VARIOUS DESIGN AND ANALYSIS TASKS FROM CONCEPTUAL AND PRELIMINARY DESIGN APPLIED TO THE SMR AIRCRAFT CONFIGURATION DLR-D2AE

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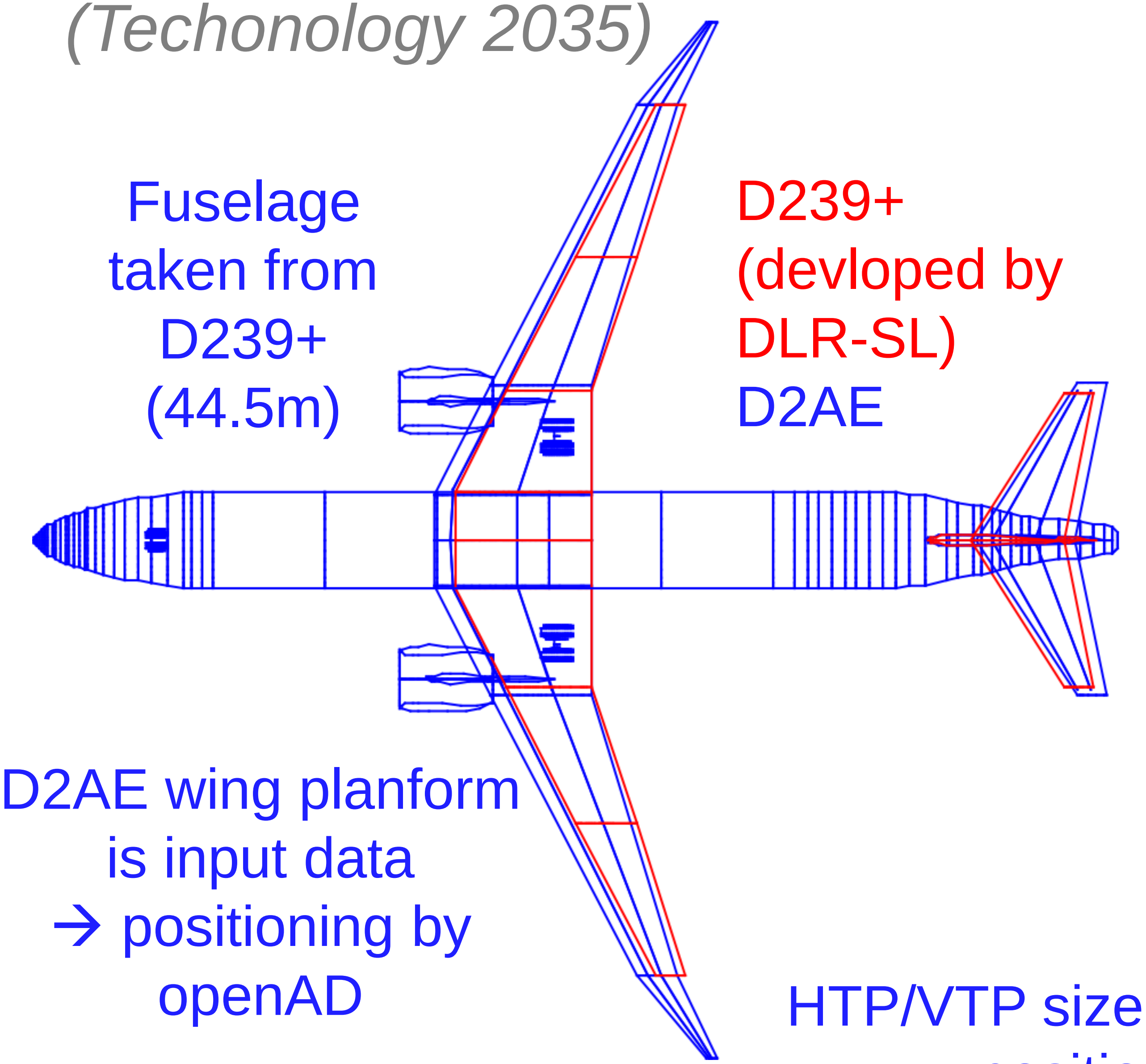
Overview

- The D2AE configuration
- DLR-AE/LAE aeroelastic design group capabilities
  - Conceptual Design Loads
  - Parametric modelling for the fuselage structure
  - Aeroelastic design process cpacs-MONA
  - Composite structural optimization
  - Non linear structural analysis
- Summary and outlook

D2AE Configuration – SMR Configuration for 239 PAX

(Techonology 2035)



Fuselage taken from D239+ (44.5m)

D239+ (devloped by DLR-SL)

D2AE

D2AE wing planform is input data

→ positioning by openAD

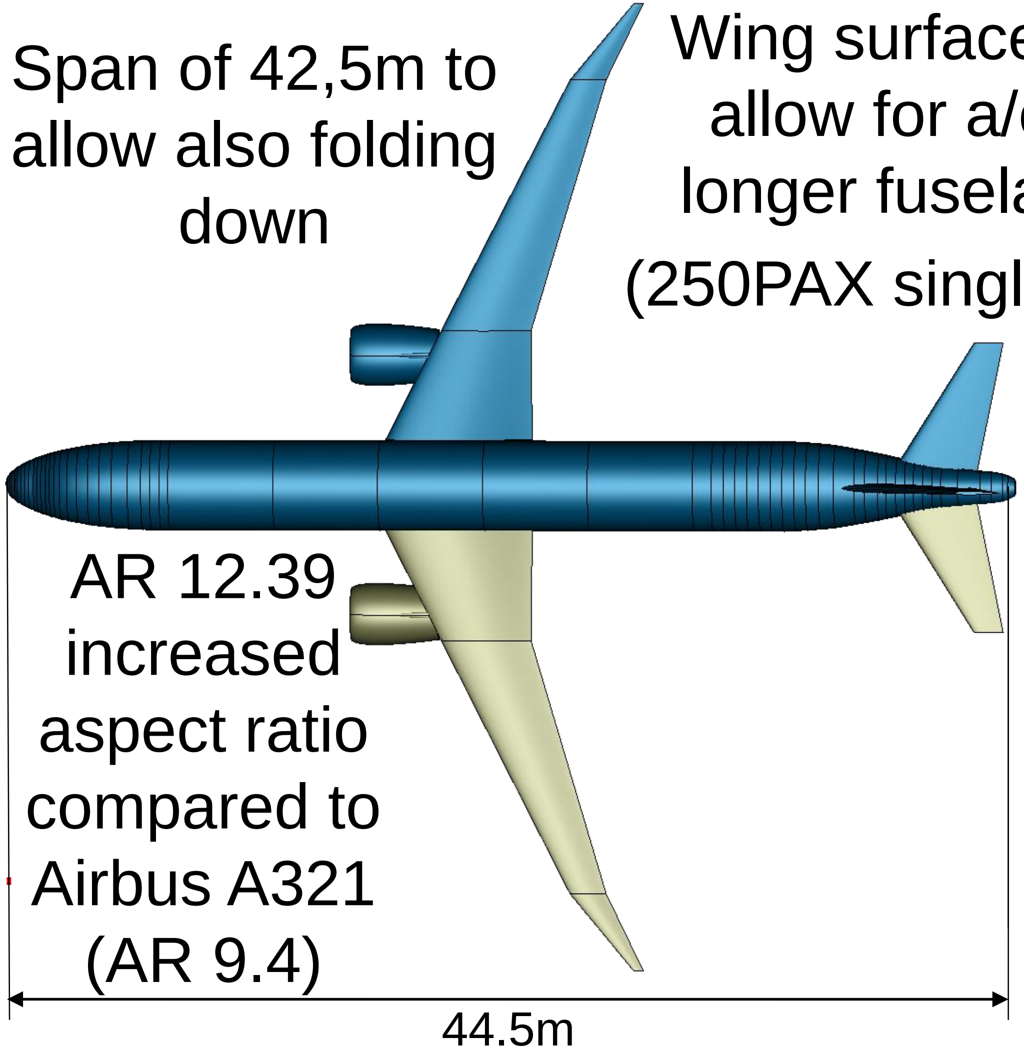
TLARs D2AE

Design Range	[nm]	2500
Design PAX (single class)	[-]	239
Mass per PAX	[kg]	95
Design Payload	[kg]	25000
Max. Payload	[kg]	25000
Cruise Mach number	[-]	0.78
Max. operating Mach number	[-]	0.8
Max. operating altitude	[ft]	40000
TOFL (ISA +0K SL)	[m]	<2200
Rate of Climb @ TOC	[ft/min]	>300
Approach Speed (CAS)	[kt]	136
Wing span limit	[m]	42.5
Alternate Distance	[nm]	200
Holding Time	[min]	30
Contingency	[-]	3%

HTP/VTP size and position, and landing gear position estimated by openAD

Results openAD – View of the D2AE Configuration

(CPACS Visualization with TiGL Viewer)

