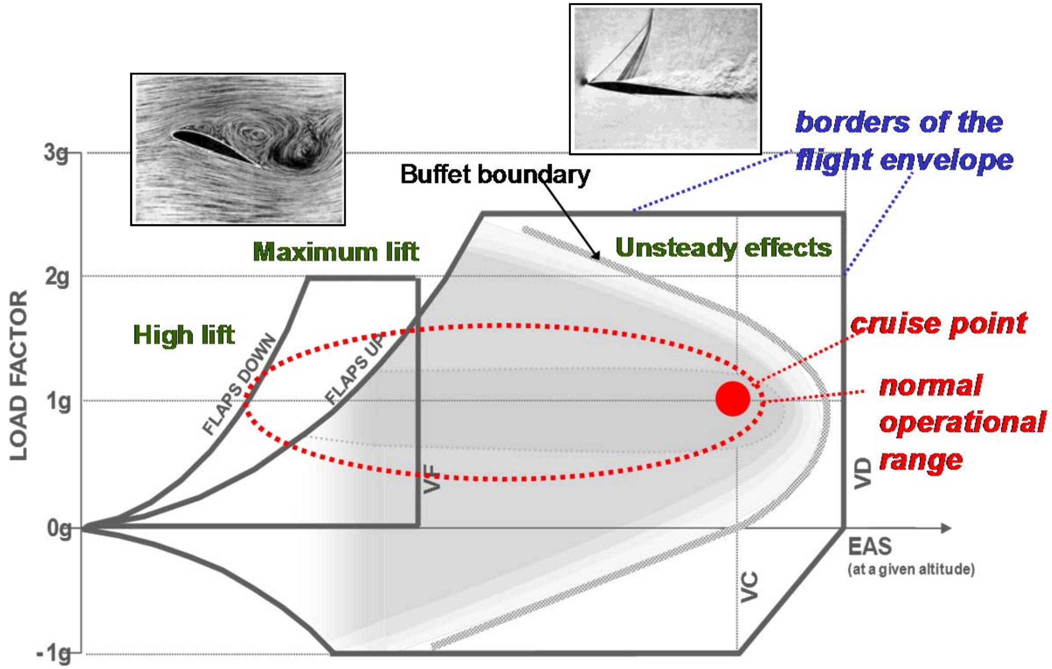
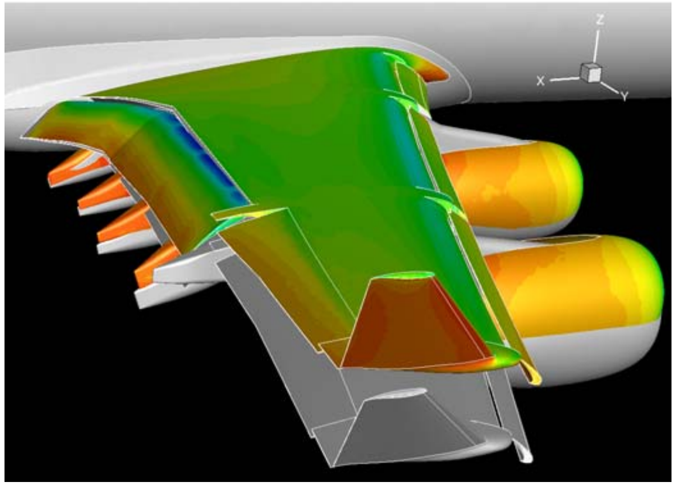




Aerodynamic performance predictions
- Cruise (L/D), high lift (Cl_{max})
- Detailed data at special points of the envelope

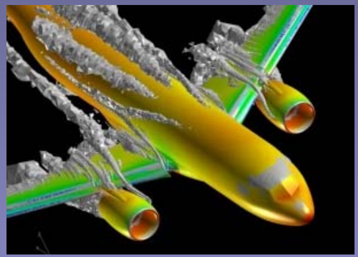
Aerodynamic loads predictions
- Critical forces and moments
- Data along the full border of the full envelope

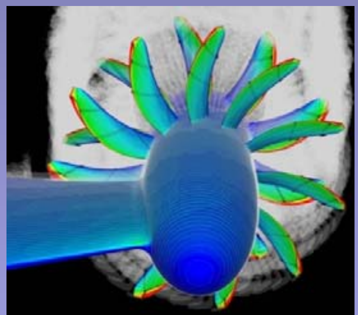
Challenges
- Flow separation
- Unsteady effects
- Moving control surfaces
- Structural properties
- Multidisciplinary analysis
- Huge parameter space

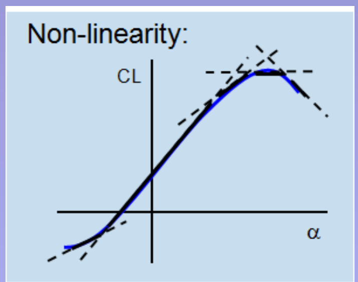
→ High-fidelity simulations

Loads Predictions

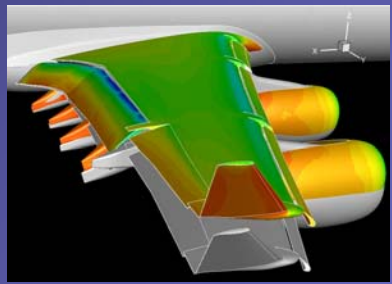
Linear/Non-Linear Steady/Unsteady Flows

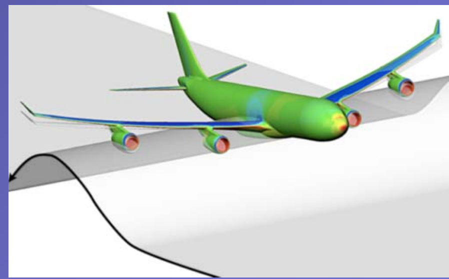






Computational Flight Testing





50 flight points
100 mass cases
10 a/c configurations
5 maneuvers
20 gust load cases
4 control laws

→ ~ 20,000,000 simulations

All Configurations

Cruise, Clean

Spoiler

High-Lift

Goal: Virtual Aircraft Model based on High-Fidelity Simulations

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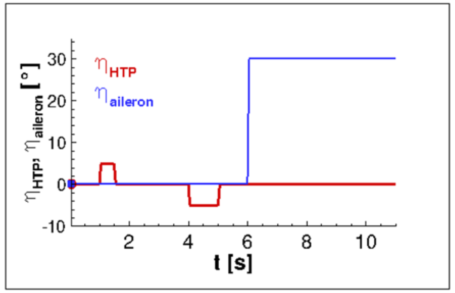
Virtual Aircraft Model

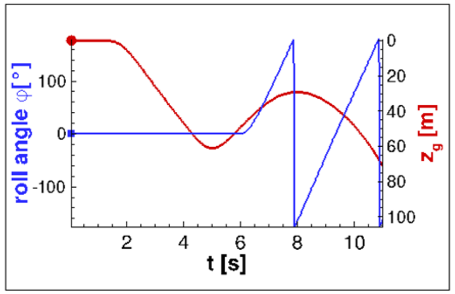
Time-accurate multi-disciplinary manoeuvring aircraft simulation

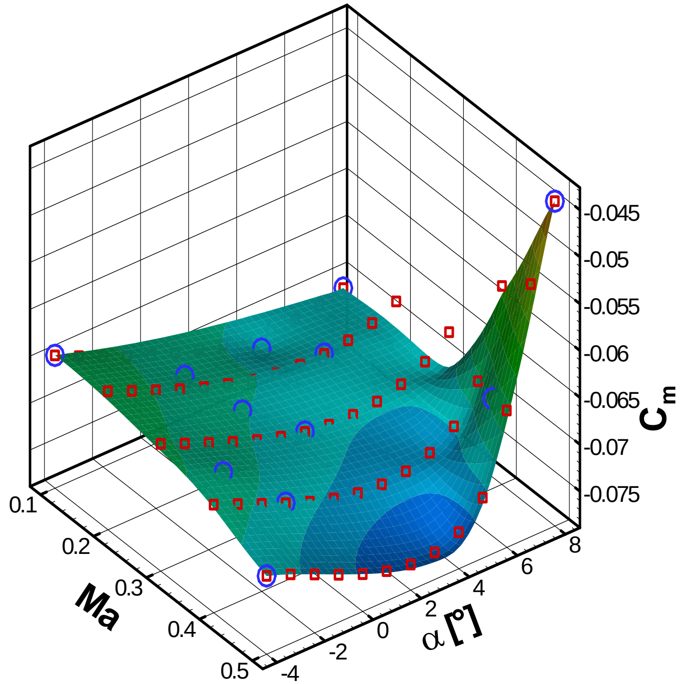
“Fly the equations”

