DEFENDING WORLD SECURITY

Multidisciplinary Airframe Design Optimization

General Approach and Applications

CASSIDIAN

28th Congress of the International Council of the Aeronautical Sciences

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Dr. Fernass Daoud, Ögmundur Peterson, Markus Wagner (Design Automation & Optimization)

Cassidian, Manching / Germany

AN EADS COMPANY

Contents

Introduction: EADS and Cassidian Structure

EADS Divisions

Airbus

Fabrice Brégier (CEO)

Airbus Military
Domingo Ureña-Raso

Eurocopter

Lutz Bertling (CEO)

Cassidian

Bernhard Gerwert (CEO)

Astrium

François Auque (CEO)

Cassidian Business Lines

- Mission Avionics
- Sensors and Electronic Warfare
- Secure Communication Solutions
- Combat Air Systems
- Mission Air Systems
- Air Services
- Integrated Systems
- Test & Services

Engineering

Aviation Products and Programs of Cassidian

Combat Air Systems


Eurofighter

Mission Air Systems


EuroHawk


SIDM


Talarion


CL-289


Tracker


A400M


ATLANTE

Technologies e.g.


UCAV/ETAP


UAV Dem.

Services

Upgrades/MRO/CPS for various aircraft types


Eurofighter


Tornado


EF-18


F-5 Tiger


AWACS


C-160 Transall


P-3C Orion CUP

Training Services


ASTA


Pilot Training


Training Operations


DO-DT Family


DO-SK6

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Contents

Motivation
Challenges of the Multidisciplinary ***Airframe*** Design ***Process***

- The aircraft design process requires the combination of a broad spectrum of commercial as well as company specific analysis and sizing methods:
  - specific strength and stability analysis methods
  - company specific aerodynamic and aero-elastic / loads analysis methods
  - company specific composite analysis, design and manufacturing methods.
- The aircraft design is therefore driven by a huge number of multidisciplinary responses and design criteria (manouevre-, gust- and ground-loads, aeroelastic efficiency requirements, flutter speeds, strength and stability criteria, manufacturing requirements etc.) handled by different disciplines (loads, flight controls, dynamics, stress etc.)
- The design process needs to consider and meet all these design driving criteria ***simultaneously***, in order to determine an ***optimum compromise solution***, i.e. all disciplines and design criteria driving the airframe structural sizes and the composite lay-up need to be combined and have to interact within an **integrated airframe design process**.

Challenges of the Multidisciplinary ***Airframe*** Design ***Process***

- General Challenges:
  - The performance requirements and technical complexities for new aircraft are increasing compared to previous developments.
  - Customer needs and competition enforce reduced development time and cost.
  - Intervals between complex military A/C projects are long $\Rightarrow$ experience gets lost.
  - There is very little time to develop sufficient understanding about complex, multidisciplinary interactions early enough within the decisive design phases.

- Opportunities
  - **Numerical simulation** methods allow to **analyse and understand** complex technical interactions early in the design process
  - **Numerical concept optimization methods** allow to **determine optimum design concepts** in early design phases
  - **Numerical parameter optimization methods** allow to **improve the product performance** (e.g. by achieving performance requirements with minimum weight) **and simultaneously to reduce time and cost** in all design phases !

NATO AVT Panel Recommendation for the future Vehicle design process

The comprehensive Integration of Tools and Processes has been identified as key measure in order to develop affordable air vehicles by the NATO-Research and Technology Organisation (RTO).

One key element of such an integrated process is the:

“Acceleration of the design and decision process by extensive use of mathematical modelling and simulation combined with **Multidisciplinary Design Optimization (MDO) methods**. These methods shall be applied at the detailed level as well as on system level, in order automate and accelerate the overall design process as well as to assist human creativity.

Major Benefits

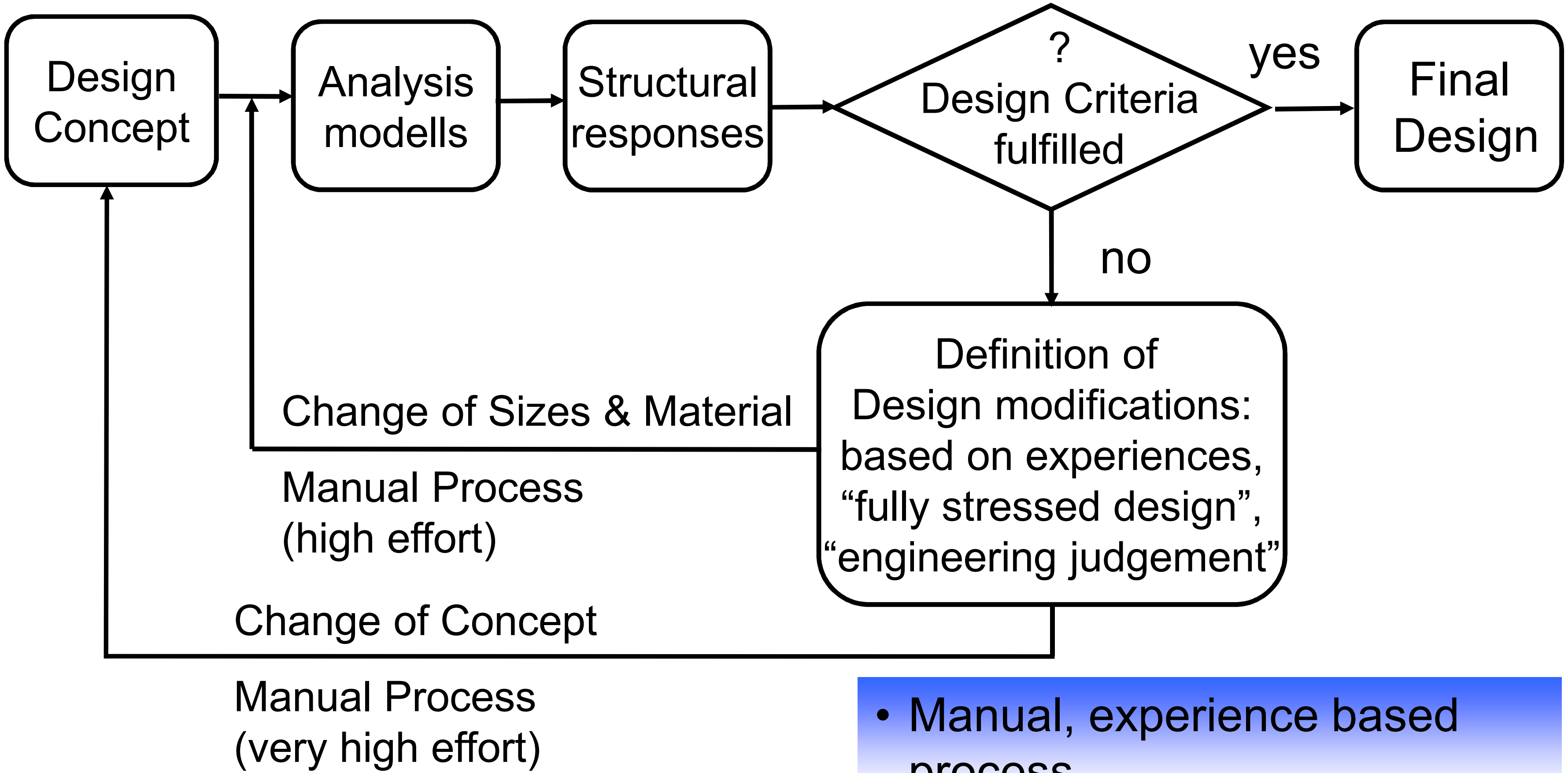
- improved process integration & automation, reduced manual effort
- design cycle reduction
- improved product performance (weight, flight performance….)
- reduced development time (up to -50% accord. to RTO-report)

Multidisciplinary Design Optimization Development at Cassidian

- Commercial Optimization Tools *including analysis capabilties* are based on standard FE- and / or CFD-Methods and they are primarily tailored for and applied within the automotive industry. They do not provide the full spectrum of (company-specific) analysis methods required to analyze and optimize an airframe.
- Commercial Optimization *Frameworks (i.e. without analysis capabilities) a*llow to link company-specific analysis modules with optimization algorithms. However, they are based on numerical sensitivities resulting in high CPU-Time requirements & computational limits w.r.t. the size of the optimization problem (driven CPU time for the analysis and the number of design variables).
- Cassidian has started to develop it´s in-house airframe optimization tool LAGRANGE already in 1984. Within the past 3 decades LAGRANGE has been applied within various military and civil aircraft projects (Eurofighter, X31, A400M, A380, A350, Talarion, ATLANTE as well as different future aircraft projects).
- The capabilities of LAGRANGE have been continuously extended in order to meet the requirements and challenges of todays airframe development process.
- In parallel, the data-management and the overall program structure is currently modernized (Fortran 95) in order to cope with the challenges of maintaining and further developing a software platform with approximately 3.500.000 Lines of Code.

Contents

The traditional, iterative structural design process



- Manual, experience based process
- Limited number of iterations

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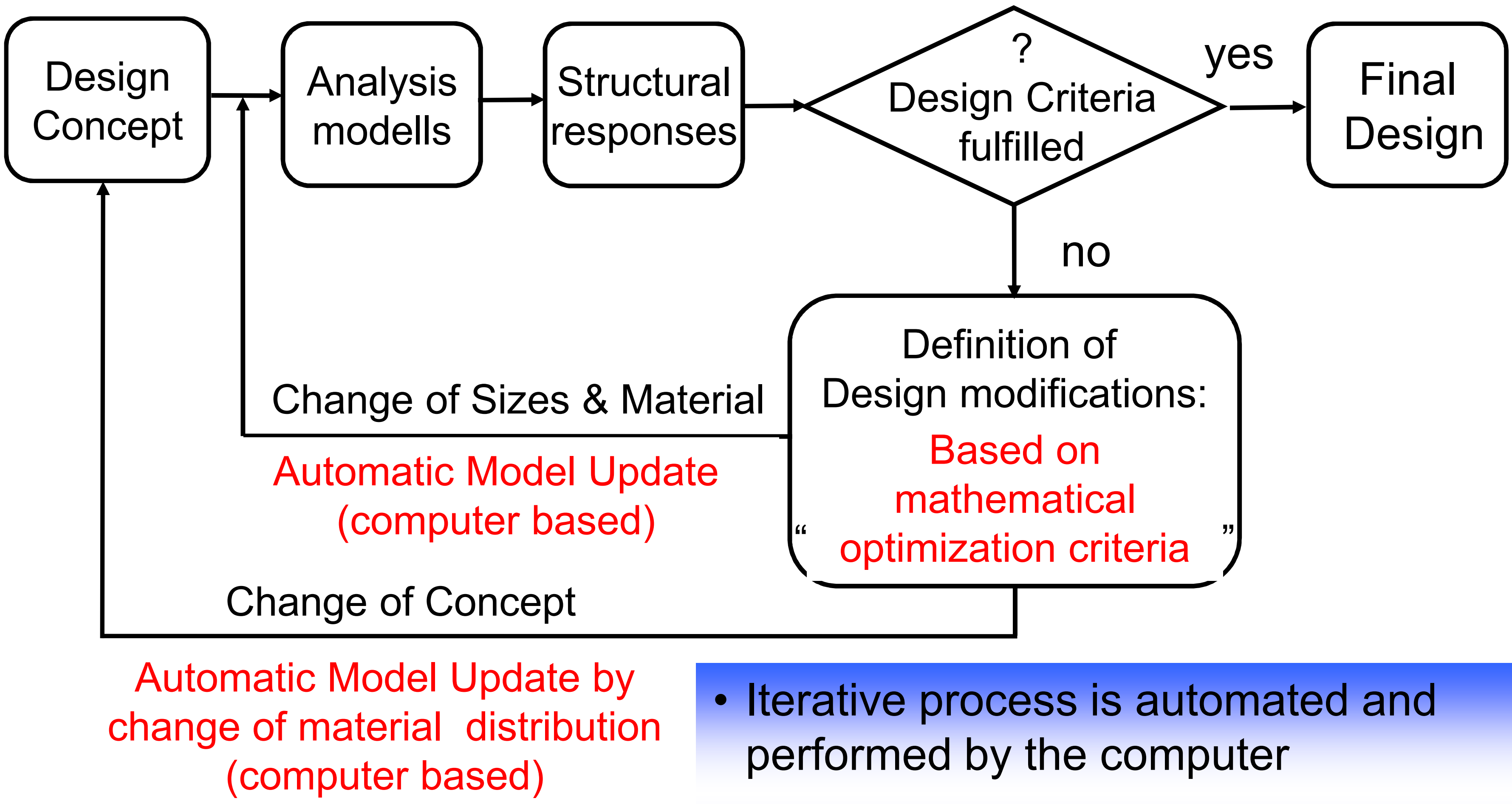
Automation of the structural design process by optimization methods



- Iterative process is automated and performed by the computer
- Significant Time & Cost Reduction as well as performance improvement !

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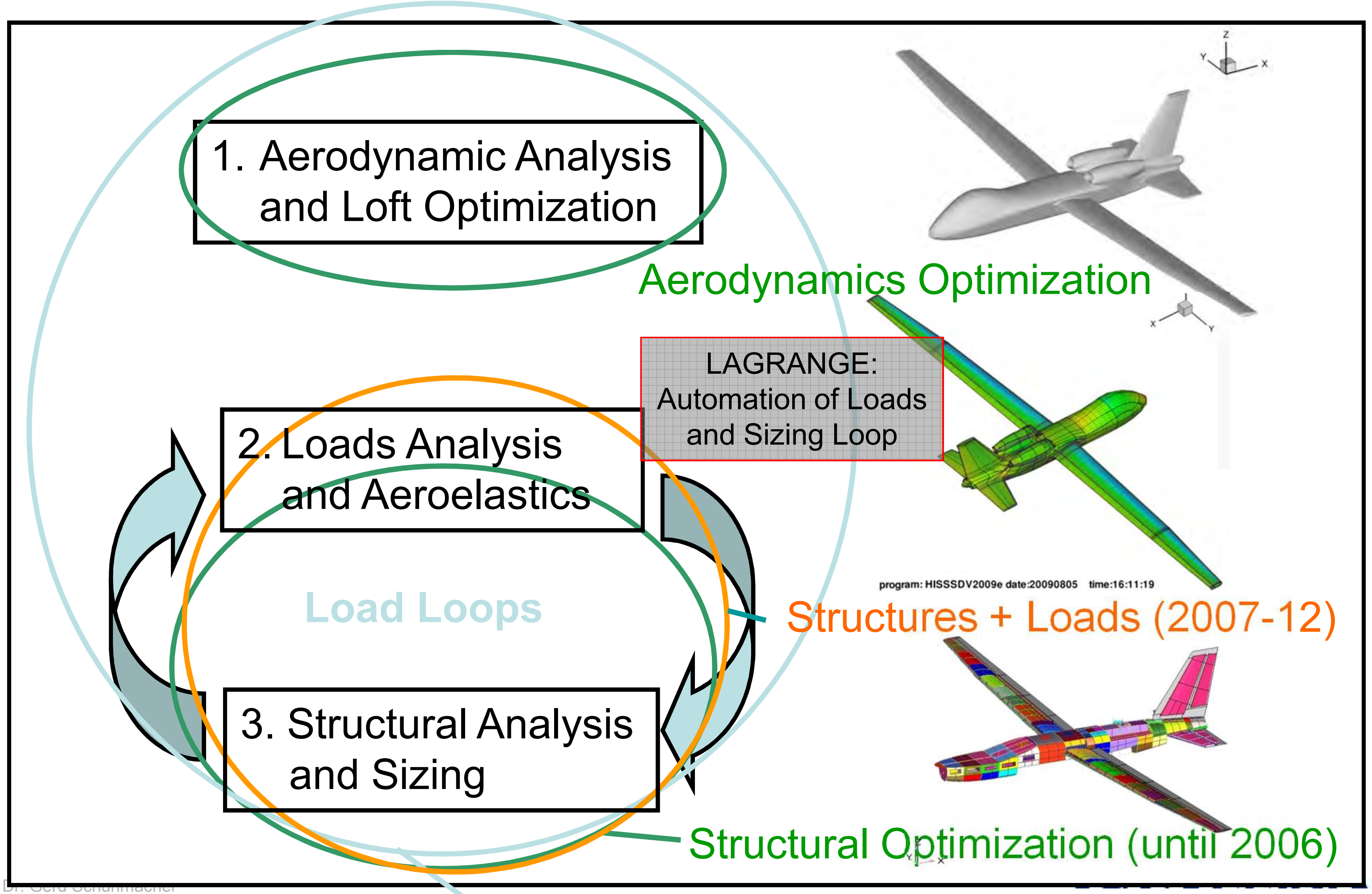
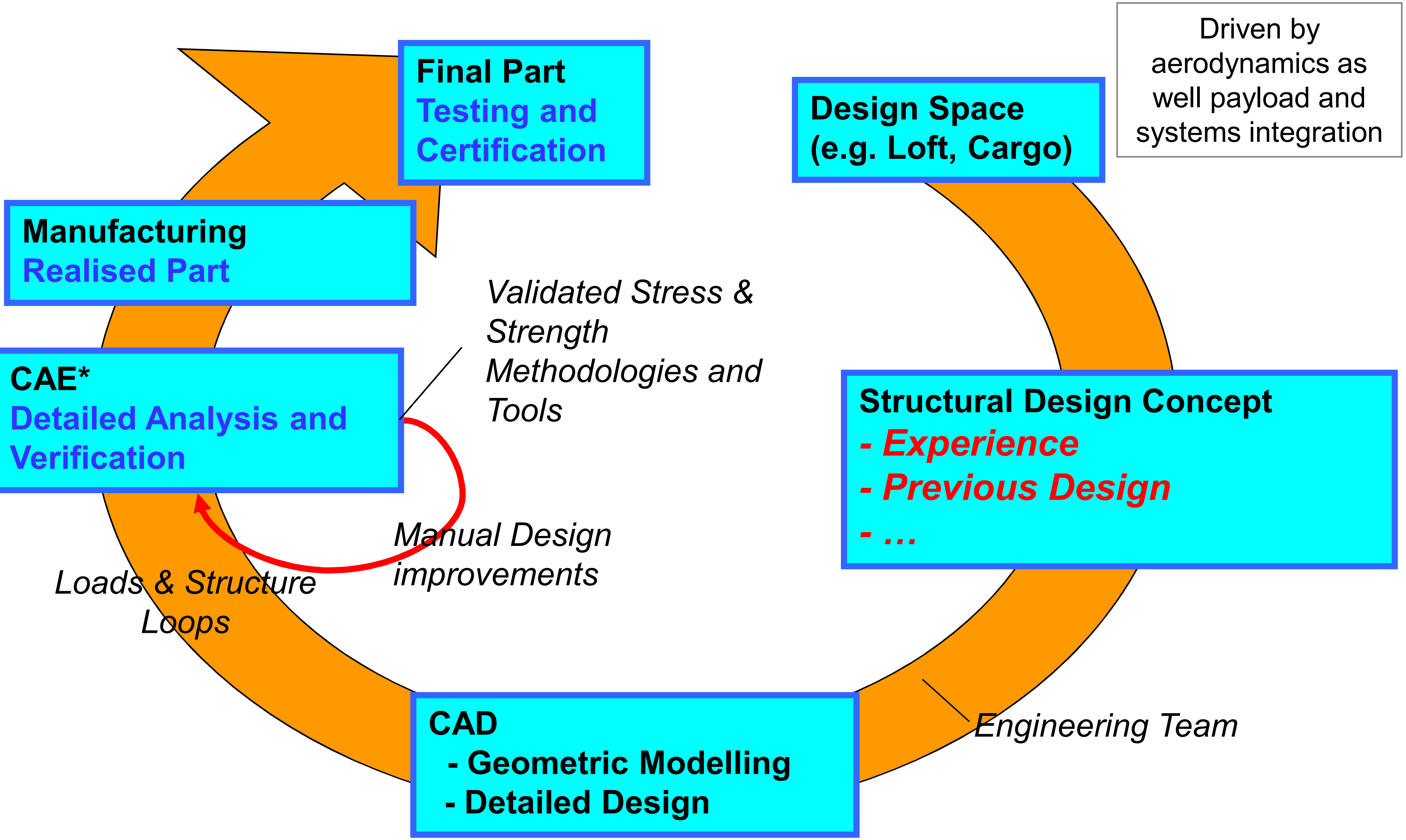
Automation of the Global Airframe Development Process