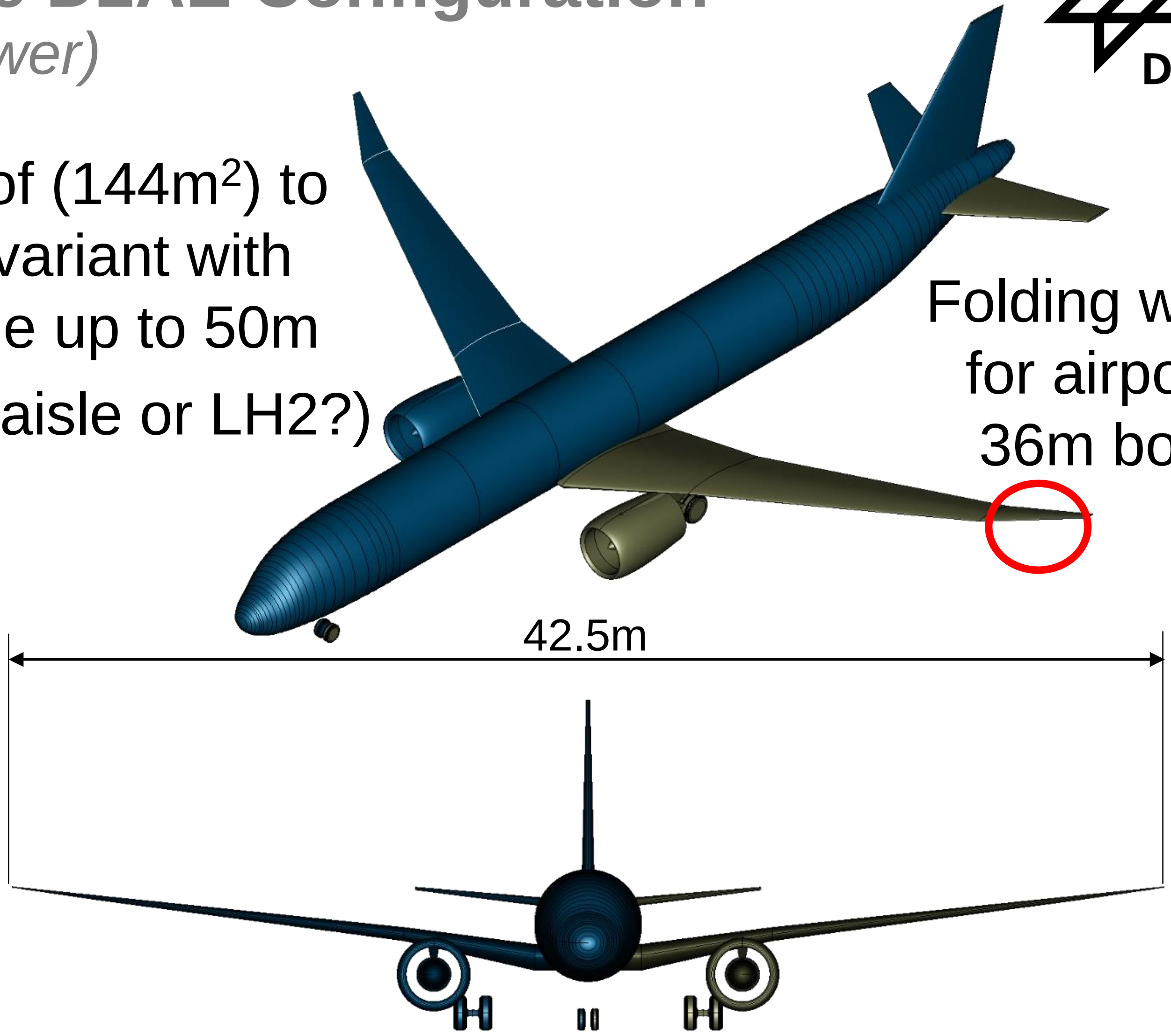


Span of 42,5m to allow also folding down

Wing surface of ($144m^2$) to allow for a/c variant with longer fuselage up to 50m

(250PAX single aisle or LH2?)

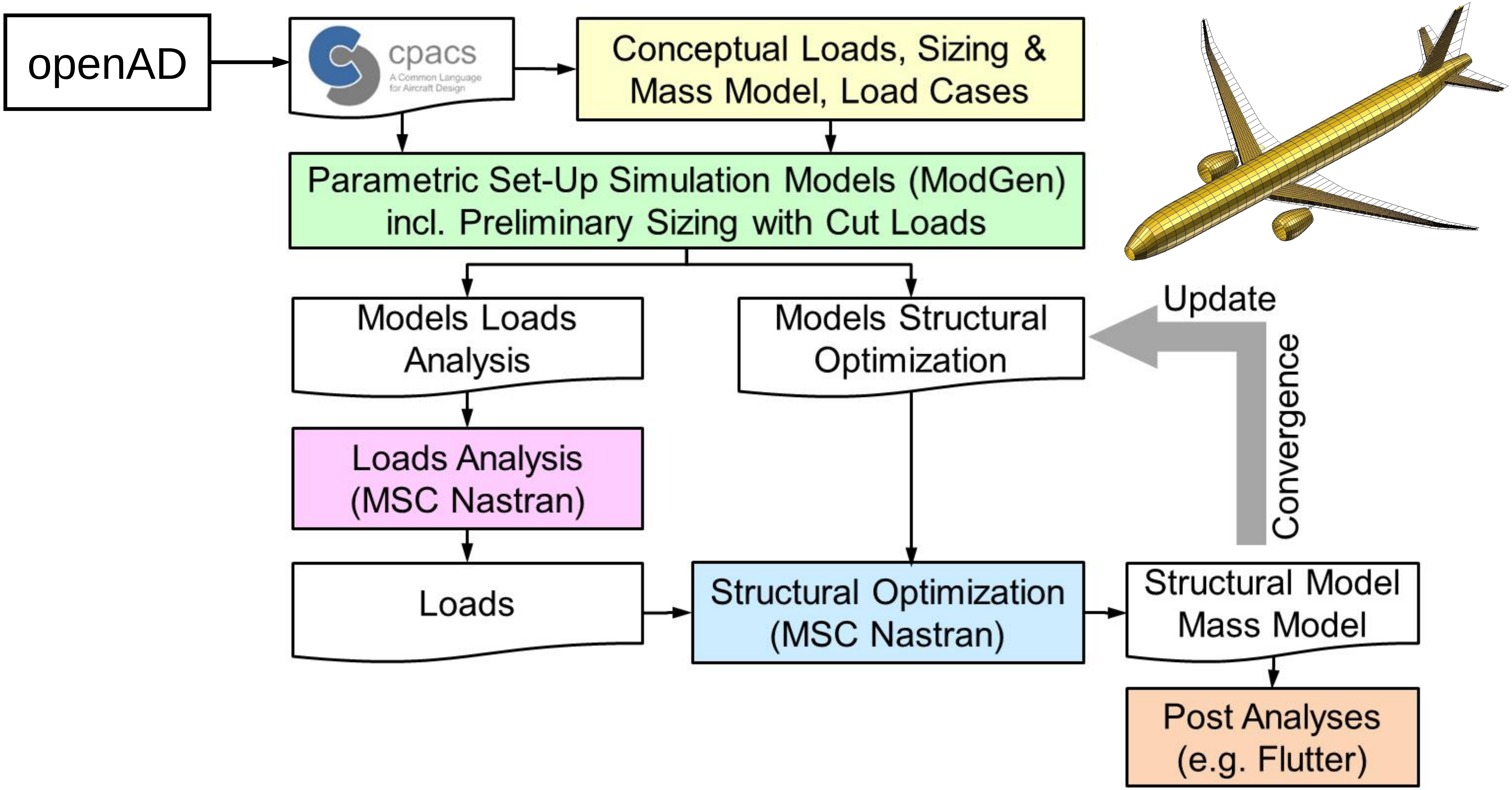
AR 12.39 increased aspect ratio compared to Airbus A321 (AR 9.4)



Folding wing for airport 36m box

Root chord enlargement to keep main landing at the wing

cpacs-MONA – Parametric Aeroelastic Design Process



Resulting Data cpacs-MONA

- Various loads for the complete aircraft (conceptual and preliminary)
- Mass estimation for aircraft components
- Structural model as finite element model for the complete aircraft (MSC Nastran)
- Detailed Mass model available for various mass configurations
- Aerodynamic Model as Doublet Lattice model (correction parameters implemented, e.g. camber data, fuselage correction)

DLR-AE/LAE Aeroelastic Design Group Capabilities

- Conceptual Design Loads
- Parametric modelling for the fuselage structure
- Aeroelastic design process cpacs-MONA
- Composite structural optimization
- Non linear structural analysis