Generation of surrogate model of sampled static & dynamic aerodynamic data relying on high-fidelity tools

“Fly through the database”







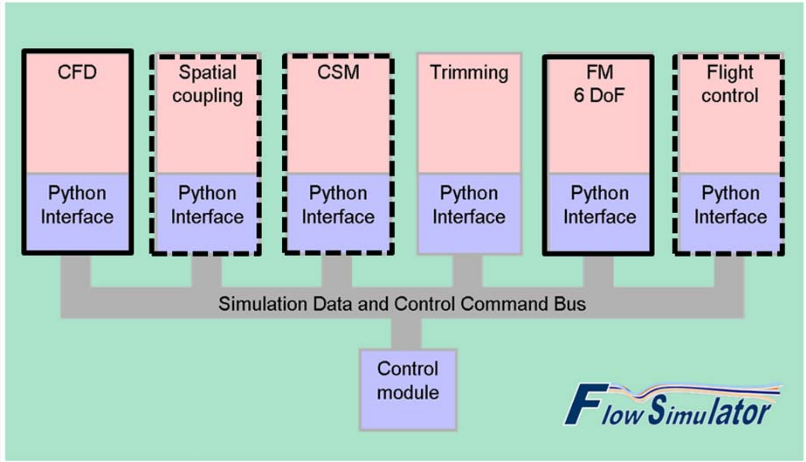
M.D. Salas
Digital Flight: The Last CFD Grand Challenge; Journal of Scientific Computing, 2006

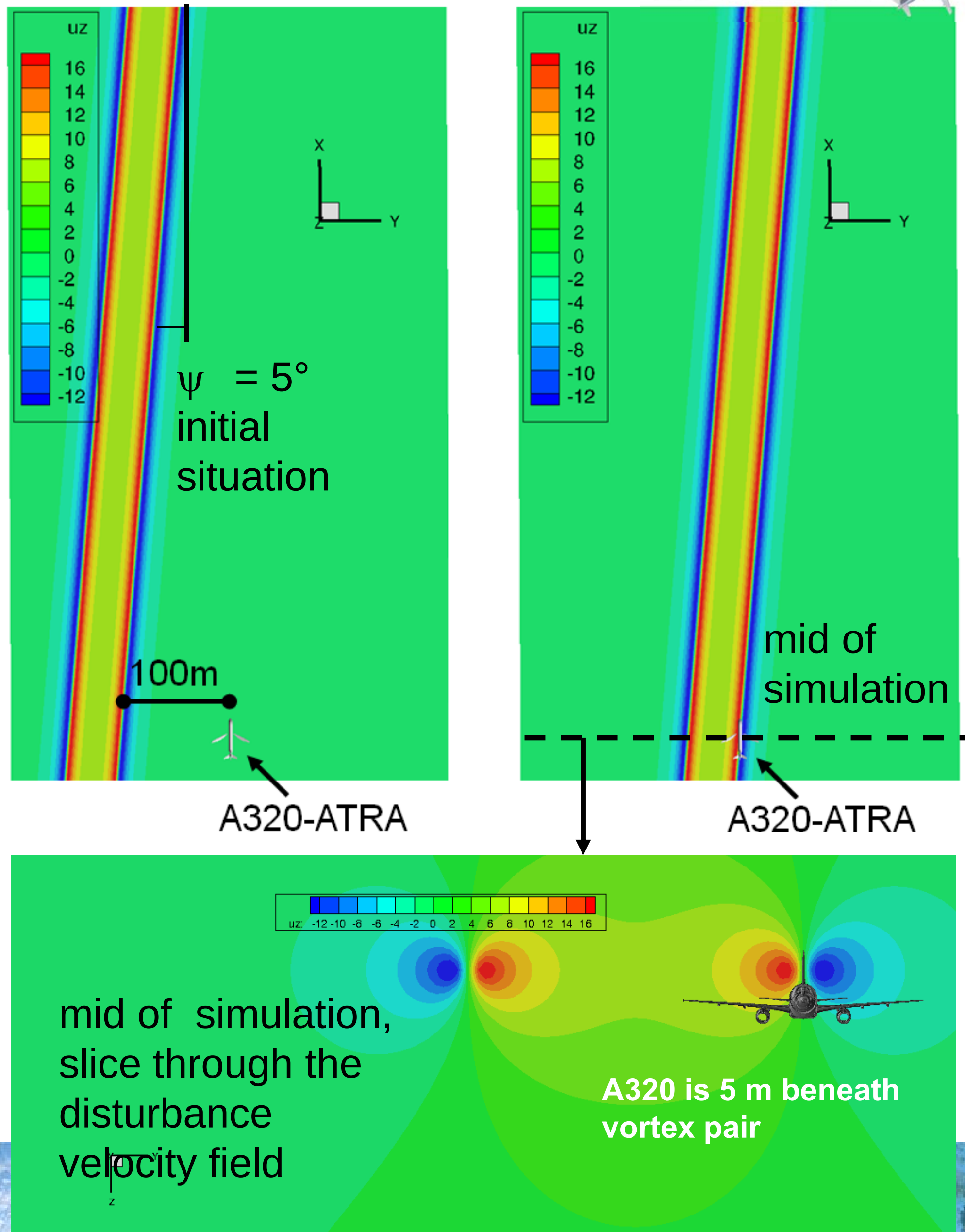
Virtual Aircraft Model: “Fly the Equations”

Wake Vortex Encounter

- A320 flying through wake vortices of A340
- Ma = 0.78, h = 37.000 ft
- m_{A320} = 70 t
- m_{A340} = 190 t

- Perform unsteady coupled simulation (CFD-FM)





Virtual Aircraft Model: "Fly the Equations"

