Overall Aircraft Design Synthesis, Loads Analysis, and Structural Optimization – Parameterized Disciplinary Sub-Processes within High-Fidelity-based Aircraft MDO

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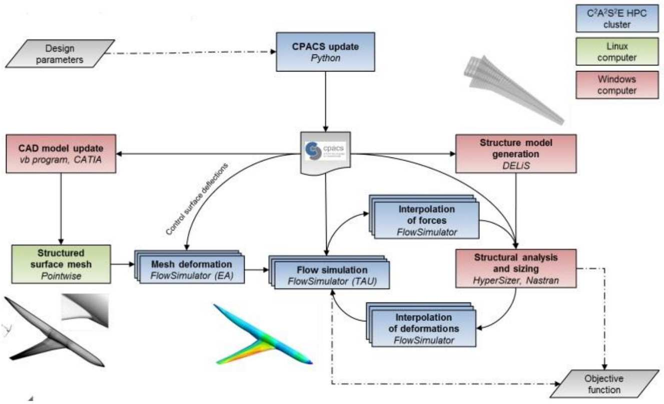
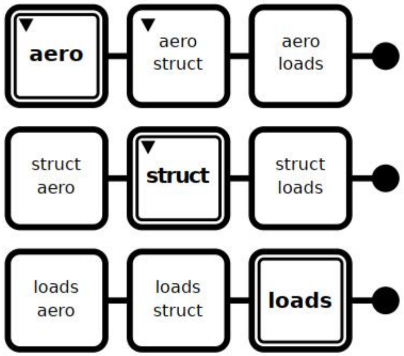
Motivation – MDO Processes @ VicToria

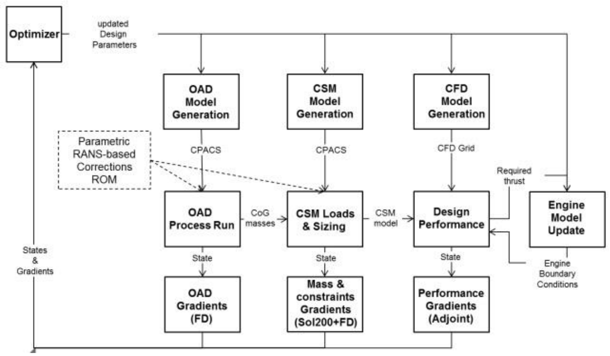
Integrated Aero-Structural Wing Optimization (IAWO)



Many Discipline Highly-Parallel Approach (MDHP)



Multi-Fidelity Gradient-Based Approach (MFGB)



- Three MDO processes within VicToria/HAP2 presented @ DLRK2018 (e.g. Ilic et al.[a])
- Aerodynamics is covered by various presentation (e.g. Ritter et al.[b] and Merle et.al.[c])
- **Missing Disciplines:**
  - Overall Aircraft Design (OAD)
  - Structural Analysis and Design
  - Loads Analysis

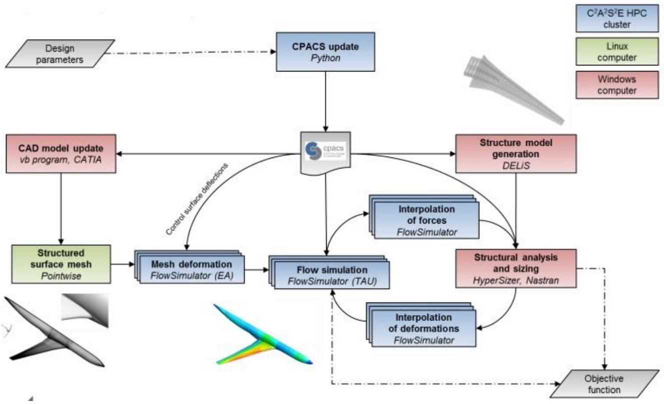
a) *C. Ilic[1], M. Abu-Zurayk[1], T. Wunderlich[1], J. Jepsen[1], M. Schulze[1], M. Leitner[1], A. Schuster[1], S. Dähne[1], M. Petsch[1], R.-G. Becker[1], S.-A. Zur[1], S. Gottfried[1]; [1]DLR, DE*
Overview of Collaborative High Performance Computing-Based MDO of Transport Aircraft in the DLR Project VicToria

b) *M. Ritter, DLR AE, DE; L. Reimer[1], R. Heinrich[1], W. Mönnich, DLR FT, DE; [1]DLR AS, DE*
Maneuver Simulation of a Flexible Transport Aircraft with HiFi-Methods and Comparison to Experimental Data

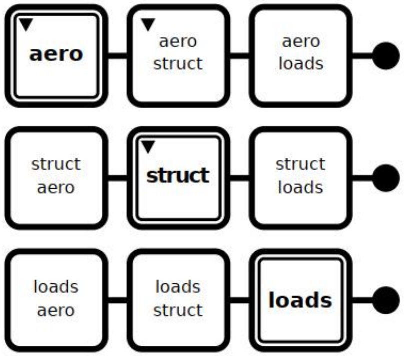
c) *Andrei Merle[1], Arno Ronzheimer[1], Philipp Bekemeyer[1], Stefan Görtz[1], Stefan Keye[1], Lars Reimer[1]; [1]DLR, DE*
Gradient-based Optimization of a Flexible Long-Range Transport Aircraft using a High-Dimensional CAD-ROM Parameterization

Motivation - Disciplines Besides Aerodynamics

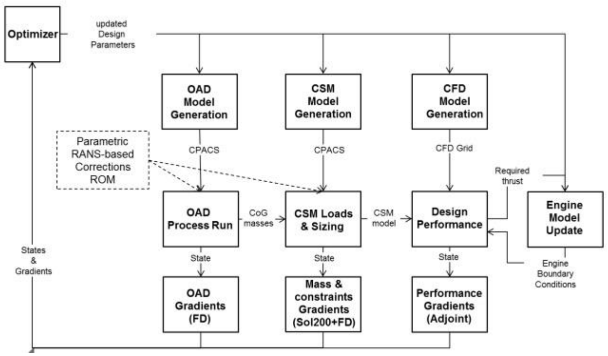
Integrated Aero-Structural Wing Optimization (IAWO)



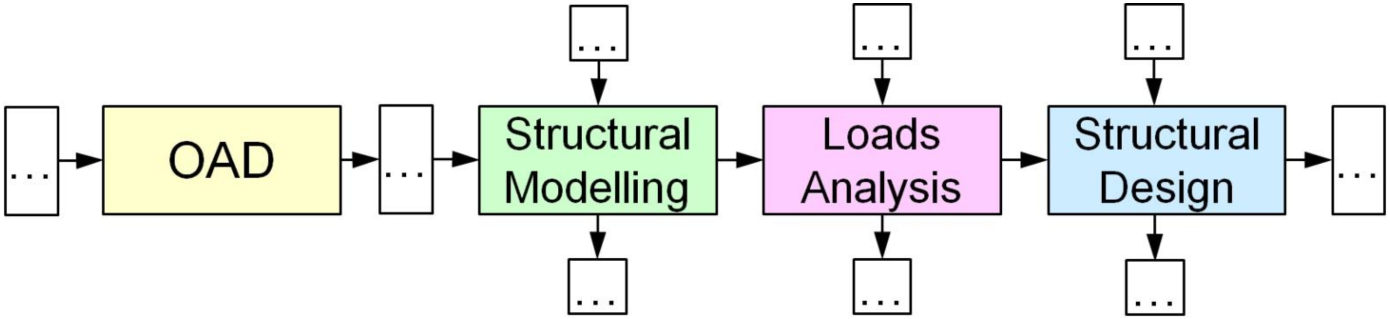
Many Discipline Highly-Parallel Approach (MDHP)



Multi-Fidelity Gradient-Based Approach (MFGB)

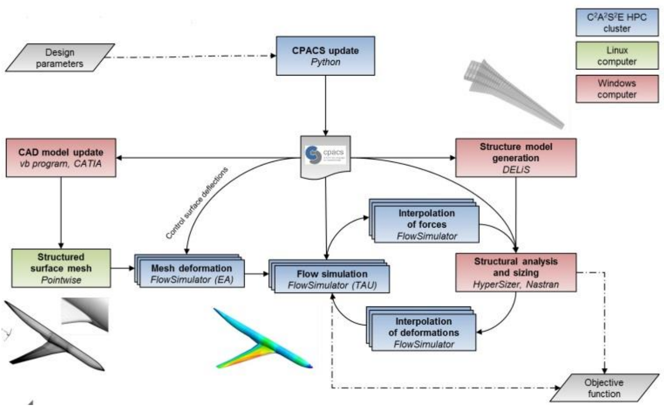


Sorting and bringing the „other“ disciplines besides aerodynamics „in-line“:

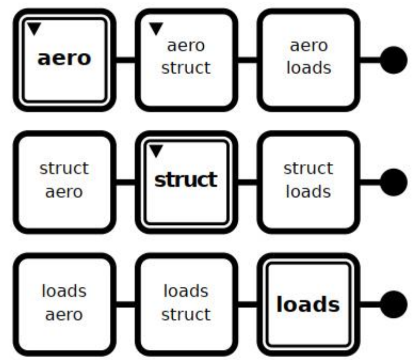


Motivation - DLR Institutes Involved

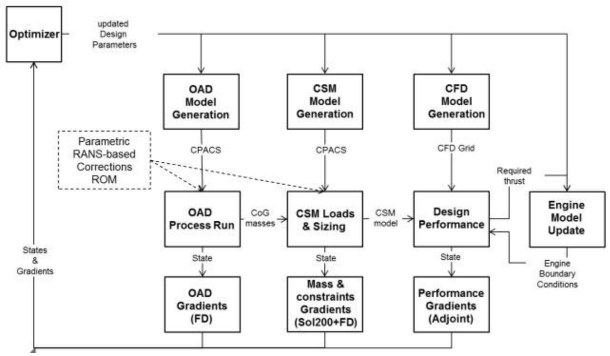
Integrated Aero-Structural Wing Optimization (IAWO)

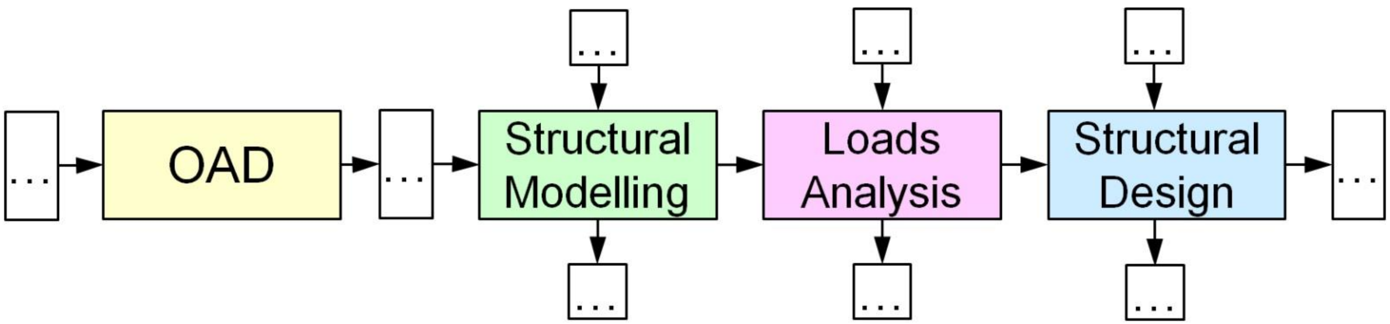


Many Discipline Highly-Parallel Approach (MDHP)



