Optimization Assisted Design of Military Transport Aircraft Structures

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Contents

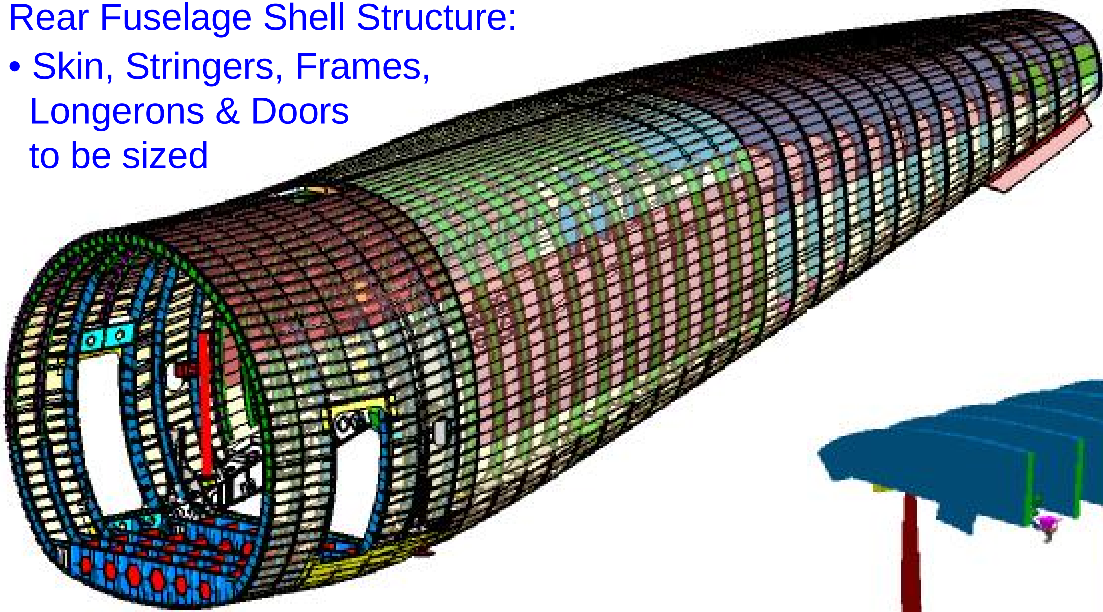
1. Design Task

A400M European Military Transport Aircraft

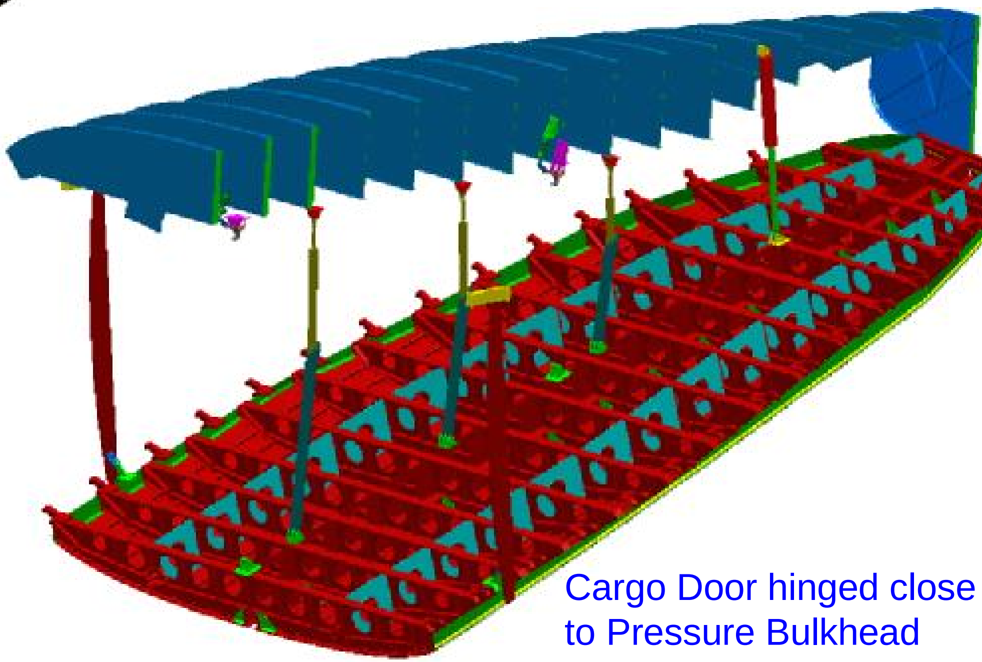
A400M Rear Fuselage Design Task

Rear Fuselage Shell Structure:

- Skin, Stringers, Frames, Longerons & Doors to be sized



3. Door opening & closing under max gust loads



Cargo Door hinged close to Pressure Bulkhead

Design Requirements:

1. Minimum weight

2. Adequate Strength: Stress, Fatigue, Postbuckling

Optimisation-Assisted Design Process

Loft / Part Geometry

Topology Optimisation
- Load Paths
- Material Accumulation and Orientation
- Stiffness Distribution
- Structural Concept Clues

Geometry
- Interpretation of Topology Optimisation
- Structural Concept

Structural Optimisation
Dimension and Shape of Structural Members

CAD
- Geometric Modelling of Structural Optimisation Results
- Detailed Design

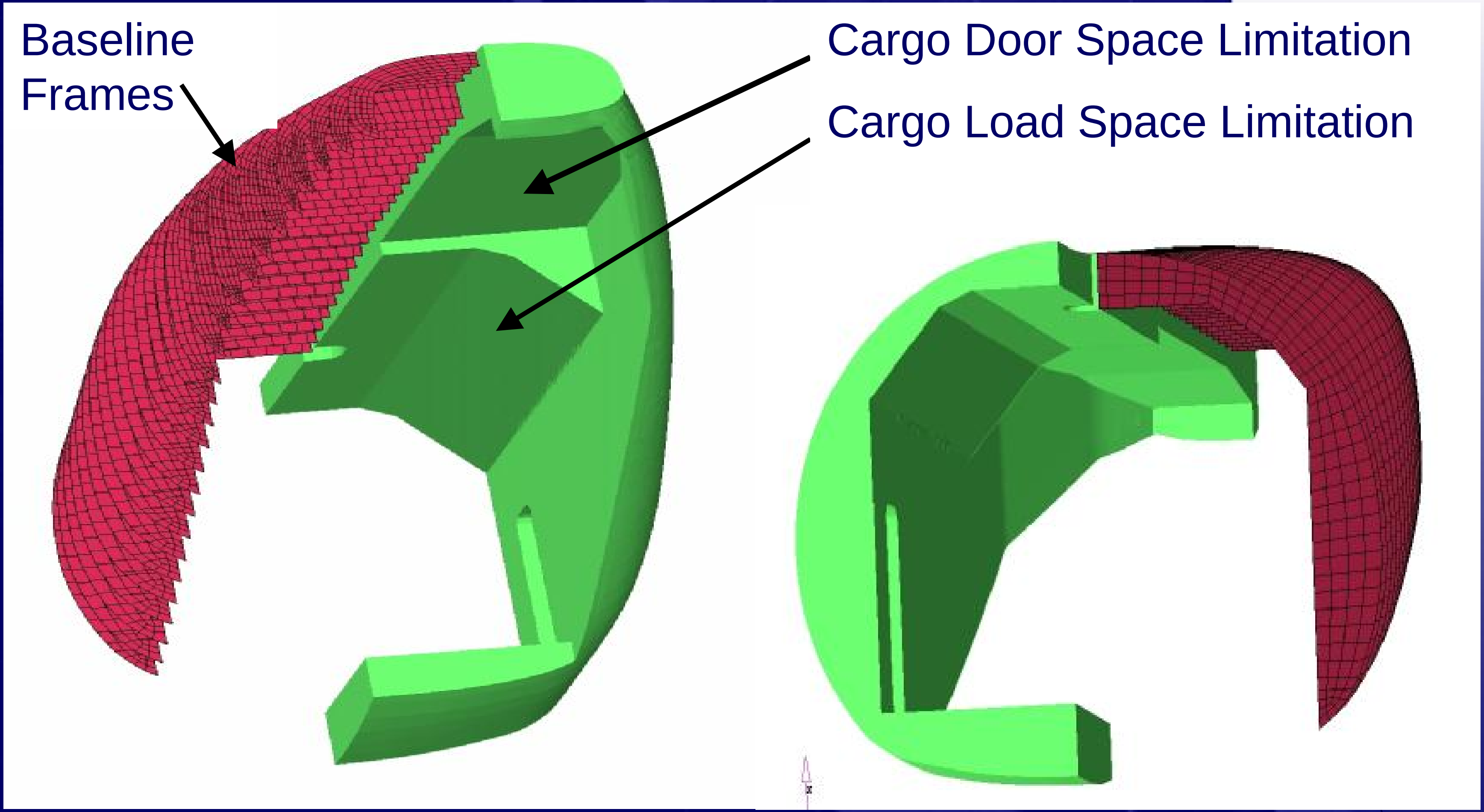
CAE
- Detailed Analysis and Verification