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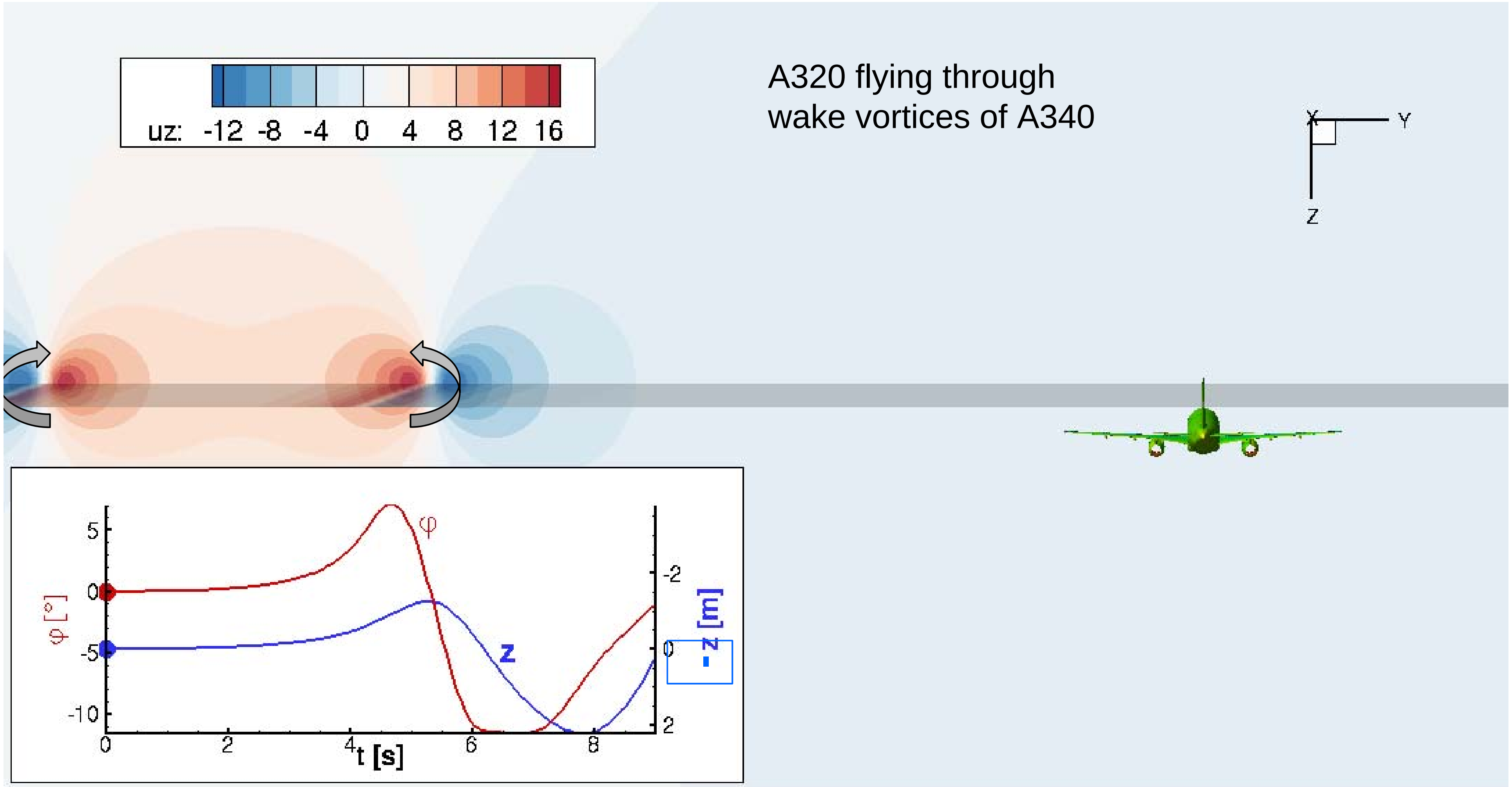
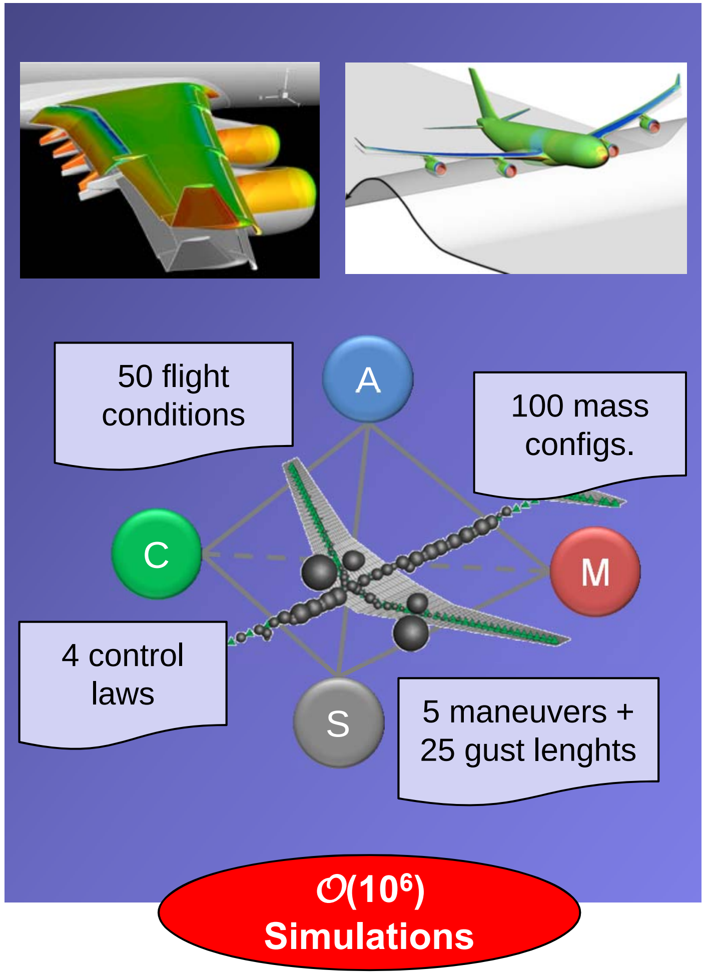


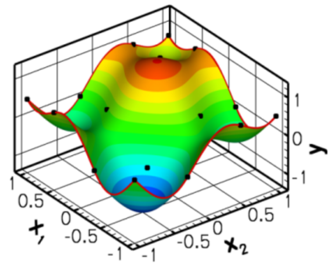
Virtual Aircraft Data Model
"Flying through the Data Base"

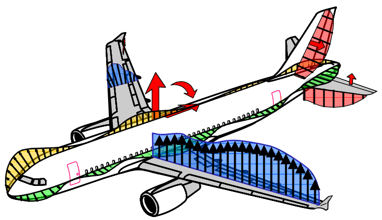
Huge sets of aerodynamic data required for complete flight envelope as input for
- Flight simulator data base
- Development of flight control system
- Layout of control surfaces
- Structural layout and sizing



Surrogate Models based on high-fidelity simulations

- Accurate & fast predictions
  - Static / dynamic loads
  - Forces/moments, derivatives
  - Surface pressure, skin friction, ..





Aerodynamic Data for Loads

Reduced Order Modeling (ROM)

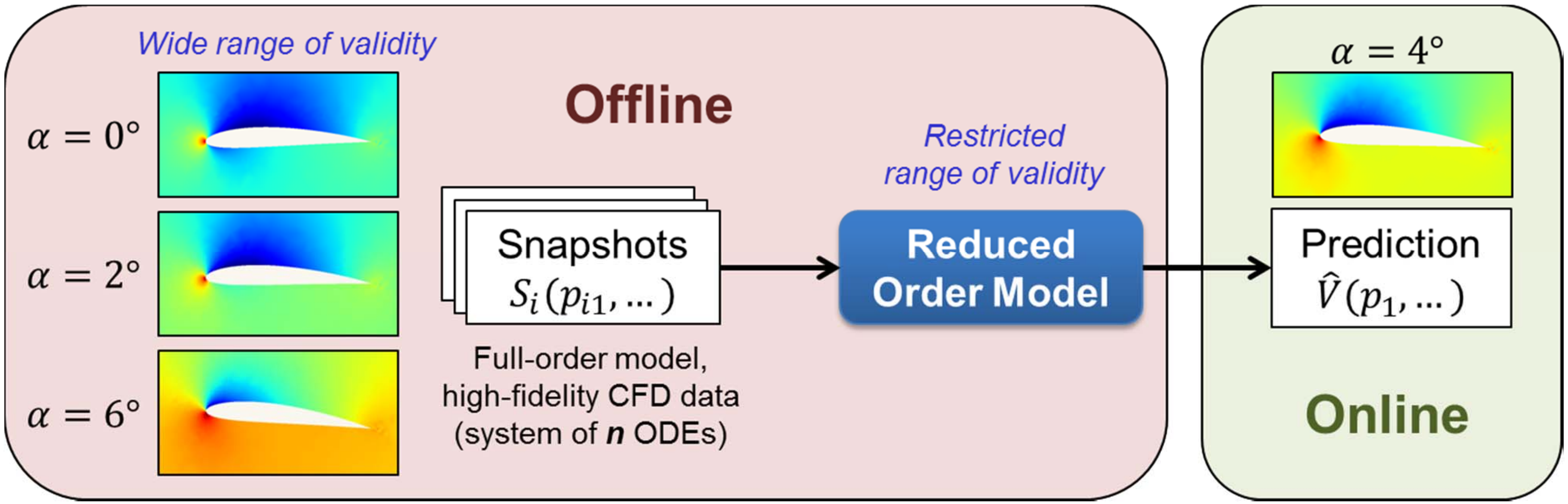
Goal

- Provide quantitatively accurate descriptions of the aerodynamics with fewer degrees of freedom than the original CFD model

ROMs

- Operate on parameterized generated data (snapshots)
  - scalar quantities: lift, drag and moment coefficients C_L, C_D, C_M
  - surface quantities: pressure and shear stress c_p, c_f
  - volume quantities: primitive variables ρ, v_i, p, T

steady



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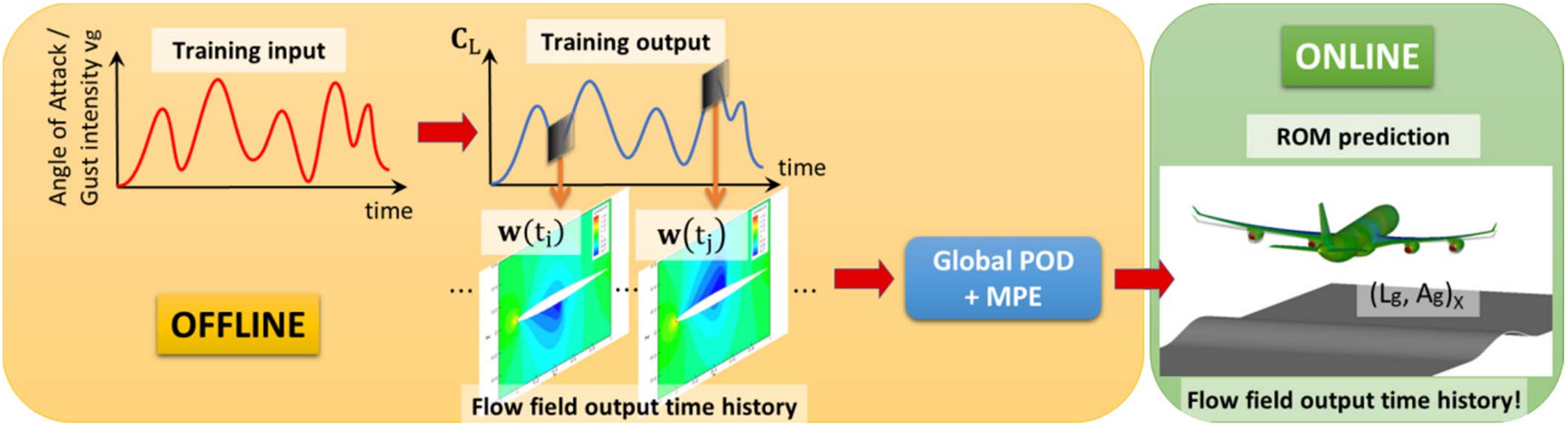
unsteady