"Traditional" Design Process



* CAE: Computer Aided Engineering

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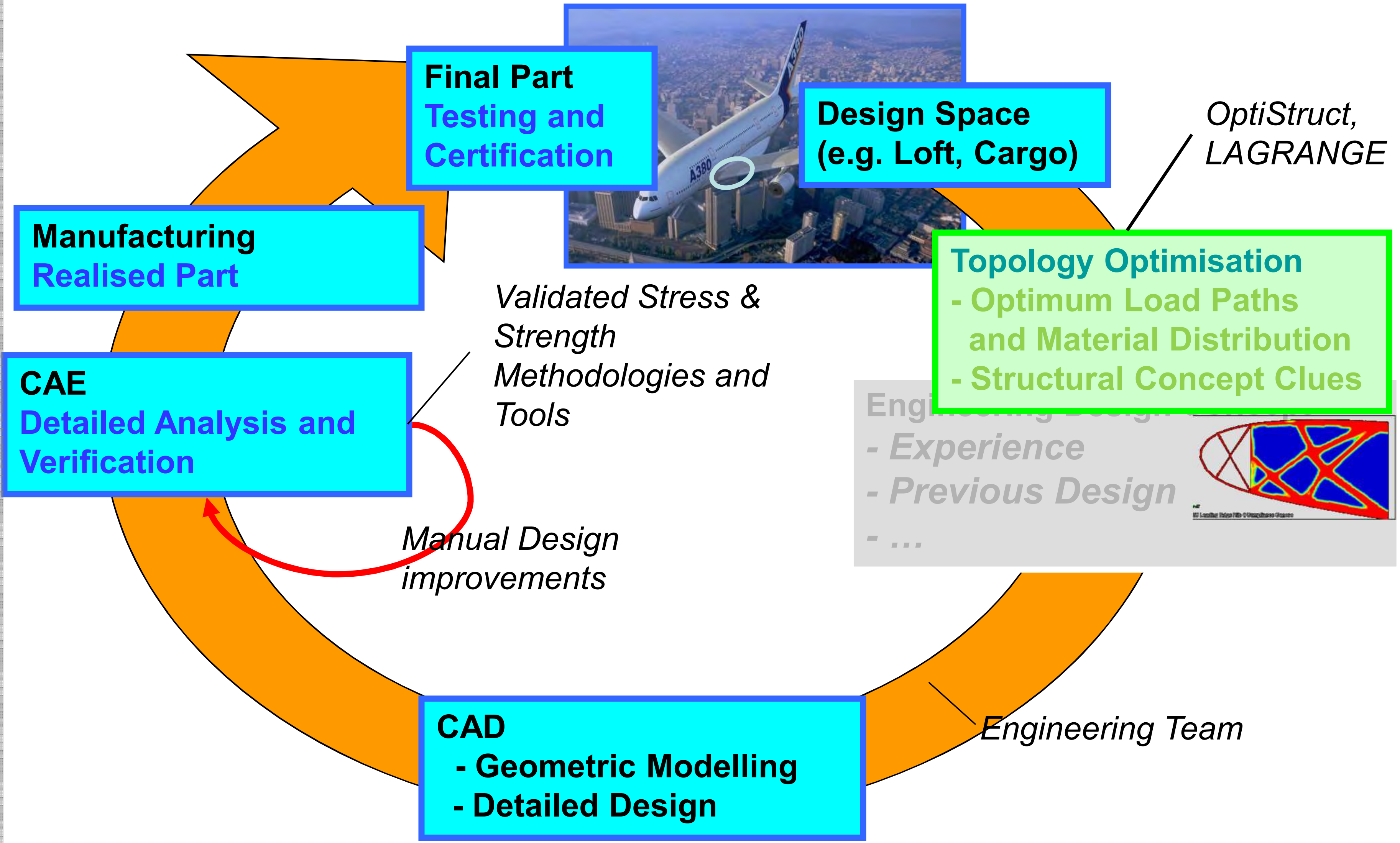
The Optimisation Assisted Cassidian Air Systems Design Process



CAE*: Computer Aided Engineering

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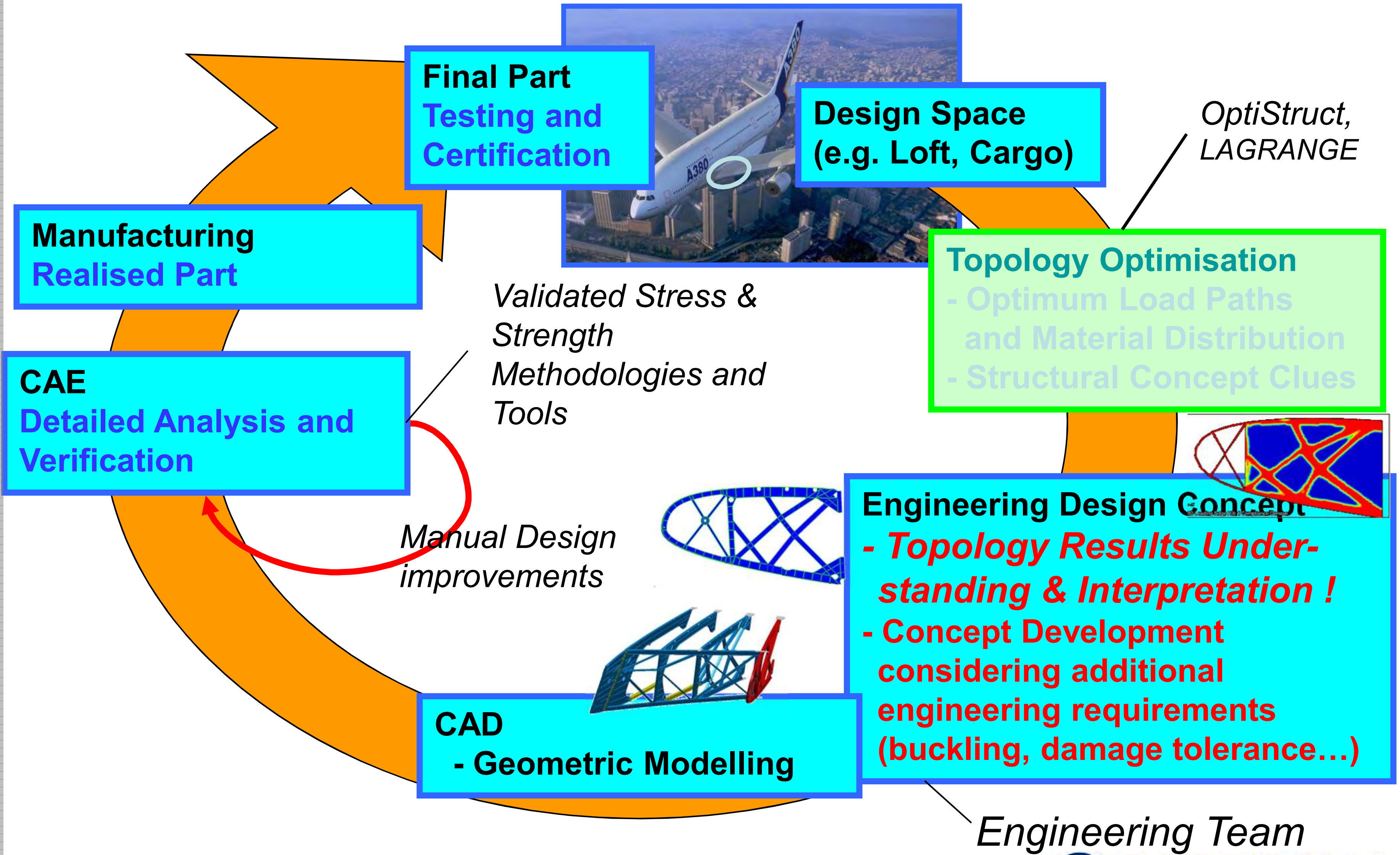
The Optimisation Assisted Cassidian Air Systems Design Process



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The Optimisation Assisted Cassidian Air Systems Design Process

Final Part
Testing and Certification

Design Space (e.g. Loft, Cargo)

OptiStruct, LAGRANGE

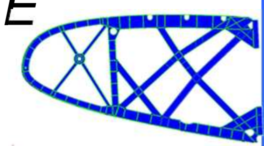
Topology Optimisation
- Optimum Load Paths and Material Distribution
- Structural Concept Clues

Manufacturing
Realised Part

Validated Stress & Strength Methodologies and Tools

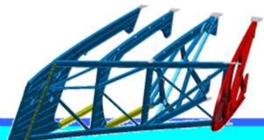
CAE
Detailed Analysis and Verification

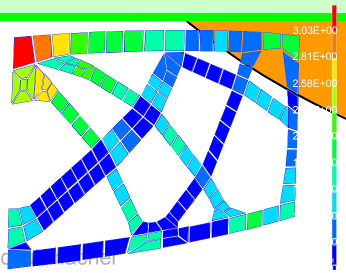
LAGRANGE



Engineering Design Concept
- ***Topology Results Under-standing & Interpretation !***
- **Concept Development considering additional engineering requirements (buckling, damage tolerance…)**

Structural Design Optimisation
- **Multidisciplinary Shape and Sizing Optimisation**





CAD
- **Geometric Modelling**

Engineering Team

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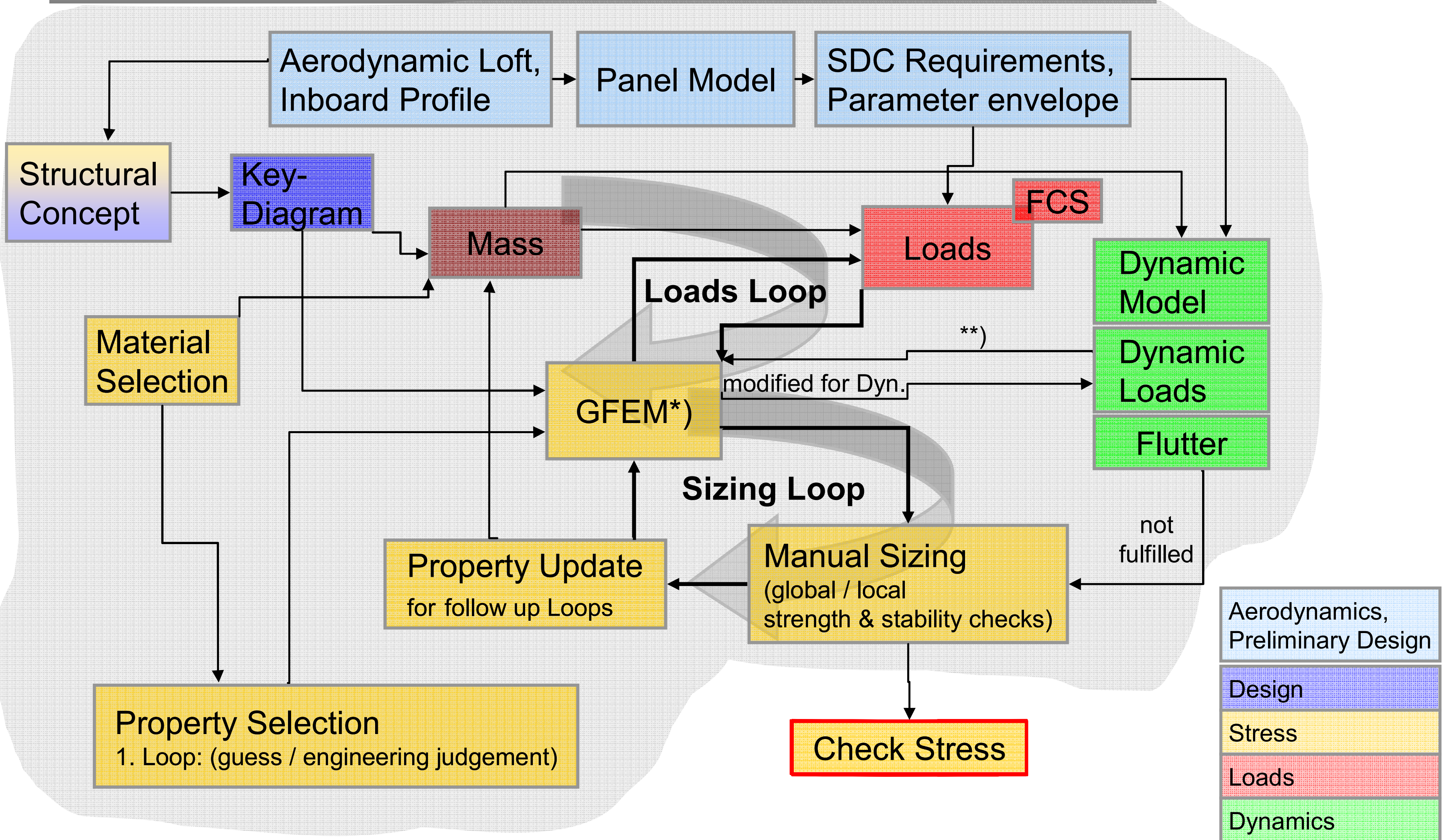
CAE*: Computer Aided Engineering