Manufacturing
Realised Part

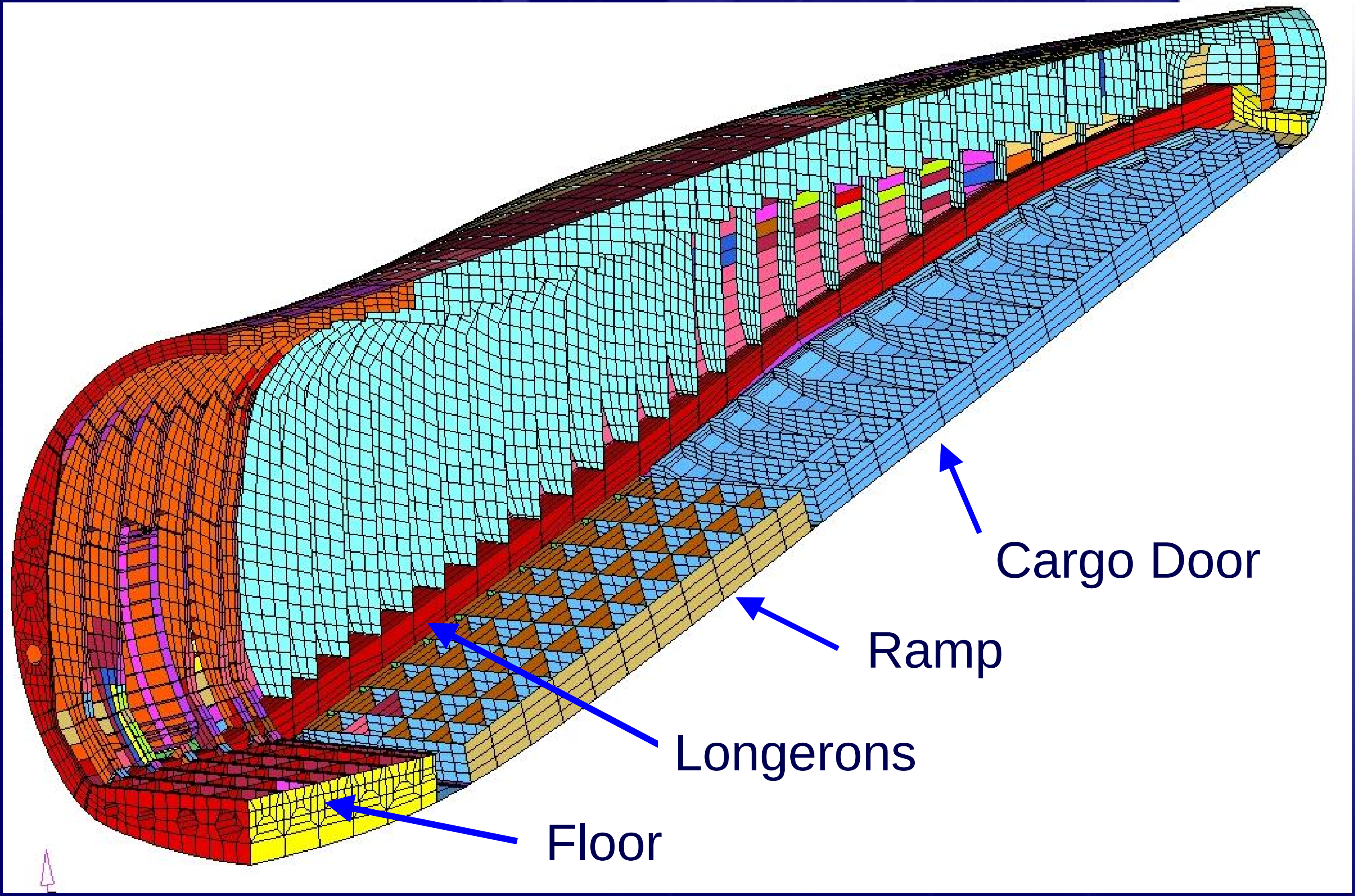
Final Part
Testing and Certification

2. Modelling

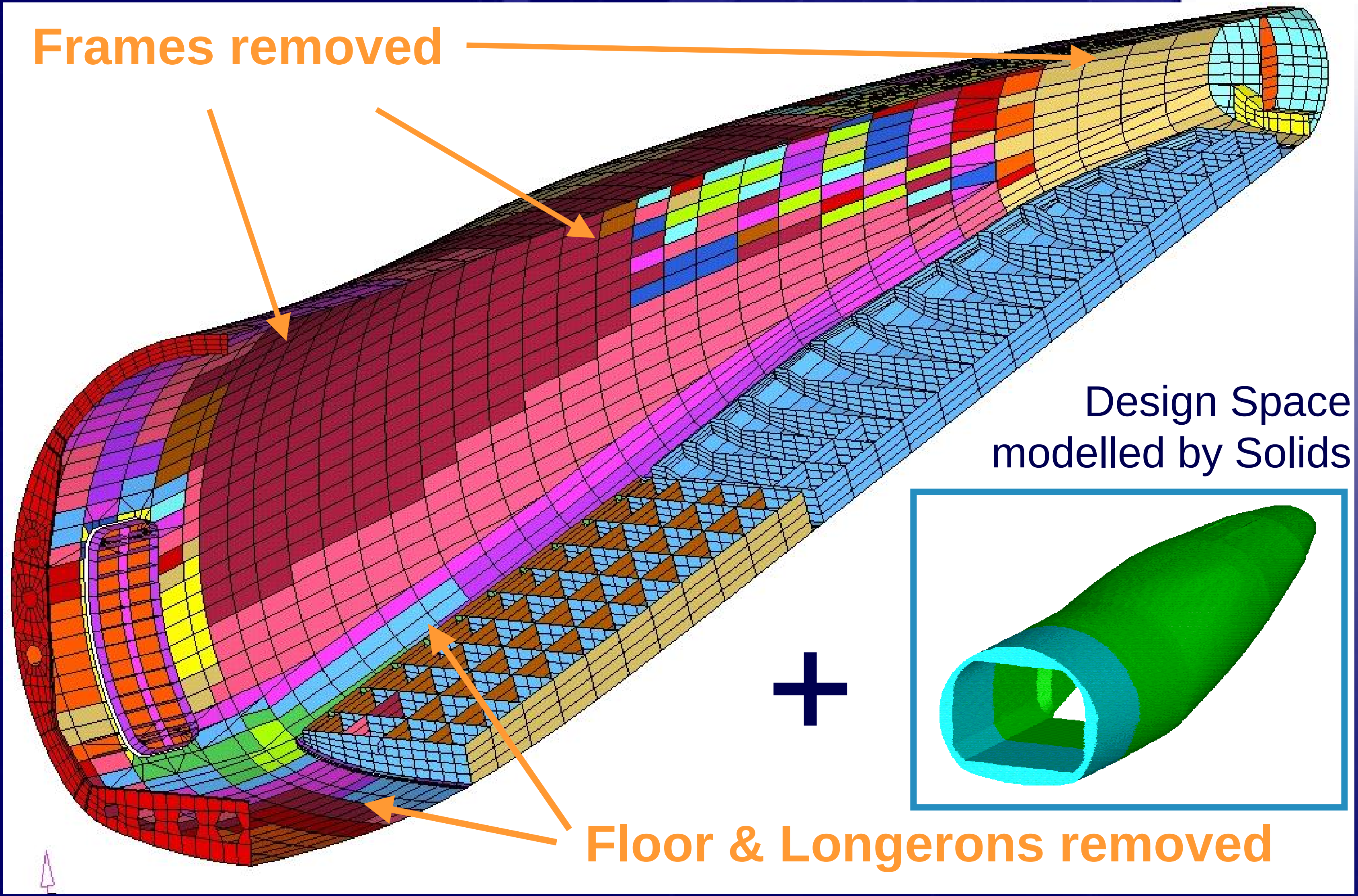
Design Space Definition