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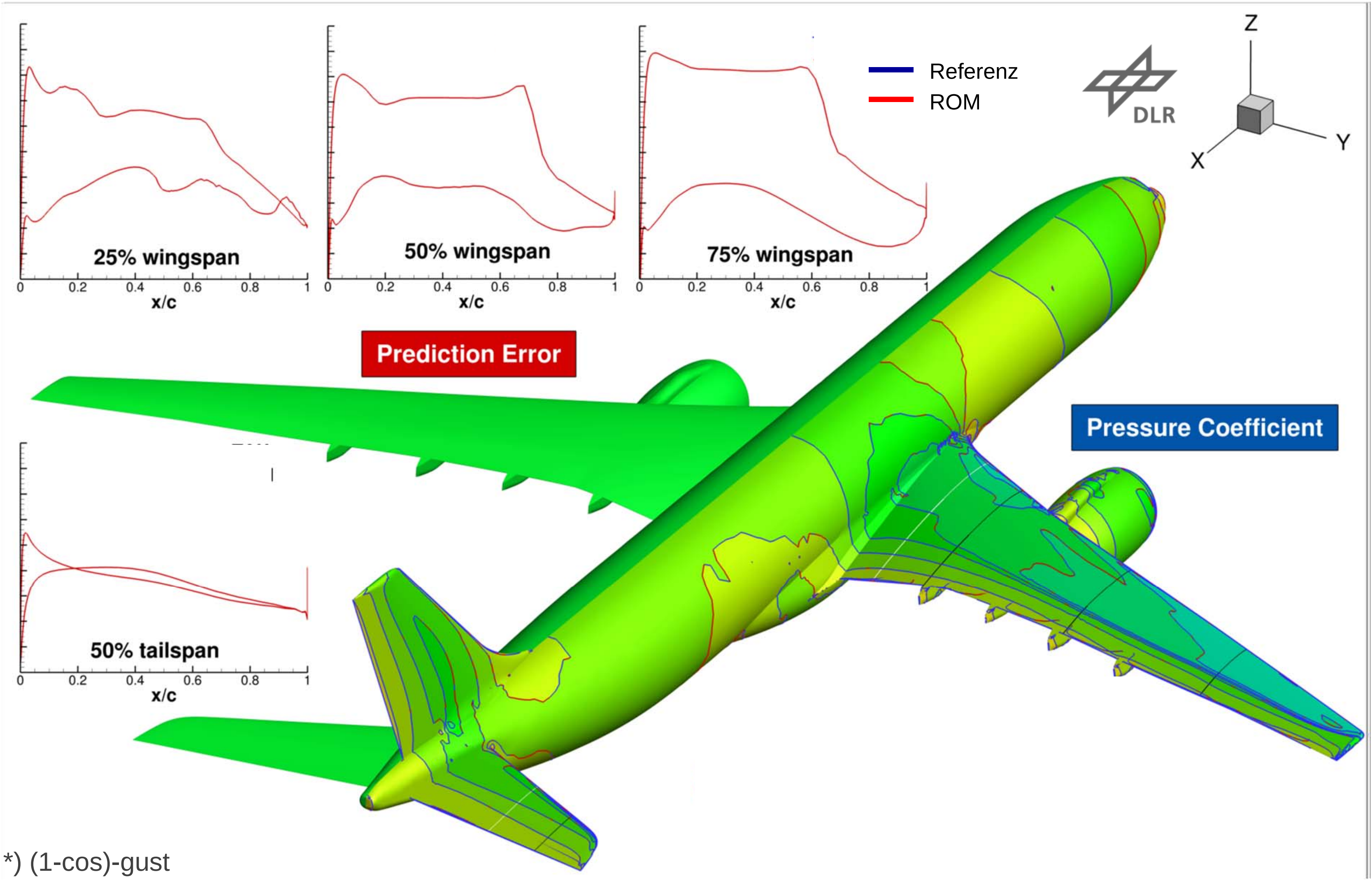
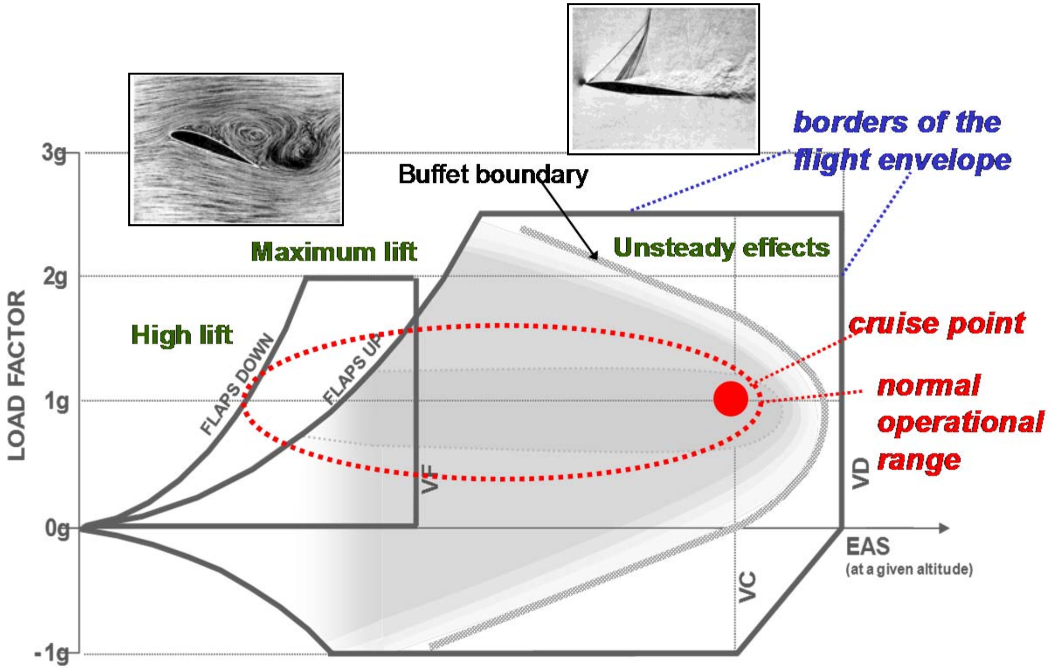
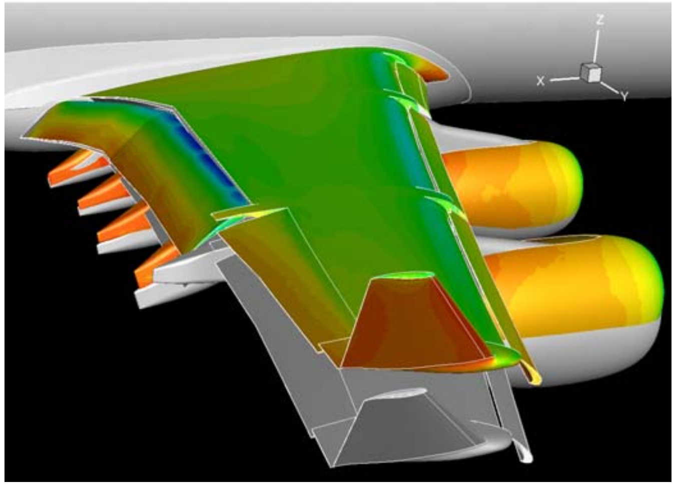
Loads Prediction* – Time Accurate Surrogate



*) (1-cos)-gust

Which Simulations are Required?