➢ Applied to the D2AE configuration

➢ Basis D2AE openAD CPACS-Dataset and cpacs-MONA results

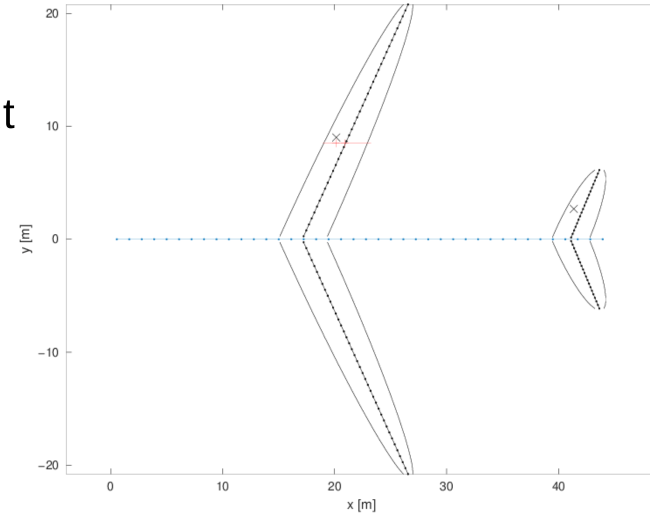
Conceptual Design Loads

Background

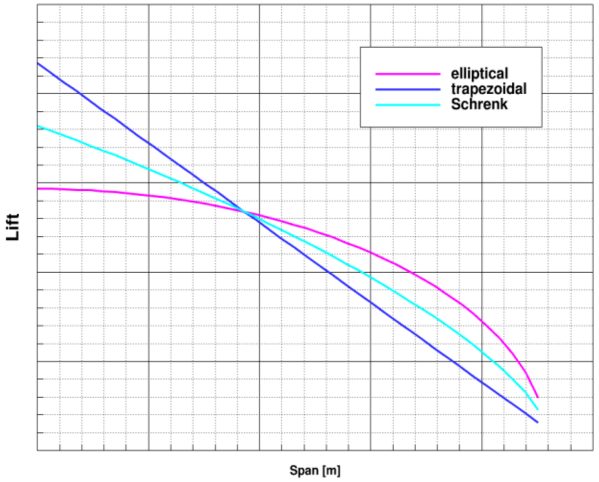
Fast and simple flight loads estimation with minimal input

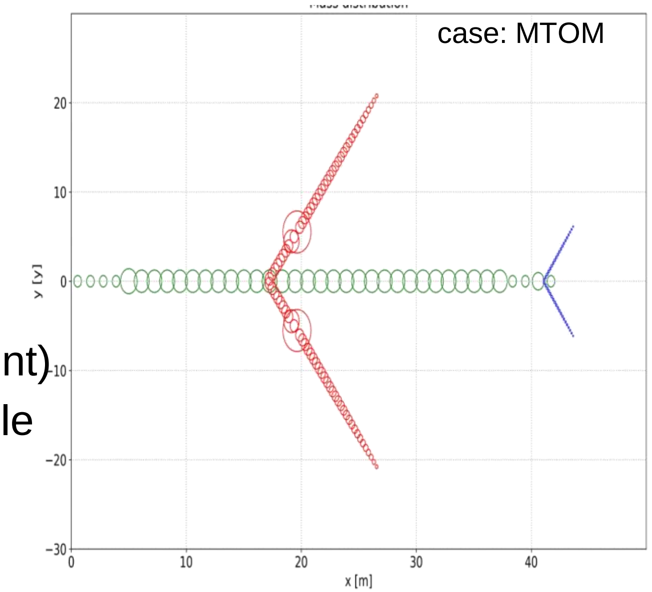
- Set up of simple geometry model – rigid
  - Example – elliptical chord distribution
  - ➢ Resulting lift distribution is elliptical
  - ➢ Other lift distributions: trapezoidal and Schrenk (combined)
- Set up of simple mass model OEM, MZFM, MTOM
  - Point masses (e.g. engines)
  - Line related masses (e.g. fuselage)
  - Area related masses (e.g. wing)
  - Volume related masses (e.g. fuel)
- Set up of load cases (CS25) and resulting load factor (quasi-static)
  - Manoeuvre loads 2.5g Pull-up -1g push-down with EAS speed (altitude independent)
  - Gust loads according to Pratt – additional load factor (in CS23, for CS25 acceptable in conceptual design)
- Sum of loads for aerodynamics and inertia loads → nodal and cut loads