Finite Element Model - Baseline



Finite Element Model - Optimization

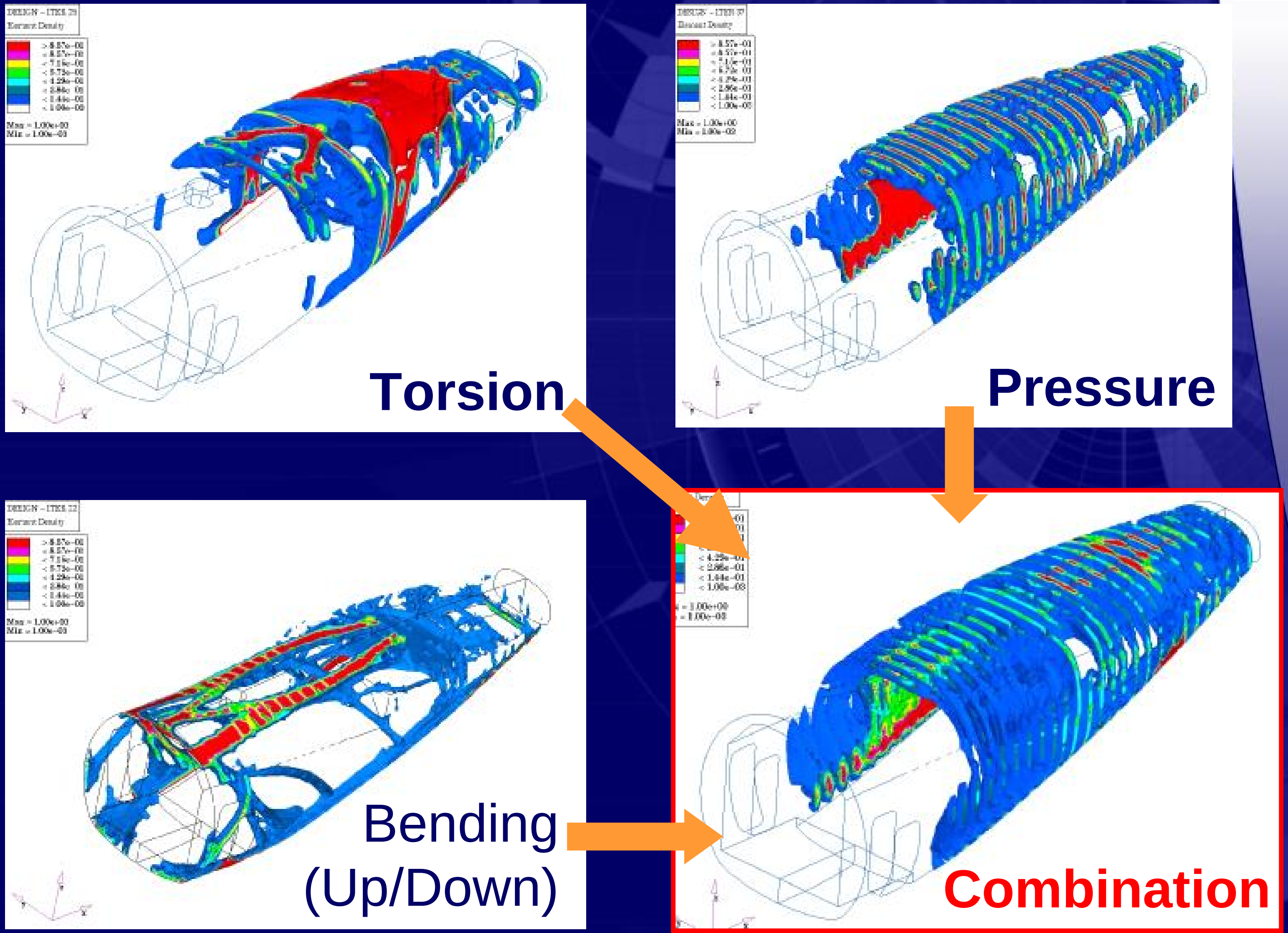


3. Topology Optimization with 3D Finite Elements

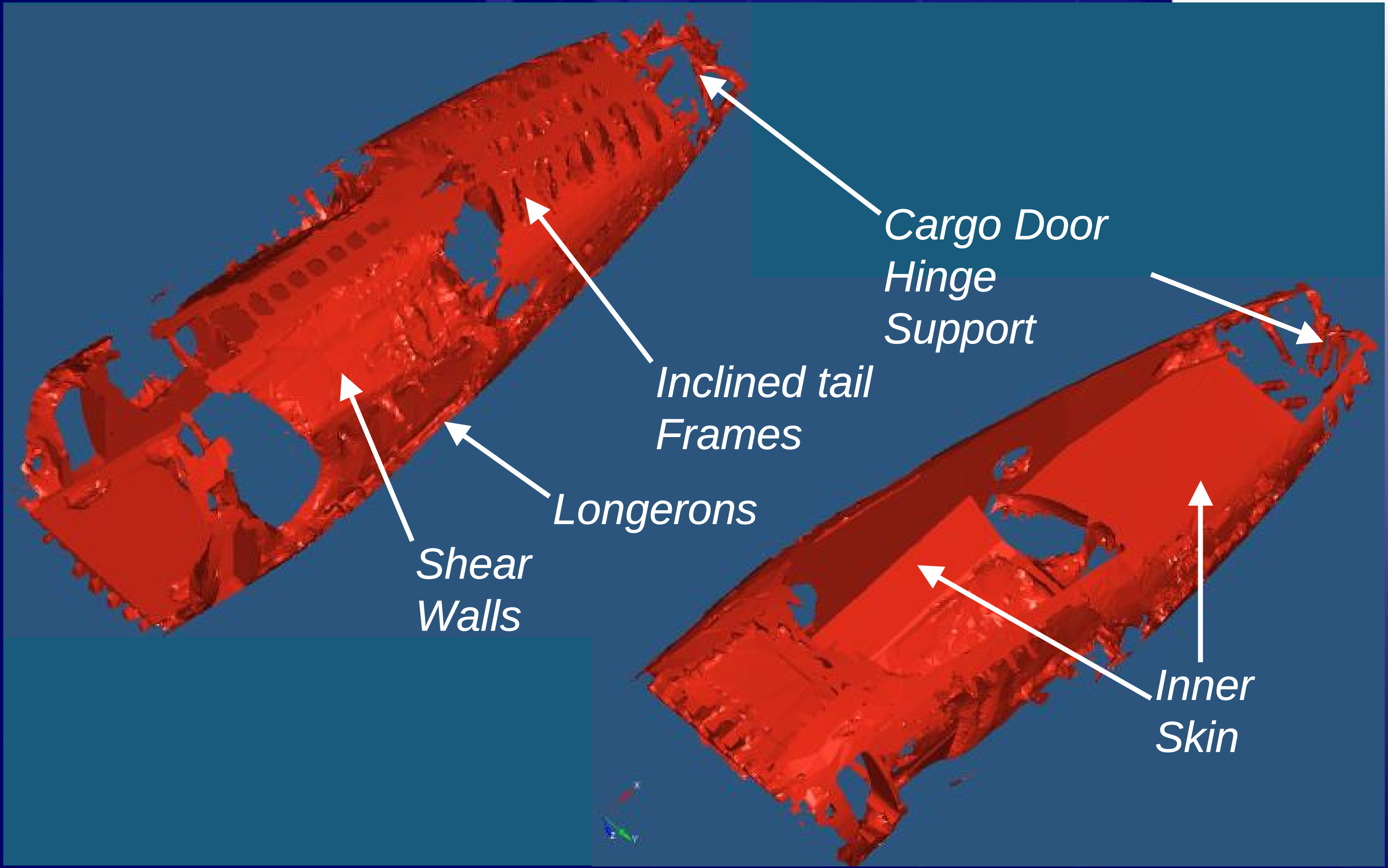
Goal:

Determine Overall Load Paths and Material Distribution

Solutions for Single and Multiple Load Cases

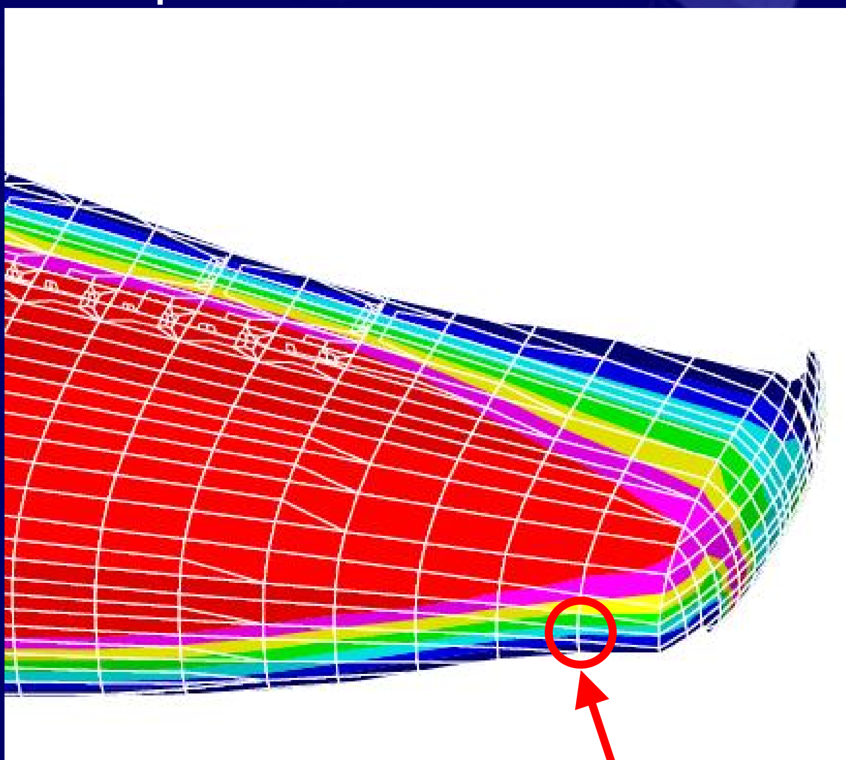


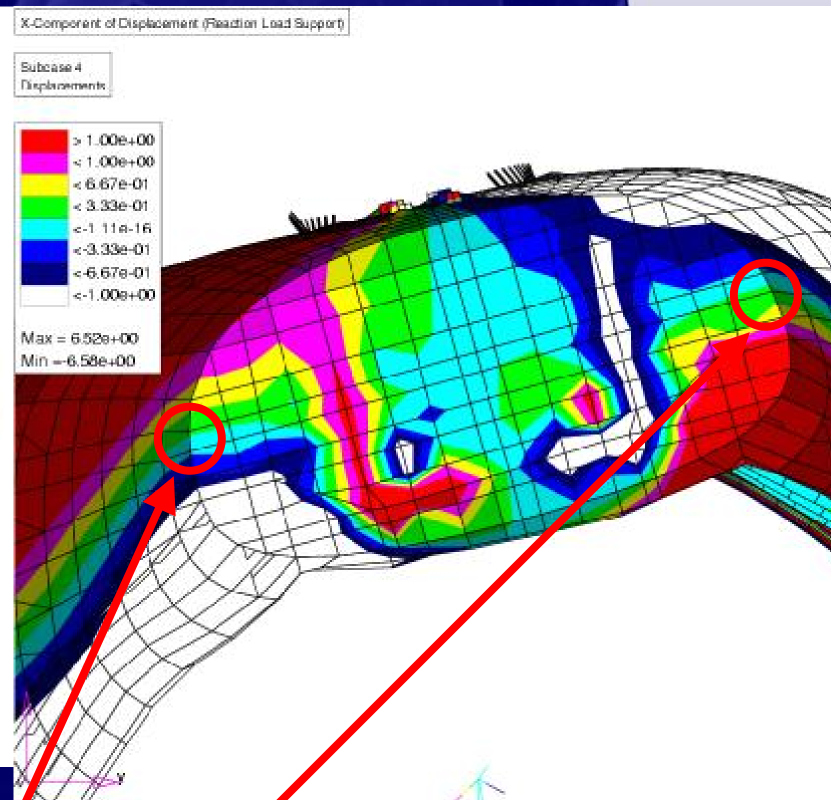
Key Features



Early Cargo Door Attachment Detail Study

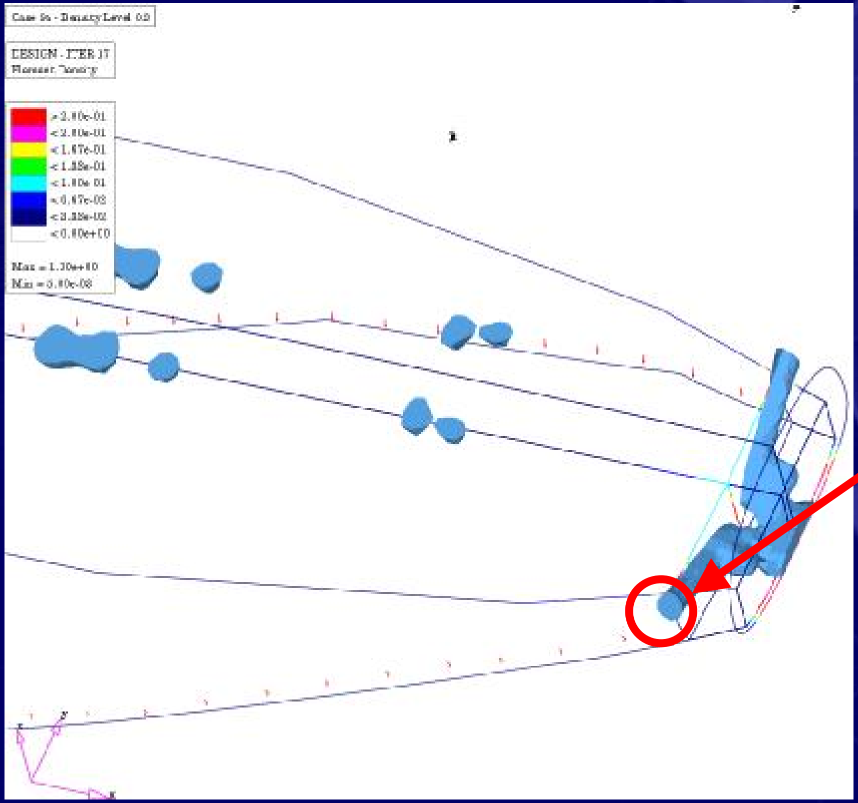
x-Displacements of Baseline FE Model





location of small longitudinal displacement
in lateral gust load case

Early Cargo Door Attachment Detail Design
A Compliant Mechanism



door hinge attachment to baseline FE (Shell) model at locations of minimum x-deflection reduces door yaw deflection and thus gap between door and fuselage

Conclusion of Topology Optimization with 3D Finite Elements

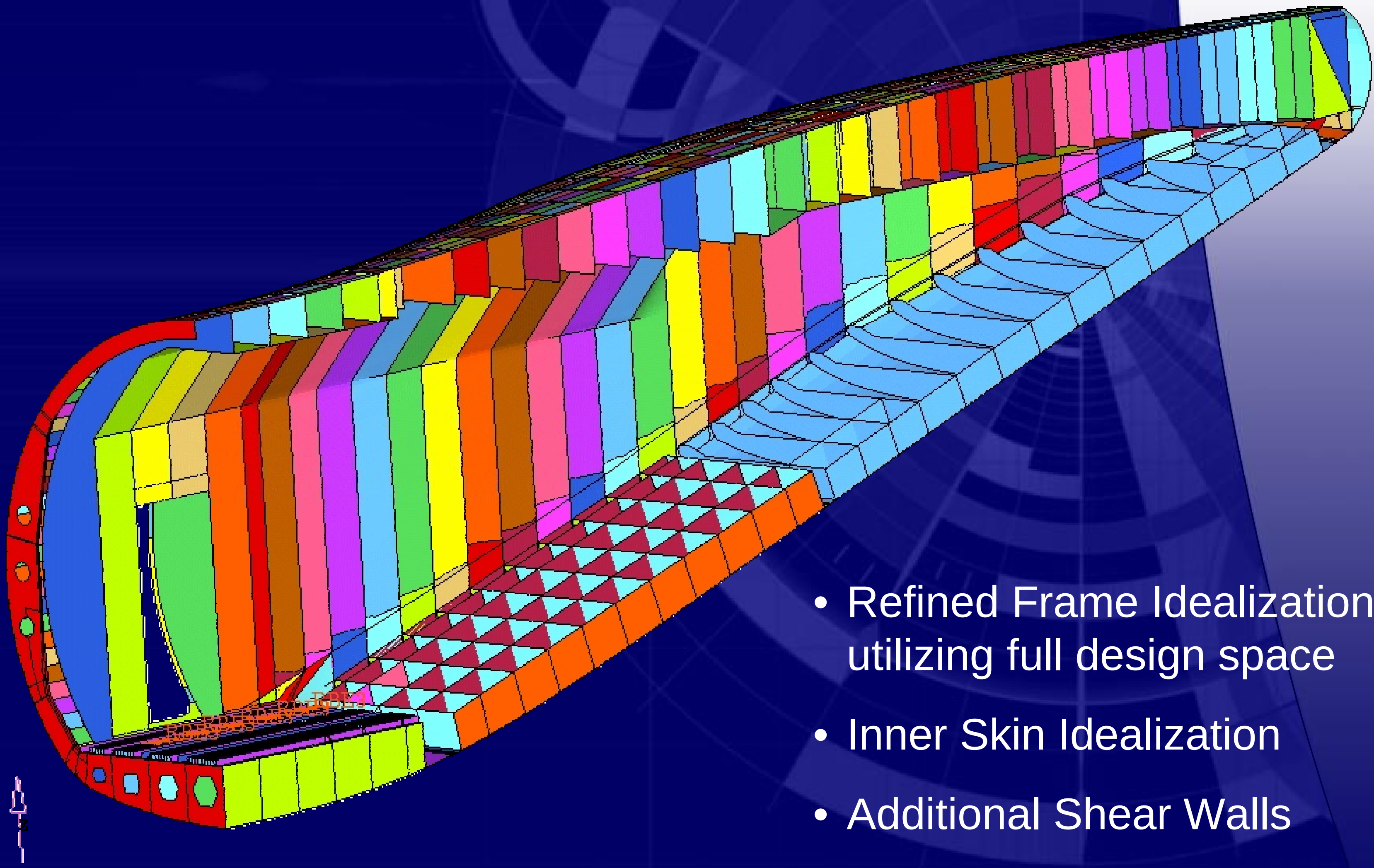
- Key features identified
- major load paths visible
- model too coarse to identify details
- implementation of some features impossible within overall structural concept of rear fuselage