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– Structural properties
– Multidisciplinary analysis
– Huge parameter space

→ Multi-Disciplinary Optimization

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Gradient-Based High-Fidelity MDO Chain

Aero-Structural Optimization

Wing design

$$Objective = \frac{1}{C_W} * \frac{C_L}{C_D}, \text{ with } C_W = \frac{Current\ structural\ mass}{Reference\ mass}$$

Design parameter

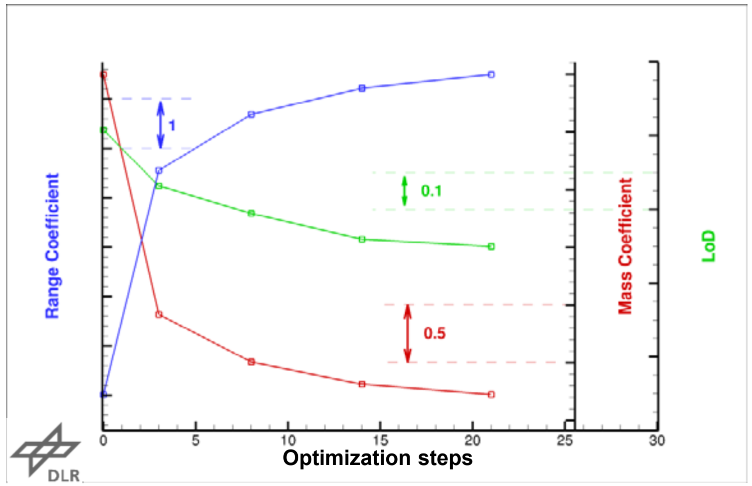
- **360** shape design variables
- **350** structural thickness variables

Constraints

- Lift & pitching moment coefficients
- Strength & buckling

CFD/CSM-simulation per optimization step

- Cruise point
- 7 critical load cases for structural sizing



Range increase ~ 4%

Airbus XRF1 configuration

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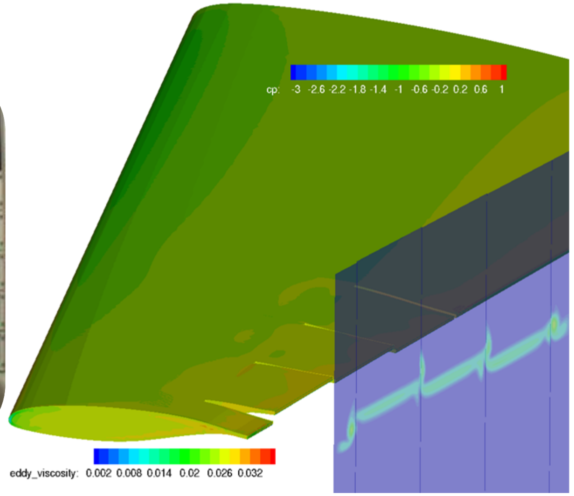
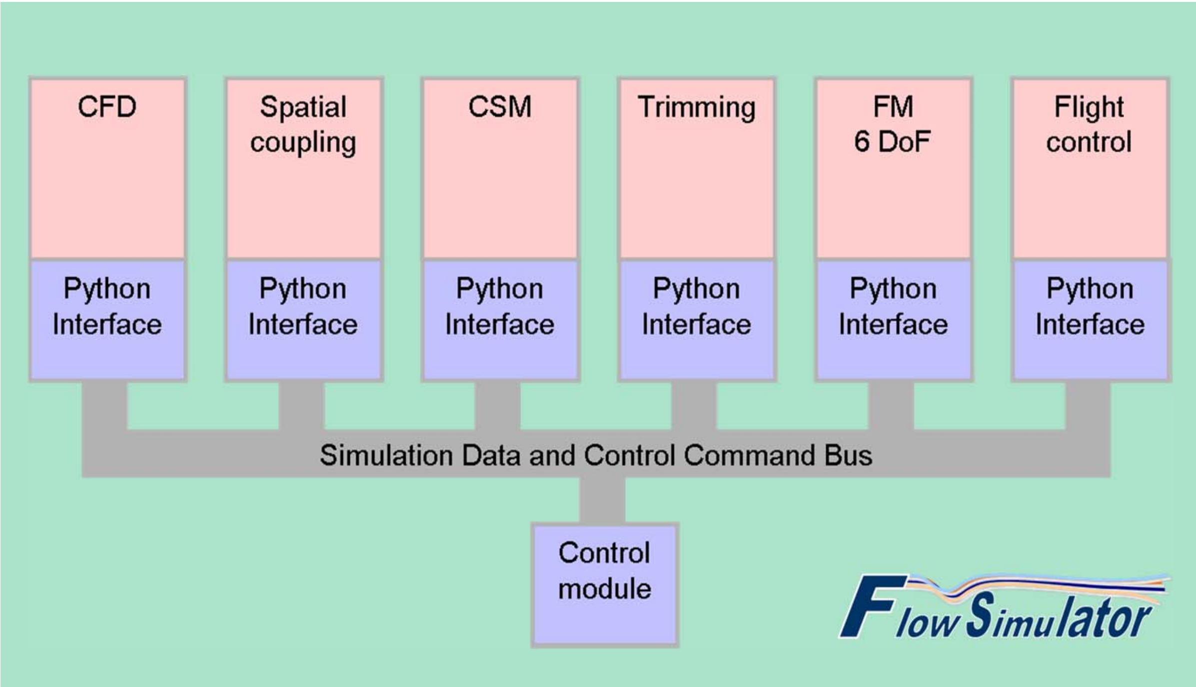
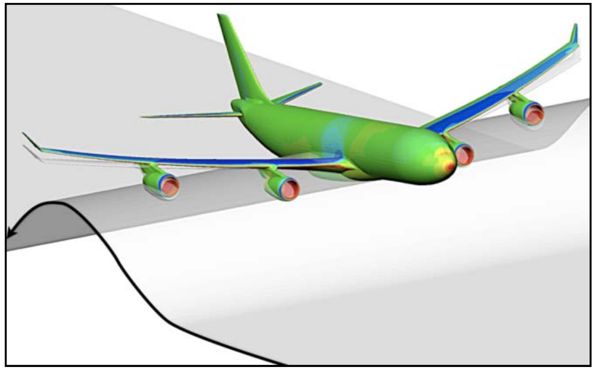
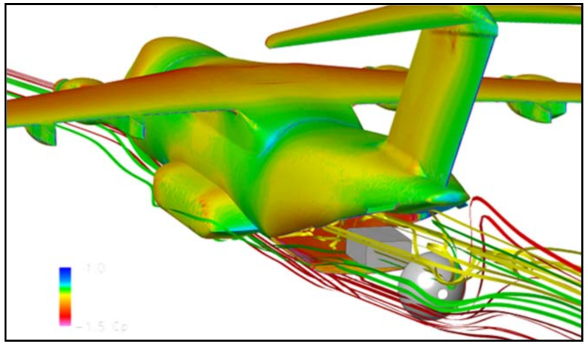
DLR Research & Development Areas
Simulation Framework

- Tight coupling of all relevant aircraft disciplines (high-fidelity methods)
- Modeling of moving control surfaces
- Huge unsteady computations
- High performance computing
- Parallel multi-disciplinary environment









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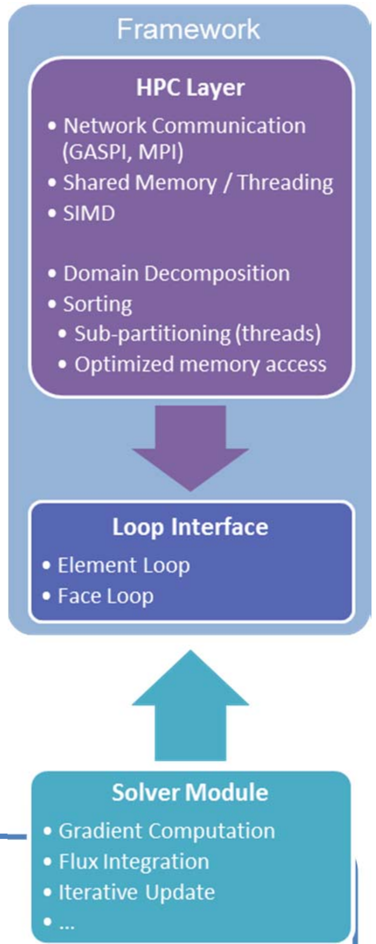
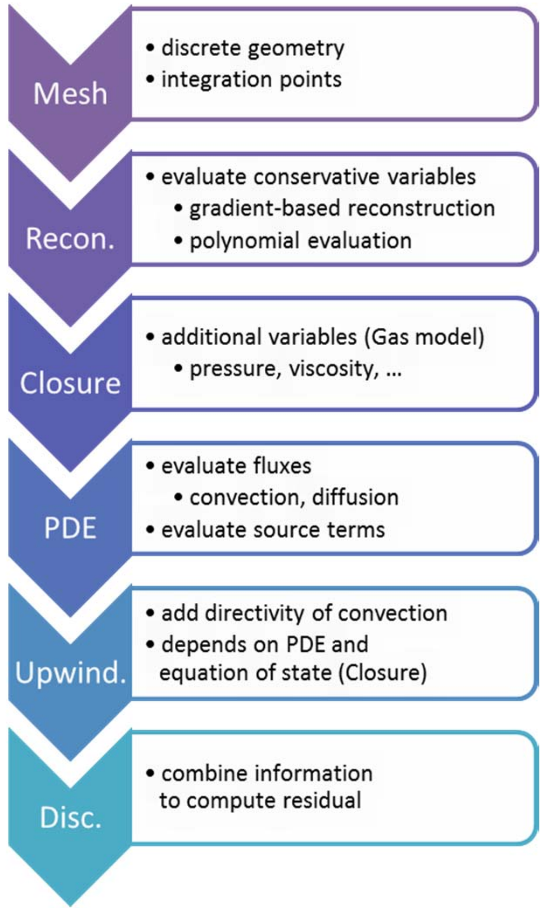
DLR Research & Development Areas