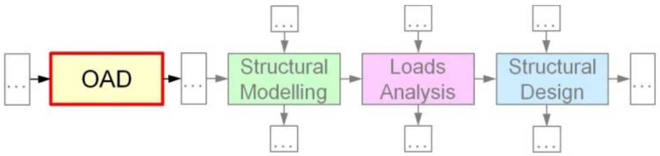
Multi-Fidelity Gradient-Based Approach (MFGB)

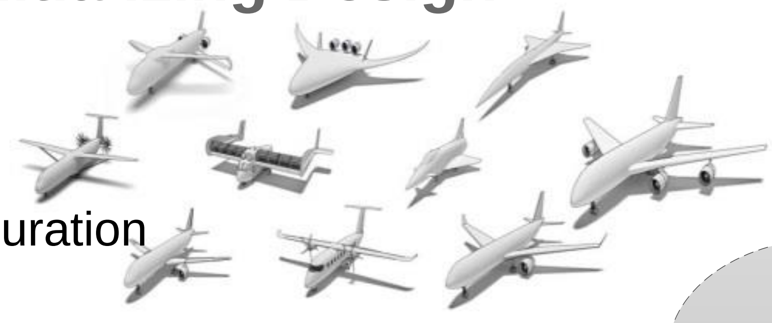




DLR Institutes: SL FA BT AE AE SR FA BT AE

OAD – Initializing Design

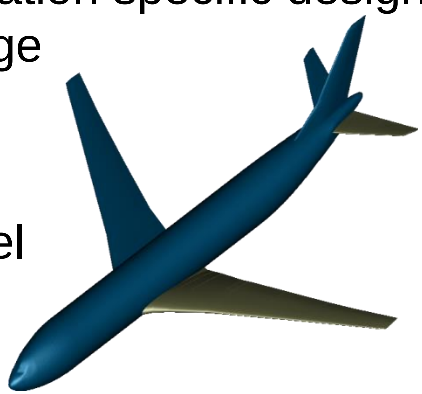


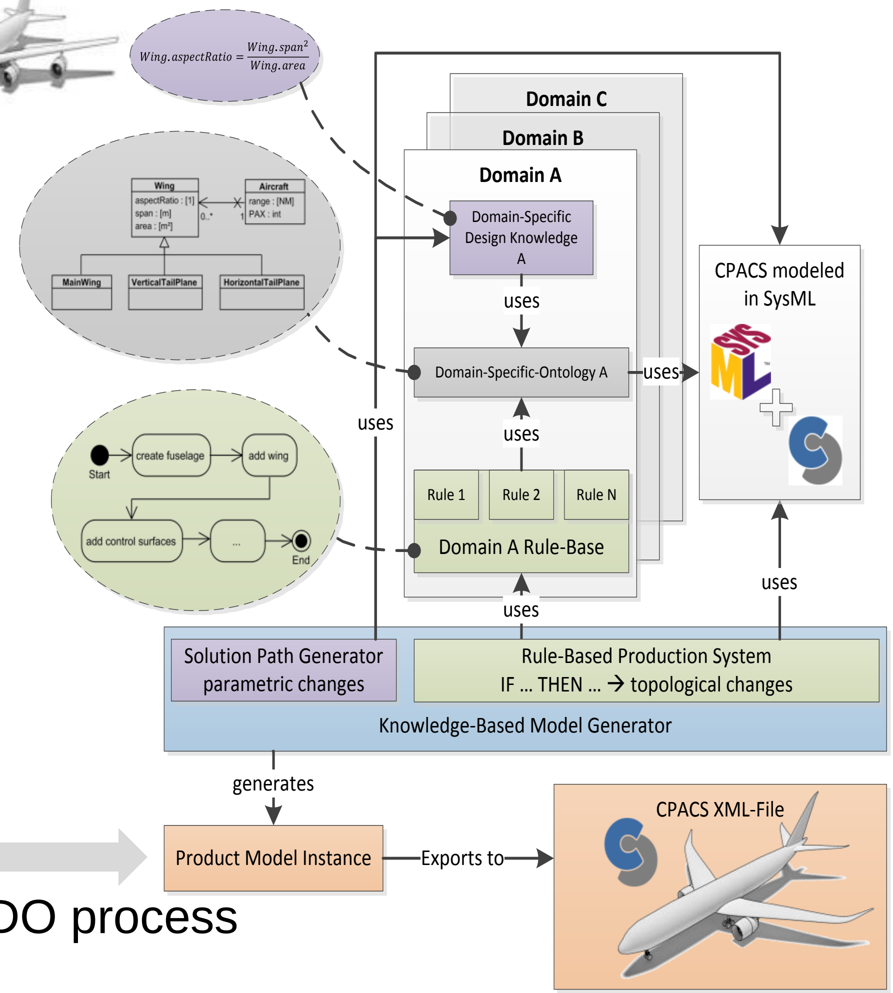


Inputs:
- AC configuration
- TLAR

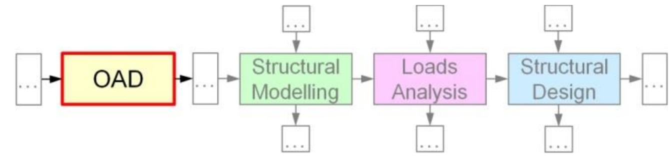
Using:
- Topological rules to initialize configuration
- Configuration specific design knowledge

Outputs:
- AC model (CPACS Dataset)

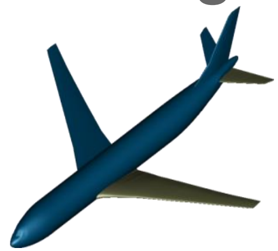




VicToria MDO process database



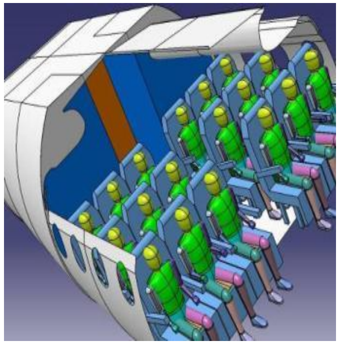
OAD – Enhanced Design

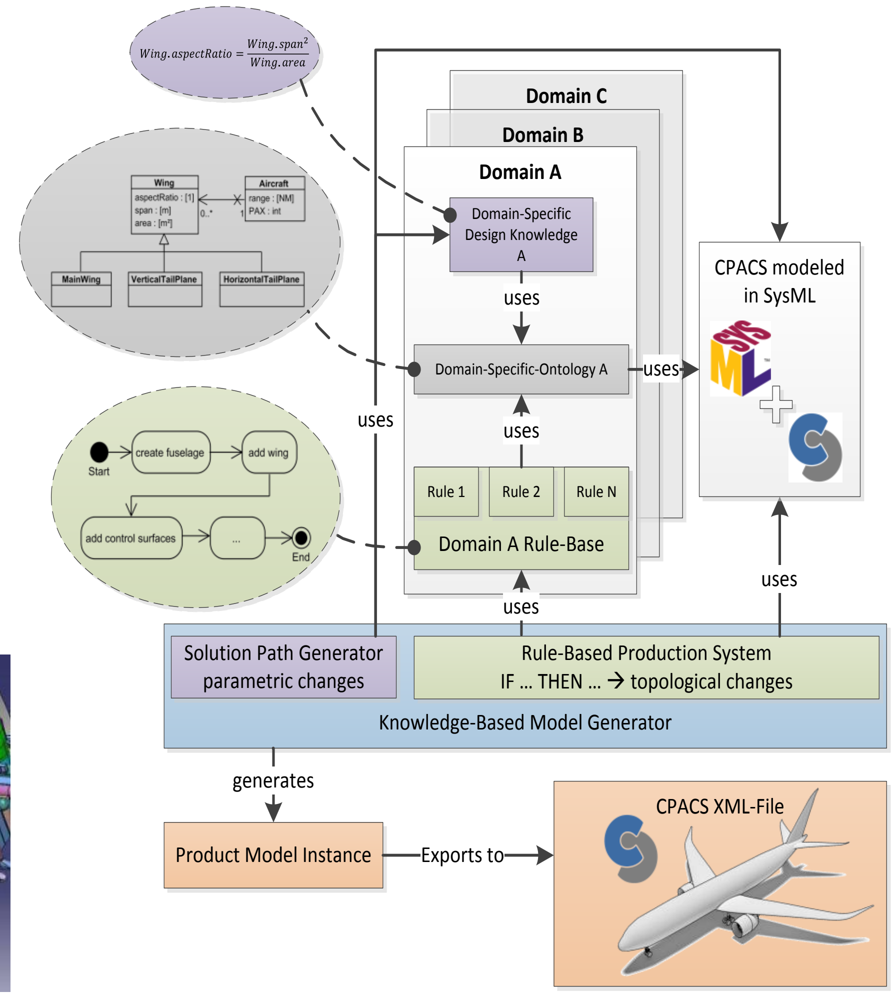


Inputs:
- AC model
- Enhancement specification

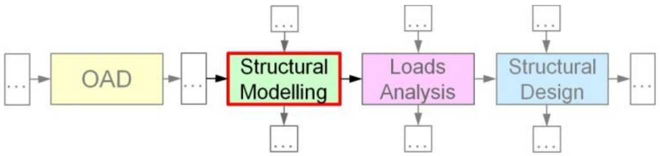
Using:
- Topological rules to initialize details
- Design knowledge (configuration and component specific)

Outputs:
- Enhanced AC model (e.g. added structure, control surfaces, cabin layout …)





Structural Modelling – General Tasks

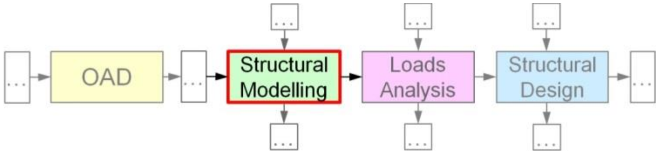


Set-up structural models as finite element models (FEM) to:

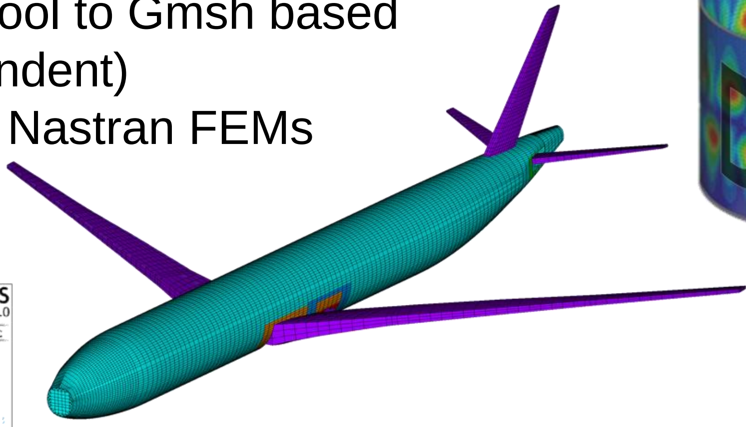
- Estimate component/structural mass
- Use the elastic model for loads, aeroelastic, controller design, and performance analysis (together with CFD)
- Investigate detailed/local structural characteristics (e.g. holes)
- Investigation of the structural concepts (e.g. fuselage for crash analysis)
- Use structural dimensioning methods (sizing, structural optimization with aluminum and/or carbon fibre reinforced plastic)