4. Topology Optimization with 2D Finite Elements

Goal:

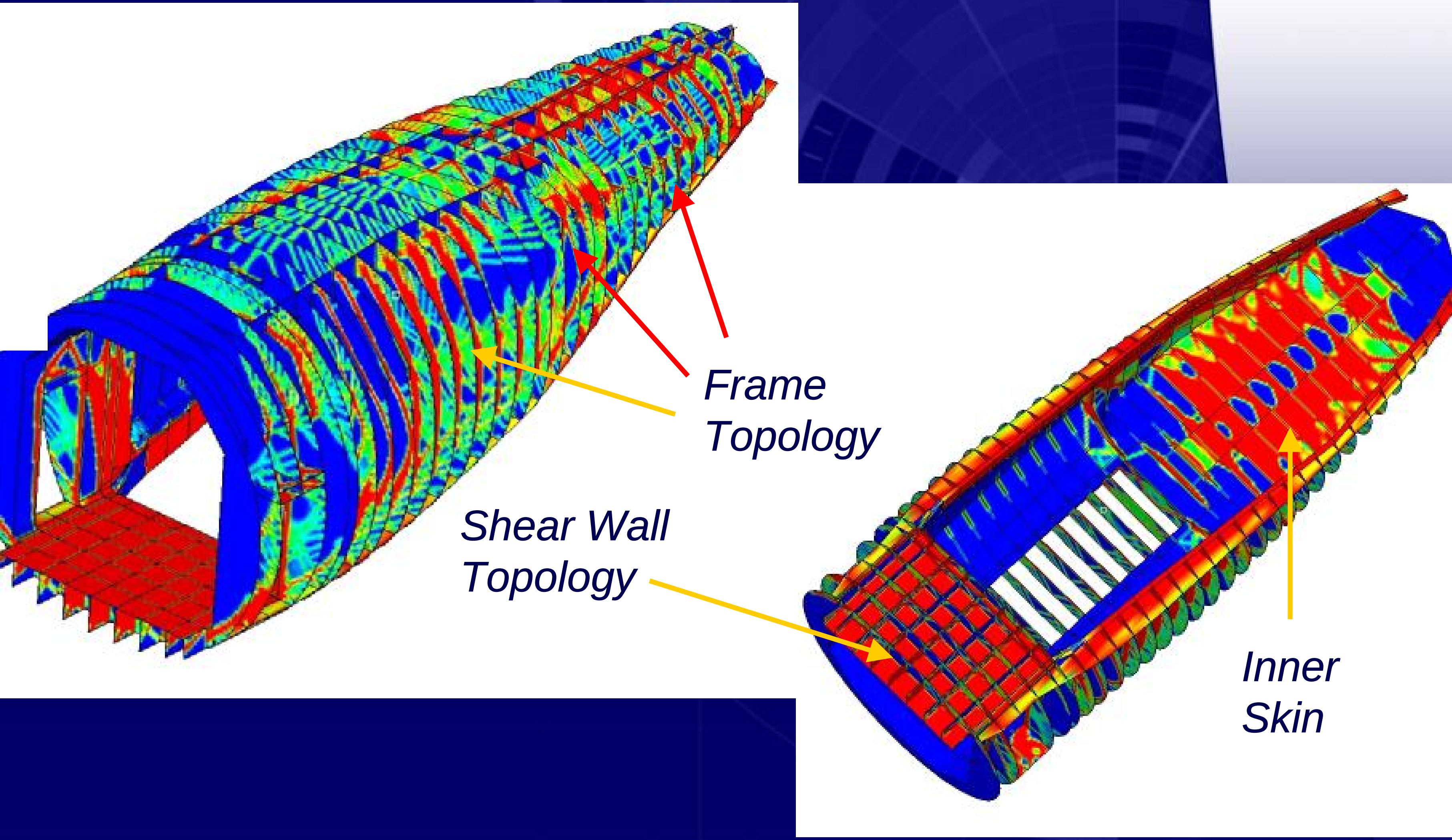
Refine Material Distribution within reduced Design Space (Frames etc.)

Refined Modelling of Internal Structure

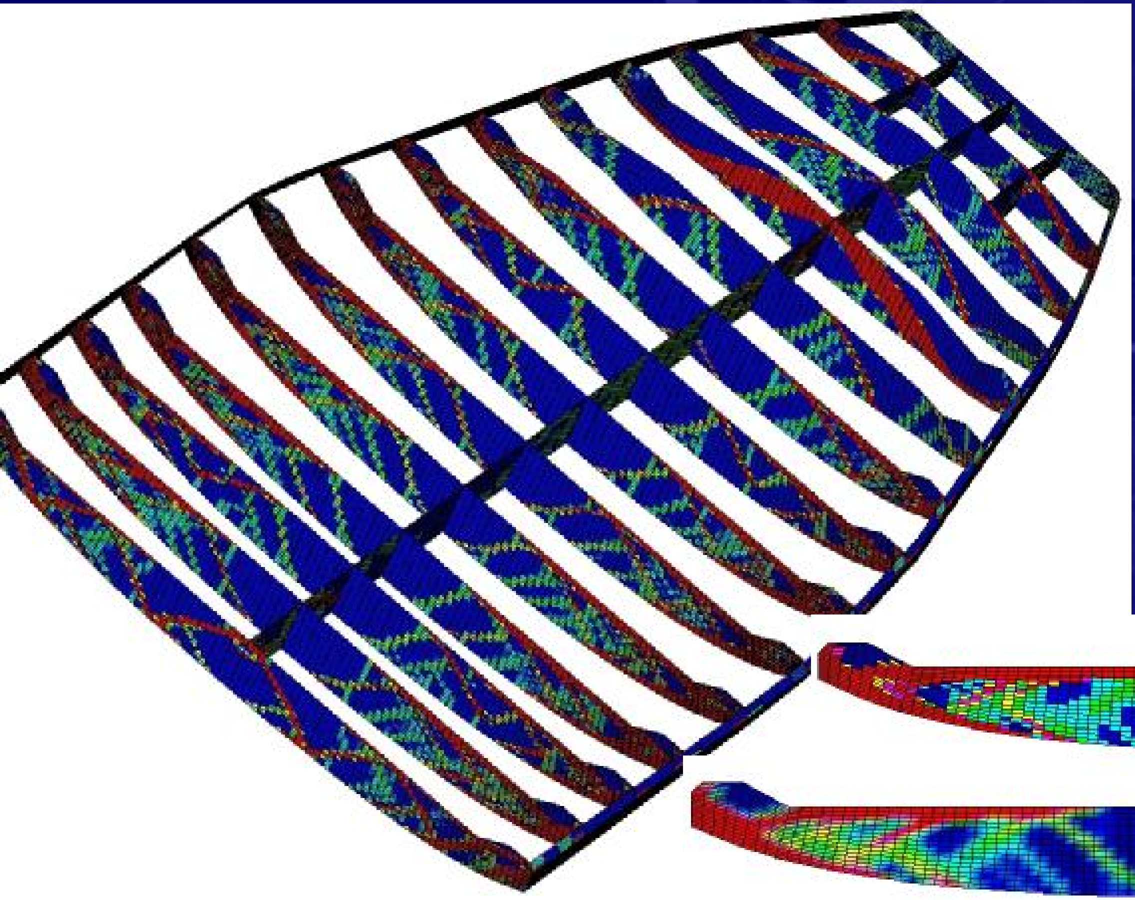


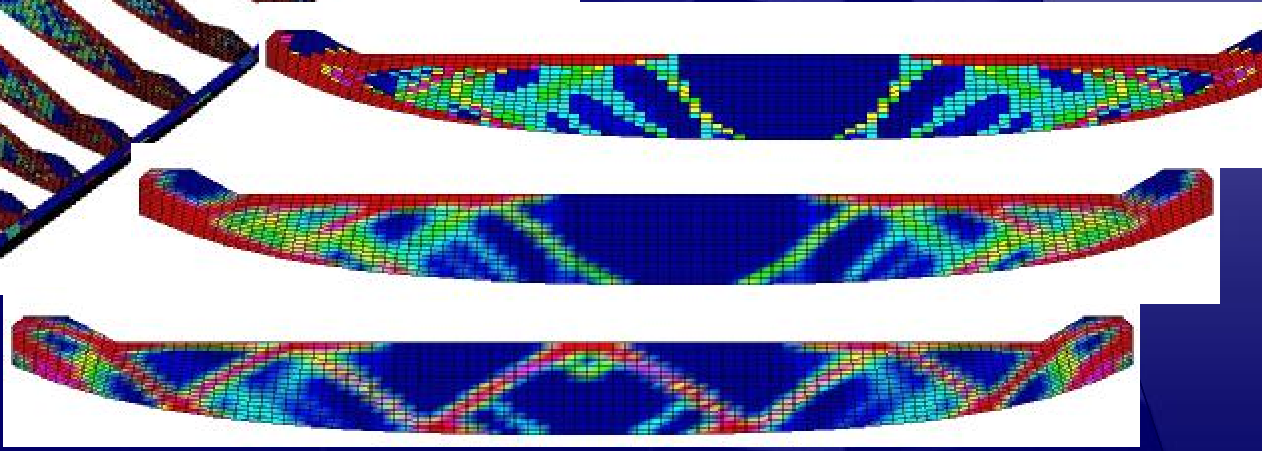
- Refined Frame Idealization utilizing full design space
- Inner Skin Idealization
- Additional Shear Walls