Next Generation Flow Solver *Flucs*

- Full exploitation of future HPC systems
- Flexible building blocks
- Basis for innovative concepts & algorithms e.g. high-order-finite element discretization, adaptivity, …
- Extension of application range
- Seamless integration into multidisciplinary simulation environment FlowSimulator
- State-of-the-art software engineering methods



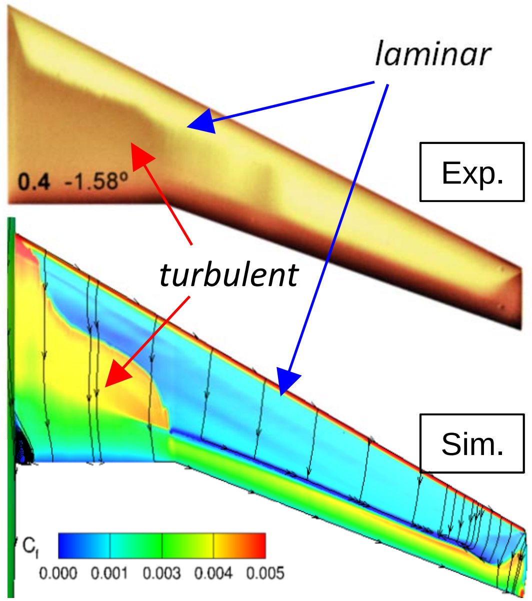


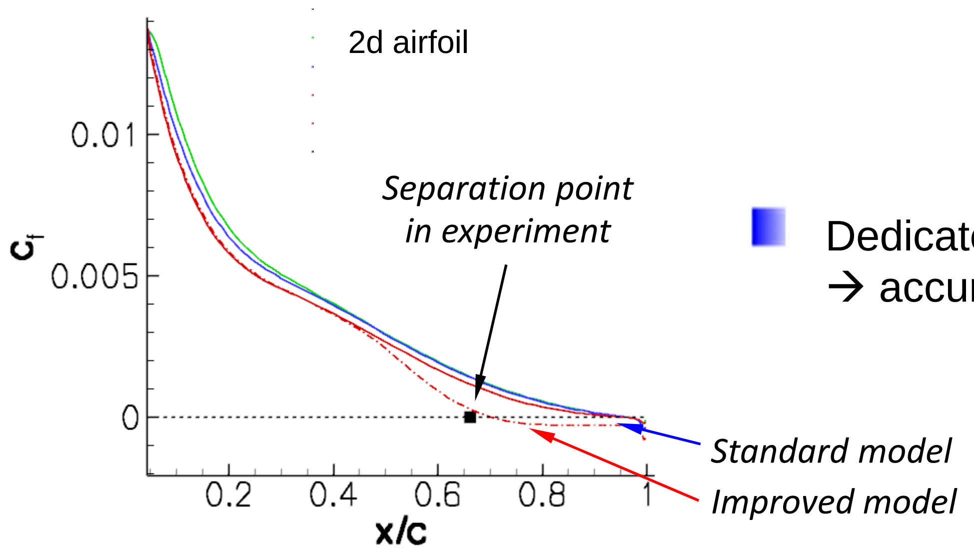
- Separation of *what* is done *locally* (loop body) from *how* it is done *globally*
  - Implementation of the *how* logic just once in an HPC layer of the code framework (loop interface).
  - Only this has to be changed for porting to a new architecture.

DLR Research & Development Areas
Physical Modeling

Turbulence and Transition

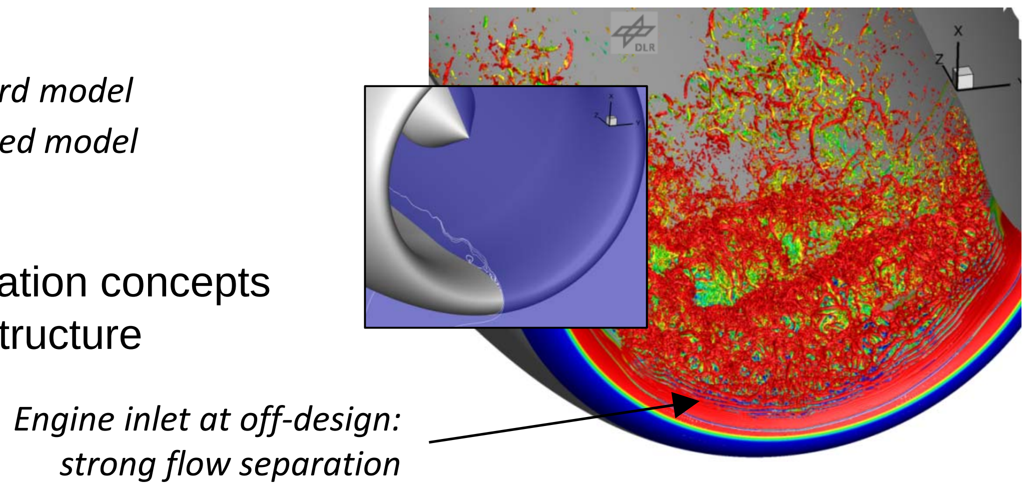
- Accurate prediction of laminar and turbulent flows → Transition





- Dedicated turbulence model improvement → accurate prediction of flow separation

- Specific turbulence models and simulation concepts → resolution of detailed turbulence structure

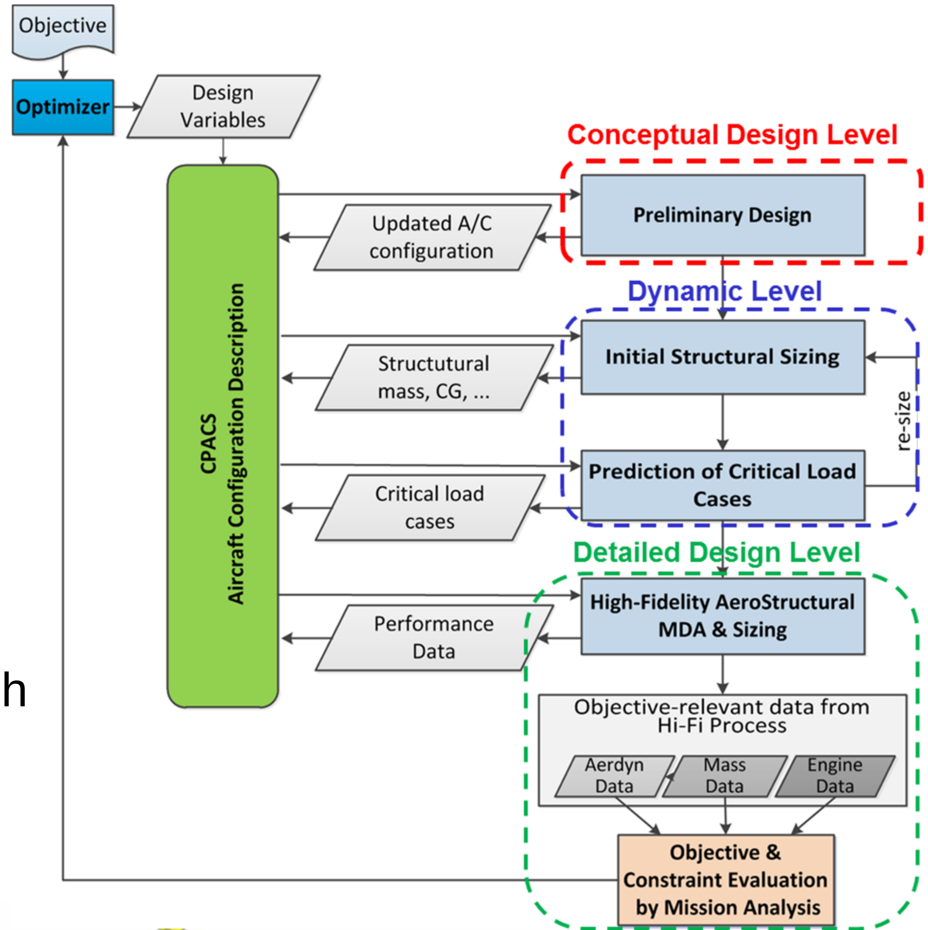


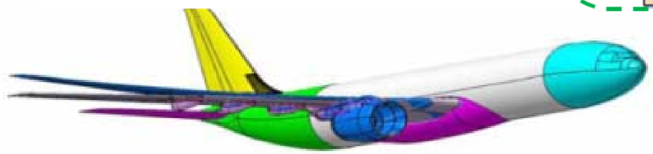
DLR Research & Development Areas
Multidisciplinary Optimization Environment