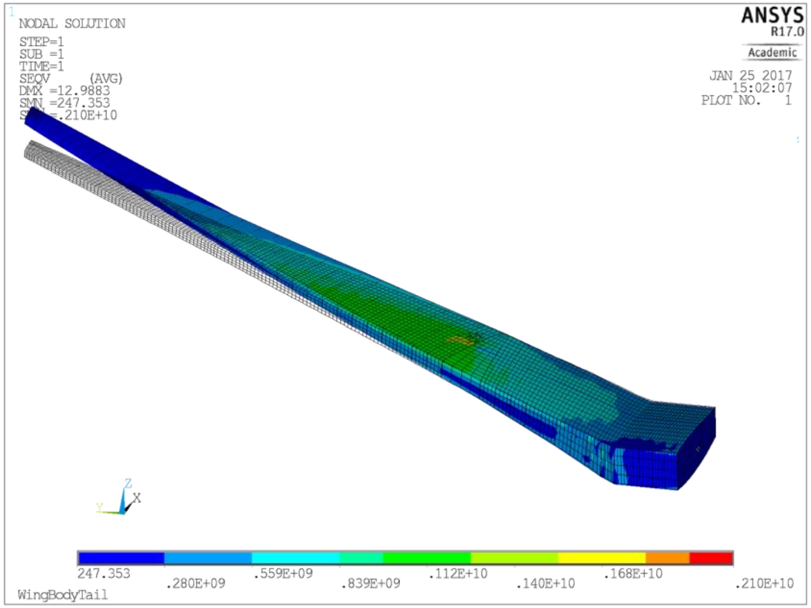
→ **Various model generator methods and tools have been developed by FA, BT, and AE to serve the individual requirements and tasks in the three MDO processes.**

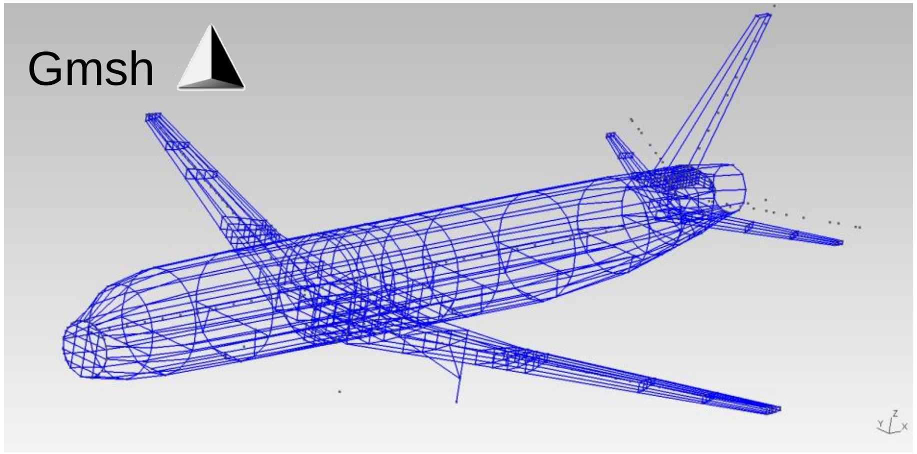
Structural Modelling – Wing & Tail with DELiS (FA)



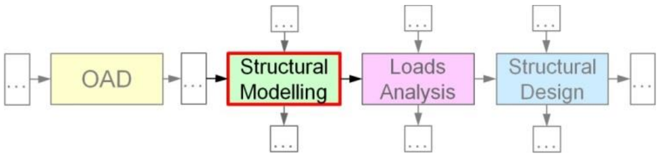
- Further development of DELiS (FA) for structural model generation from ANSYS tool to Gmsh based mesh generator (FE-tool independent)
- Generation of ANSYS and MSC Nastran FEMs



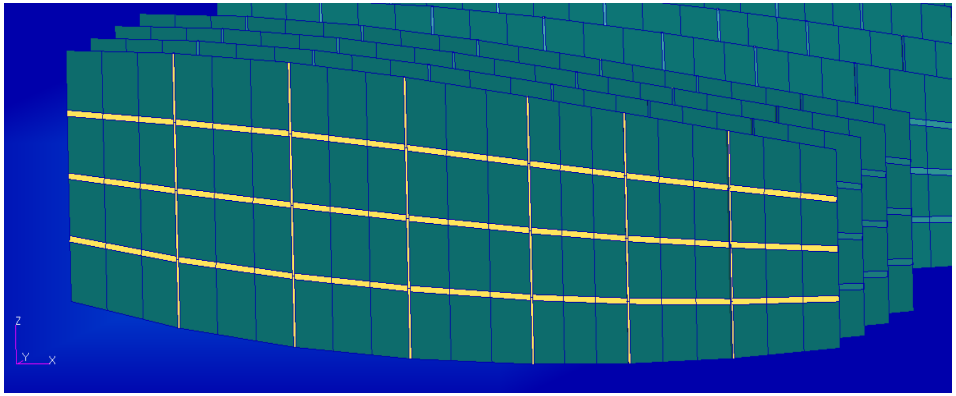




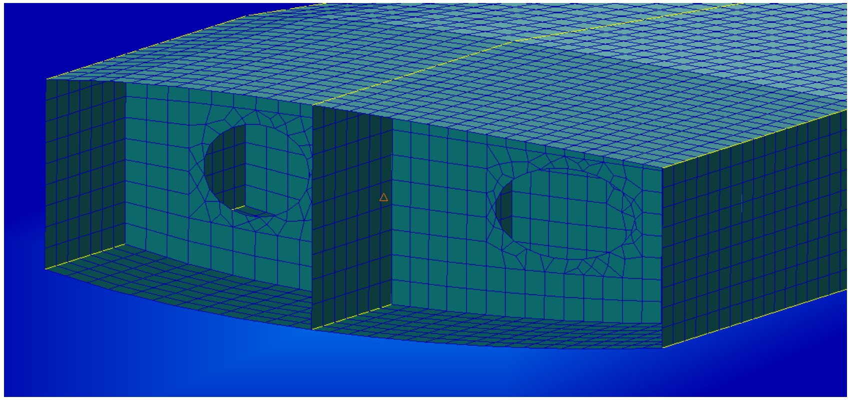
Structural Modelling – Wing & Tail with DELiS (FA)



- Consideration of detailed structural modelling for global aircraft finite element model (e.g. stiffener elements, rib holes)
- Connection to fast analytical methods (e.g. surrogate models for efficient failure prediction of the detailed structure)

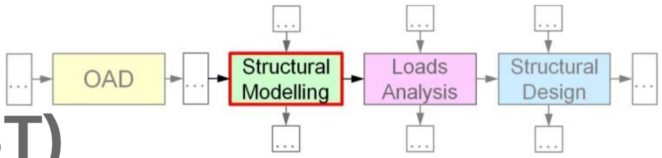


Rib stiffener elements

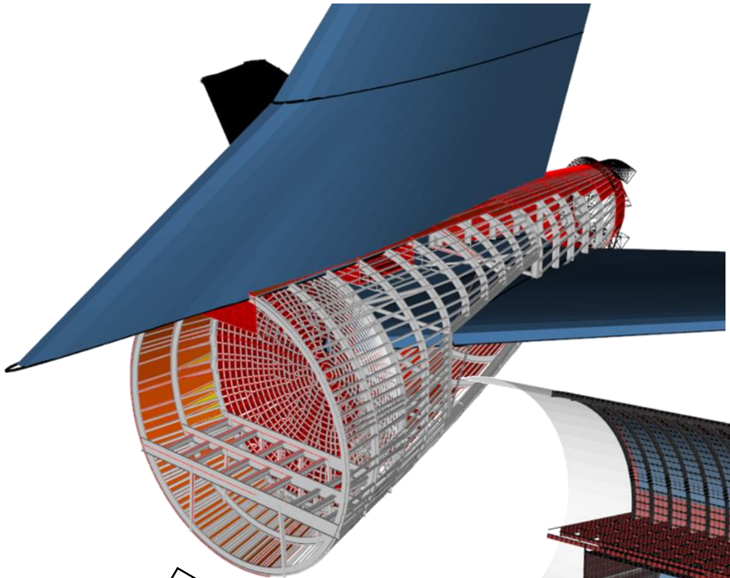


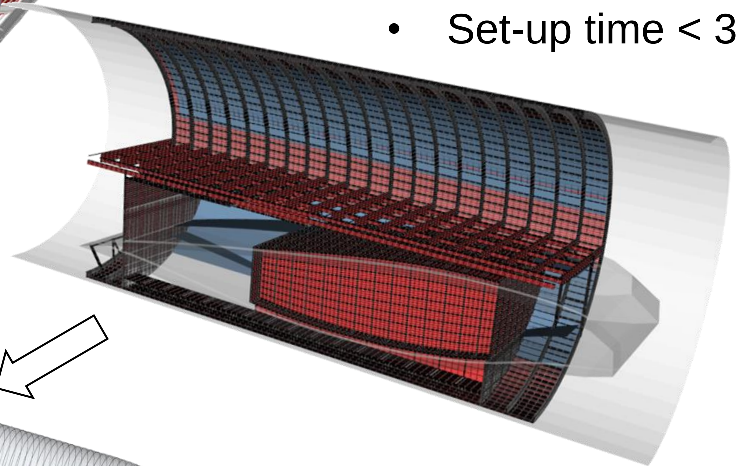
Rib holes (e.g. for maintenance)

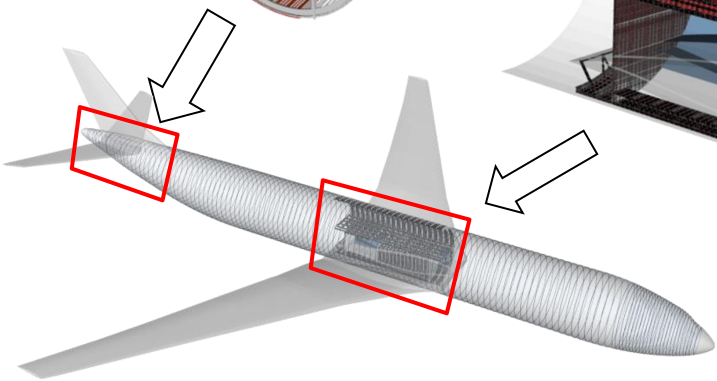
Structural Modelling – Fuselage Structure with PANDORA (BT)

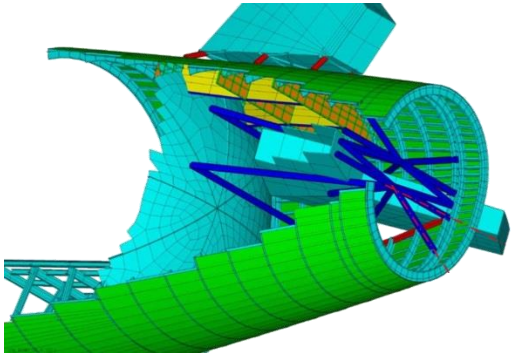


- Python based modelling tool
- Usage via scripting or a comprehensive GUI
- Provides fuselage models in various formats (incl. ANSYS, MSC NASTRAN, B2000++, …)
- Complex inner fuselage structure and detailed interfaces to wing and tail are included
- Set-up time < 3 min.