Key Features



Cargo Door Frame Optimization





Conclusion of Topology Optimization with 2D Finite Elements

- Key features supported
- load paths visible within components
- model too coarse to identify details

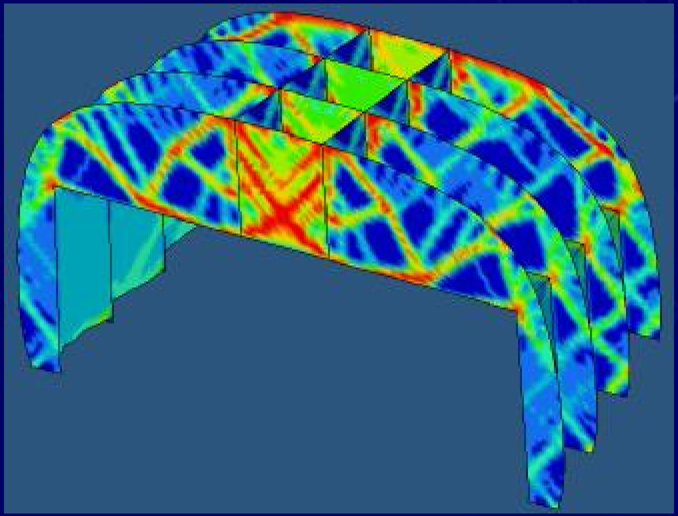
5. Topology Optimization of Tail Plane Frames

Goal:

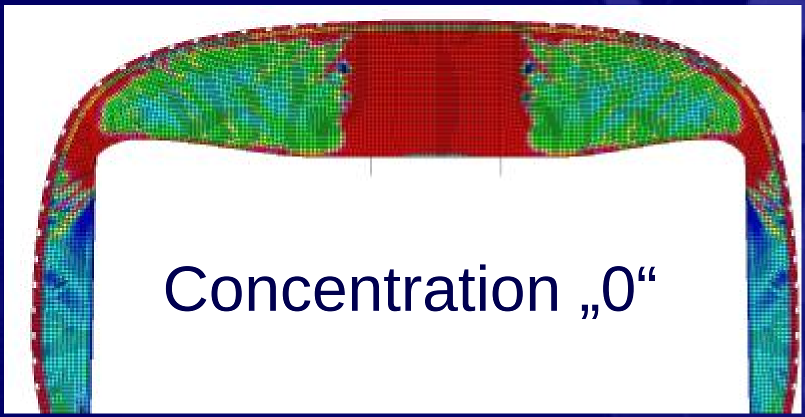
Propose alternative, weight-reduced Frame Designs

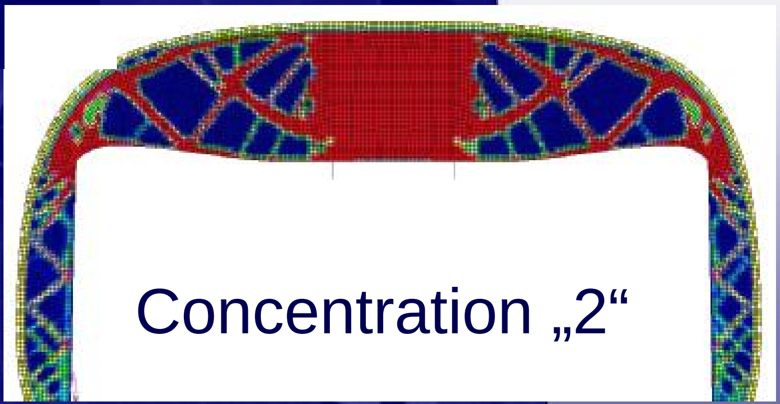
Embedding Topology Design Spaces in Elastic Structures

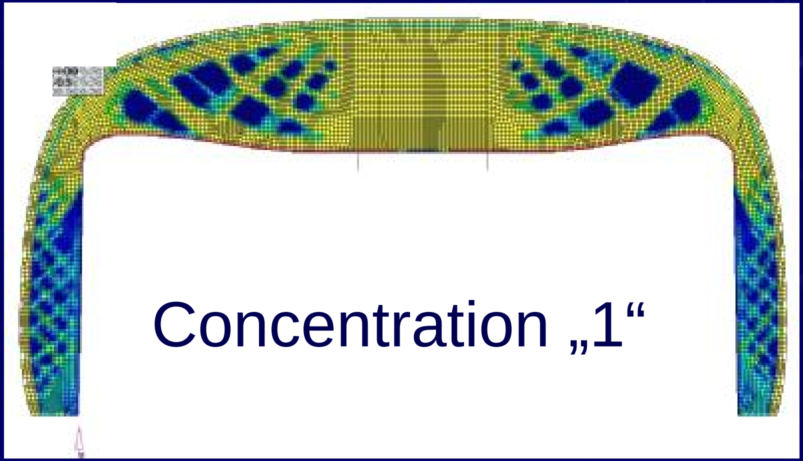
1) Elastic Support via Stiffness Matrix
    1) design of rear fuselage, condensation of front fuselage
    2) design of section underneath tail interface, condensation of remaining rear fuselage
2) Use of Interface Loads on Frame only