Simple geometry



lift distributions

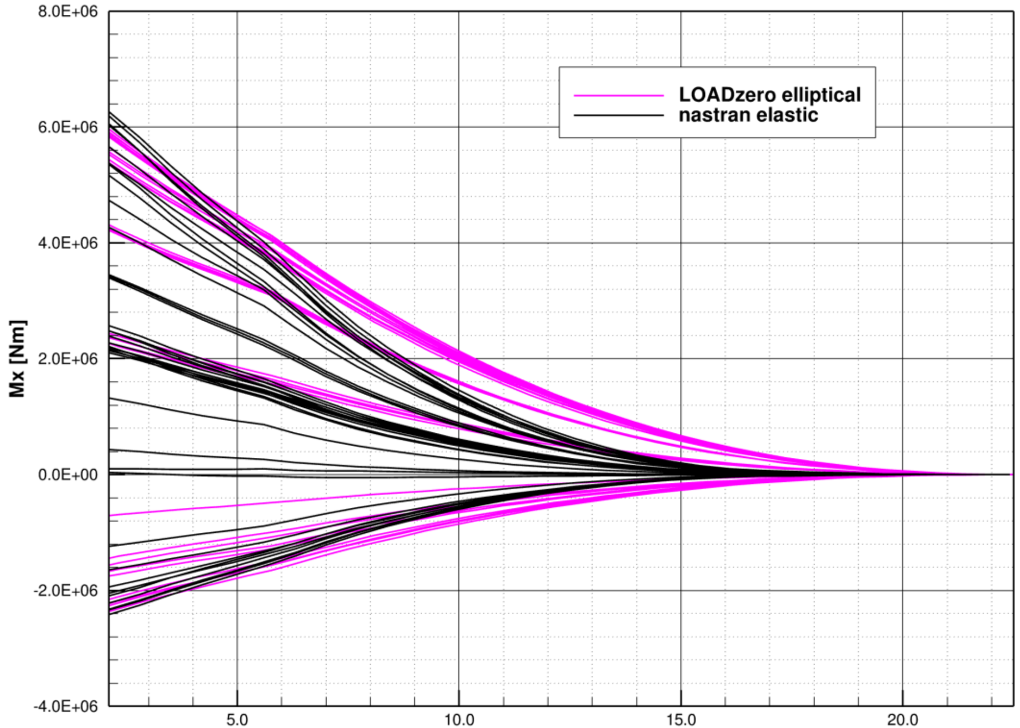




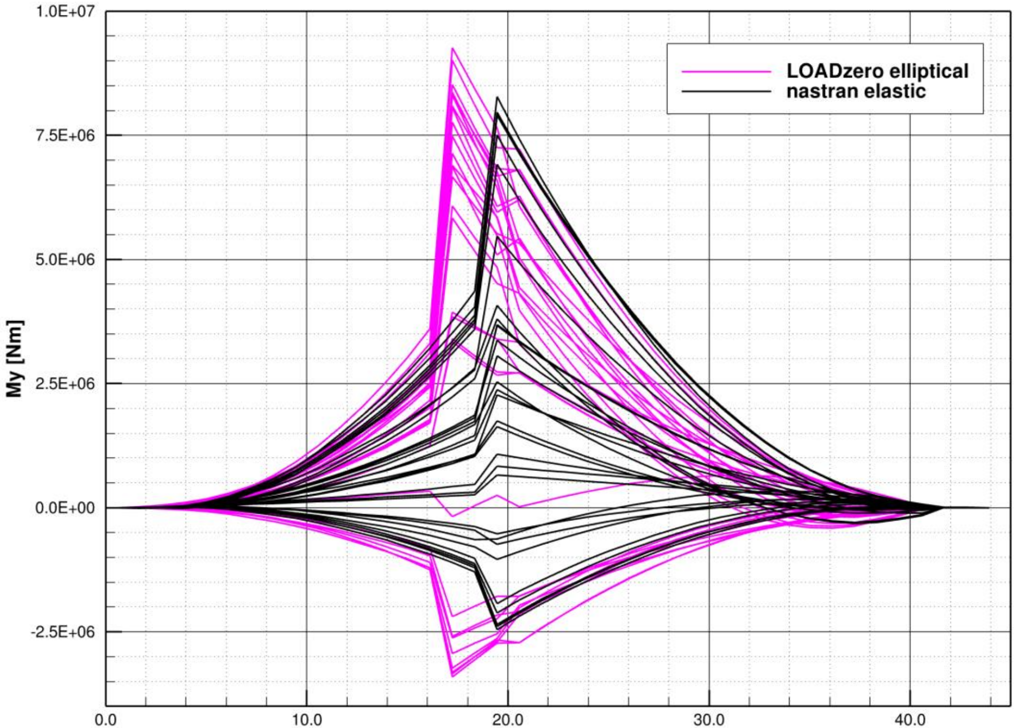
Conceptual Design Loads

- Comparison conceptual loads with cpacs-MONA loads

Wing



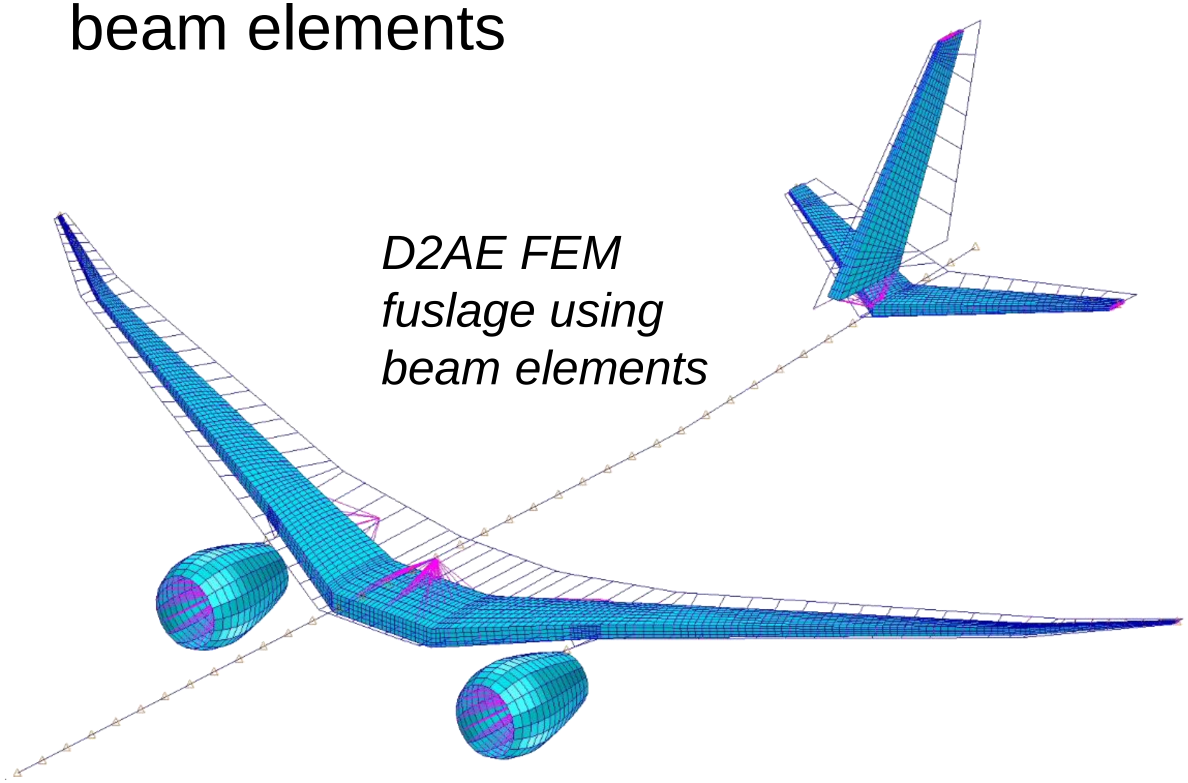
Fuselage



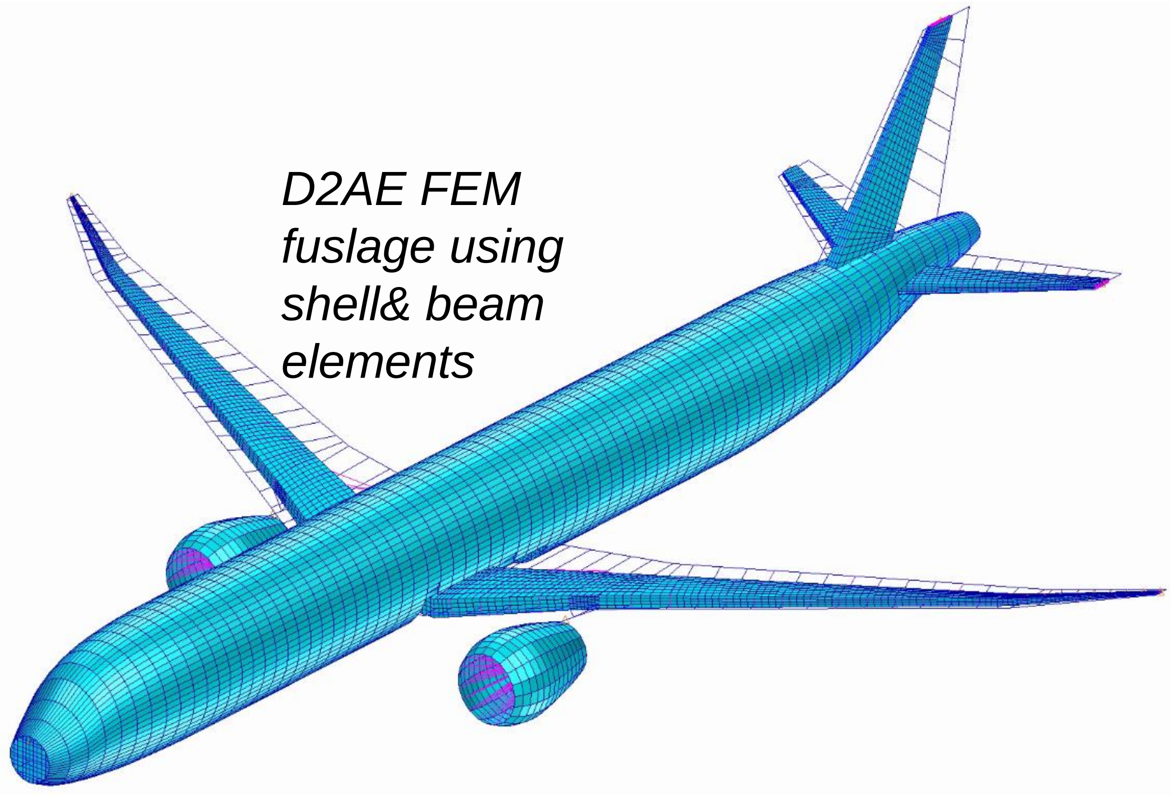
➢ Overall good agreement at a conceptual level

Parametric modelling for the fuselage structure

- CPACS allows for a detailed structural description also for the fuselage
- Further development of ModGen to generate fuselage fems with shell and beam elements