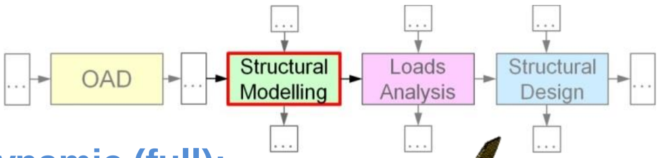




PANDORA also includes sizing algorithm
→ later more in „Structural Design“

DLR

Structural Modelling – Complete A/C with ModGen (AE)



Global Finite Element Model (GFEM/dynamic):

- For loads, aeroelastic, analysis and structural optimization

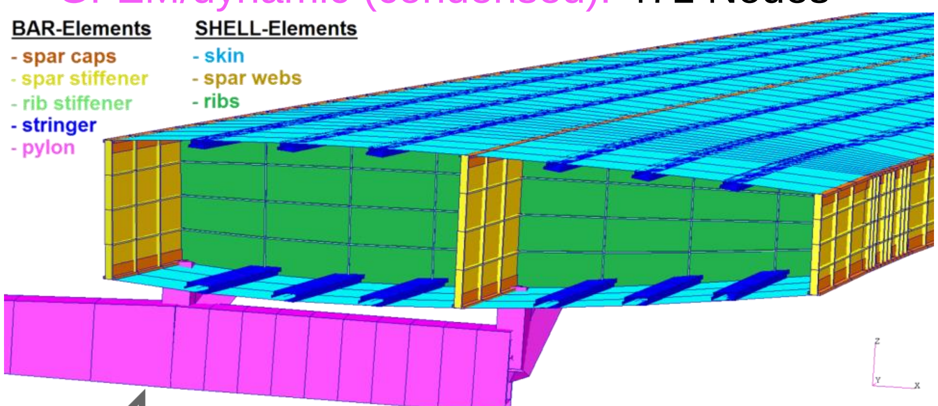
Fuselage stiffness

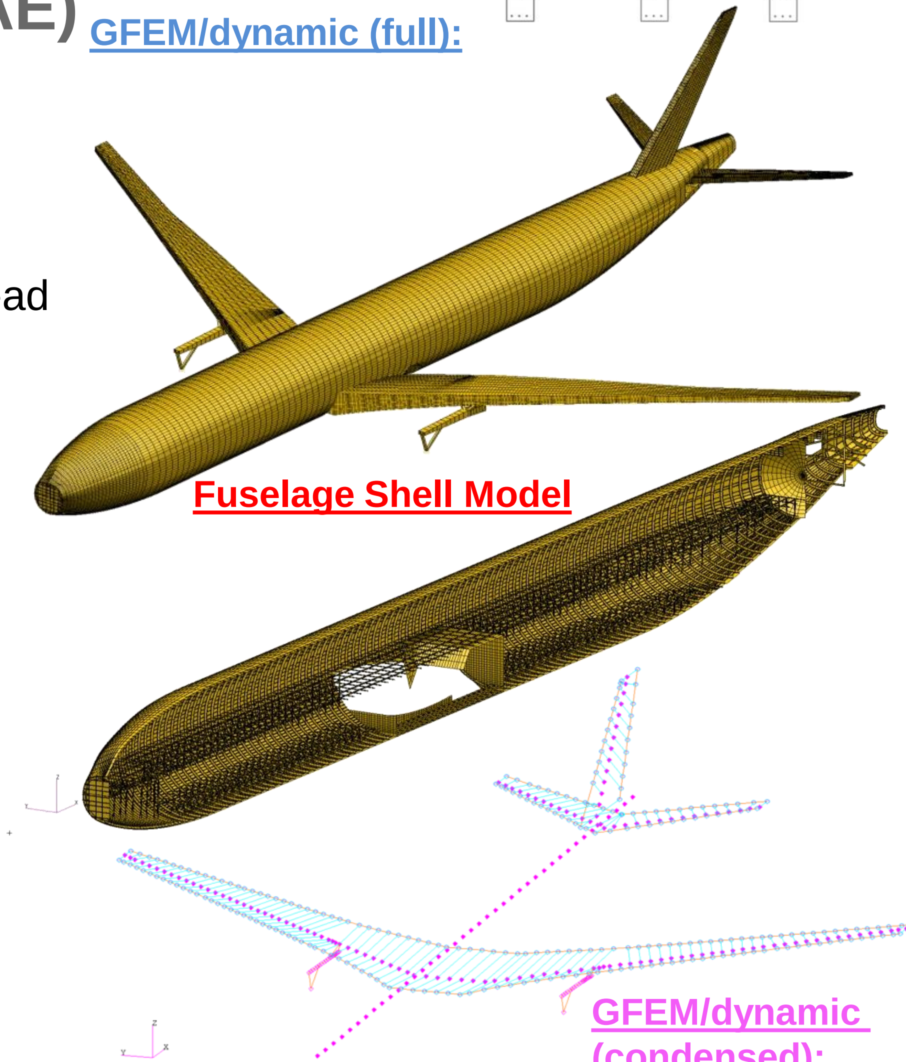
- Beam model preliminary sized / shell model ahead

Wing stiffness (topology):

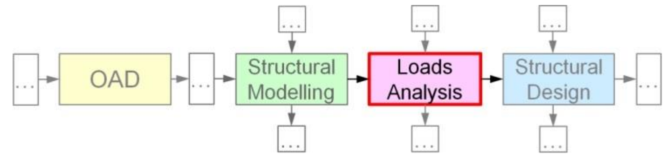
- Bar elements (stringer, spar caps, stiffener) preliminary sized
- Shell elements (spars, ribs, skin) for structural optimization and sensitivity analysis

GFEM/dynamic (condensed): 471 Nodes





Loads Analysis – Loads Process

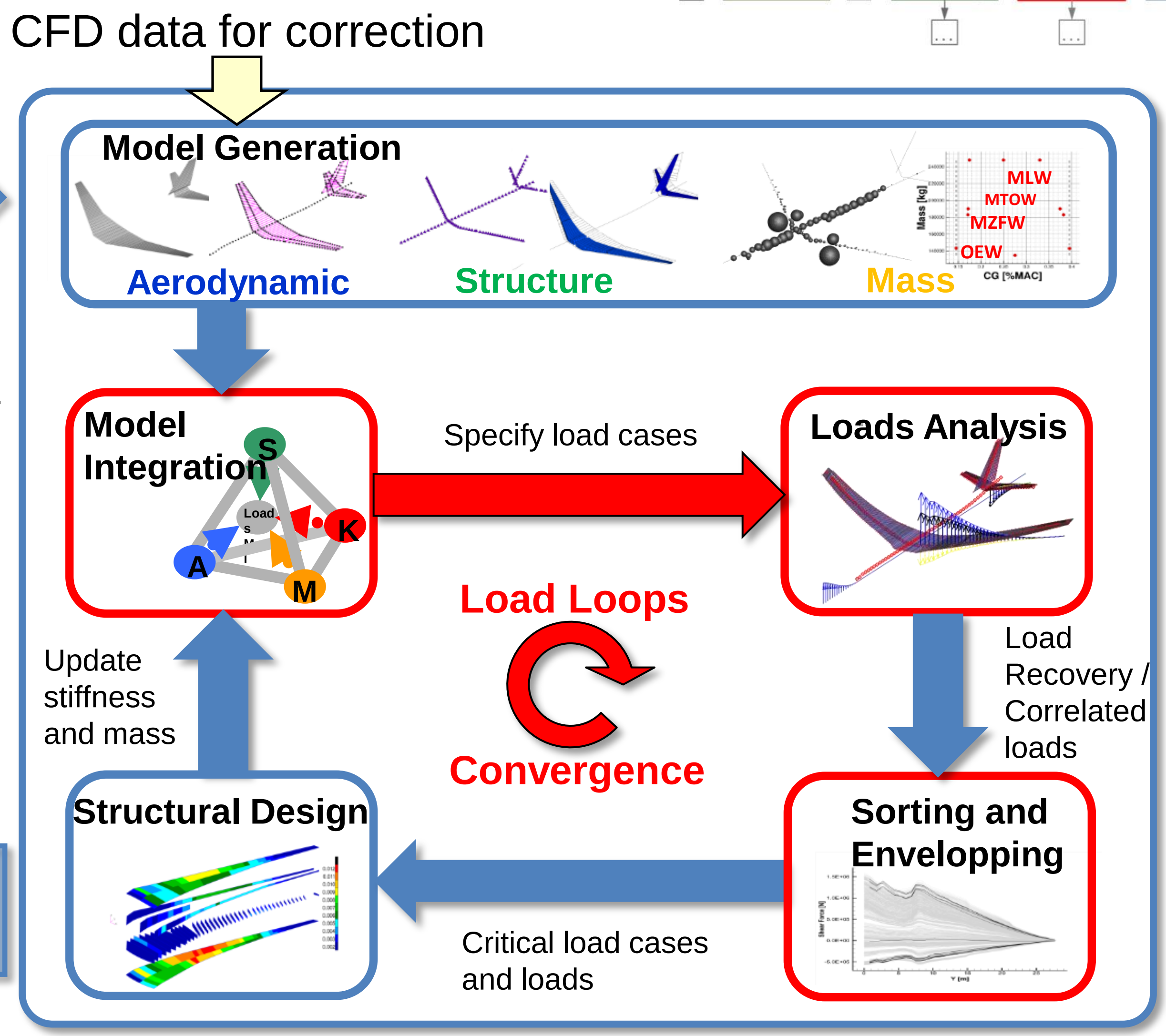


(Geometric) Design Variables

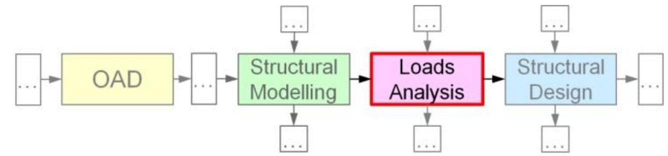
Number Load Cases:
In principle high number of load cases possible due to e.g.:

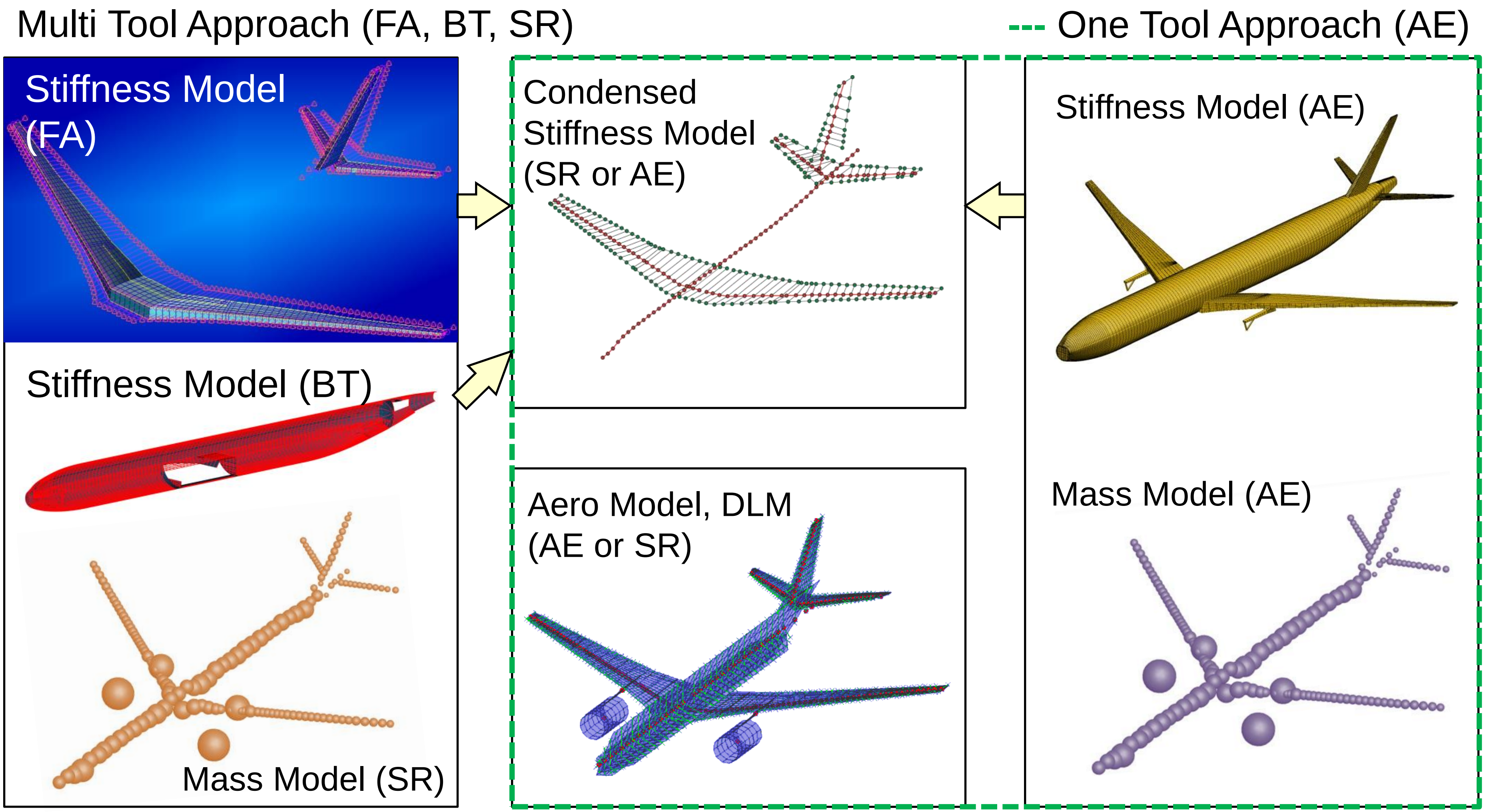
- various mass configurations
- various flight points
- gust conditions (according to CS25)

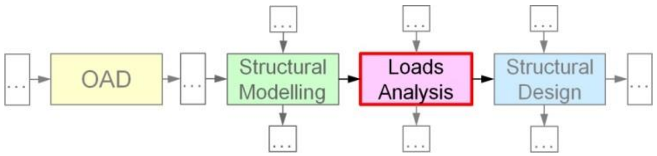
Sized Structure / Critical load cases and loads



Loads Analysis – Simulation Models





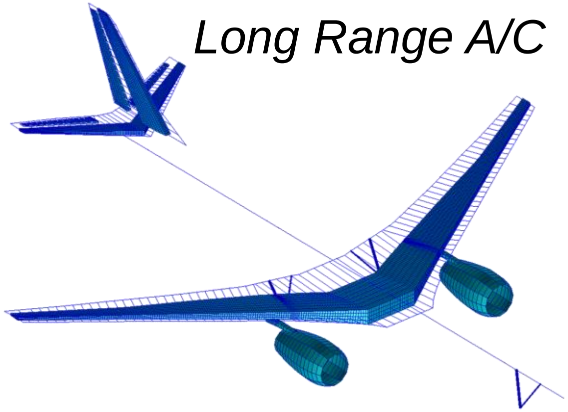


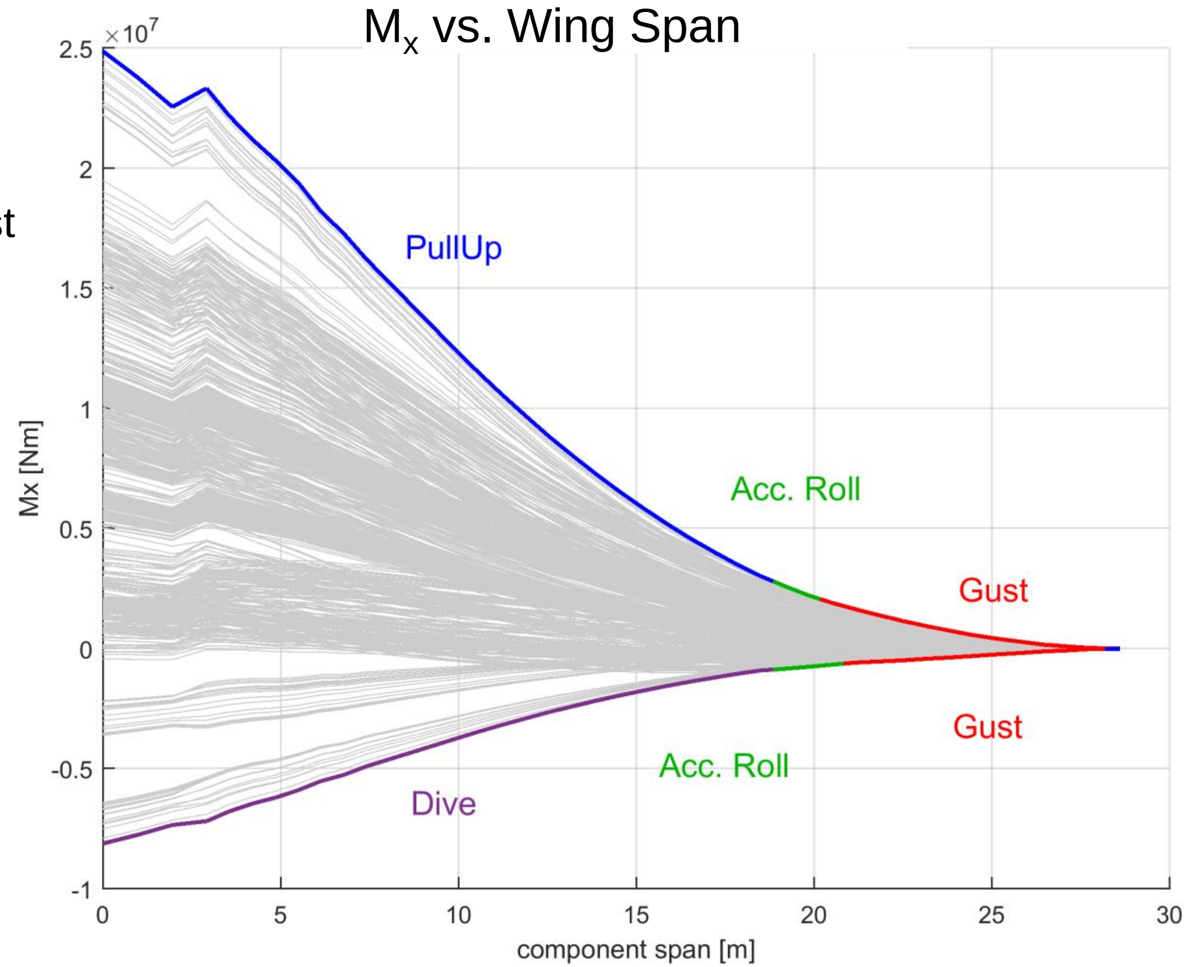
Loads Analysis – Results
Maneuver & Gust Loads(AE, SR)

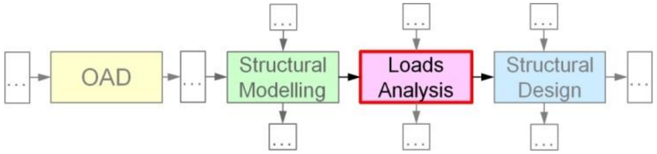
Wing Bending Moment (Mx):

- Pull Up & Push Down up to 2/3 span
- Accelerated Roll and Gust in last 1/3 span
- Dominant cases:
    - max. take off mass
    - cruise and diving speed
    - max. flight altitude