Multi-level procedure

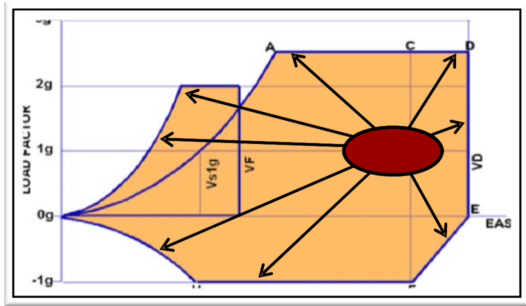
- Low-fidelity methods for overall aircraft design
- Fast methods for identification/ computation of critical load cases
- High-fidelity methods for aerodynamics and structure
- Consistent stream from preliminary to detailed design

- Parallel software platform
- Workflow management
- Sequential multi-level MDF approach
  - Easier to deal with complexity
  - Easier to implement
  - Close to industrial processes



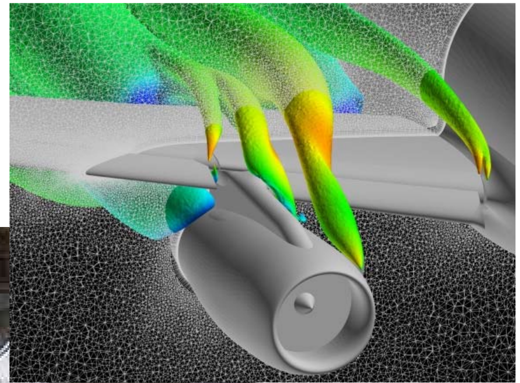


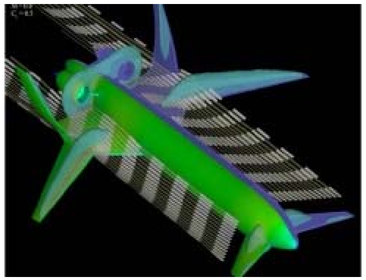
Virtual Product in Aeronautics
Potential and Requirements



Virtual design, testing and certification of future aircraft taking into account operational as well as environmental aspects

- Generation of all data necessary for certification / acceptance for complete flight envelope
- Combine / consolidate simulation data with experimental data (flight tests / windtunnel tests) as well as those of previous aircraft-design processes
- Identification and extraction of principles and rules relevant to design and certification / approval processes
- Deduction of concepts for future aircraft design process
- Data access and extraction, information management, knowledge generation





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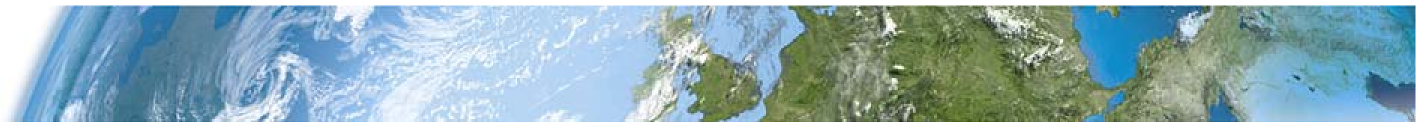
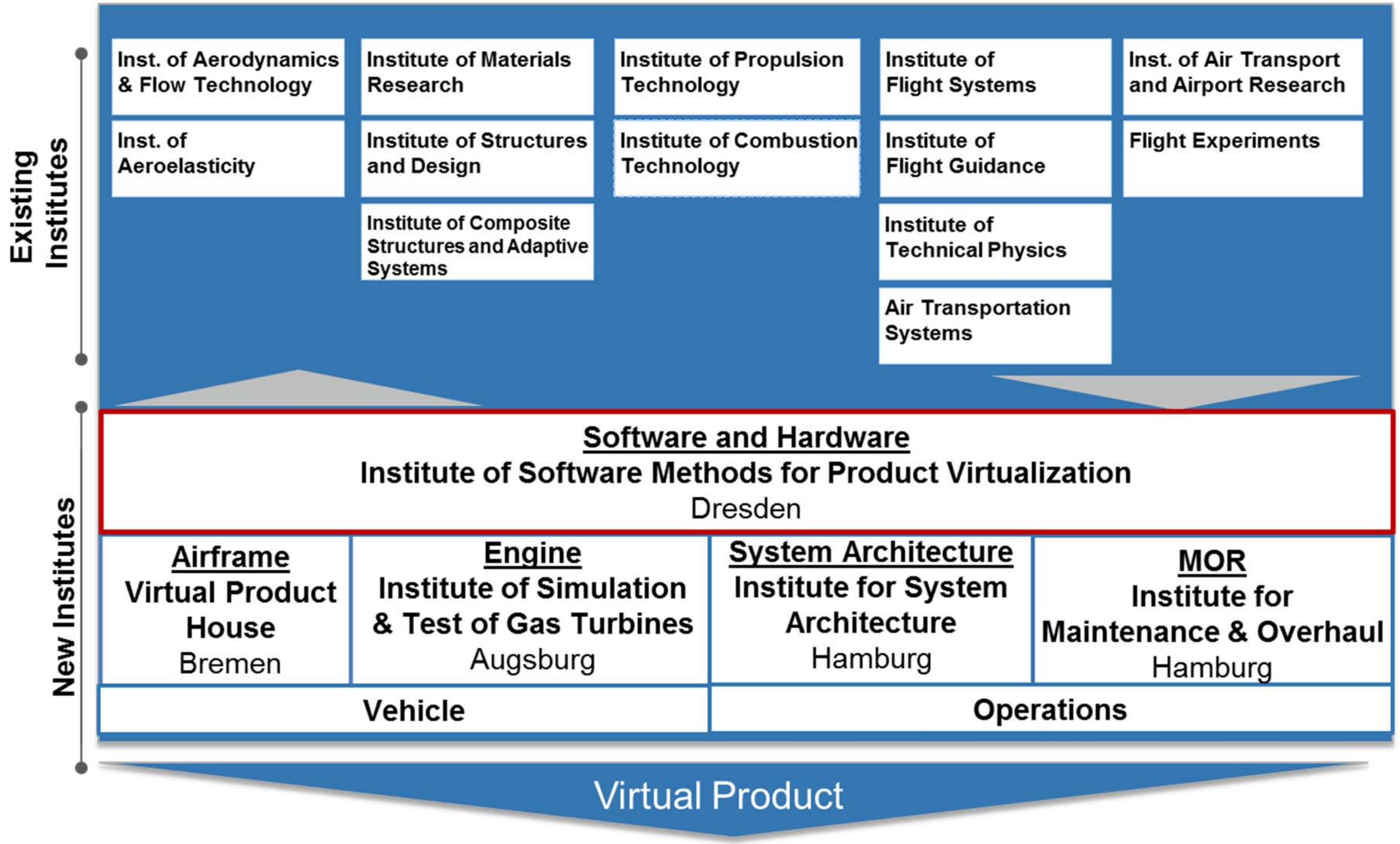