Traditional Sizing Process



*) No mass application => no correlation between stiffness & masses

**) Dynamic landing and dynamic gust loads.
NOT SYNCHRONISED with static loads

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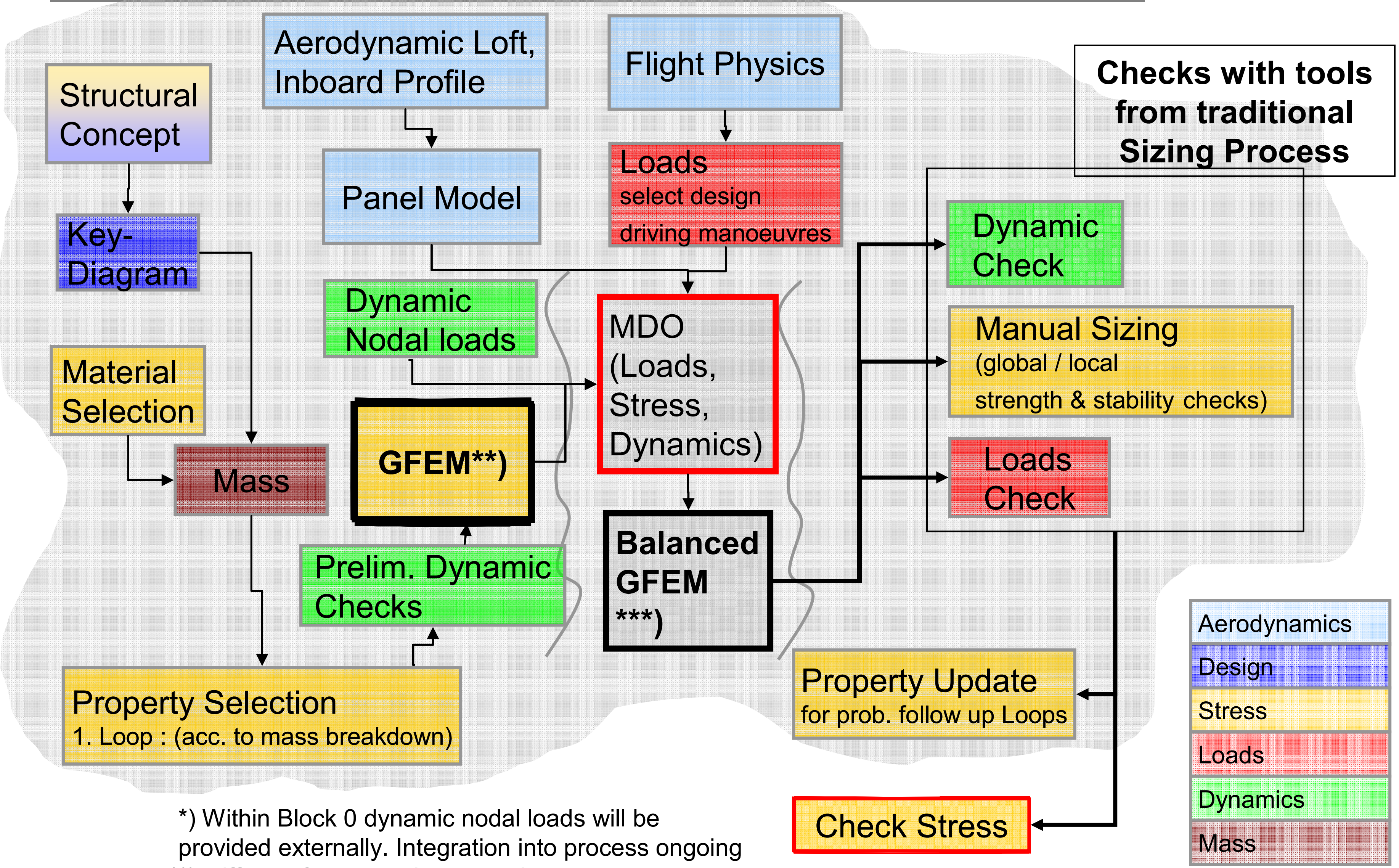
Multidisciplinary Airframe Design Optimization Process



*) Within Block 0 dynamic nodal loads will be provided externally. Integration into process ongoing

**) stiffness & masses in correlation

***) 1st Global Sizing Loop performed

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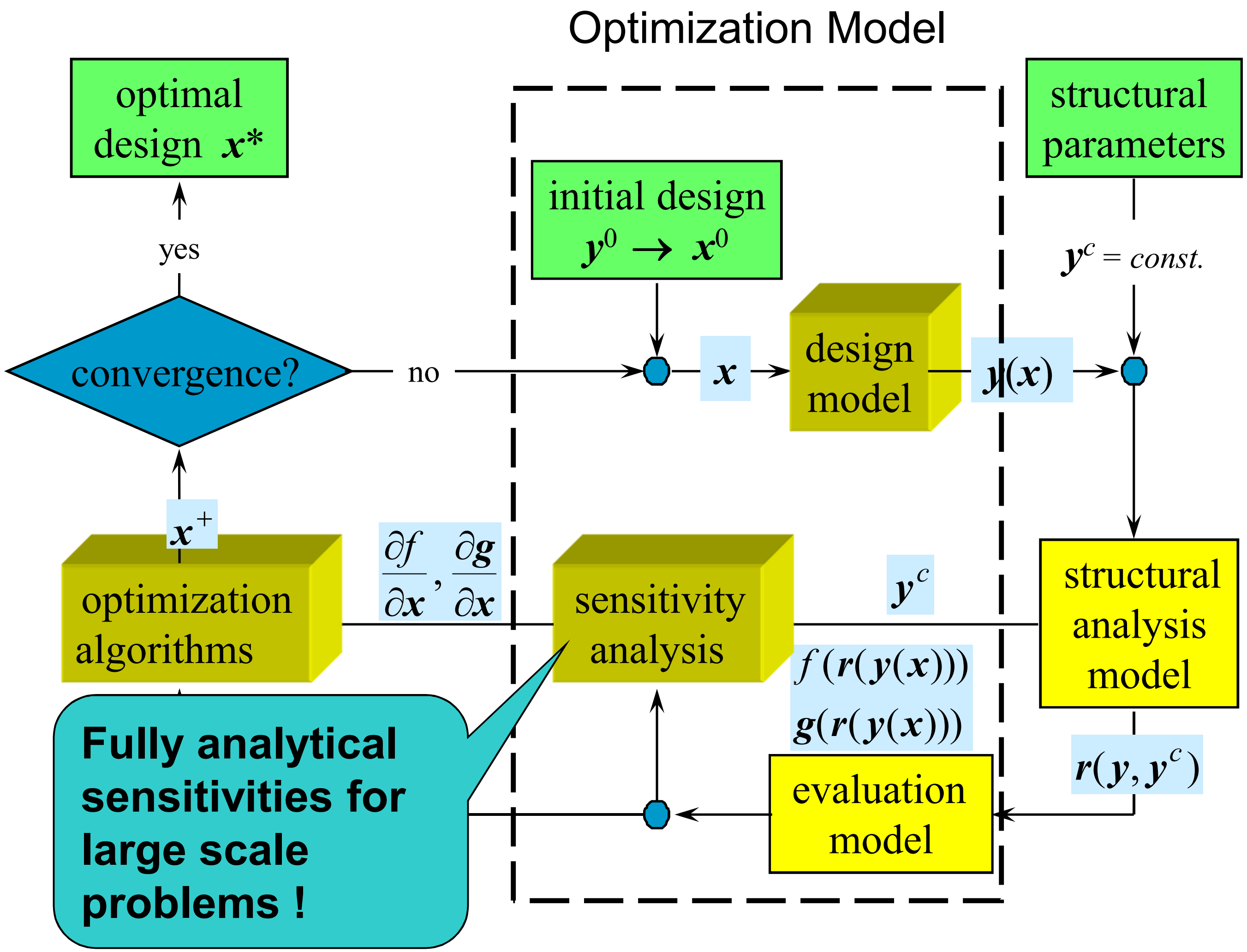
General Data Flow within the Numerical Optimization Process



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Disciplines within the LAGRANGE Airframe Optimization Process

- Simultaneous consideration of aiframe design driving disciplines during analysis and optimisation:

Optimisation

Optimisation model

Criteria model

Optimisation runs

Stress

Stressing criteria (strength & stability)

On basis of GFEM (with mass data)

Loads

Selected design driving manoeuvres including flight conditions for each manoeuvre

Aerodynamic HISSS model

Coupling model (Beaming)

Manufacturing

Minimum & maximum thickness / dimensions

Composite manuf. rules

Thickness jumps, etc.

Dynamics

Frequency requirements

Flutter speed

DLM model for unsteady aeroelasticity

Aeroelasticity

Aeroelastic efficiencies

Flutter speed

Gust

Aeroelastic requirements

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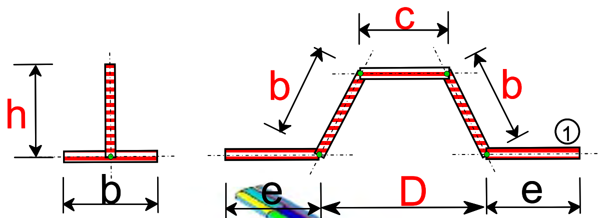
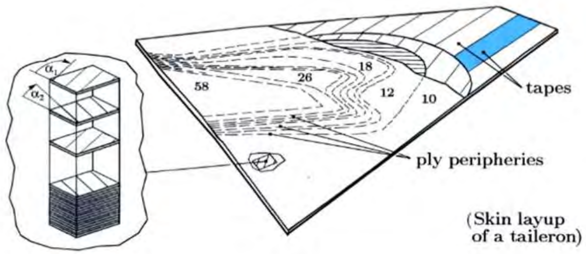
Structural Components to be optimized



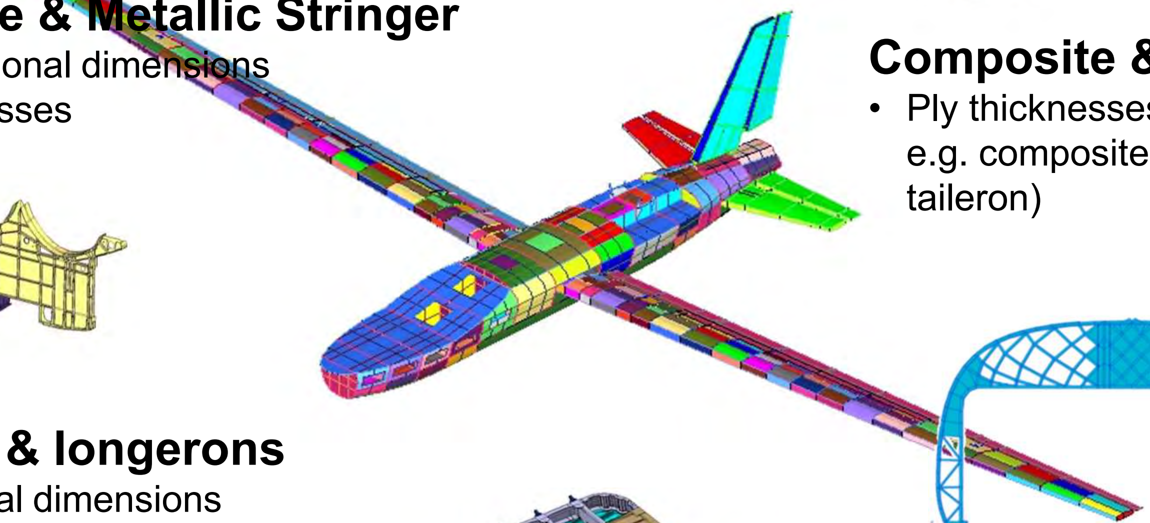
Composite & Metallic Stringer

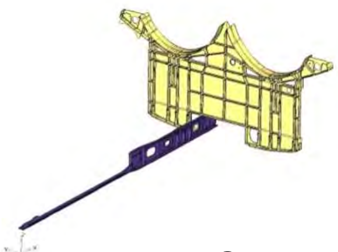
- Cross-sectional dimensions
- Ply thicknesses



Composite & Metallic Skin:

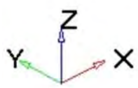
- Ply thicknesses / fibre orientation e.g. composite skin (wing, fuselage, taileron)

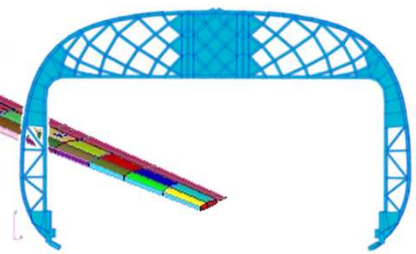




Shear walls & longerons

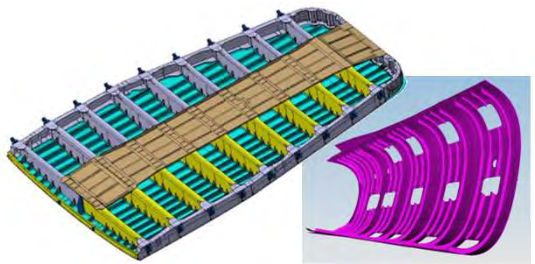
- Cross-sectional dimensions
- Skin thicknesses





Metallic frames:

- Cross-sectional dimensions



Stringer-stiffened panels:

- Cross-sectional dimensions
- Skin thicknesses

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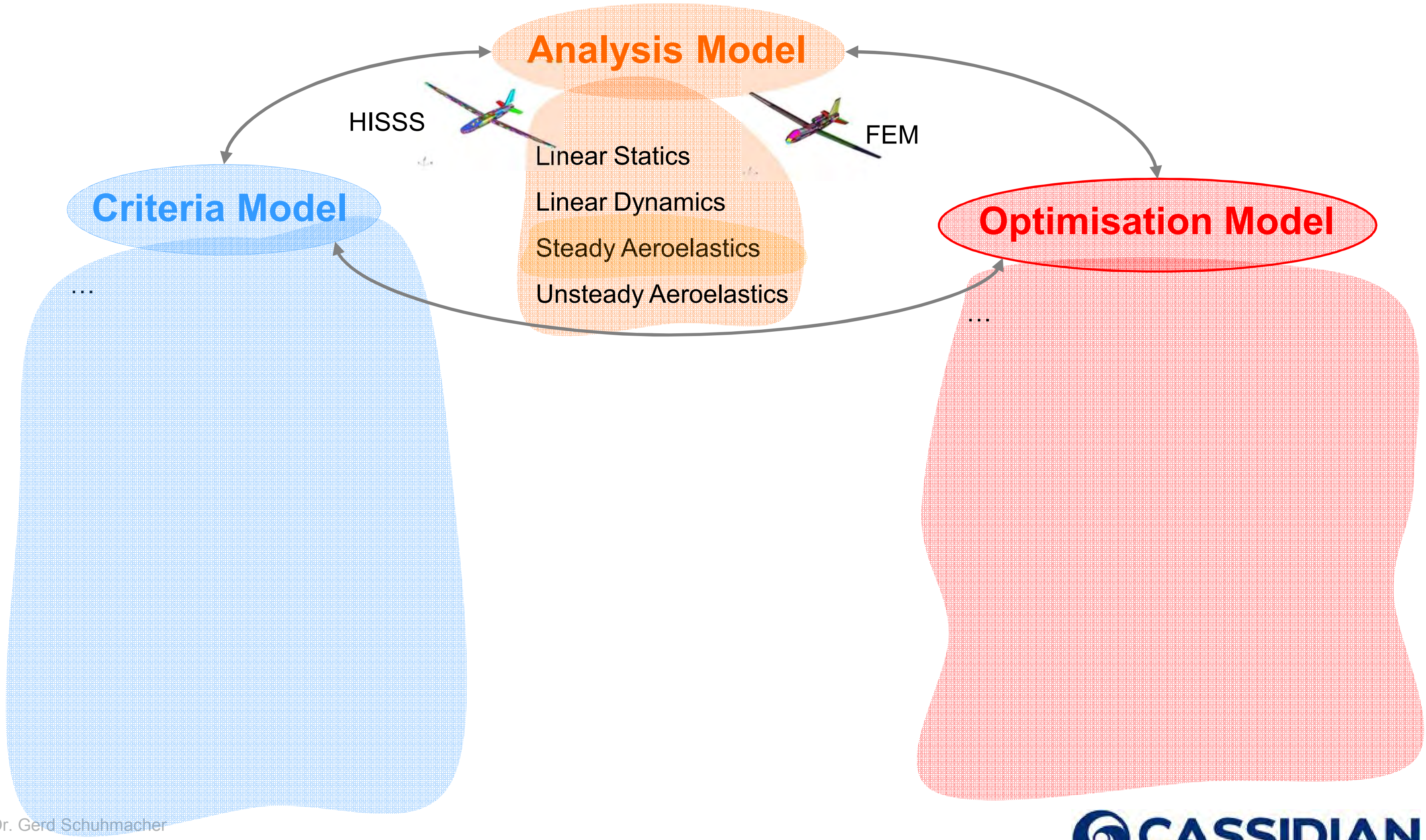
Multidisciplinary Analysis Types