Long Range A/C

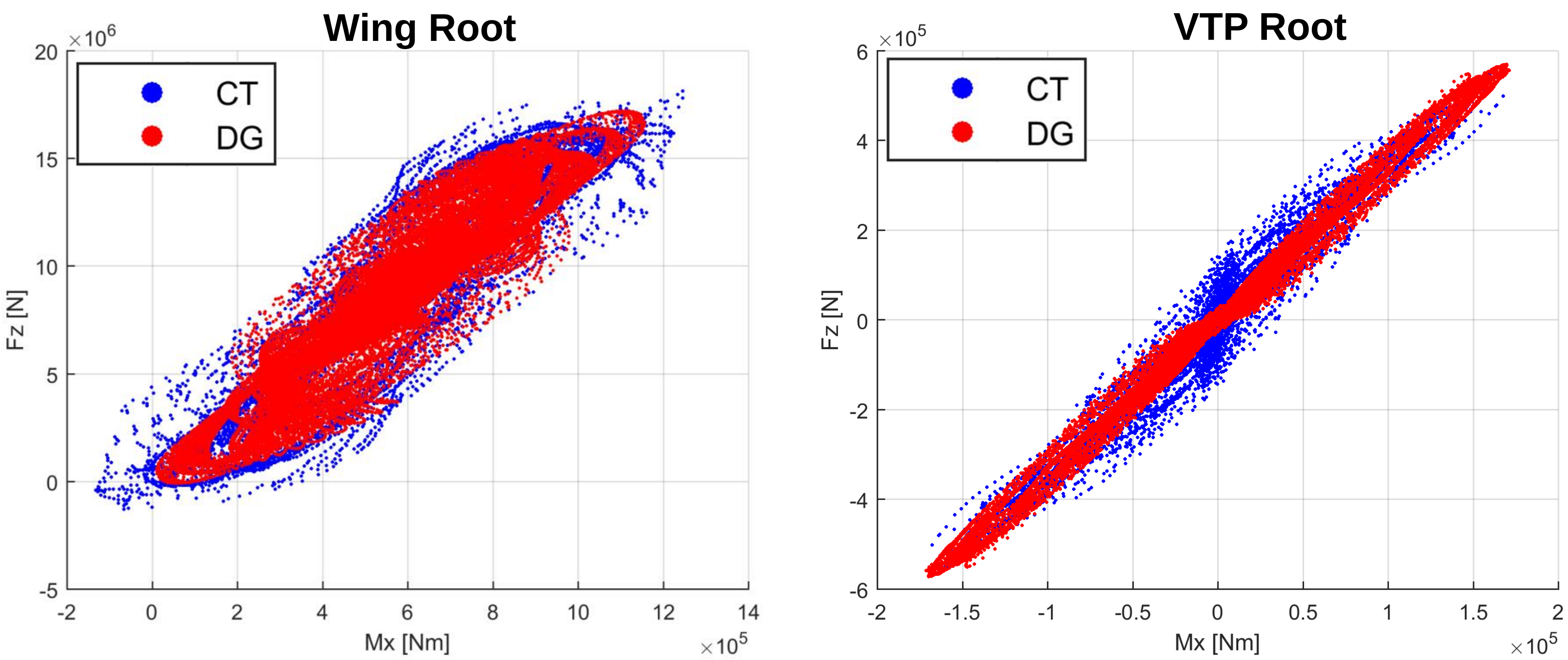




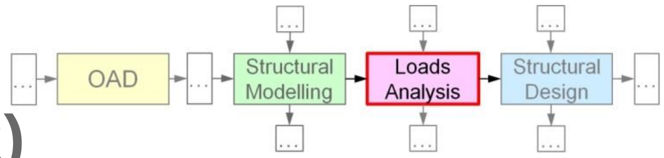


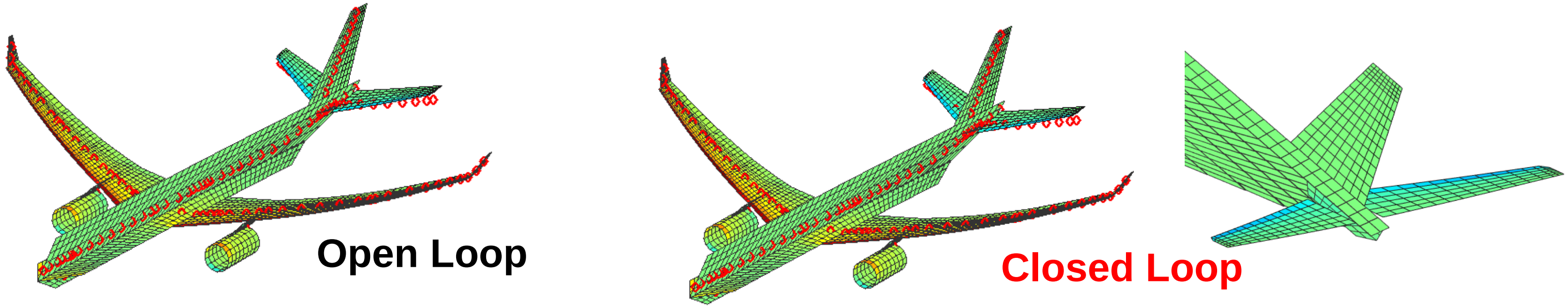
Loads Analysis – Results Continuous Turbulence (SR)

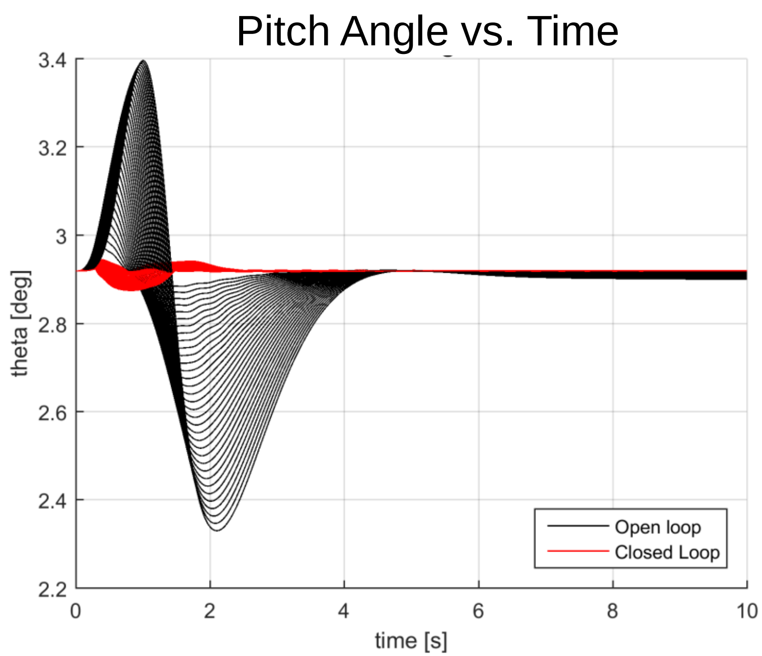
- Comparison continuous turbulence (CT) to discrete gust (DG) cases in a 2D-Envelope (wing root and VTP root)

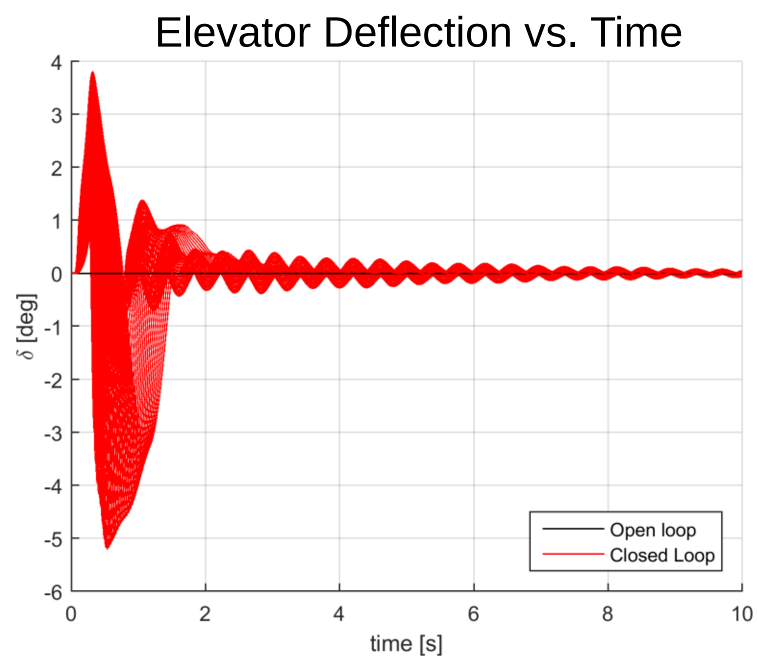


Loads Analysis – Results
Gust Loads with Flight Controller (SR)

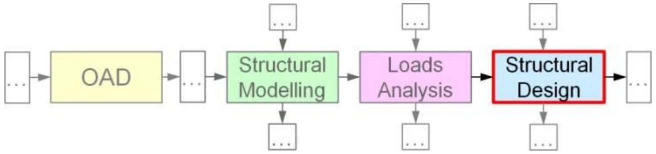








Structural Design – Task

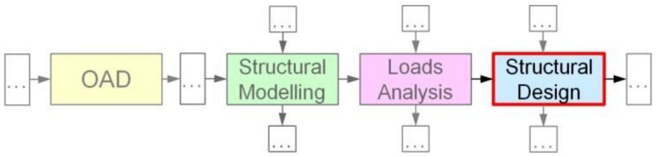


- Estimation of structural dimensions
- For carbon fibre material in addition material parameter, lay-up, layer orientation etc.
- Consideration of design loads (number of considered load cases depend on the objective of the structural design and the capabilities of the design method
- Consideration of various constraints: stress, strain, buckling, aileron efficiency
- Consideration of manufacturing constraints (e.g. min. thickness, transition between different lay-ups/thickness)

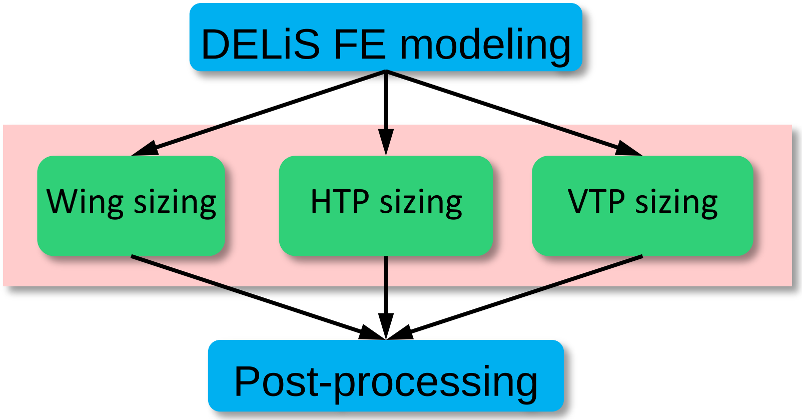
→ **Two basic approaches:**

1. Sizing methods based on fully stressed design concept (BT, FA)
2. Gradient-based structural optimization methods (AE, FA)

Structural Design – Wing Sizing DELiS / S-BOT (FA)



- Fully-stressed design approach
- Use of preselected subset of load cases (only critical load cases)
- Parallel sizing of wing components
- Performance (S-BOT): 8h for 17 iterations

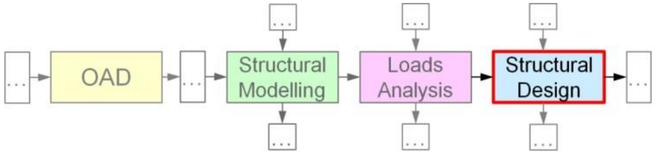


Further improvements by using new sizing tool from BT (next slides)

Further developments:

- Beam based preliminary sizing module in DELiS
- Preliminary sizing step before FE based sizing)

Structural Design – Fuselage PANDORA Framework (BT)

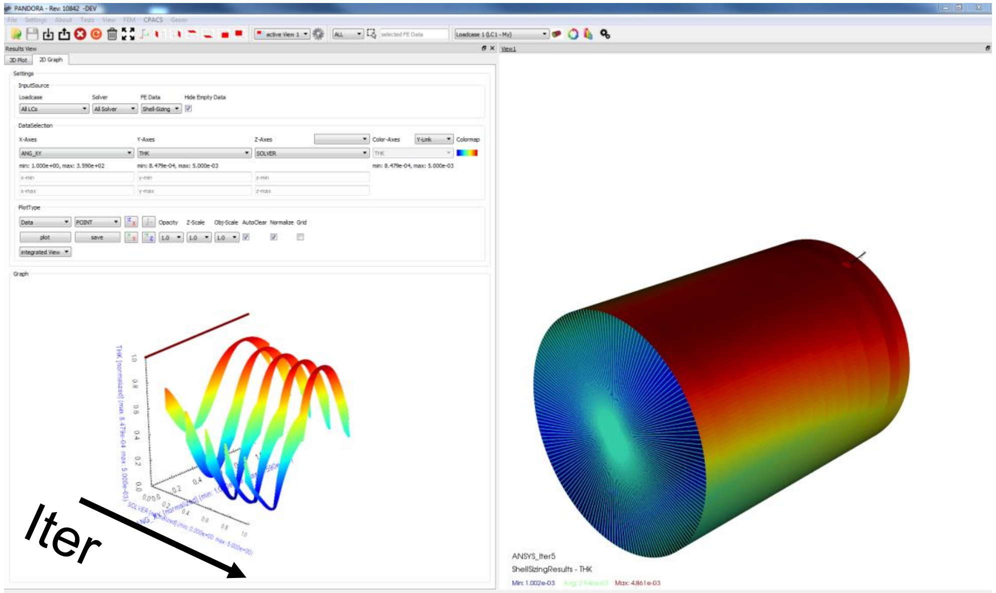


Objective

- Development of a fast and flexible sizing module fe_sizer within PANDORA
  - FE solver independent
  - Flexible algorithm to add additional sizing criteria

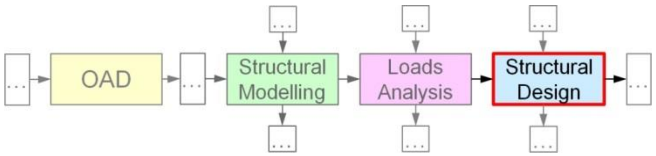
Status

- Usage via scripting or GUI
- Transfer of strength and buckling criteria from predecessor tool S-BOT+
- Connection to various solvers
  - ANSYS, MSC Nastran
  - Open Source solvers (e.g. B2000++) to be added, soon