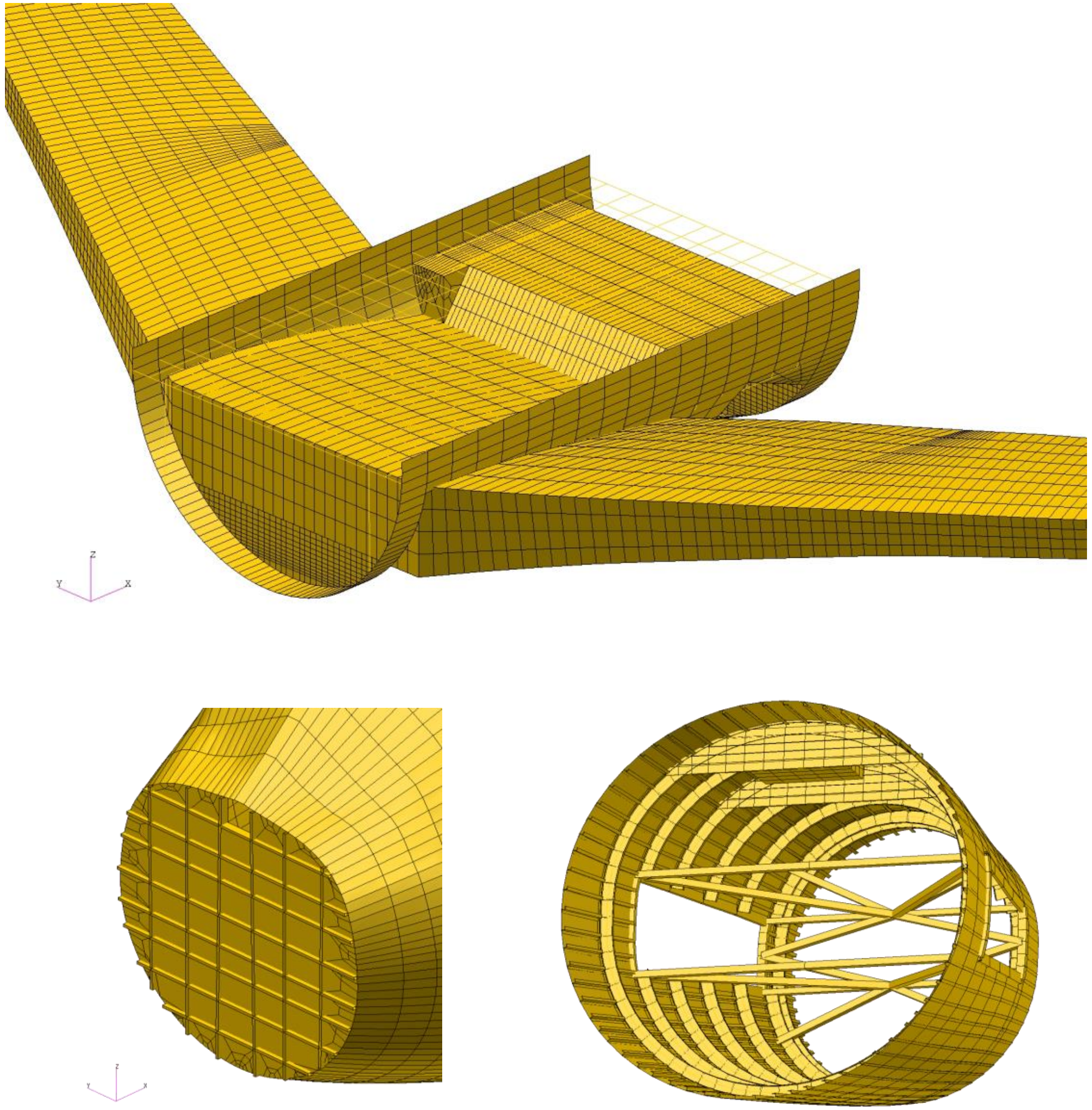
D2AE FEM fuslage using beam elements



D2AE FEM fuslage using shell& beam elements

Parametric modelling for the fuselage structure

- Details of structural description
- Advantages
    - More realistic wing/fuselage integration
    - HTP and VTP integration
    - Loads transfer more realistic especially for landing loads
    - Better distributed mass estimation and modelling
    - More realistic stiffness and dynamic characteristics
- Structural optimization methods already predeveloped

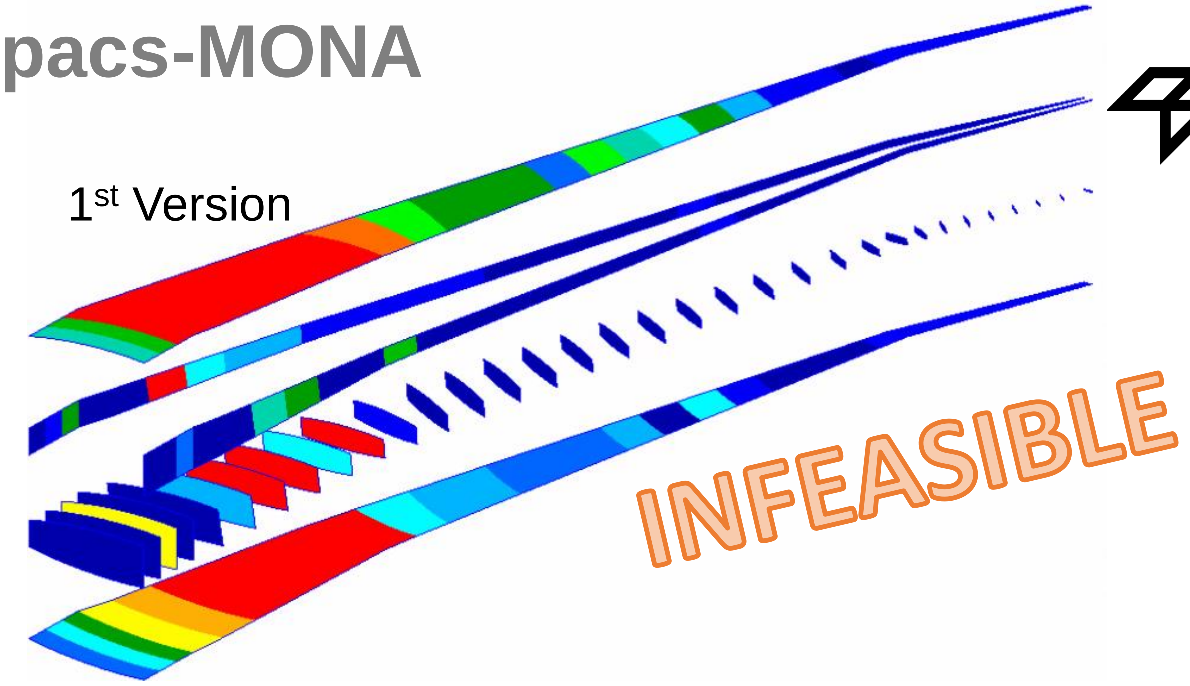


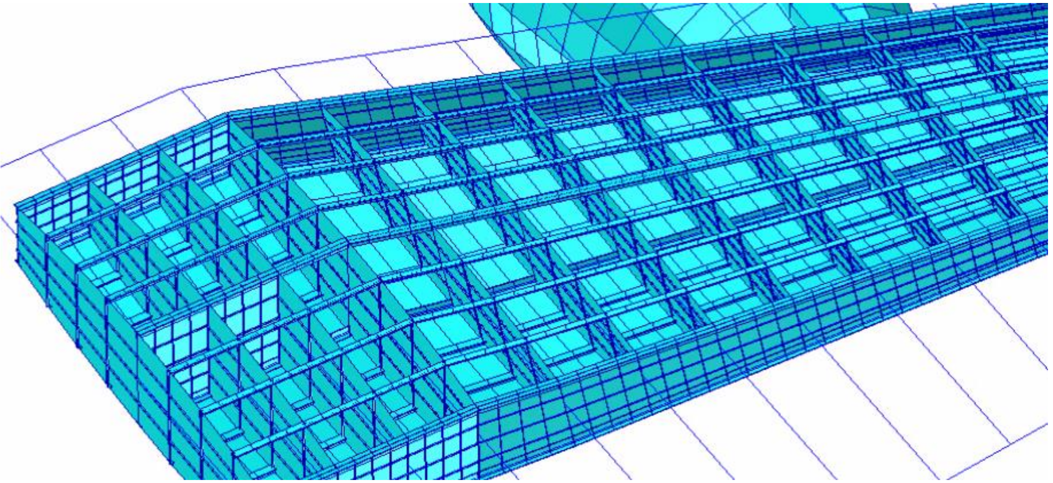
Aeroelastic design process cpacs-MONA
Design Adaption

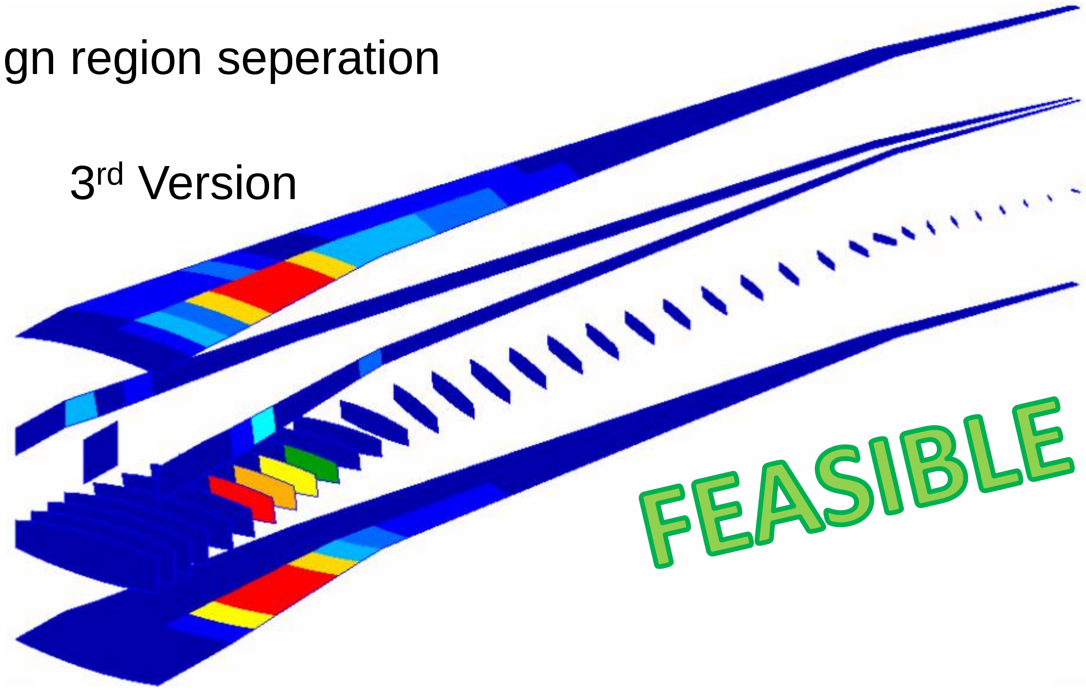
- 1st version leads to infeasible design
  - High loads around the landing gear
- Adaptions for 2nd version:
  - Shifed rear spar backwards
  - Shifted landing gear forward
  - Introduced a mid-spar