Virtual Product in Aeronautics
Research Perspective at DLR

Dedicated new institutes



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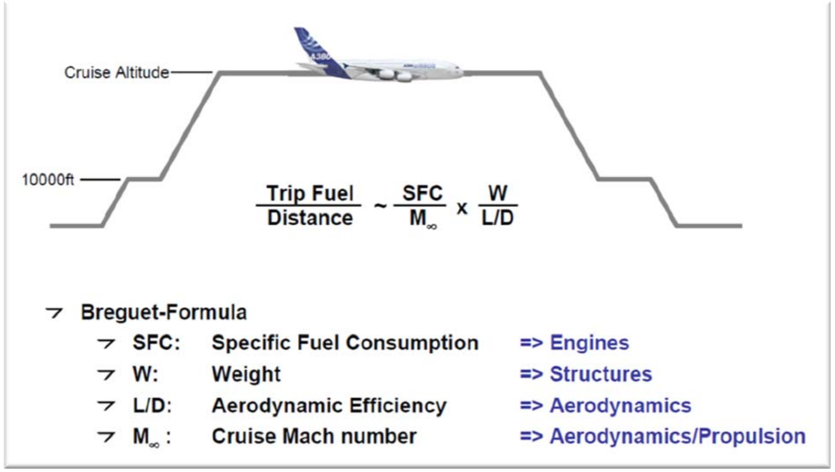
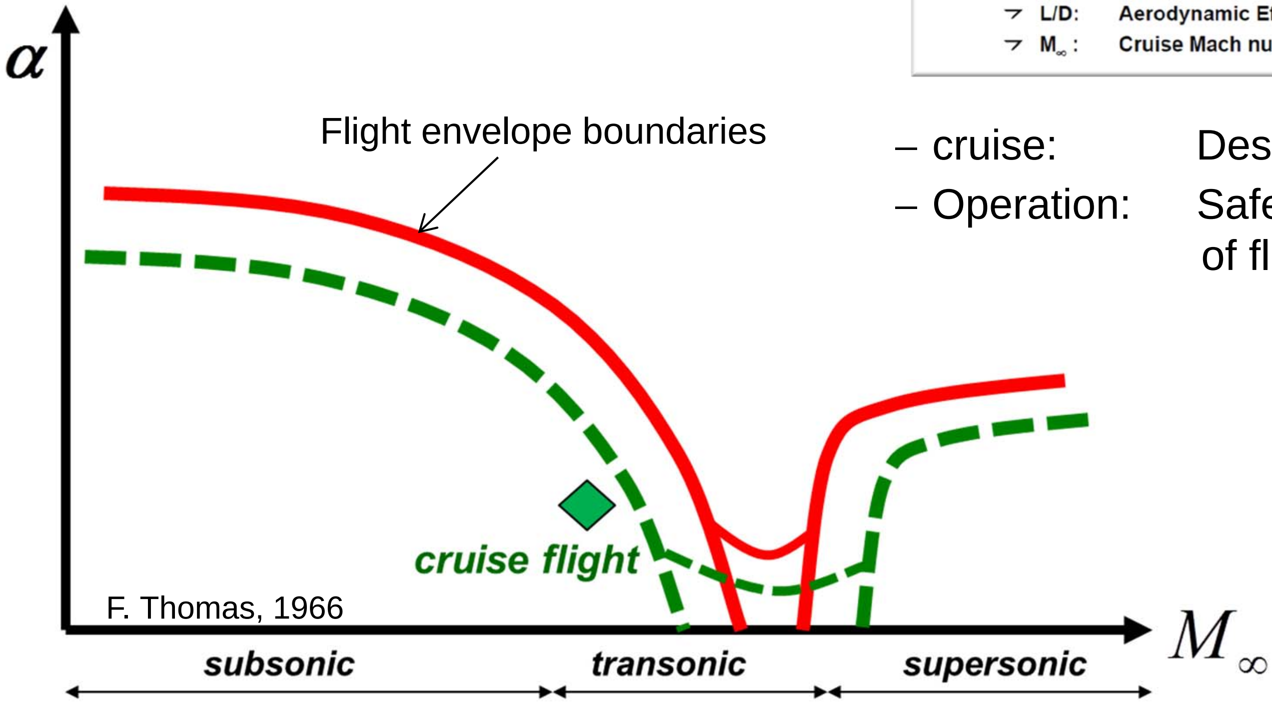
Virtual Product in Aeronautics
Improvement of Aircraft Performance

Digital Aircraft MDO & MDA

– Trade-off between disciplines





– cruise: Design for Performance

– Operation: Safety margins to boundaries of flight envelope

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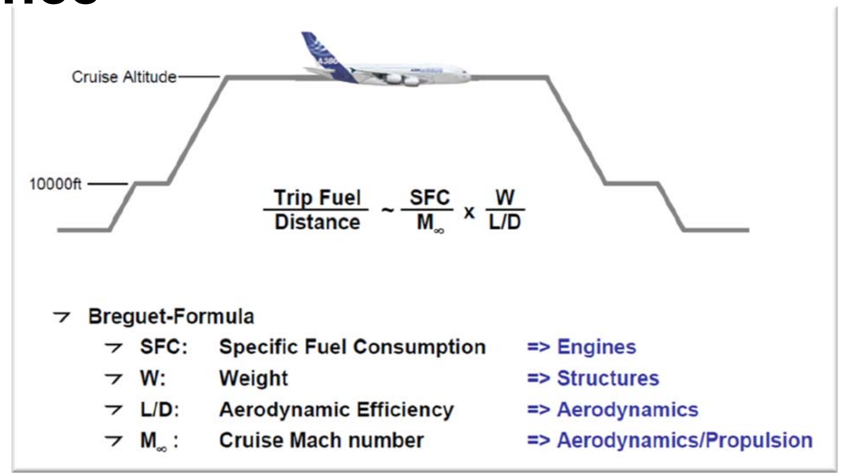
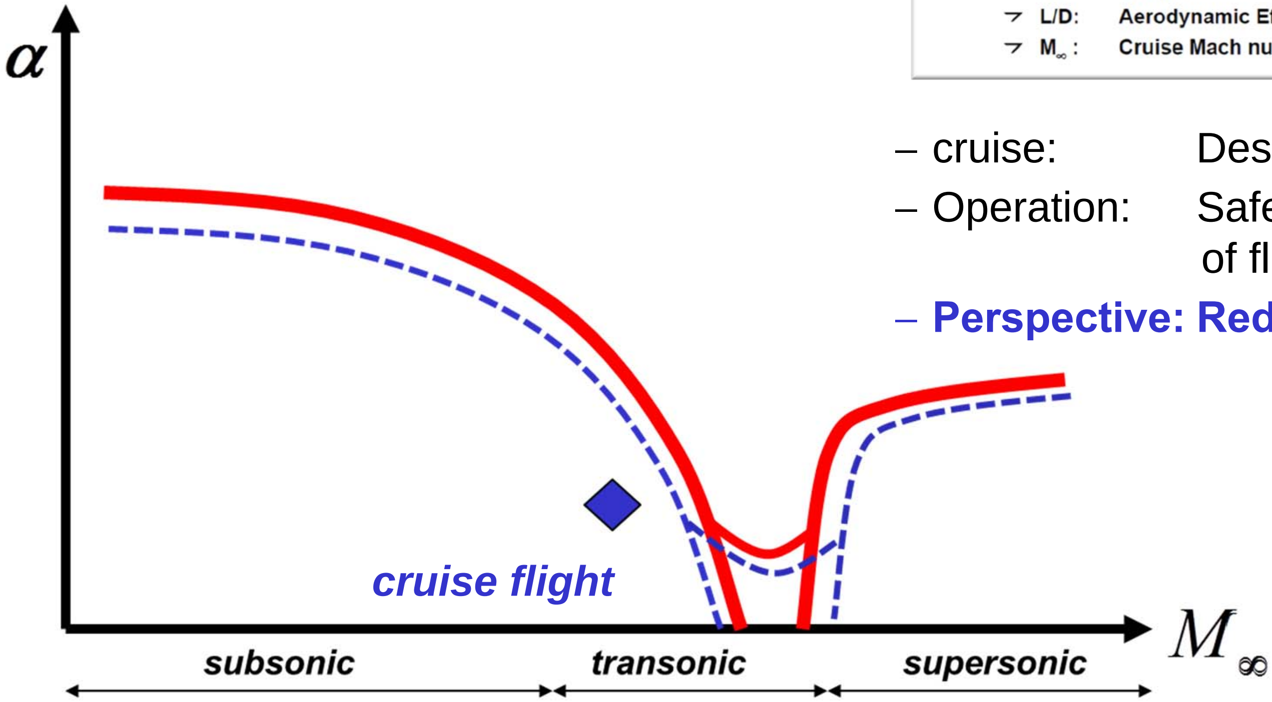
Virtual Product in Aeronautics
Improvement of Aircraft Performance

Digital Aircraft MDO & MDA

– Trade-off between disciplines

– Assessment of operational limits





– cruise: Design for Performance

– Operation: Safety margins to boundaries of flight envelope

– **Perspective: Reduction of margins**

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Virtual Product in Aeronautics
Simulation Based Certification

Status

- A/C Certification relies mainly on physical tests
- In some cases, certification is supported by simulation (e.g. flutter)

Future

- Simulation Based Certification
- Validated virtual testing procedures
- Comprehensive virtual product analysis – in particular in limit cases

Requirements

- Improvement of simulation reliability
- Software and certification standards
- Close collaboration with authorities

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