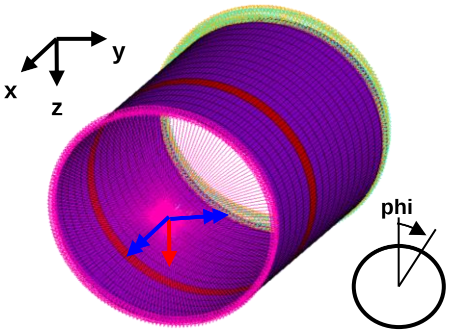


Exemplary sizing of a fuselage barrel

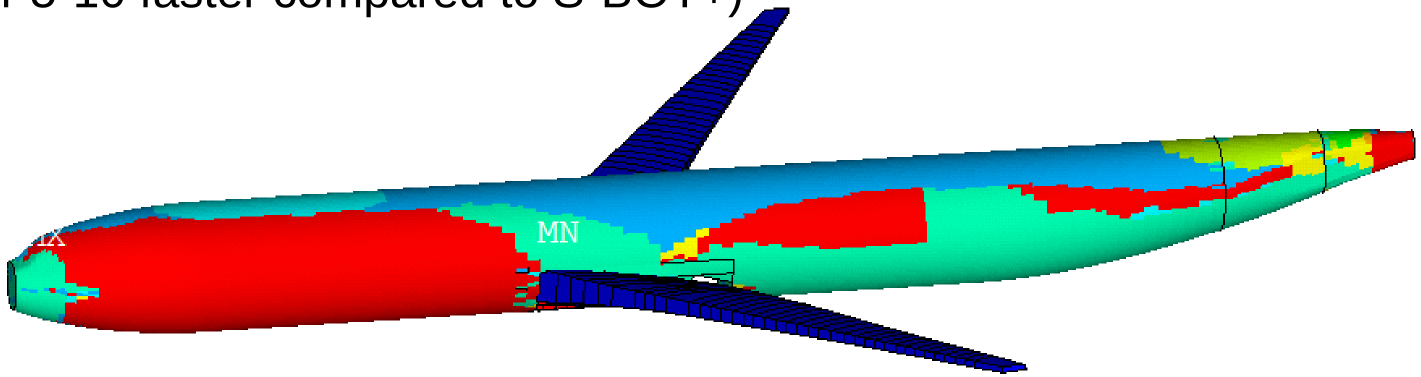
Structural Design – Fuselage PANDORA Framework (BT)



- Validation according validation plan in progress
  1. Generic **fuselage barrel** (analytical results available)
     ➔ Good correlation

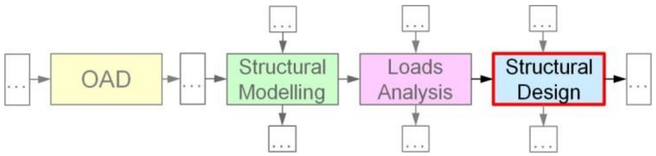


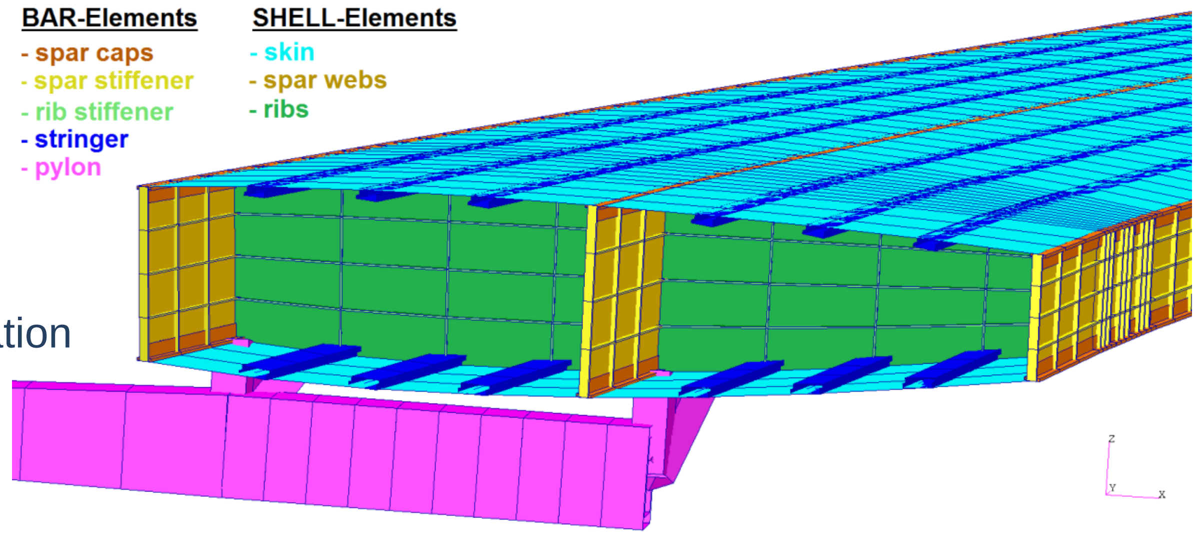
  2. Long range a/c fuselage model benchmark
     (17 Load cases, 3 Iterations)
     ➔ Detailed analysis of results ongoing
     ➔ Significant reduction of computing time
     (Factor 5-10 faster compared to S-BOT+)



Critical Loadcases for fuselage panels

Structural Design – Gradient-based Structural Optimization (AE)





Preliminery Sizing (ModGen):

- Fuselage beam
- Wing bar elements (stringer, spar caps, stiffener)

Design variables:

- Thickness (Al, CFK) and lamination parameter (CFK) of the skin, ribs and spars *(optimization regions)*

Constraints:

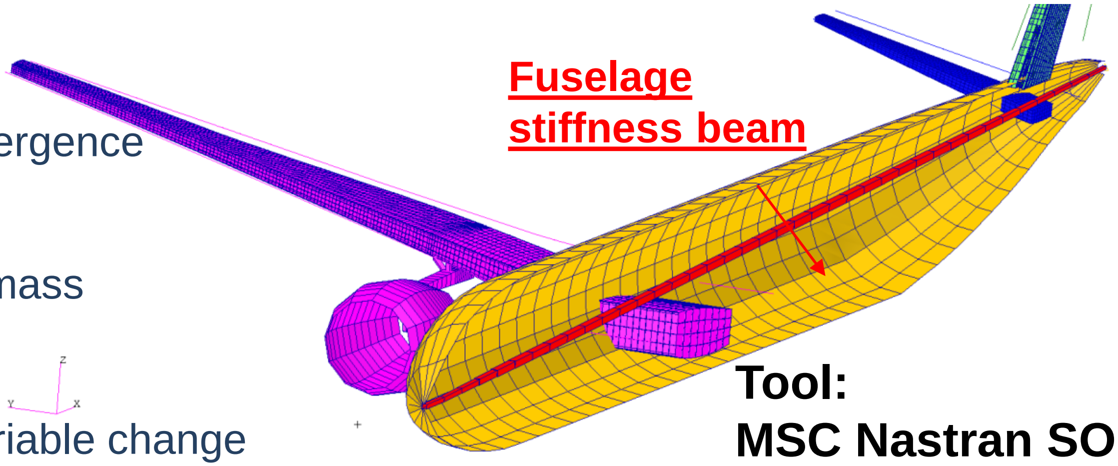
- Stress, strain, buckling, control surface efficiency, divergence

Objective function:

- Minimization of the wingbox mass

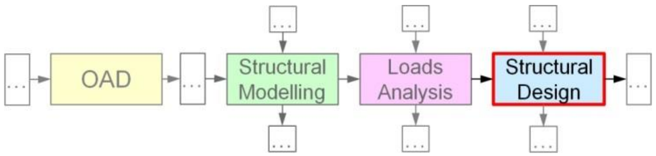
Convergence criteria:

- Relative mass and design variable change



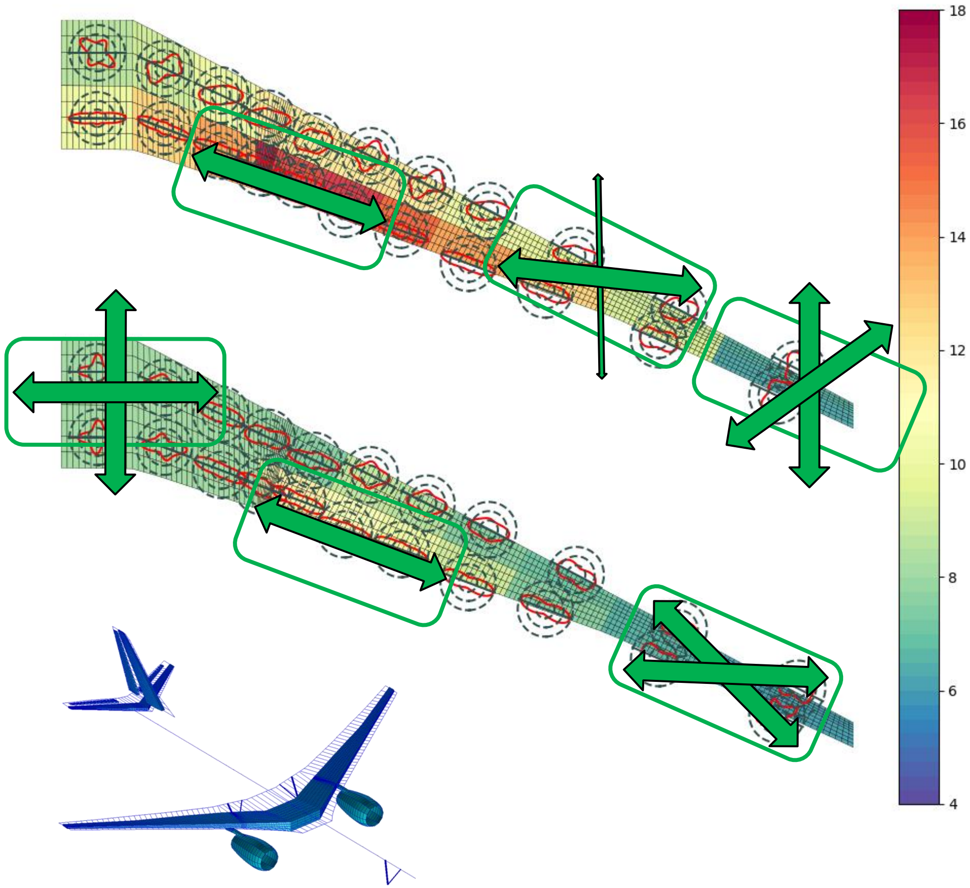
Tool: MSC Nastran SOL200

DLR

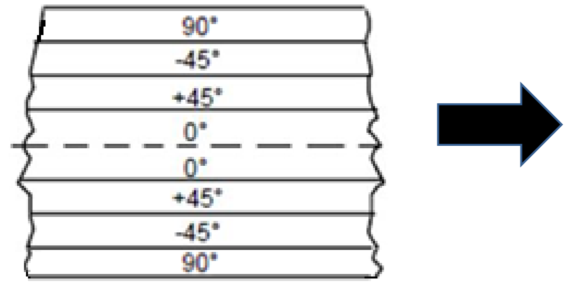


Structural Design – Structural Optimization of Composites (AE)