FEASIBLE

- Adaptions for 3rd version:
  - Changed the mid-spar to a „tiny“-spar → design region seperation without a „stuctural“ reinforecement

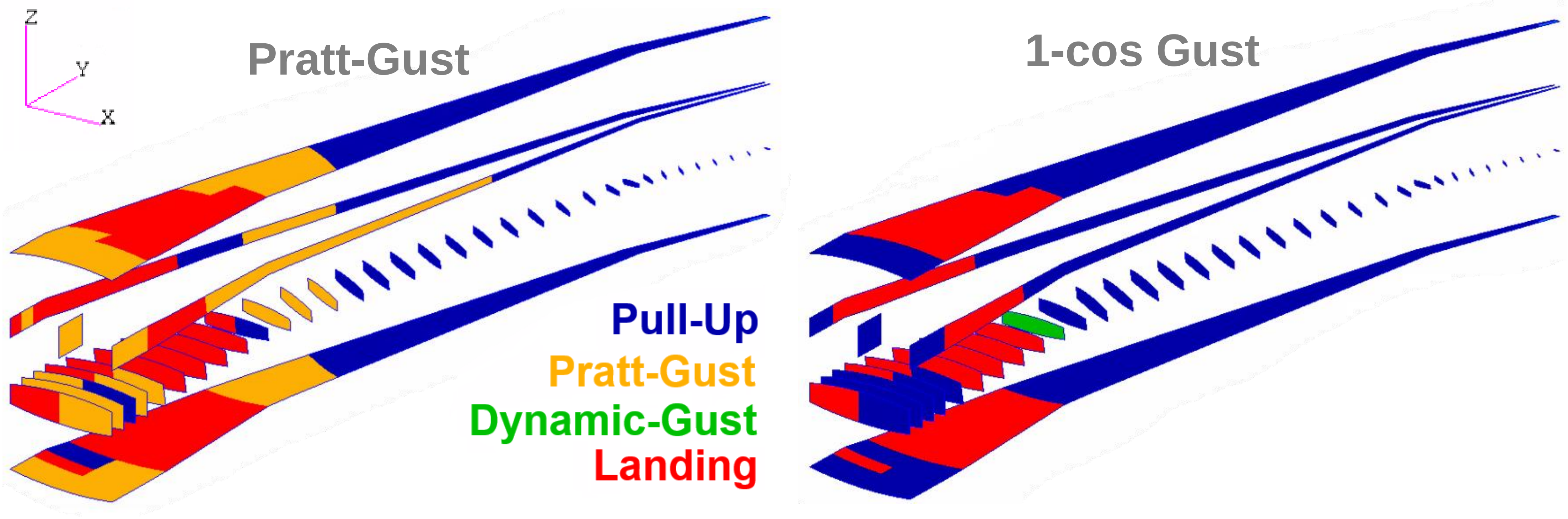






Aeroelastic design process cpacs-MONA

Pratt-Gust vs. Dynamic 1-cos Gust



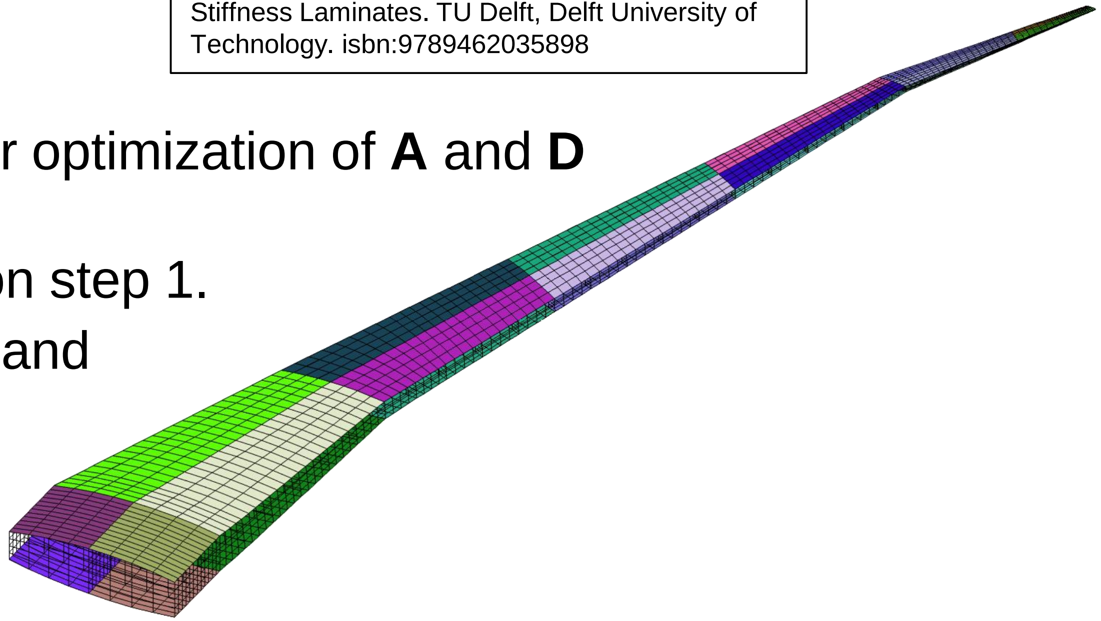
Parameter	Pratt-Gust	1-cos Gust
Wing primary mass	8832 kg	8597 kg
Max. Mx	$7.08e^6$ Nm	$6.85e^6$ Nm
1st elastic Eigenfreq. (OEM)	3,371 Hz	3.366 Hz

Composite structural optimization

Overview

[1] Dillinger, J. K. S. et al. (2013). Stiffness optimization of composite wings with aeroelastic constraints. Journal of Aircraft
[2] Dillinger, J. (2014). Static Aeroelastic Optimization of Composite Wings with Variable Stiffness Laminates. TU Delft, Delft University of Technology. isbn:9789462035898

- two-step aeroelastic optimization process:
  - continuous, gradient-based lamination parameter optimization of **A** and **D** stiffness matrices
  - discrete stacking sequence optimization based on step 1.
  - Nastran used to generate and export responses and sensitivities, optimization performed externally



- optimization model setup:
  - design field definition:
    - each featuring one set of **A** and **D** (sample: 14+14=28 fields)
  - response definition:
    - e.g. mass, element stress to compute strain and buckling failure, displacement, twist, root bending moment, aileron efficiency, eigenfrequency, …
  - load case definition:
    - e.g. static +2.5g pull-up, -1.0g push-down, fixed angle of attack, aileron deflection, static loads