- Multidisciplinary structure optimisation (variable structure & variable loads)



Design Variables and Design Criteria

- Multidisciplinary structure optimisation (variable structure & variable loads)

Analysis Model

HISSS

FEM

Linear Statics

Linear Dynamics

Steady Aeroelastics

Unsteady Aeroelastics

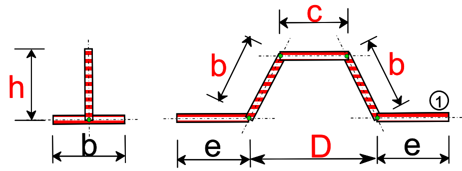
Criteria Model

…

Optimisation Model

Parametric model defining the design variables:

- Cross-sectional area of bars (sizing)
- Thickness of shell or membrane elements (sizing)
- Ply thickness of composites (sizing)
- Fibre orientation in composite stacks (angles)
- Coordinates of FE nodes (shape)
- Coordinates of control points (CAD, NURBS)
- Trimming variables (angles of attack)



- Omega profile
- T profile
- Box profile
- C profile
- LZ profile

⇒ Geometric Sizes + Composite-Lay-up

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Design Variables and Design Criteria

- Multidisciplinary structure optimisation (variable structure & variable loads)

Analysis Model

HISSS

FEM

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…

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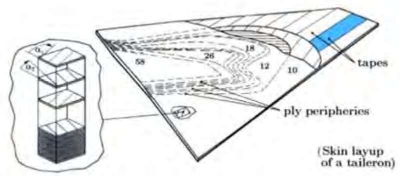

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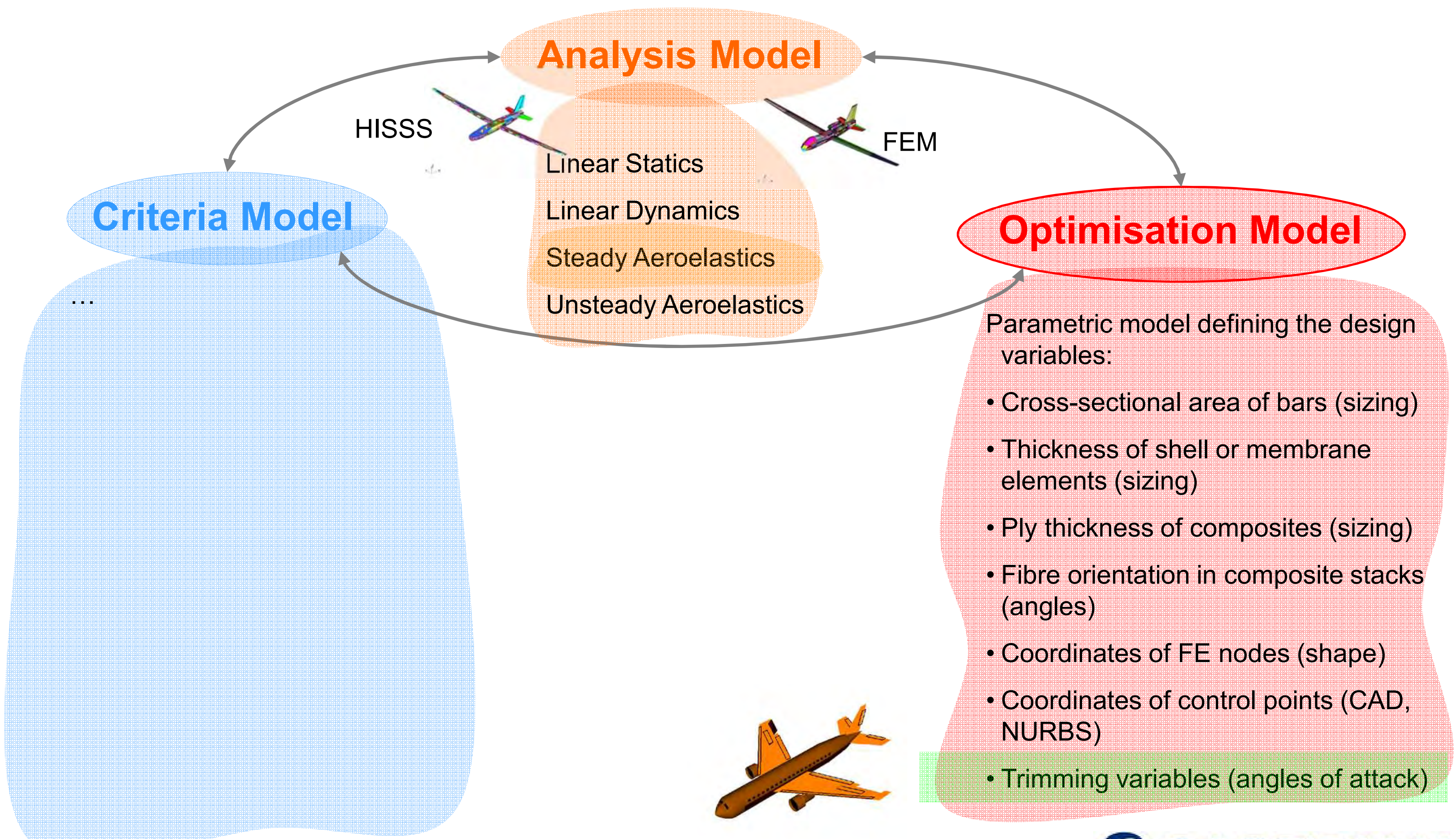
Design Variables and Design Criteria

- Multidisciplinary structure optimisation (variable structure & variable loads)



Design Variables and Design Criteria

- Multidisciplinary structure optimisation (variable structure & variable loads)

Analysis Model

HISSS

FEM

- Linear Statics
- Linear Dynamics
- Steady Aeroelastics
- Unsteady Aeroelastics

Criteria Model

- Strength (diverse models depending on failure criteria)
- Analytical buckling analysis (also theory 2nd order)
- Local stability analysis (for critical parts of cross-section), crippling
- Displacements (stiffness requirements)
- Constraints for natural frequencies
- aeroelastic requirements (steady, unsteady): efficiencies, flutter, etc.
- Manufacturing constraints
- Constraints for trimmed flight and landing manoeuvres

Damage Tolerance & Repairability

$$\varepsilon_{allow}^{comp} = -3000\,\mu s$$

$$\varepsilon_{allow}^{tens} = 4500\,\mu s$$

- Yamada-Sun
- Puck
- Tsai-Hill
- ….

Optimisation Model

Parametric model defining the design variables:

- Cross-sectional area of bars (sizing)
- Thickness of shell or membrane elements (sizing)
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Design Variables and Design Criteria

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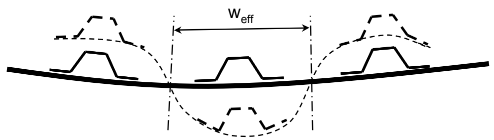
Constraints for natural frequencies

aeroelastic requirements (steady, unsteady): efficiencies, flutter, etc.

Manufacturing constraints

Constraints for trimmed flight and landing manoeuvres



- Skin & Column Buckling for isotropic, orthotropic and anisotropic skins
- Post-Buckling for isotropic and composite structures

Optimisation Model

Parametric model defining the design variables:

- Cross-sectional area of bars (sizing)
- Thickness of shell or membrane elements (sizing)
- Ply thickness of composites (sizing)
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- Coordinates of FE nodes (shape)
- Coordinates of control points (CAD, NURBS)
- Trimming variables (angles of attack)

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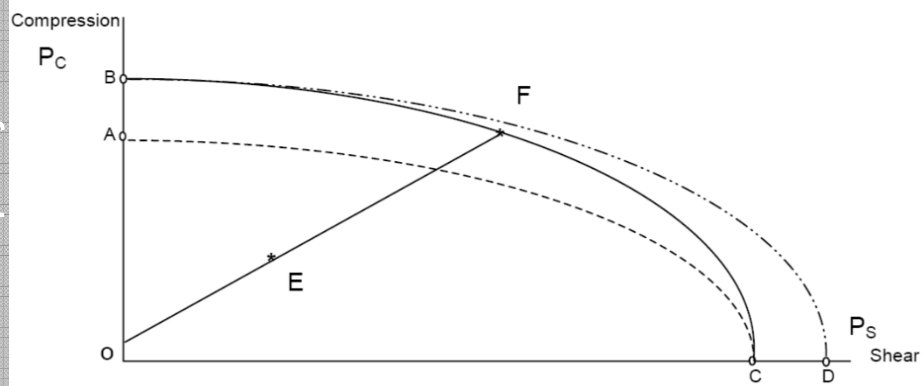
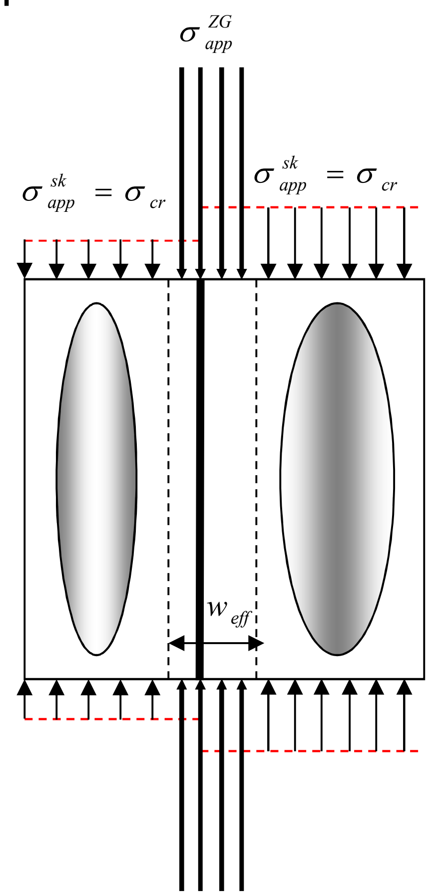
Lagrange Postbuckling Analysis

Postbuckling criteria

- Postbuckling (fast analytical approach) for metal and composite structures
  - Buckling onset strategy (combined compression and shear)
  - Diagonal Tension due to shear loads
  - Load redistribution
  - Composite stringers and frames (including local buckling and enforced crippling)





- Point A: Panel local buckling under pure compression loads
- Point B: Column buckling failure under pure compression loads (after panel local buckling took place)
- Point C: Panel buckling under pure shear loads
- Point D: Column buckling failure incl. diagonal tension effects after panel local buckling due to shear took place

Design Variables and Design Criteria

- Multidisciplinary structure optimisation (variable structure & variable loads)

Analysis Model

HISSS

FEM

- Linear Statics
- Linear Dynamics
- Steady Aeroelastics
- Unsteady Aeroelastics

Criteria Model

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- Trimming variables (angles of attack)

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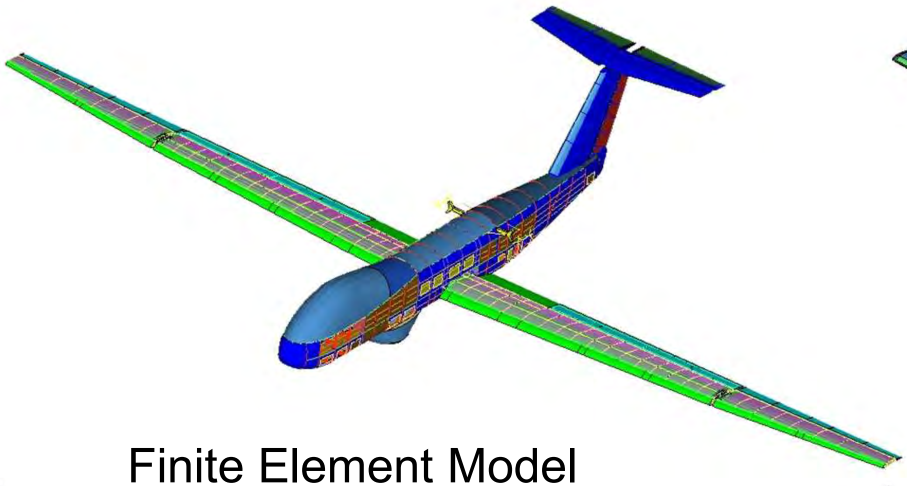
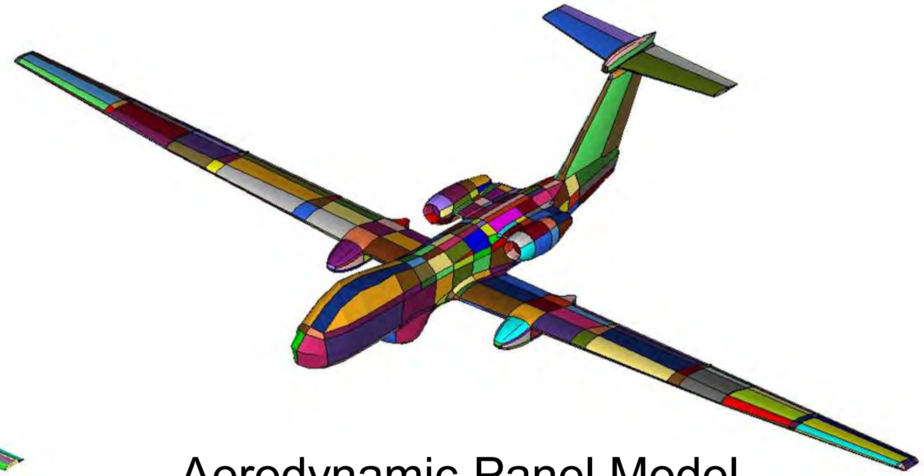
Multidisciplinary Analyses Models within the Optimization Process

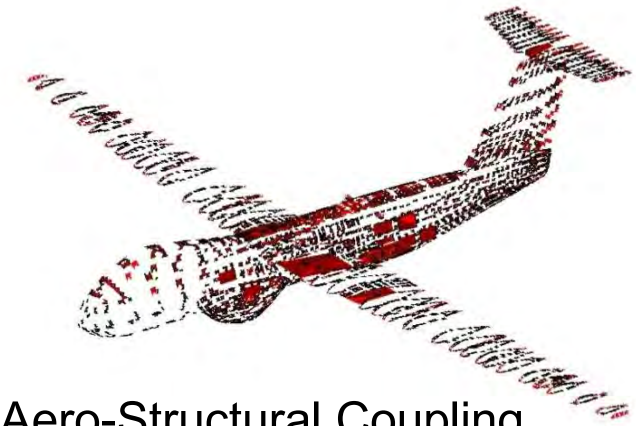


Finite Element Model



Aerodynamic Panel Model
for steady state manoeuvres

Doublet Lattice Panel Model for
dynamic analysis (gust, flutter)



Aero-Structural Coupling
Model (Beaming)

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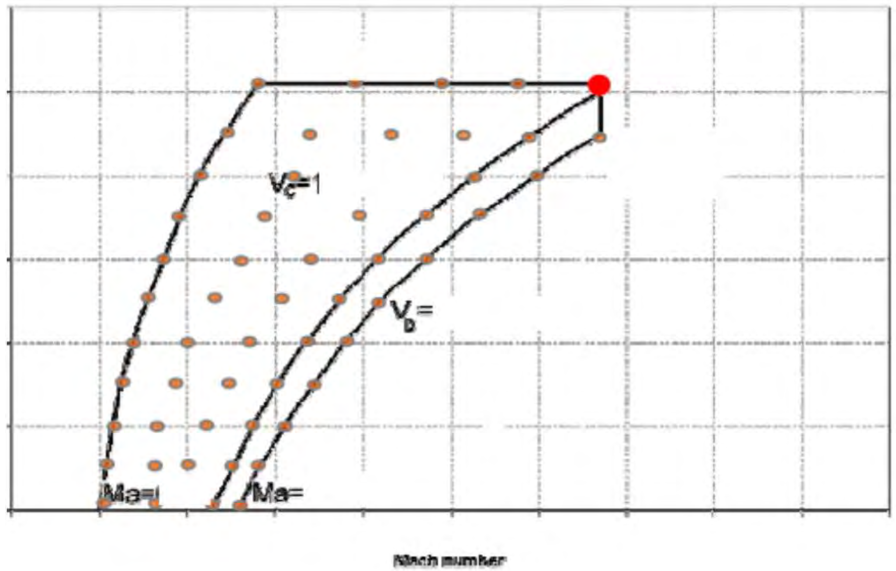
Steady manoeuvre loads analysis within LAGRANGE

Manoeuvre Load Simulation

- Based on the Mission and Structural Design Criteria the flight envelope is established and scanned (10^3 - 10^5 manoeuvres) in order to determine the design driving, steady manoeuvres with maximum loads

⇒ Down selection of design driving steady manoeuvres (~10^2 manoeuvres).