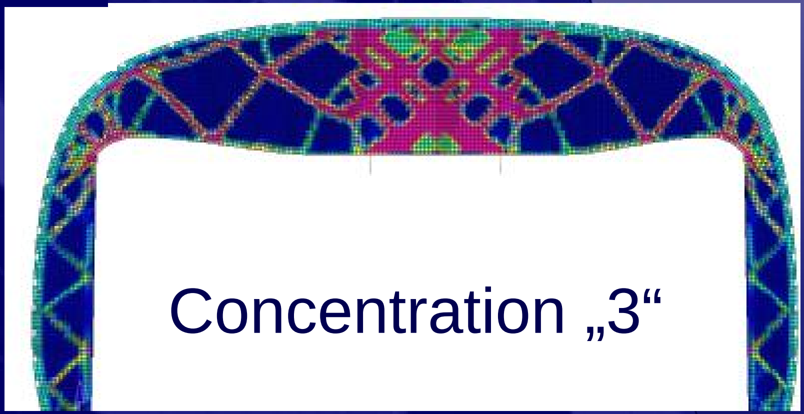


Effect of MinMemberSize and Shell Thickness Variation

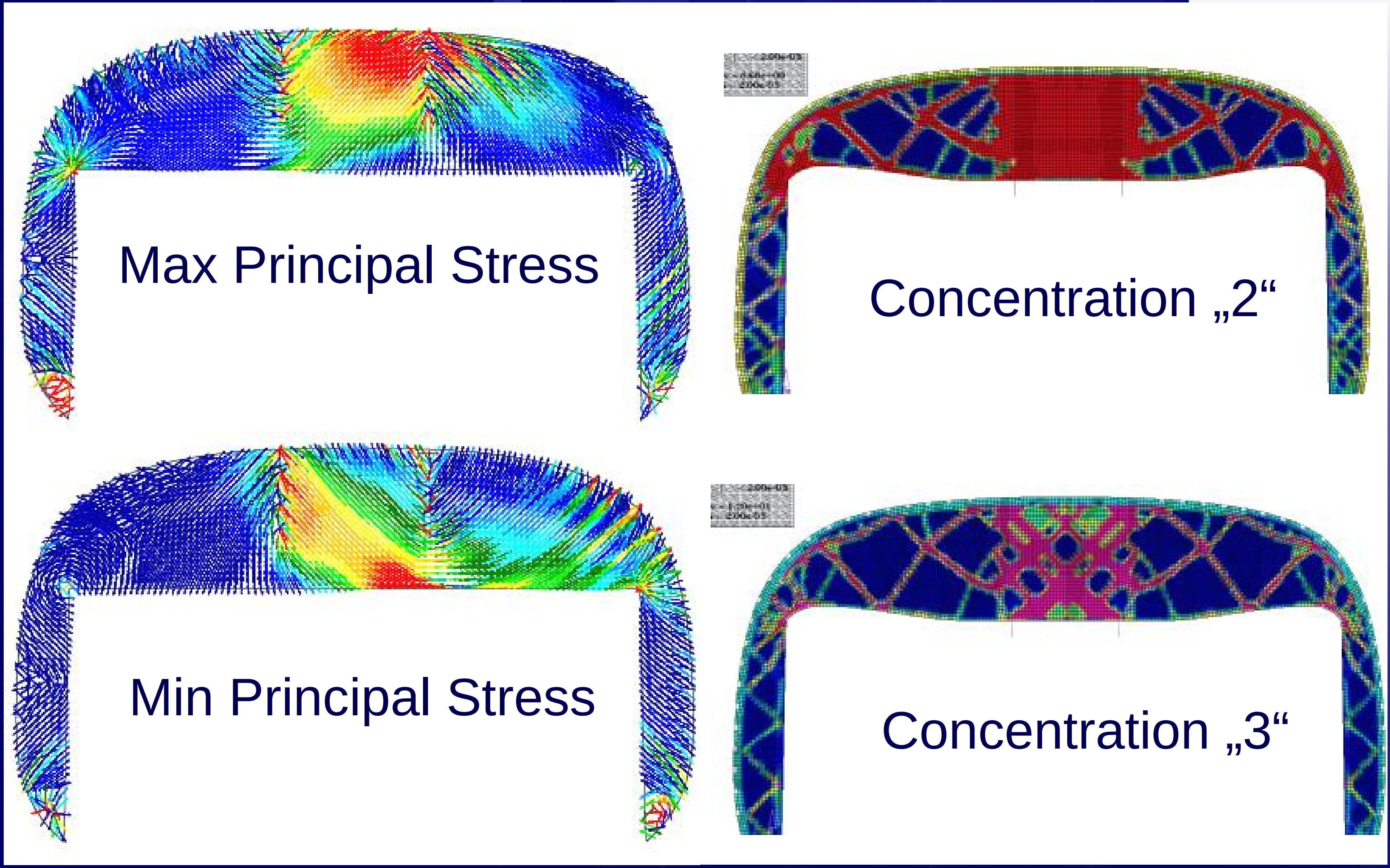








Correlation of Topology Design with Principal Stress Directions in the Dominant Load Case



Conclusion of Topology Optimization with 2D Finite Elements

- key features in alignement with theory (dominant load case)
- approach to embedding of single components in elastic structure substantiated
- truss design proposed
- exact interpretation of topology design unknown
- feasibility with respect to stability and strength unknown

7. Sizing Optimization of Tail Plane Frames

Goal:

Assure feasibility wrt. Strength and Stability

Assess Topology Design Variants

Permit substantiated weight trend statements

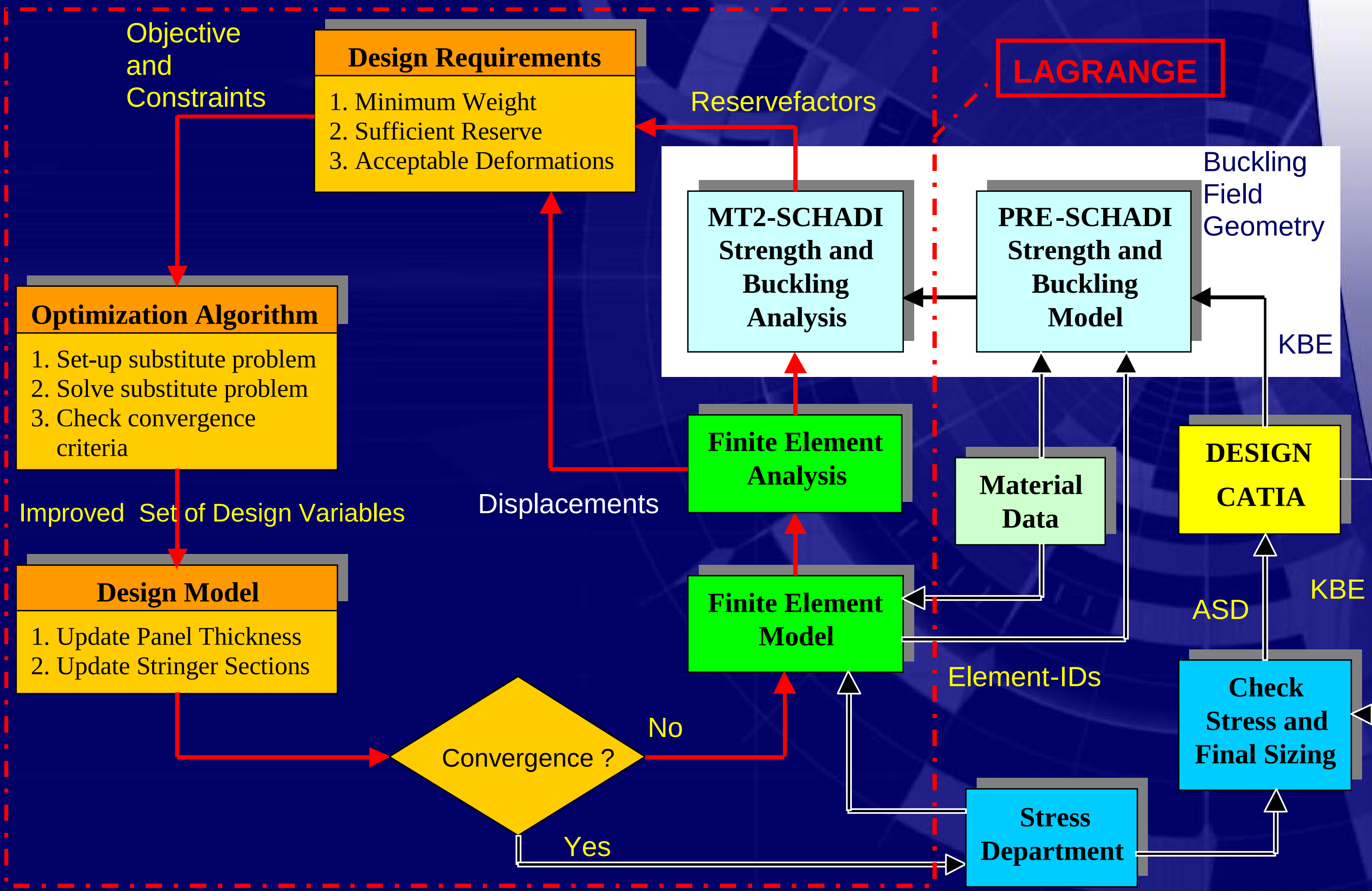
EADS In-House Sizing and Shape Optimization System *MBB*-Lagrange

- **Objective**
  - weight reduction (max. frequency etc.)
- **Constraints**
  - strength
  - buckling as well as post-buckling of fuselage shells
  - displacement (static, modal)
  - dynamics (natural frequencies, time and frequency response)
  - aeroelastic effectiveness and flutter
  - composite manufacturing (tape curvature, drop-off)

Theory based on AIRBUS design methods (=> ISSY)

- **Design Variables**
  - Sizing: element thickness/cross-section/concentrated mass
  - Composite Fiber Orientation
  - Shape
  - Constructive Design Elements