constraints in the following sample

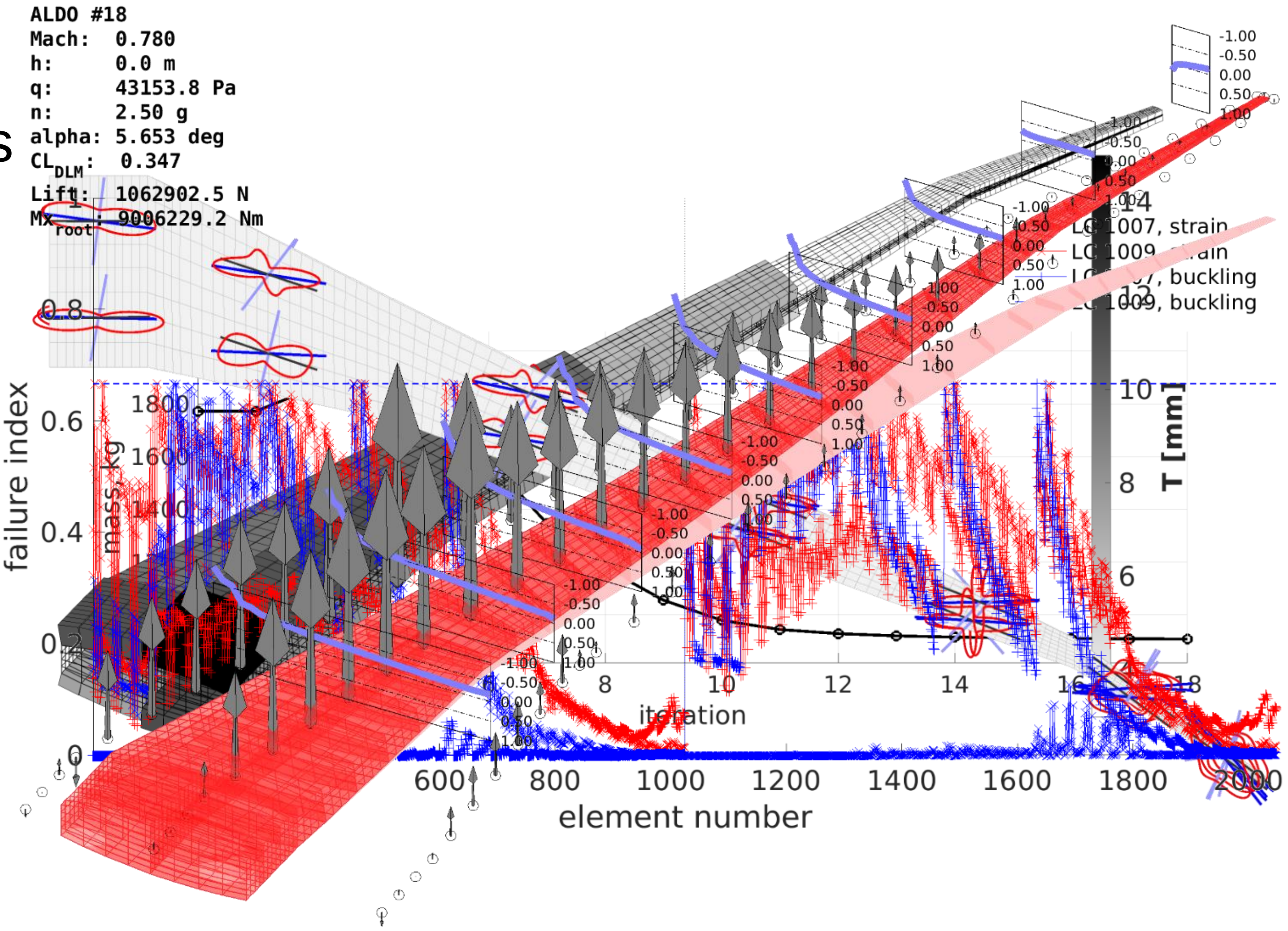
objective in the following sample

load cases in the following sample

Composite structural optimization

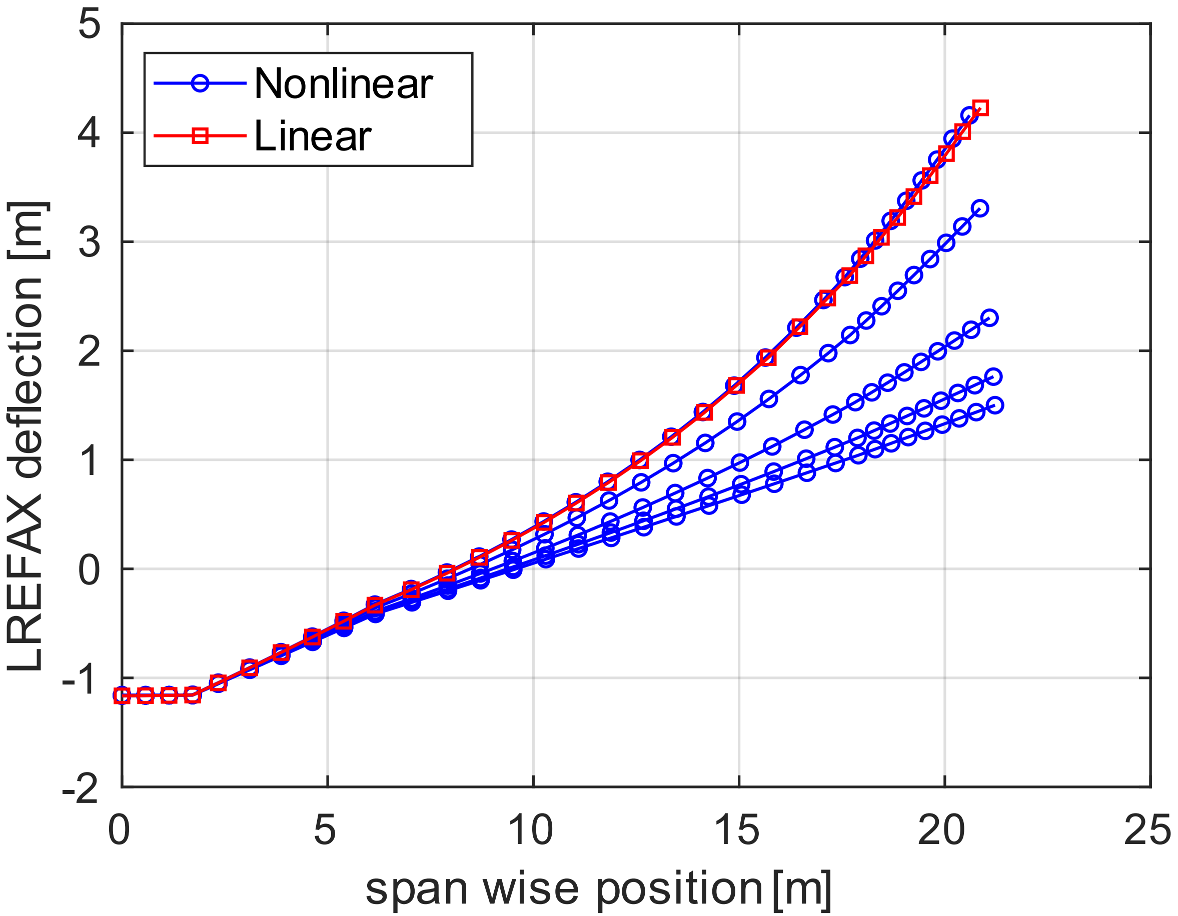
Sample Results

- development of wing skin mass throughout the iterations
- optimized thickness
- optimized polar E-modulus per design field
- failure indices for +2.5g and -1.0g load cases
- sample of aeroelastic loading generated with the coupled doublet lattice model



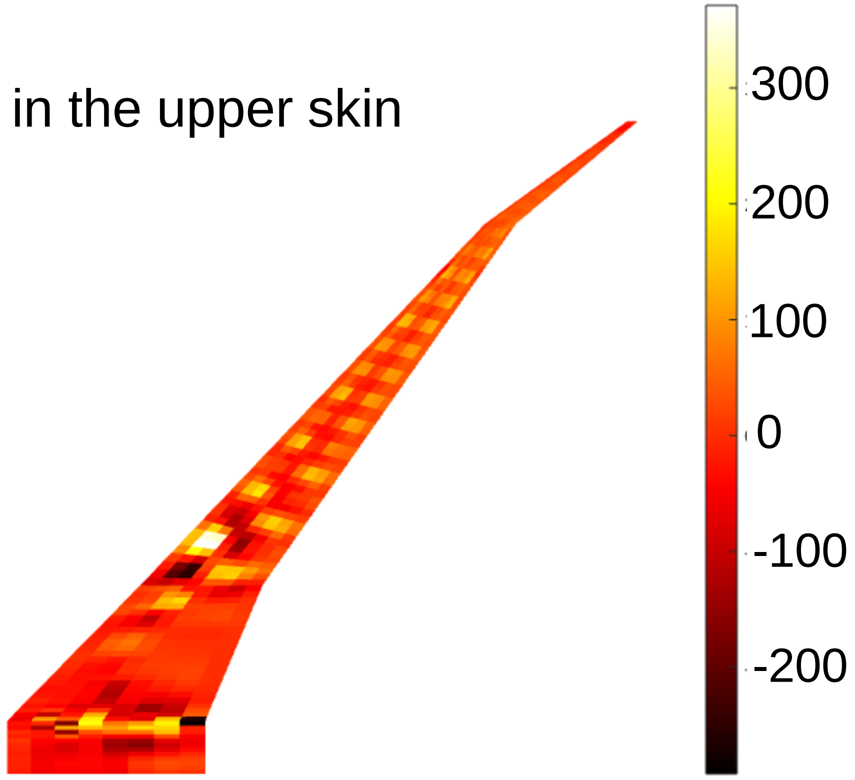
Nonlinear structural analysis - Displacements

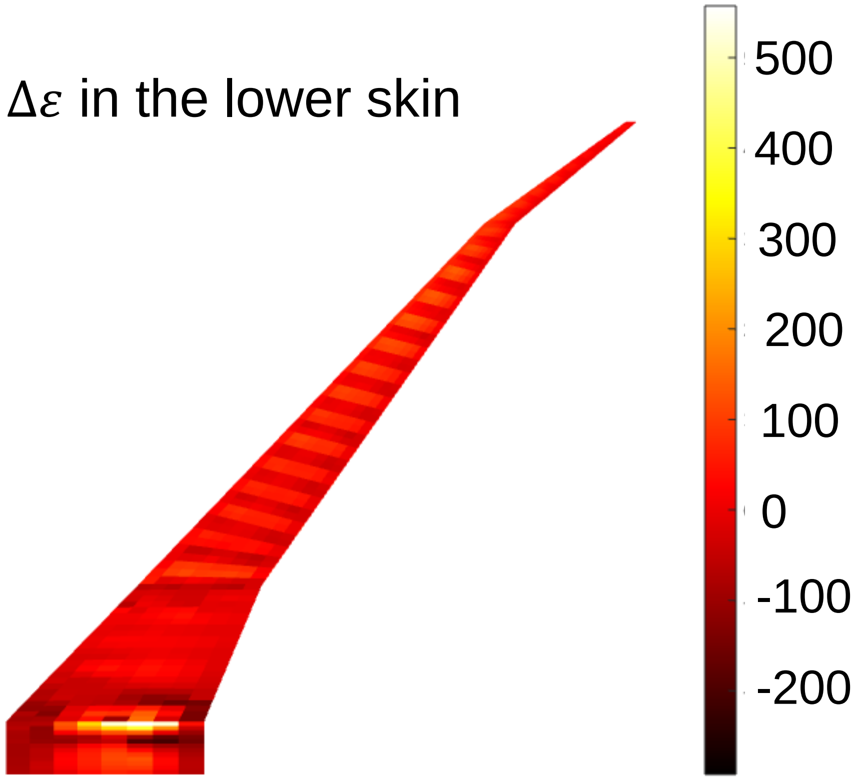
- Nonlinear analysis of the clamped wing structure conducted (SOL 400 MSC Nastran)
- 2.5g manoeuvre load case generating the maximum tip deflection ~13 % of half-span applied in the study.
- Nonlinear transverse displacement ~ 2.5 % lower than linear case
- Nonlinear spanwise in-plane displacement ~ 42 % higher than linear case.