Case		Mach[]	nx[g]	ny[g]	nz[g]	dp[rad/s^2]	dq[rad/s^2]	dr[rad/s^2]
10. 1G Roll	mtom	0.26	-0.5	0.3	-1.0	2.5	0.0	0.2
10. 1G Roll	mtom	0.26	1.0	-0.3	-1.0	-2.5	0.0	-0.2
11. 1G Roll	4223kg	0.26	-0.5	0.1	-1.0	0.3	0.0	-0.6
11. 1G Roll	4223kg	0.26	1.0	-0.1	-1.0	-0.3	0.0	0.6
11. 1G Roll	4223kg	0.26	1.0	-0.3	-1.0	0.3	0.0	-0.6
11. 1G Roll	mtom	0.26	-0.5	-0.3	-1.0	0.2	0.0	-0.4
11. 1G Roll	mtom	0.26	-0.5	0.0	-1.0	-0.3	0.0	0.2
11. 1G Roll	mtom	0.26	-0.5	-0.3	-1.0	0.3	0.0	-0.6
11. 1G Roll	mtom	0.26	-0.5	-0.2	-1.0	0.3	0.0	-0.6
11. 1G Roll	mtom	0.26	1.0	0.1	-1.0	-0.3	0.0	0.4
11. 1G Roll	mtom	0.26	1.0	0.3	-1.0	-0.3	0.0	0.6
12. 1G Roll	mtom	0.26	-0.5	-0.1	-1.0	0.3	0.0	-0.4
12. 1G Roll	mtom	0.26	1.0	0.2	-1.0	-0.3	0.0	0.6
13. lateral Gust	mtom	0.23	0.0	-0.2	1.0	0.0	0.0	0.0
13. vertical Gust	mtom	0.23	0.0	0.0	-0.9	0.0	0.0	0.0
13. vertical Gust	mtom	0.23	0.0	0.0	2.9	0.0	0.0	0.0
2. Pull Out Steady	mtom	0.26	-0.5	-0.4	2.8	0.8	0.0	-0.6
2. Pull Out Steady	mtom	0.26	1.0	0.3	2.8	0.8	0.0	0.5
2. Pull Out Steady	mtom	0.26	1.0	0.4	2.8	-0.8	0.0	0.6
3. Pull Out Response	mtom	0.26	-0.5	-0.1	2.8	0.0	-1.5	0.0
3. Pull Out Response	mtom	0.26	1.0	-0.1	2.8	0.0	0.6	0.0
4. Push Over Steady	mtom	0.26	-0.5	0.0	-1.0	0.3	0.0	-0.2
5. Push Over Steady	mtom	0.26	-0.5	-0.3	-1.0	0.4	0.0	-0.6
5. Push Over Steady	mtom	0.26	1.0	0.3	-1.0	-0.4	0.0	0.6
6. Push Over Response	mtom	0.26	1.0	-0.1	-1.0	0.0	1.5	0.0
7. 2G Rolling Pull Out	mtom	0.26	-0.5	-0.4	2.0	-2.5	0.0	-0.6
7. 2G Rolling Pull Out	mtom	0.26	1.0	-0.4	2.0	-2.5	0.0	-0.4
8. 2G Rolling Pull Out	4223kg	0.26	1.0	-0.1	2.0	-0.3	0.0	0.6
8. 2G Rolling Pull Out	mtom	0.26	1.0	0.4	2.0	0.3	0.0	0.6



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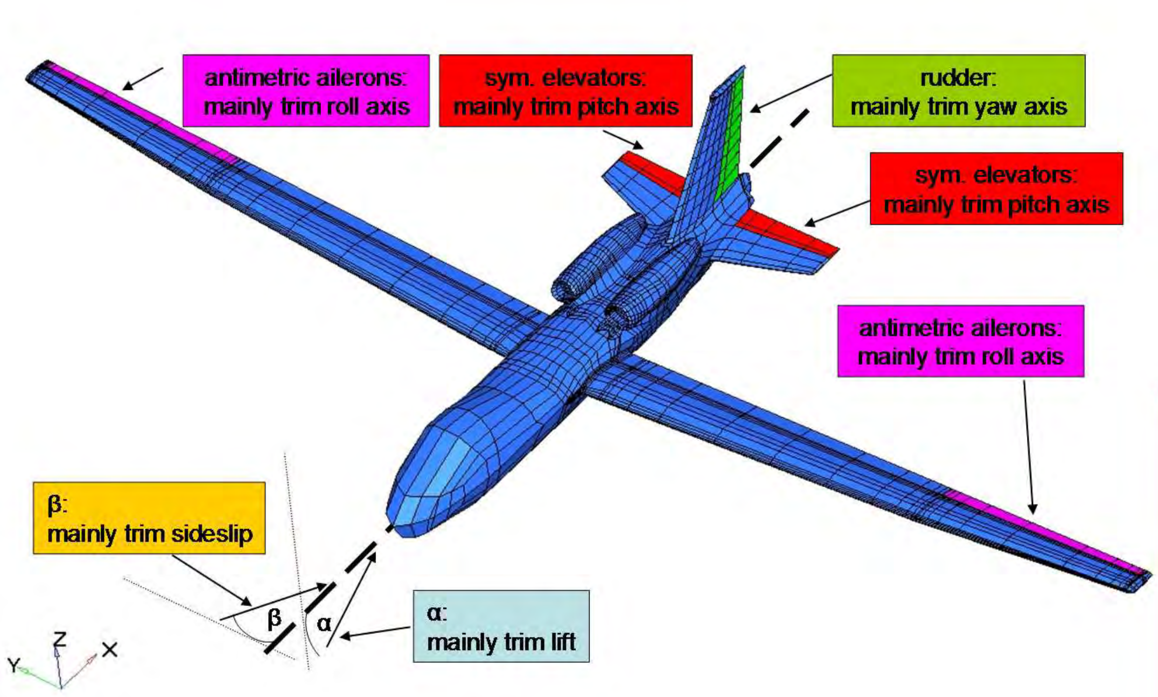
Steady manoeuvre loads analysis within LAGRANGE

Trimming Process

- For each steady manoeuvre (Mass, CoG, Altitude, Mach, Accelerations) the angles of attack (pitch angle, yaw angle and the AoA of the control surfaces) are defined as design variables to be optimized in such a way, that the residual forces are vanishing in the overall optimization process.



F_y(inertia) + F_y(aerodynamic) = 0

F_z(inertia) + F_z(aerodynamic) = 0

M_x(inertia) + M_x(aerodynamic) = 0

M_y(inertia) + M_y(aerodynamic) = 0

M_z(inertia) + M_z(aerodynamic) = 0

alpha = - xx °

beta = - yy °

delta aileron = zz °

delta elevator = hh °

delta rudder = kk °

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Steady Aeroelastic Analysis (HISSS)

Governing equations:

- Basic aeroelastic discritised equation

aerodynamic loads (function of deformation)

$$K \cdot u = F^{inertia}\left(X^s, u(x)\right) + F^{aero}\left(X^t, u(x)\right)$$

$$F^{aero} = q \cdot S \cdot C_P \cdot T_{LS}$$

transformation matrix into structural system

aerodynamic pressure coefficient

$$C_P = \frac{2}{\kappa \cdot M_\infty^2} \cdot \left(\left(1 + \frac{\kappa - 1}{2} \cdot M_\infty^2 \cdot \left(1 - V^2\right)\right)^{\frac{\kappa}{\kappa-1}} - 1 \right)$$

- The local panel velocity is calculated by

$$\left.\begin{aligned} V_x &= V_{\infty x} + PAIC_x^{-1} \cdot B_{CN} \\ V_y &= V_{\infty y} + PAIC_y^{-1} \cdot B_{CN} \\ V_z &= V_{\infty z} + PAIC_z^{-1} \cdot B_{CN} \end{aligned}\right\}$$

$$B_{CN} = -\left(V_{\infty x} \cdot n_{cx} + V_{\infty y} \cdot n_{cy} + V_{\infty z} \cdot n_{cz}\right)$$

$$\vec{n}_c = \frac{\beta \cdot \vec{n}}{\left(1 - 2 \cdot M_\infty^2 \cdot n_x^2 + M_\infty^4 \cdot n_y^4\right)^{\frac{1}{4}}}$$

Compressible normal

Neumann boundary condition

$$\vec{n} = \vec{u}_{24} \times \vec{u}_{31}$$

Panel normal direction

Panel diagonals including update due to **structural displacements**

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Steady manoeuvre loads analysis within LAGRANGE

Sensitivity Analysis

- In order to incorporate the loads analysis into the optimization process, i.e. automation of both loads and sizing loops, sensitivities of aerodynamic loads with respect to both sizing and trimming variables are required.
- Analytical sensitivities are essential for the of sake numerical efficiency!!!
- Analytical aeroelastic sensitivities are determined by LAGRANGE:

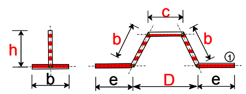
$$\frac{du}{dx} = K^{-1} \cdot \left(\frac{dF^{\text{inertia}}\left(X^{s}, u(x)\right)}{dx} + \frac{dF^{aero}\left(X^{t}, u(x)\right)}{dx} - \frac{dK}{dx} \cdot u \right)$$

$$\frac{dF^{aero}}{dx} = q \cdot S \cdot \frac{dC_P}{dx} \cdot T_{LS}$$

$$\frac{dC_P}{dx} \rightarrow \frac{dV}{dx} \rightarrow \frac{dn}{dx} \rightarrow \frac{du}{dx}$$

Design variable x

Sizing | Trimming



$$x = X^{s} + X^{t}$$

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Gust load case definition

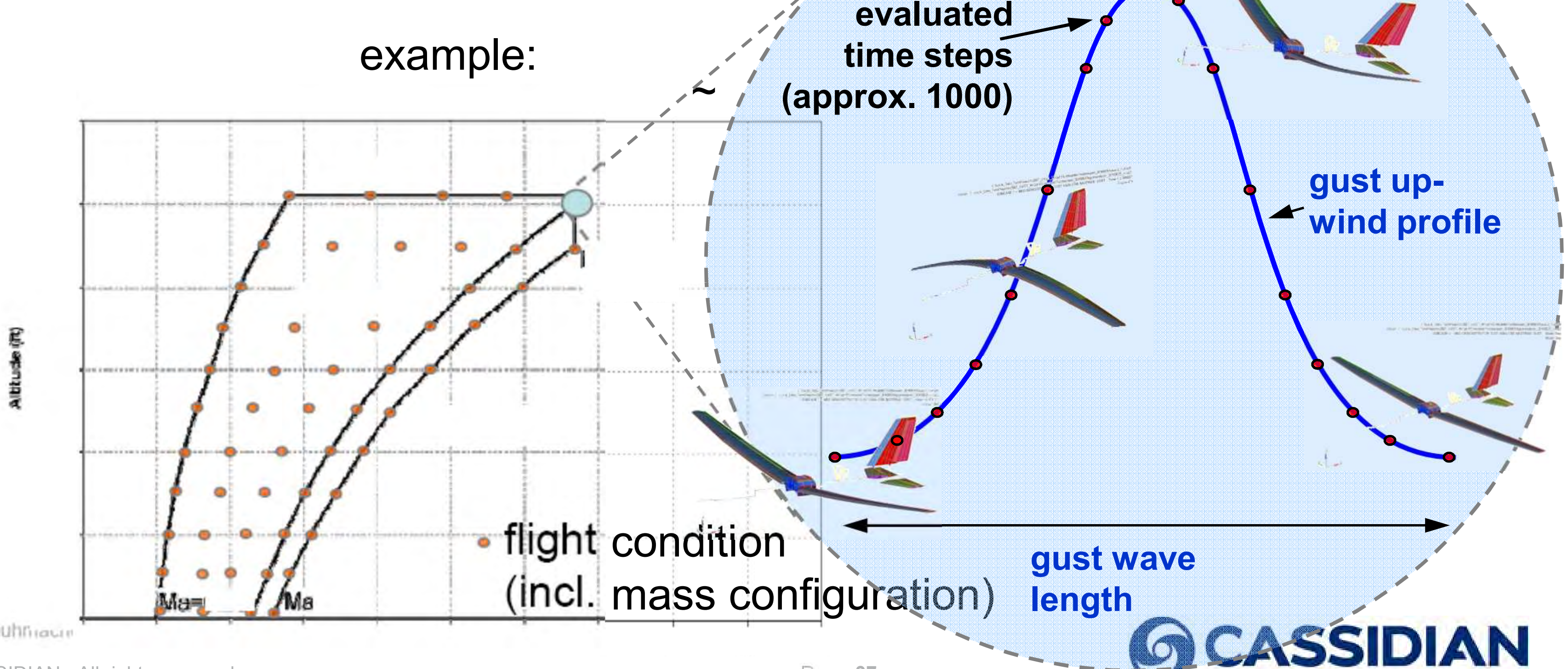
A “*gust case*” is defined as a combination of:

a) steady manoeuvre: flight condition and mass configuration (c.o.g. position !) (altitude & aircraft speed; usually 1g cruise)

b) gust condition: wave-length and up- or down wind gust velocity and incidence angle (usually sinusoidal shaped)

⇒ leading to huge amount of different gust cases (up to ~10000), which have to be considered !

example:



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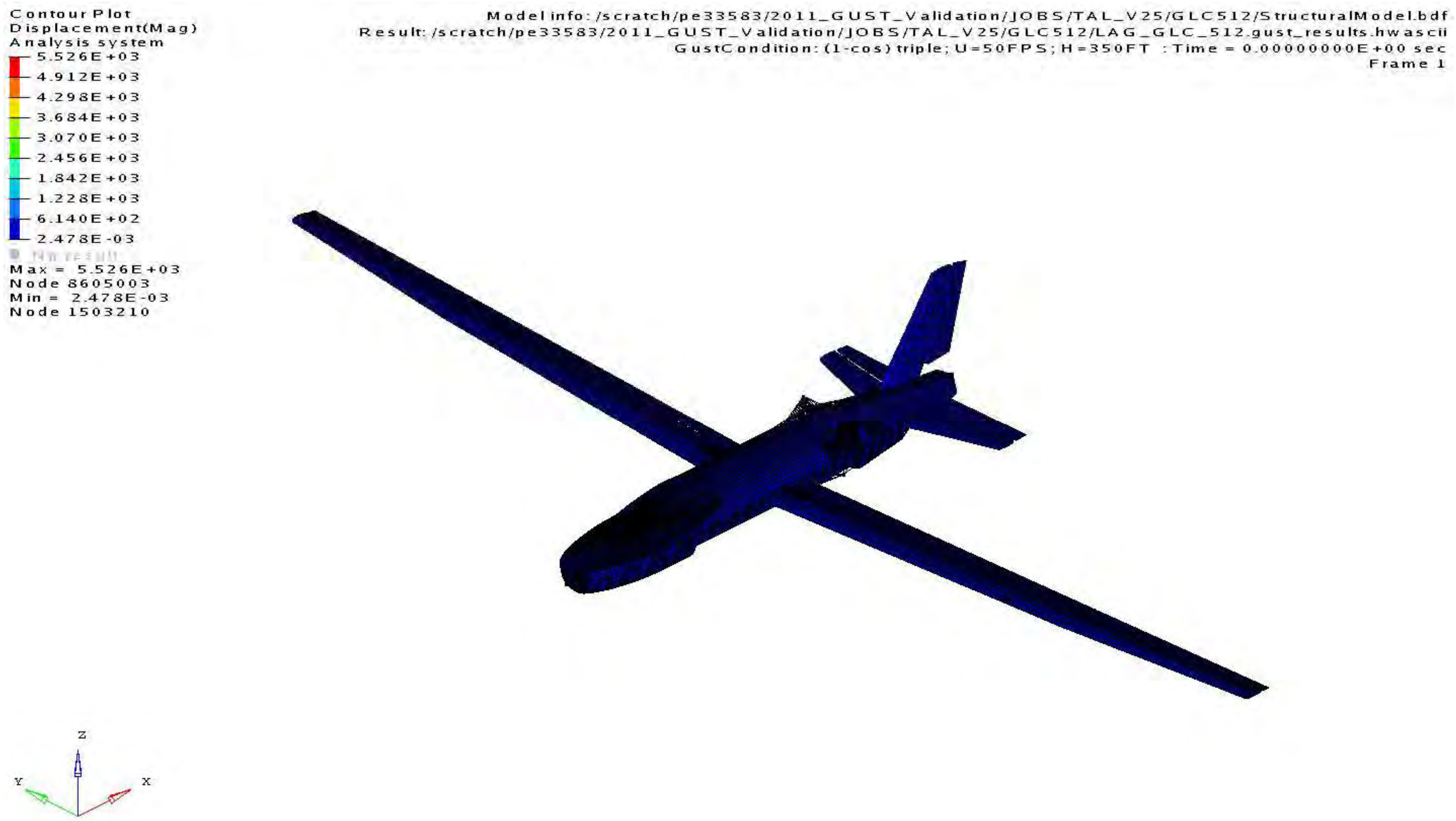
Gust response of Talarion UAV

- Flight at 20 kft, 150 KEAS, Ma 0.34
- 1 – cos shaped FAR/JAR gust with vertical peak velocity U = 50 ft/s



Gust Process

Many gust blocks

gust block for selected mass configuration

Many gust cases

gust case =

incremental gust analysis

- specific mass configuration,
- specific incidence angle,
- specific wave length,
- specific speed,
- specific altitude

+

basic flight attitude

- trimmed aeroelastic steady manoeuvre
- for specific mass configuration,
- specific altitude,
- specific speed
- to be superimposed to an incremental gust

Database (HDF5)

evaluation of all gust cases for selected mass configuration

- Implementation of the Incremental Gust Response and the Sensitivities is completed.
- Implementation process for the fully automated determination of the design driving time steps and the superposition to manoeuvre load cases is ongoing.