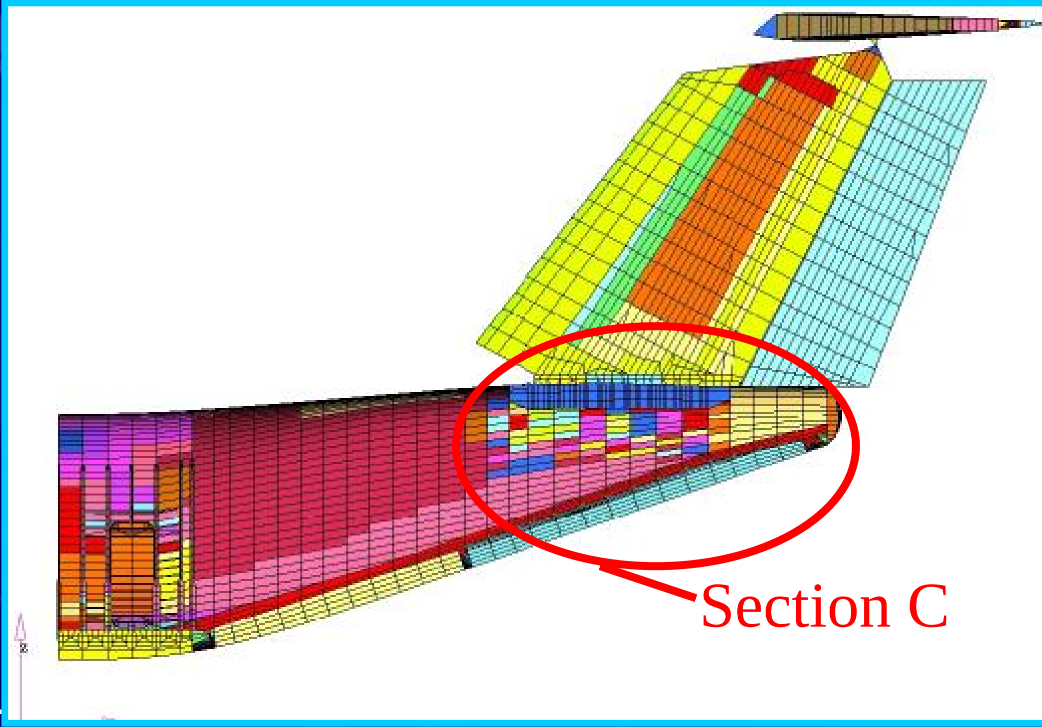
Optimization-Assisted Structural Design



Section C Design Model

Design Variables (DV):

- Skin: 247 DV
- Stringers: 28 DV
- Longerons: 42 DV
- Frames: 1009 DV



Total: 1326 DV (Symmetry applied)

Definition of the Design Problem

Objective: Minimum weight

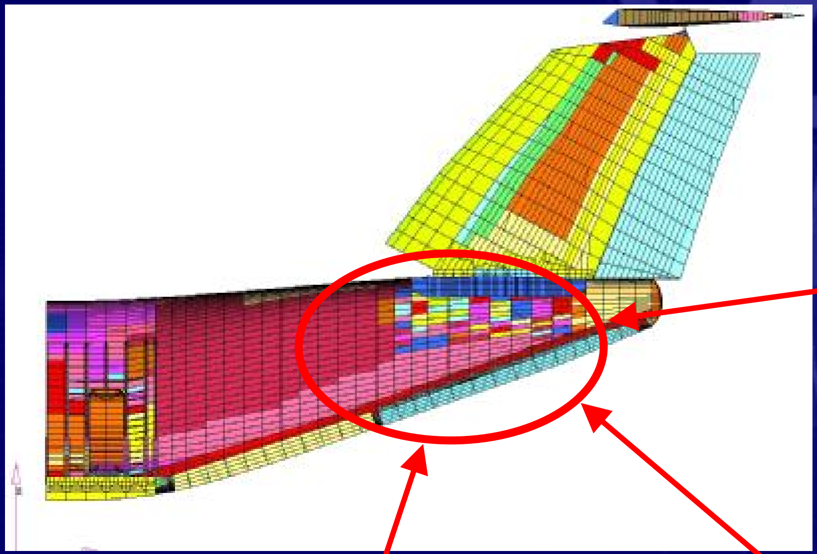
Constraints:

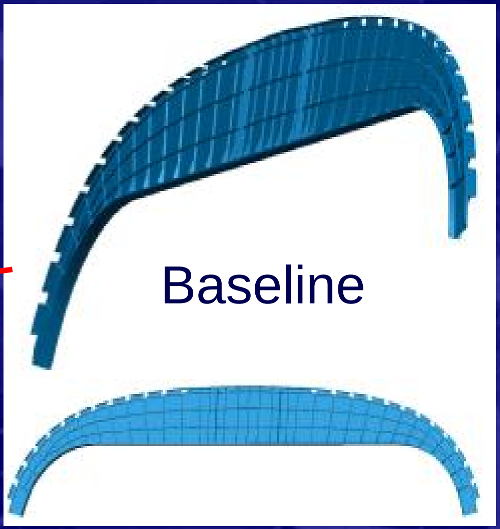
- Strength & Buckling: 8261 x 73 LC
  (Tension, Shear failure, Column Buckling, Stringer Crippling etc.)
- Fatigue : 2023 x 5 LC
- Relative Displacements: 22 x 2 LC

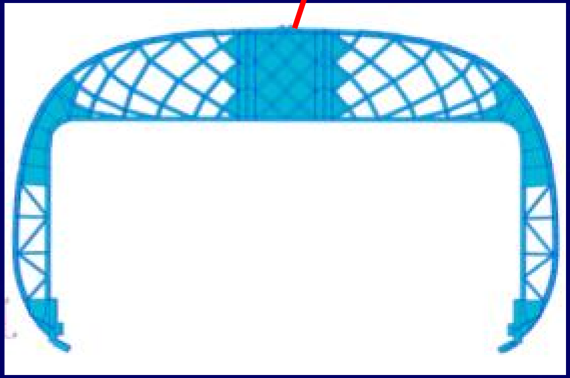
Total: 613210 Constraints

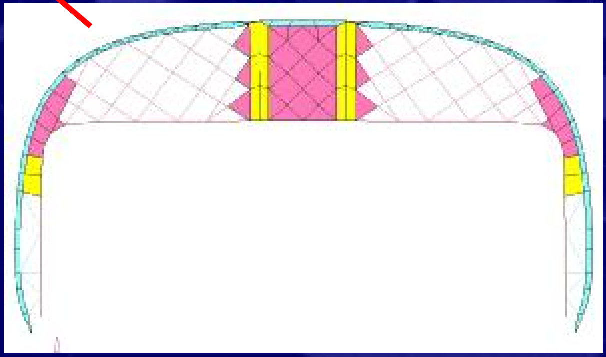
- Functionality and convergence of LAGRANGE procedure demonstrated for a sub-set of the above LC and Design Variables
- Optimization with all DV and Load Cases in progress

Tail Plane Frame Assessment









Status

- 1st Preliminary Sizing for stress & buckling performed
- Comprehensive analysis and assessment for all constraints (strength, fatigue, buckling, damage tolerance and manufacturing) in progress
- Assessment of frame concept variants in progress

7. Summary

Topology- and Structural Optimization: Application within the A400M project

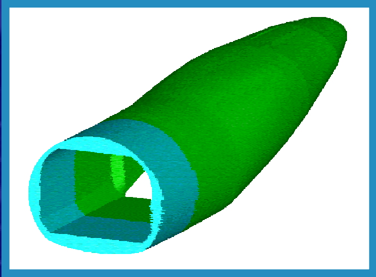
Concept Design

Part

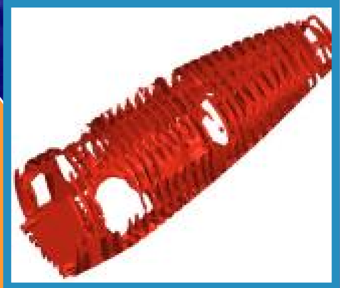
Manufacturing

Realised Part

Design Space



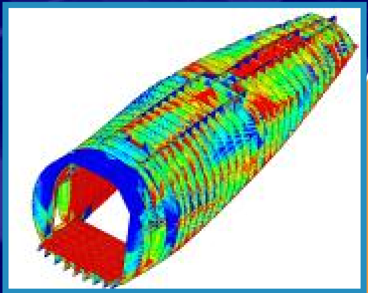
3D-Topology



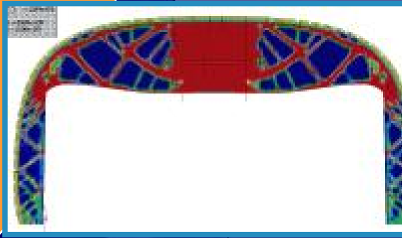
CAE

Detailed Analysis and Verfication

Refined Topology



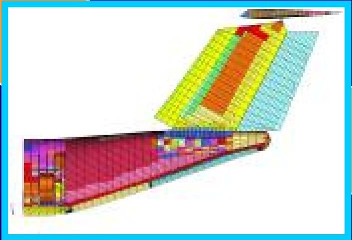
Frame Topology

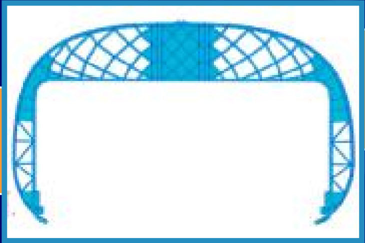


Pre-Design

CAD

Geometry Model





Frame and Shell Sizing Optimization

Summary

- Topology Optimization for the A400M Rear Fuselage System completed
- Application of Topology Optimization extended from component level to system level
- Topology Refinement for Tail Plane Frames completed
- Results Interpretation and Conceptual Sizing in progress
- LAGRANGE sizing optimization process for skin, stringers and longerons with post-buckling constraints demonstrated
- Overall Sizing Optimization for all Shells, Frames and Longerons in progress