Static deflection in the right wing for a 2.5g manoeuvre case

Nonlinear structural analysis - Strains

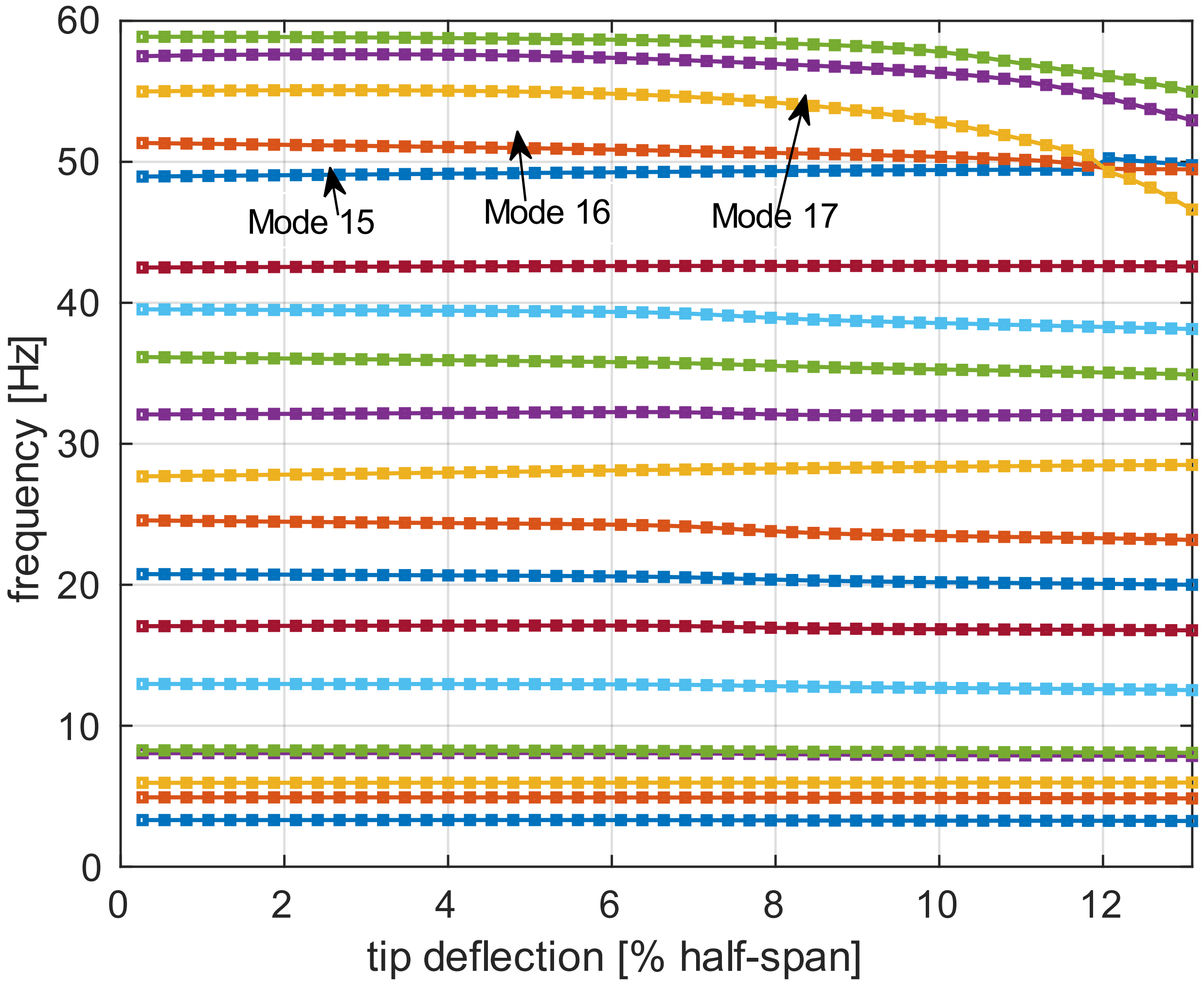

Δε in the upper skin


Δε in the lower skin

- Difference between linear and nonlinear strains in the range of -200 με and +500 με.
- Consideration of fully nonlinear strain models may have an impact on the sizing results.

Nonlinear structural analysis – Frequencies

- Linear modal analysis conducted at different states of nonlinear deflection.
- Eigenfrequencies under 20 Hz do not show much variation.
- Certain eigenfrequencies above 50 Hz show drastic variations, onset already under 10 % tip deflection.
- Intersecting eigenfrequency curves of Modes 15, 16 and 17 indicate potential mode coupling and unstable oscillations.

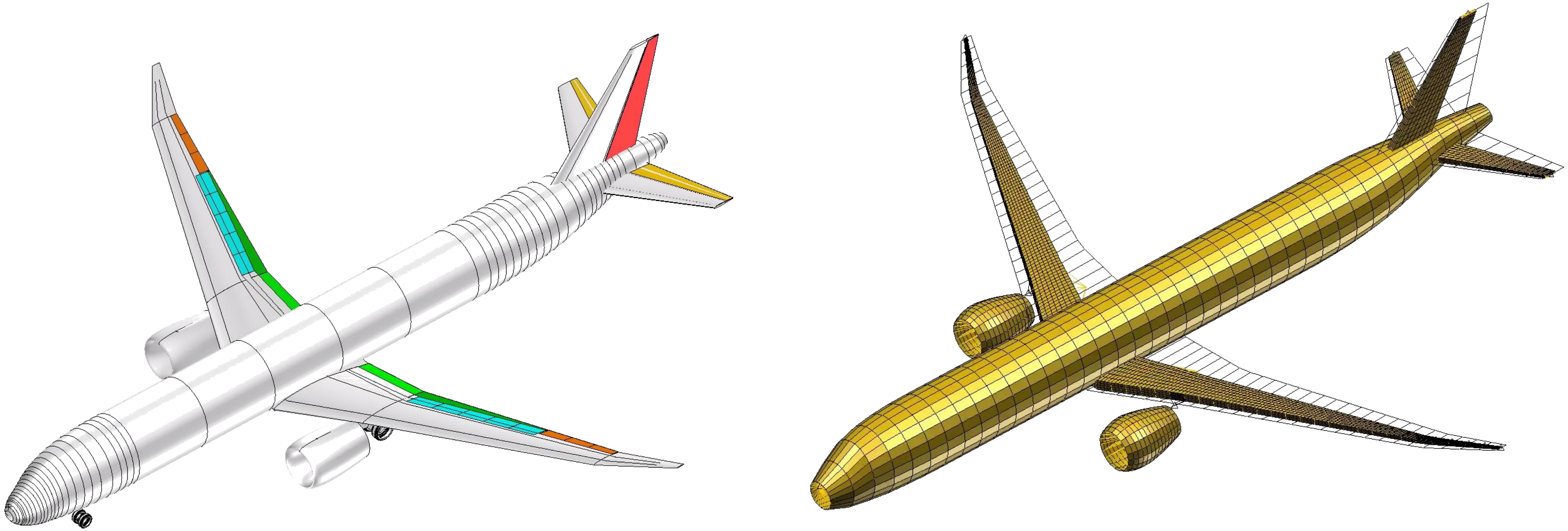


Summary Outlook

- DLR AE’s SMR configuration D2AE presented
- Various analysis and design capabilities of the design group presented from conceptual design to preliminary design

- D2AE is constantly further developed
  - Parametric modelling to smoothen the interfaces to the various analysis and design methods
  - New simulation models like structural modelling of the engine pylon with shell and beam elements → aeroelastic design tasks
  - Improvement of the geometry modelling in order to set-up CFD meshes → loads analysis

Thank you very much for your attention!



D2AE – developed @ DLR-AE