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Overall Approach for Loads in the Optimization Process

Summary for the Manoeuvre, Gust and Landing Loads Analysis Process

- The manoeuvre load simulation of the elastic aircraft (fully coupled aero-dynamic-structure model) is combined with a trimming process (optimisation task) in order to provide the distributed, elastic aircraft manoeuvre loads.
- The distributed aerodynamic and inertia loads are directly applied to the global, non-condensed FE model, providing the stresses and displacements for the subsequent strength and stability analysis.
- Gust loads are determined as incremental dynamic response. The time steps resulting in maximum local stresses are determined and the resulting deflections are superimposed to the corresponding steady manoeuvres.
- Landing Gear Loads are determined by an external Multi-Body-Analysis and then applied to the global full aircraft model in order consider them in the sizing process.
- By incorporating the manoeuvre and gust loads analysis into the optimisation platform LAGRANGE, both very time consuming loops (loads & sizing) are automated.

Optimisation Algorithms

First Order Codes:

MMA (Method of moving asymptotes) …

High number of design variables ~10^6 but few constraints

CONLIN (convex linearisation)

SLP (sequential linear program)

SCP (sequential convex program)

GRG (generalised reduced gradients)

Second Order Codes:

RQP1 (recursive quadratic program Schittkowski)

RQP2 (recursive quadratic program Powell)

QPRLT (quadratic program with reduced line-search technique)

SCPIP (sequential convex program with interior-point solver)

NLPIP (SQP/IPM-method for solving large and sparse nonlinear optimization problems)
many design variables ~10^6 many constraints up to ~10^6 - 10^8

Contents

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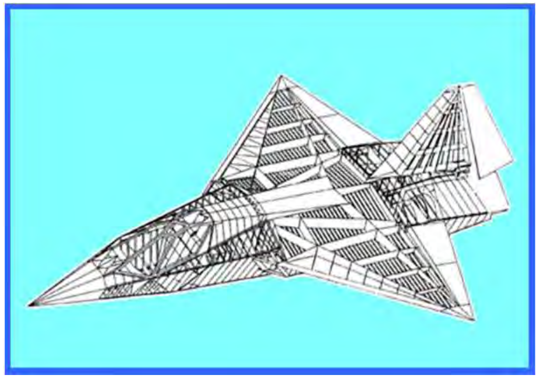
Overview on past military aircraft applications

Eurofighter (≈1985)
Composite Wing & Fin

X-31A Wing (1990)
Composite Wing

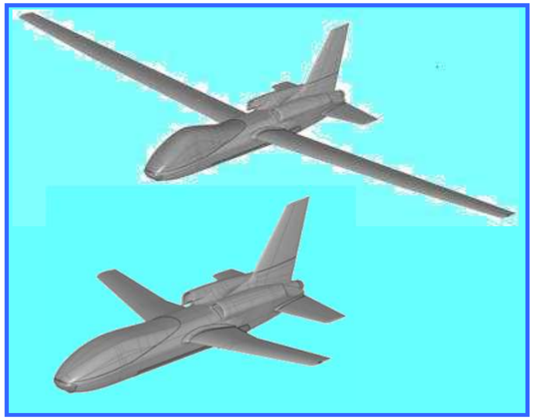
Stealth Demonstrator (1995)
Full A/C Design



Trainer Wing (2000)
Composite Wing& Fin

A400M (2004-2006)
Rear Fuselage Skin+Frames

Advanced UAV (2006 +)
Composite Wing + Fuselage



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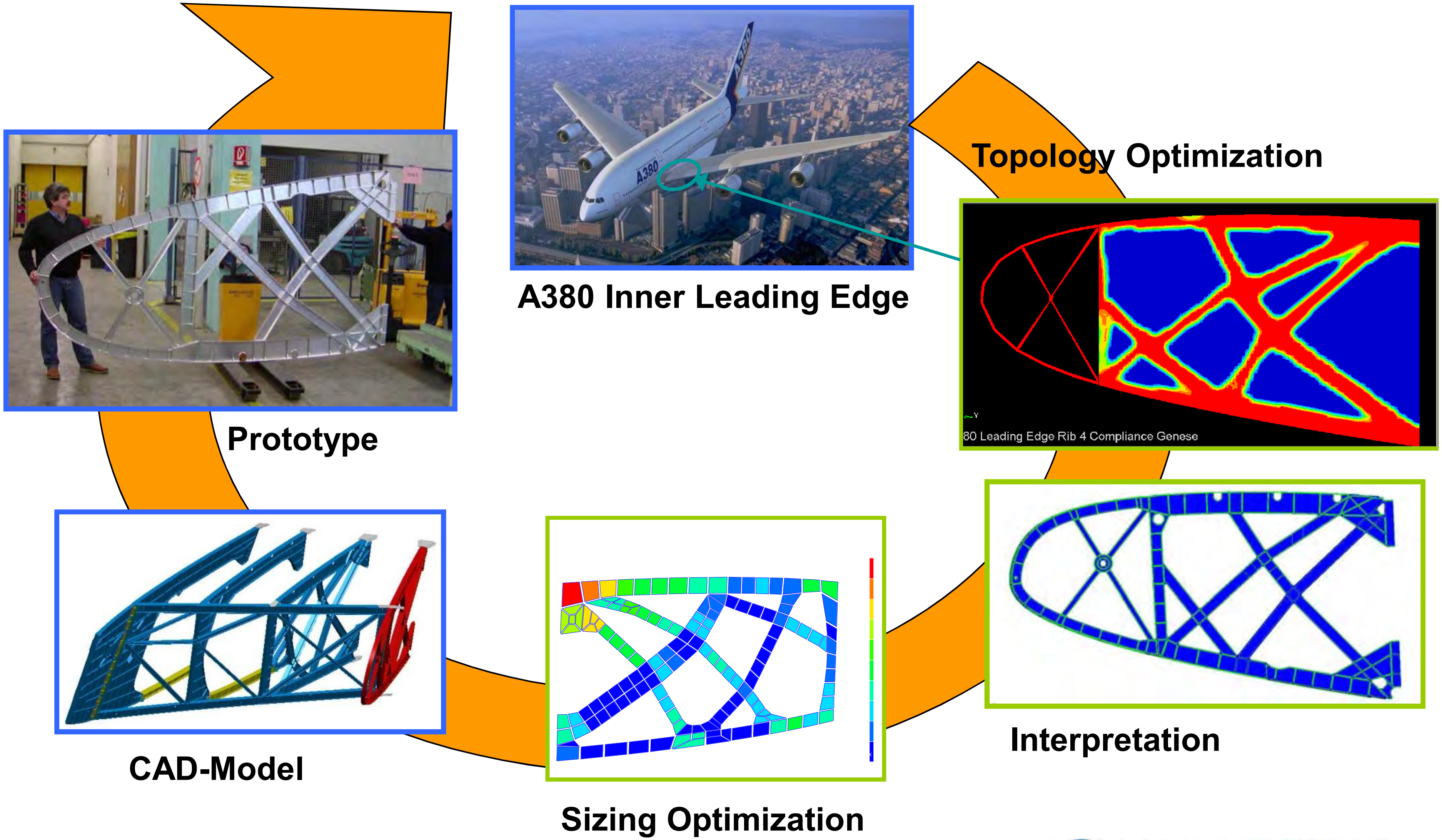
DEFENDING WORLD SECURITY

Topology and Sizing Optimization of the A380 Inner Leading Edge Ribs



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Prototype of the A380 Inner Leading Edge

A350 Fuselage Tail Section 19

Part

Manufacturing
Realised Part

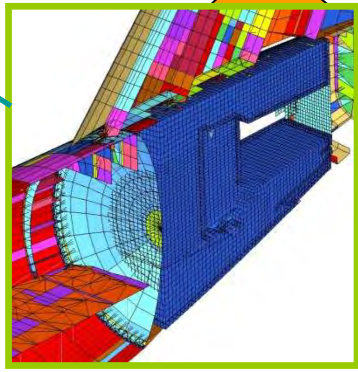
CAE
Detailed Analysis and Verfication

CAD
Geometry Model

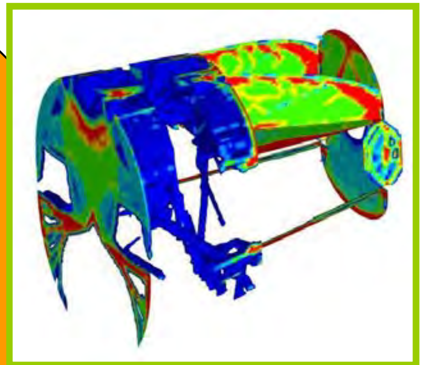
ca. 15 - 20% weight saving purely due to new concept

Topology Optimization

Design Space

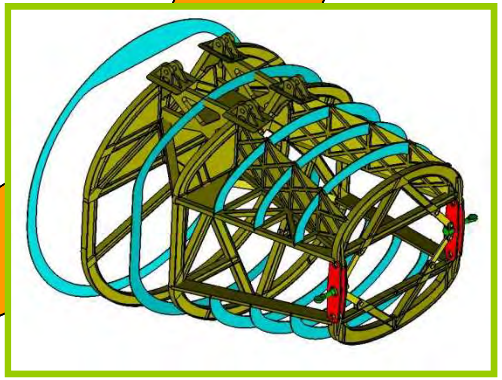


3D-Topology

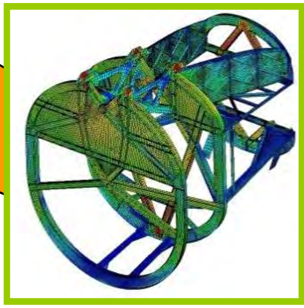


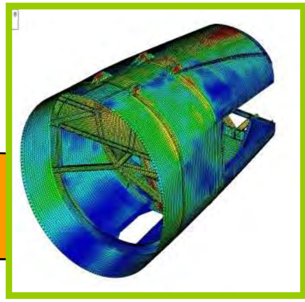
../h3ds/041222_topologie_mod_1_E4_656_no_size_200_iso_002.h3d

Design Concept



Conceptual Sizing Optimization

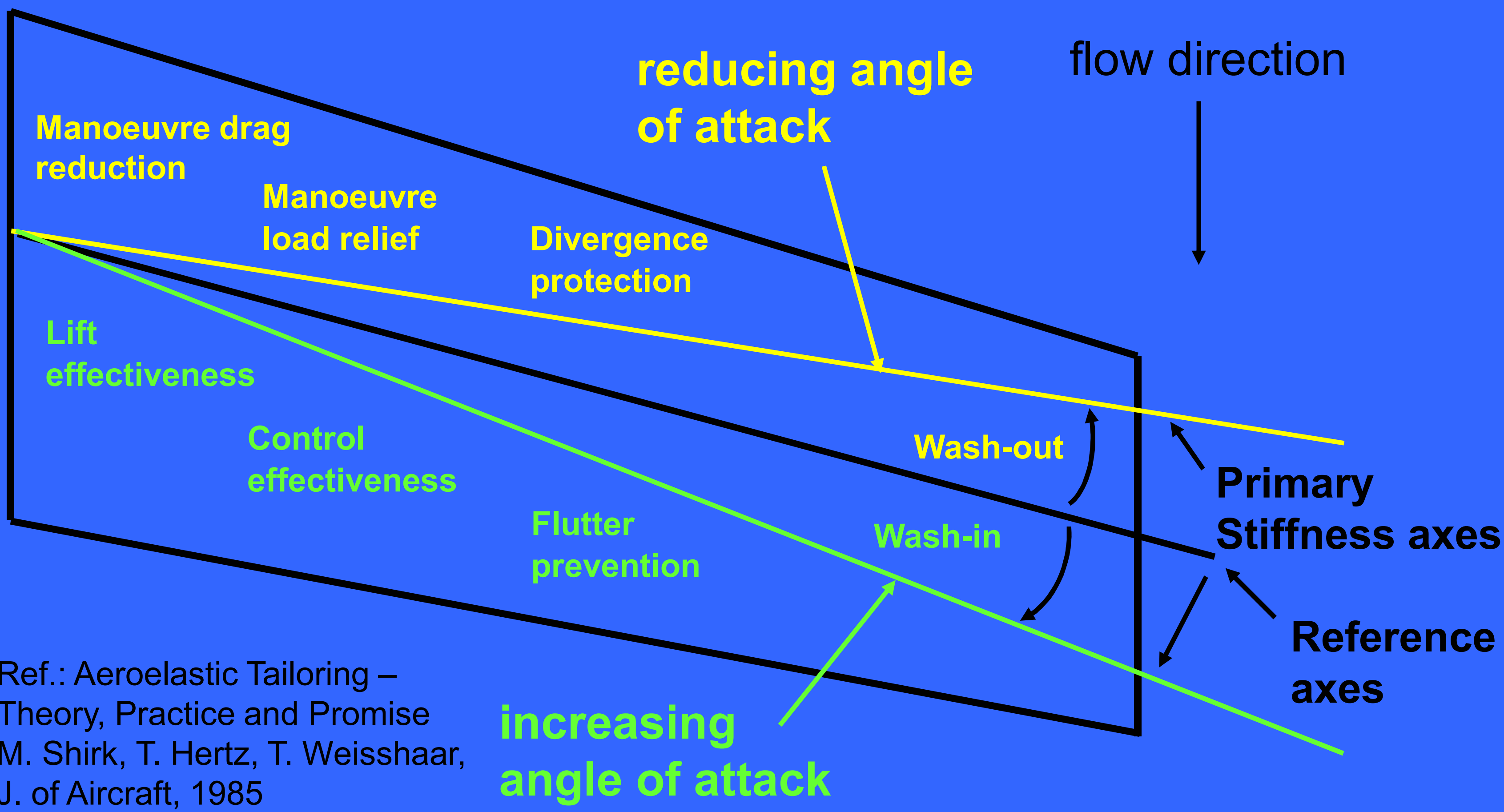




../h3ds/full_modell_sec_19_del_beam_2.h3d

Aeroelastic Tailoring of a High Aspect Ratio Composite Wing Box

Principal aeroelastic effects versus primary stiffness axes



Ref.: Aeroelastic Tailoring – Theory, Practice and Promise
M. Shirk, T. Hertz, T. Weisshaar, J. of Aircraft, 1985

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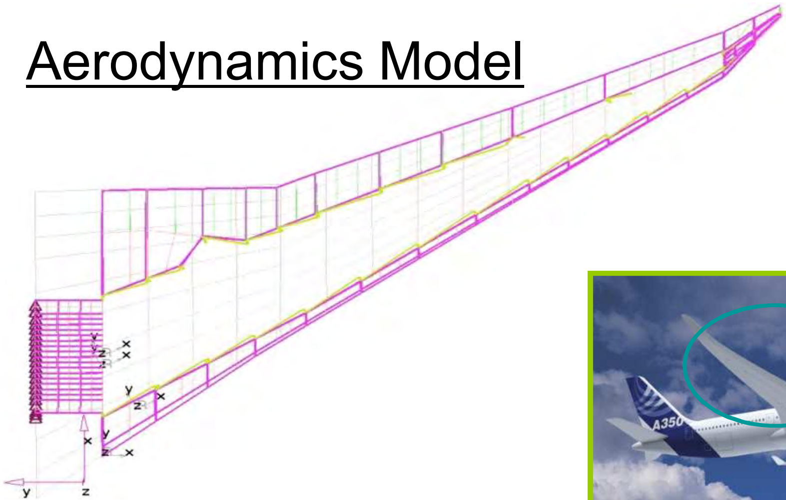
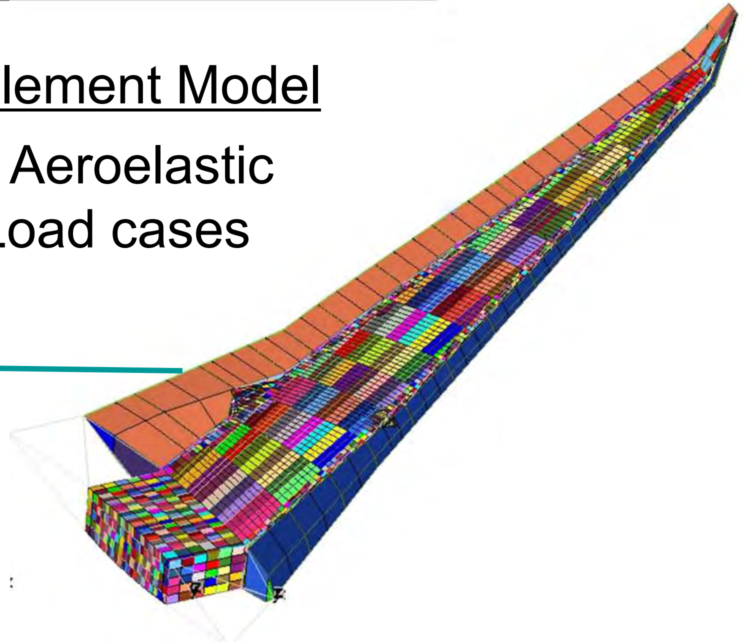
Aeroelastic Tailoring of the A350 XWB Wing Box