Primary wing structure long range a/c



Formulation of lay up with lamination parameters V

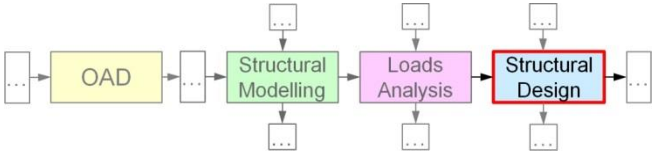


$$V^{*A,D}_{[1,2]}, T$$

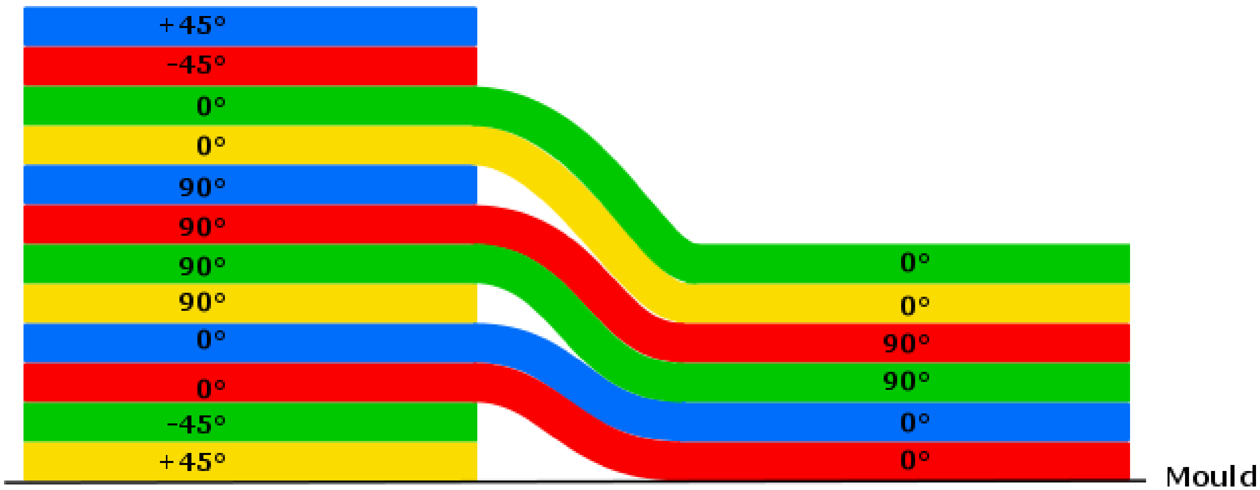
- Continuous optimization result with maximum strain criterion
- Failure criteria constraints: strength and buckling
- Manufacturing constraints: minimal thickness, blending
- Objective: min. wing box mass

DLR

Structural Design – Manufacturing Constraints (FA)



Transition of lay-ups with different thickness



Quantification

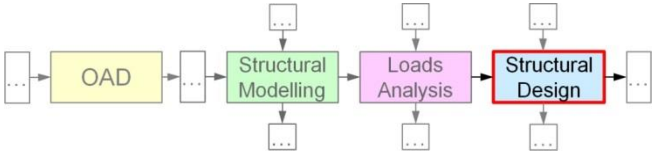
- Based on approaches for layer continuity (Liu) and blending (Adams)

Approach based on convex hull

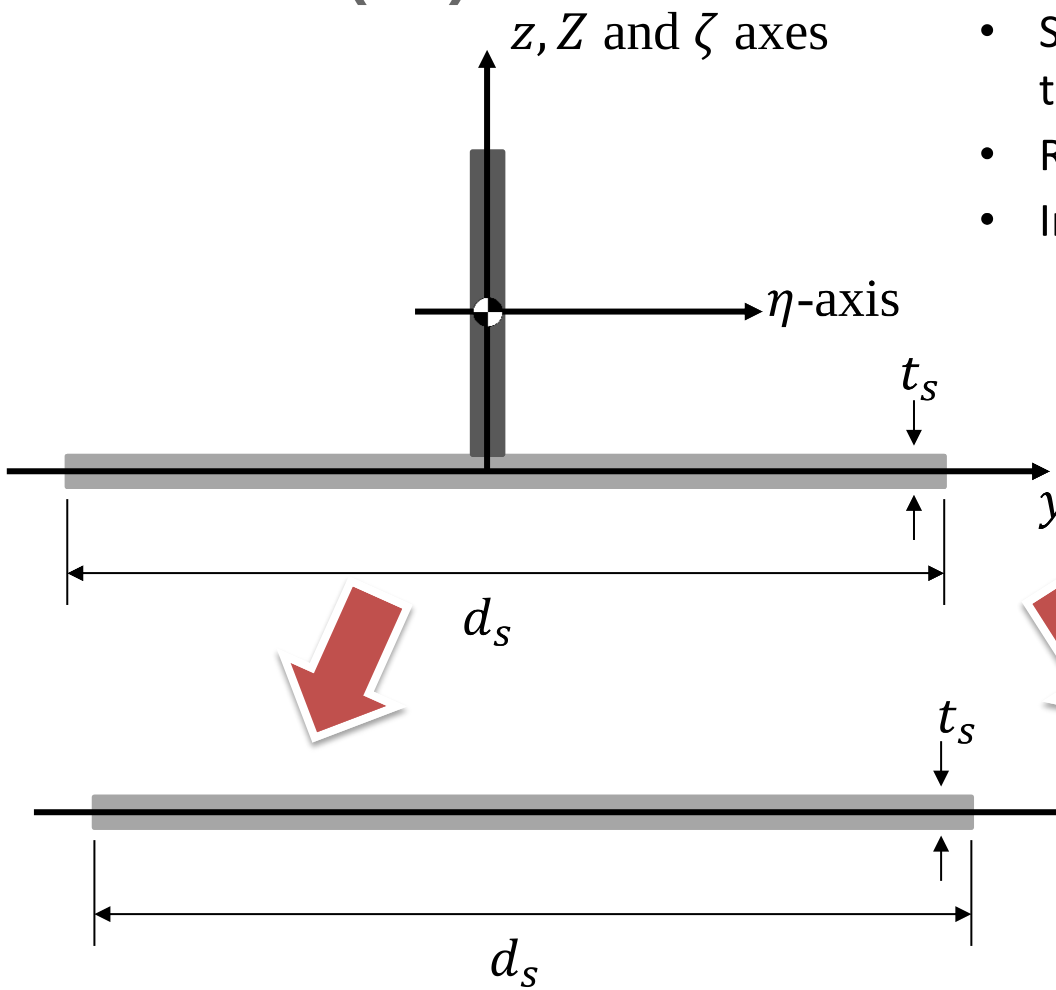
- Constraint:

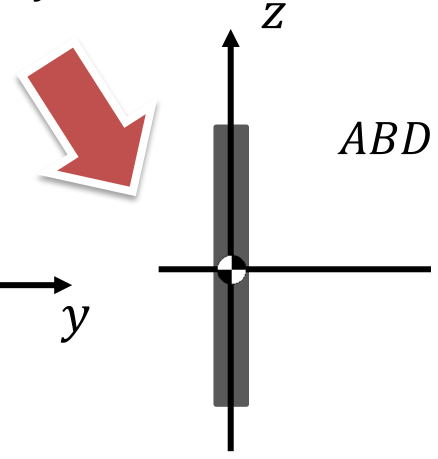
$$h_1\Delta V_1^{*A} + h_2\Delta V_2^{*A} + h_3\Delta V_1^{*D} + h_4\Delta V_2^{*D} + h_5 \leq 0$$

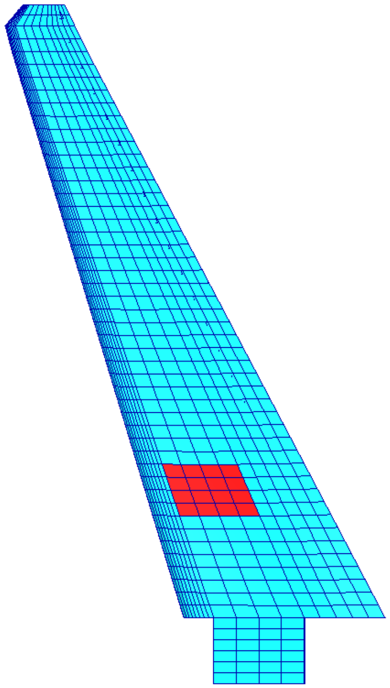
Structural Design – Smeared Stiffener (FA)



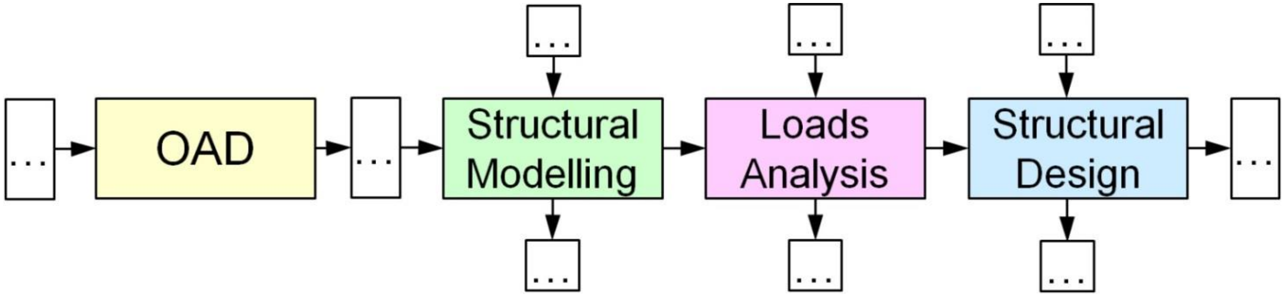
- Stiffener structure necessary to increase buckling stability
- Reduction of mass $\Delta_m \approx 20\%$
- Influence on global stiffness







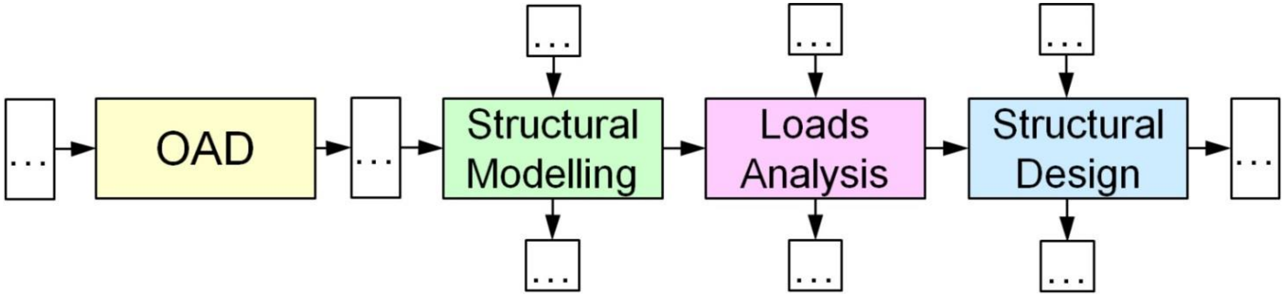
Summary and Outlook



- Various tools and methods for OAD, structural modelling, analysis, and optimization, and loads analysis were developed and successfully applied
- Individual concepts of the MDO processes + individual focal points of the DLR institutes lead to various approaches (e.g. structural modelling and design)
- Successful collaboration of DLR institutes for complement solutions (e.g. loads analysis, structural modelling)

Next Steps:

- Further development of specific and constantly improvable tools and methods
- Adaptations due to individual MDO process requirements are on going
- Full integration and application of disciplinary tools within the VicToria MDO processes



Many thanks for your attention!