Aerodynamics Model



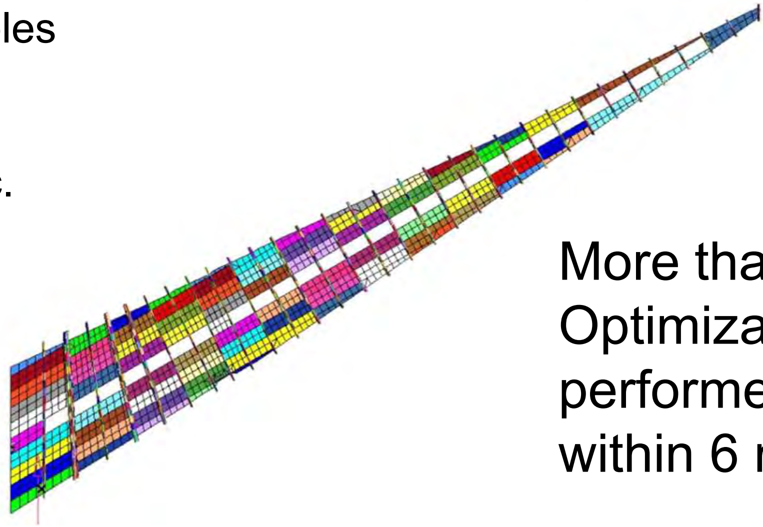
Finite Element Model

19 Ground & Aeroelastic
Manouevre Load cases



Optimization Model:

- 700 – 3000 Design Variables
  - Ply-Thicknesses
  - Fiber Orientations
  - Stringer Cross Sec.
- > 300.000 Constraints:
  - Skin Buckling
  - Column Buckling
  - Strength
  - Manufacturing



More than 40 Design Optimization Studies performed by 3 engineers within 6 month

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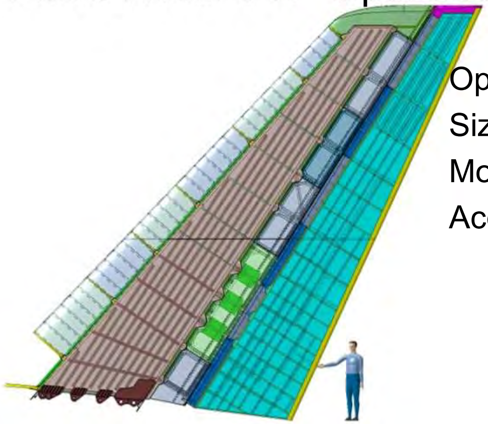
Overview on past civil aircraft applications

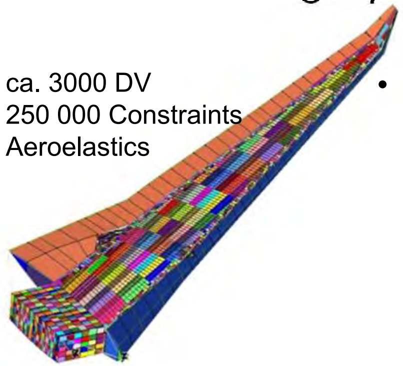
A350 XWB VTP Optimisation



Optimum Composite Sizing Layout within 2 Month (MAS-Acquisition phase)

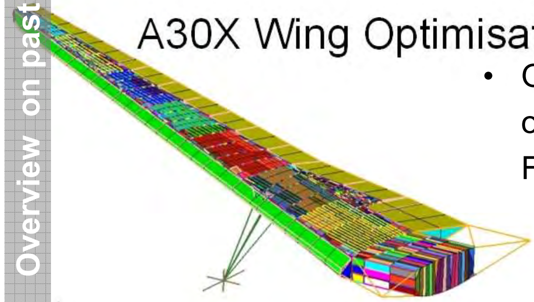
A350 XWB Wing Optimisation

ca. 3000 DV
250 000 Constraints
Aeroelastics



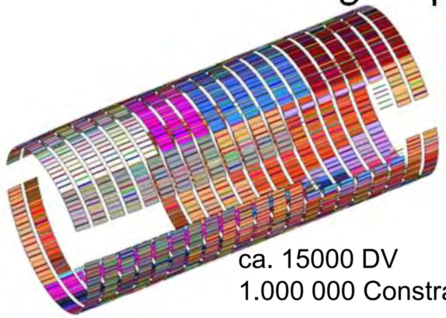
- Optimum Composite Sizing of 40 Variants with 3 FTE * 6 Month for AI Toulouse

A30X Wing Optimisation



- Optimum Composite Sizing of several variants with 2 FTE * 12 Month (AI UK)

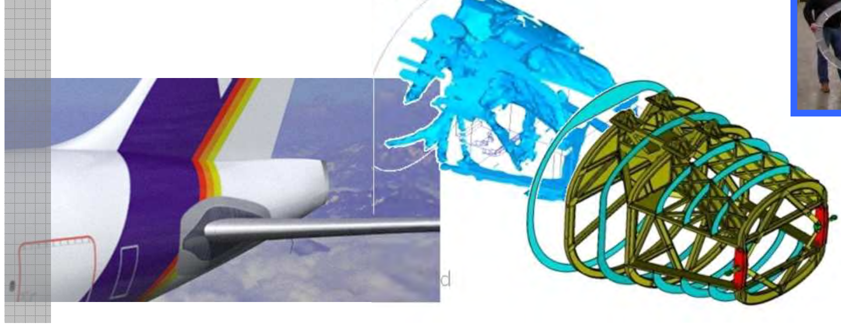
A350 XWB Fuselage Optimisation Sec. 13-14



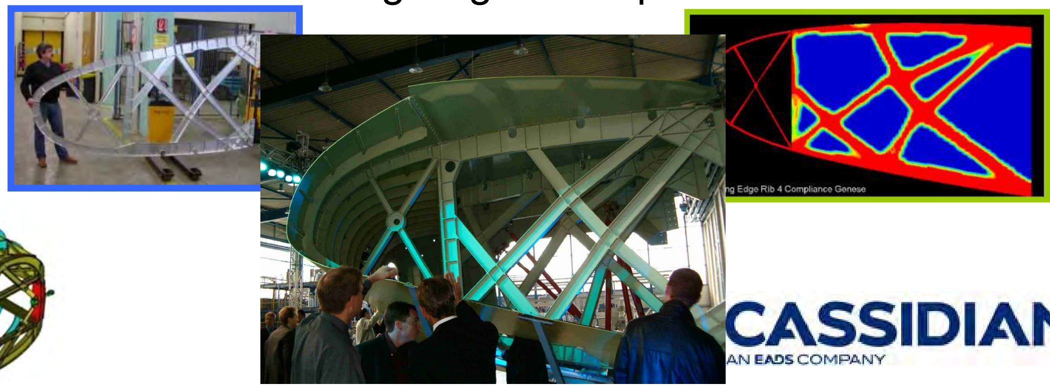
ca. 15000 DV
1.000 000 Constraints

- Optimum Composite Sizing with 2 FTE * 5 Month
- Feasible Design without weight increase ! (PAG)

Topology & Sizing Optimization of Sec. 19, A350



A380 Leading Edge Rib Optimization



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Application to the Unmanned Aerial Vehicle Talarion

Application to the Unmanned Aerial Vehicle Talarion

Unmanned surveillance and reconnaissance aircraft

Appr. Dimensions: Length: 14 m; Height: 4,5 m ; Span 26 m

Take-off weight : 8000 kg class

Performance

Loiter Speed: >200 ktas

Ceiling: > 43 kft

Endurance: > 20 h class

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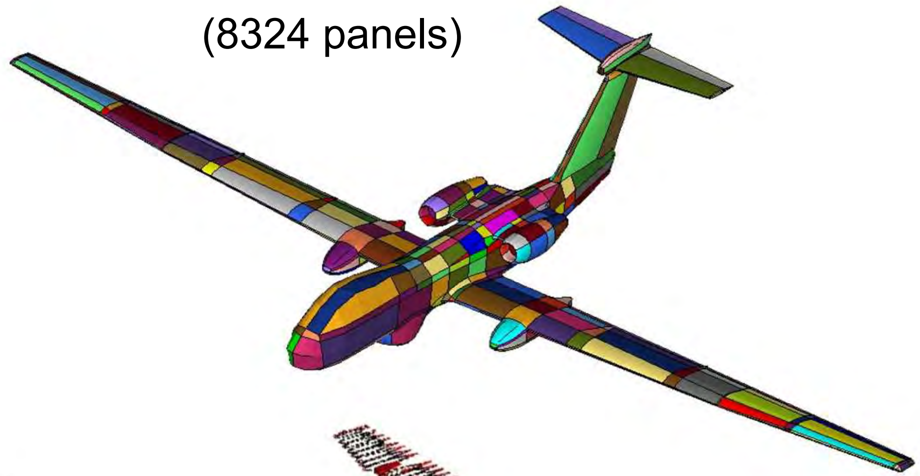
Talarion Multidisciplinary Sizing Optimization

- Objective:
  - Mass Minimization
- Constraints
  - Trimming Constraints
  - Strength
  - Stability
  - Manufacturing
  - Flutter

Aerodynamic Panel Model
for steady state manoeuvres

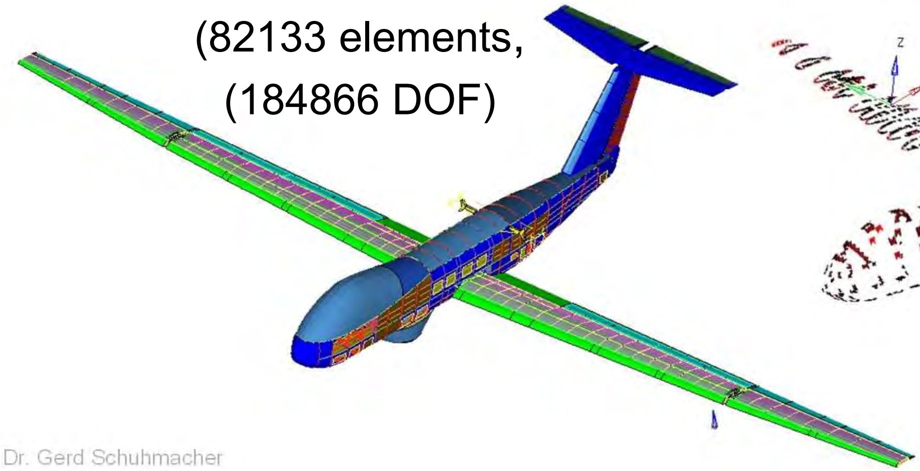
(8324 panels)

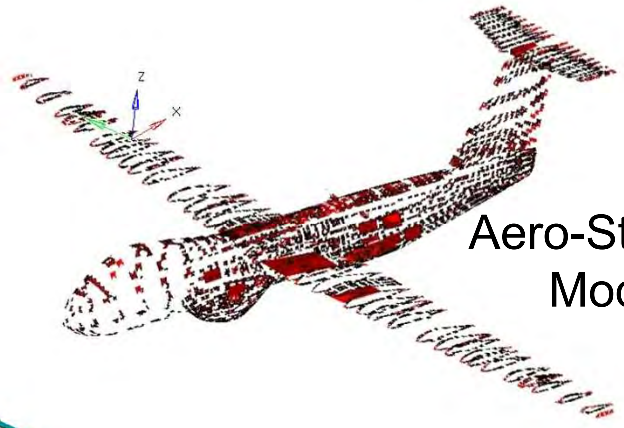


FE Model

(82133 elements,

(184866 DOF)

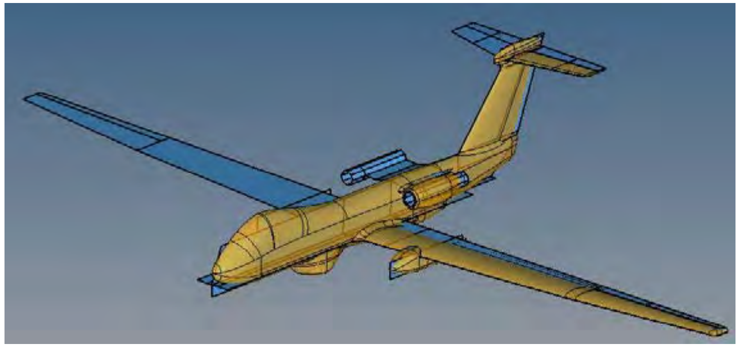




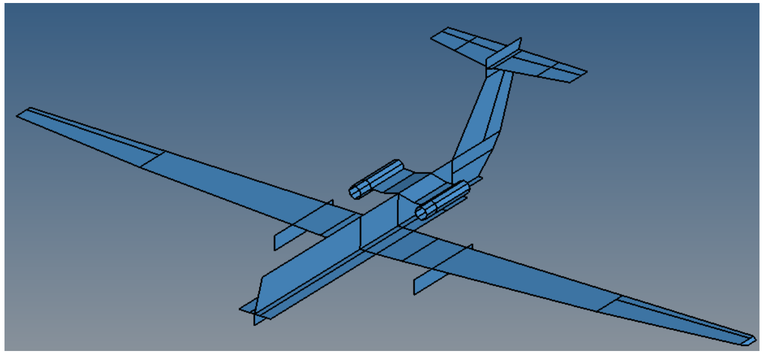
Aero-Structural Coupling
Model (Beaming)

Doublet Lattice Model for unsteady aeroelastics (flutter, gust)

CAD – DLM macropanels overlay



DLM macropanel model



DLM Panel model

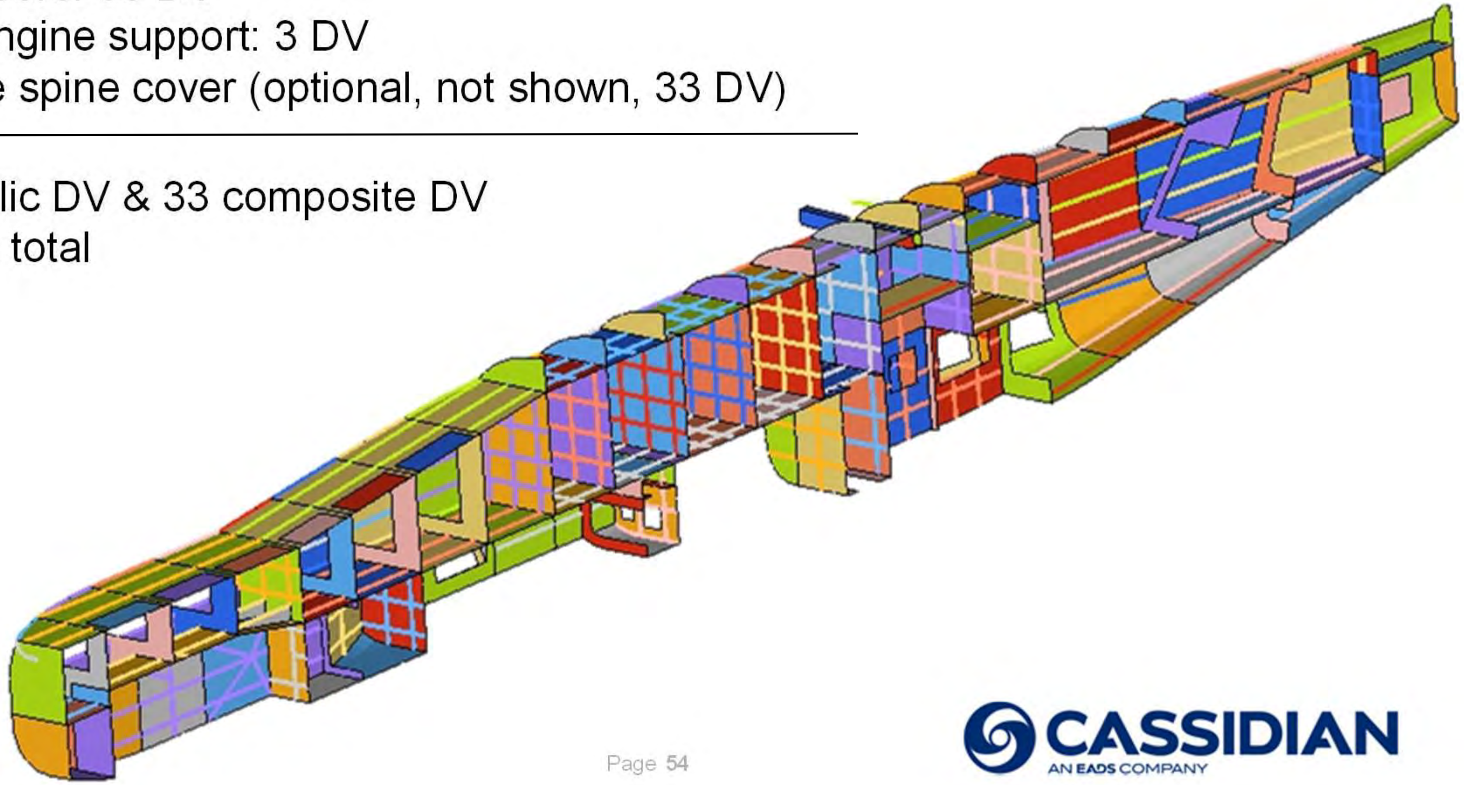
DLM Model for unsteady aeroelastics
(flutter, gusts)

Optimisation model (Design Variables)

Parametric Fuselage Model (half model shown)

- metallic skins: 55 DV
- metallic stringers multi-parametric Z-profile: 42 DV
- metallic longerons: 55 DV
- metallic shear walls: 19 DV
- metallic frames: 91 DV
- metallic floors: 60 DV
- metallic engine support: 3 DV
- composite spine cover (optional, not shown, 33 DV)

- 325 metallic DV & 33 composite DV
  358 DV in total

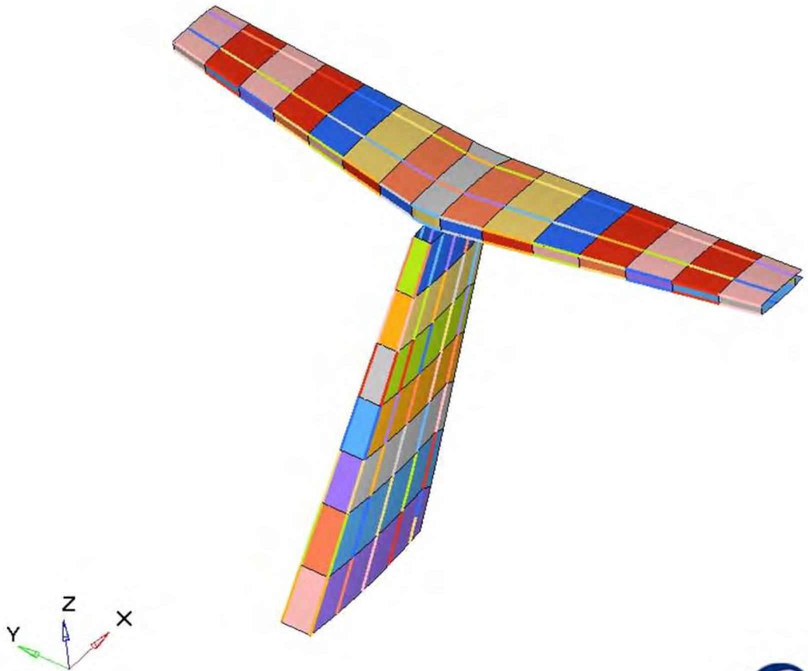


Optimisation model (Design Variables)

Parametric Empenage Model

- symmetrically linked
- composite skins: 23 areas x 3 linked layers = 69 DV
- composite stringer multi-parametric T-profile: 58 DV
- composite spars: 31 areas x 3 linked layers = 93 DV
- composite spar caps: 31 DV

- total: 241 DV

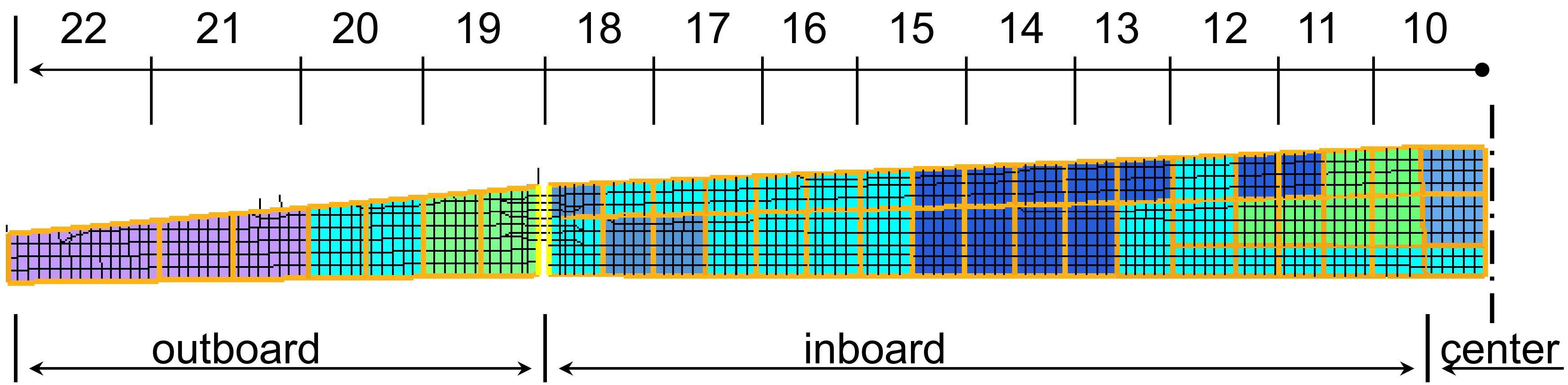


Optimisation model (Design Variables)

Parametric Wing Skin Model

- symmetrically linked
- composite skin: 25 areas x 3 layers (0º, 90º, ±45º) x 2 (top/bottom) = 150 DV
- composite skin wing centre: 3 areas x 3 layers x 2 (top/bottom) = 18 DV

- wing skin total: 168 DV



→ 13 variable sections along wing span

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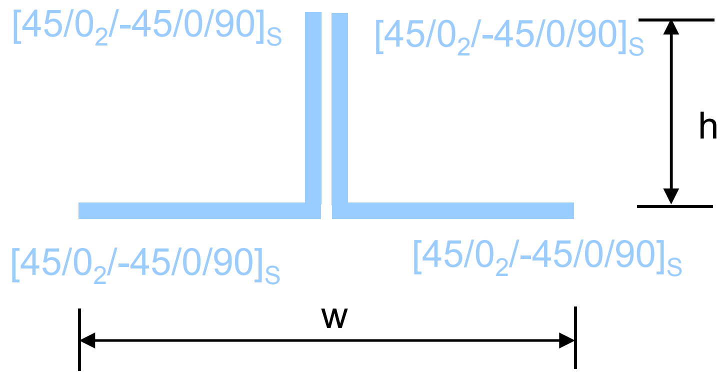
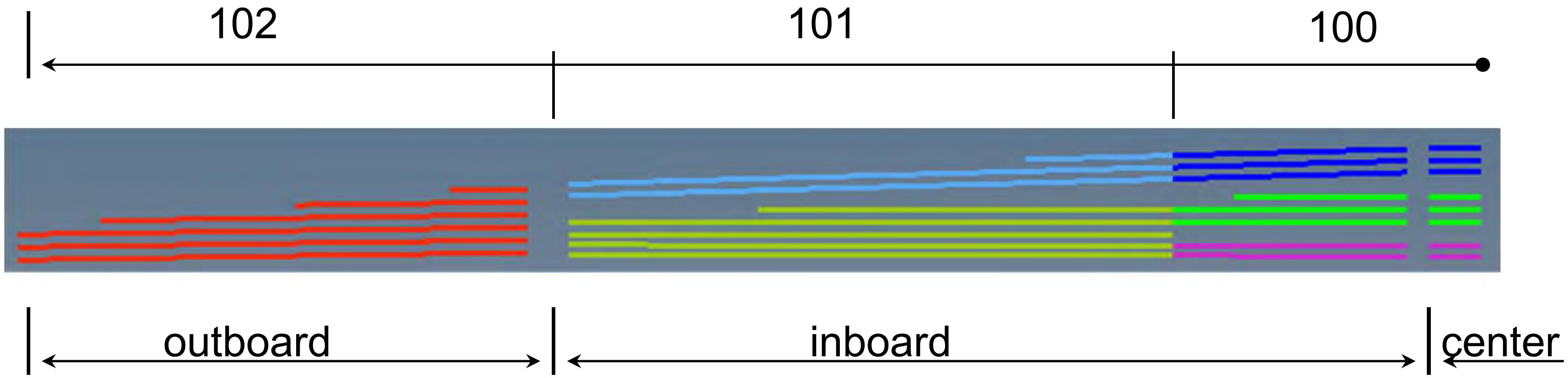
Optimisation model (Design Variables)

Parametric Stringer Model

- symmetrically linked
- 6 stringer sections x 2 (top/bottom)
- 6 variables per stringer section (height, width, 0º, 45º, 90º, 0º) = 72 DV





Total Number of Design Variables (fuselage, empenage, wing-skin,-stringers,-spars):

971 DV

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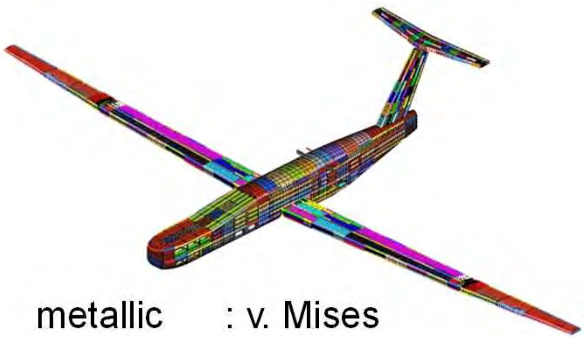
Strength & Stability Design Constraints

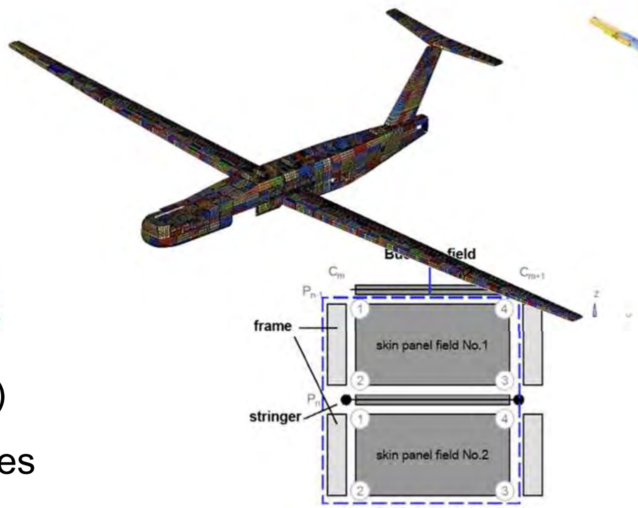
- Strength & Stability Criteria Model:

Strength	Stability

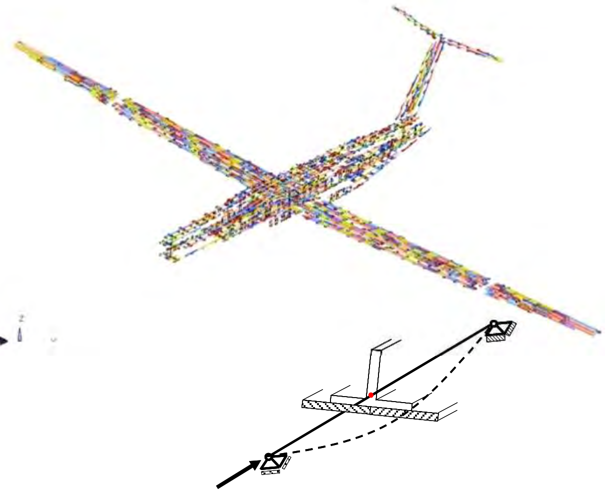


metallic : v. Mises
composites: maximum strain
(Damage Tolerance)

21915 constraints * 132 load cases



2743 Skin & shear wall buckling fields



1227 Column buckling fields (incl. local buck& crippling)

2.892.780 strength constraints 598.278 buckling constr. 6116 manufacturing constr.

Total: 3.497.174 constraints

Dr. Gerd Schuhmacher

Load Enveloping / Down selection

First Load Loop: 996 LCs have been pre-selected by the Loads Department

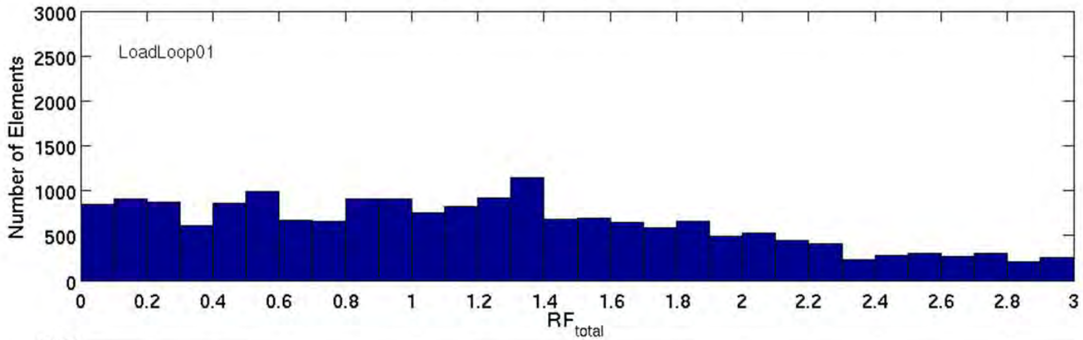
- 239 dynamic gust LCs
  (combined stationary maneuver & gust, only symmetric discrete head gust, several mass configurations)
- 757 stationary maneuver LCs
  (several trimmed flight conditions with different mass configs and control surface conditions)

Down selection: 132 LCs have been identified as design driving by the Lagrange criteria model (complying $RF_{total} \leq 1.3$):

- fuselage: 74 (4 gust, 70 stat. maneuver)
- wing: 51 (28 gust, 23 stat. maneuver)
- empennage: 33 (2 gust, 31 stat . maneuver)

- 5 LCs affect the whole structure, 107 LCs affect only fuse or wing or empenage

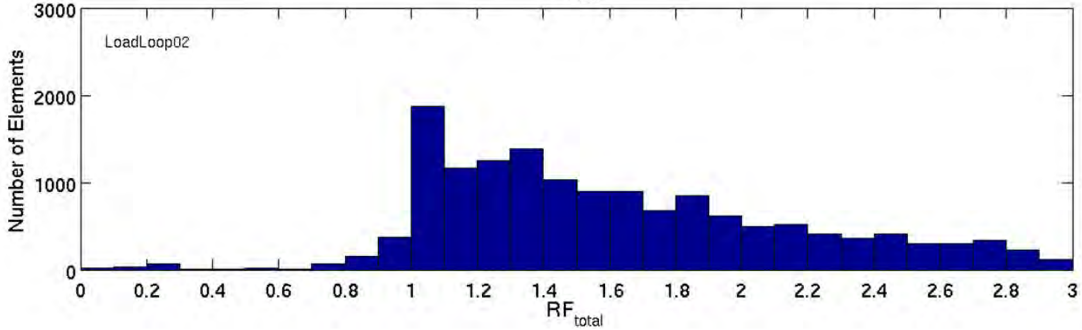
Load Enveloping / Down selection



initial design (LoadLoop 01)

143 critical LCs identified

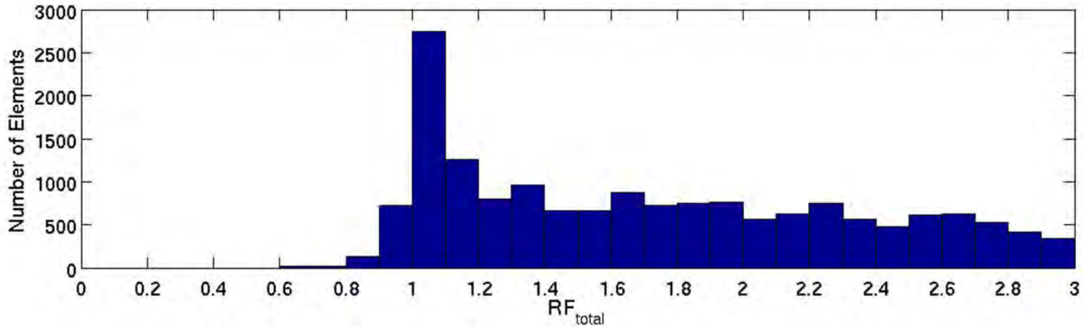
8305 elements with $RF_{tot} \leq 1.0$



LoadLoop 02

115 critical LCs identified

1279 elements with $RF_{tot} \leq 1.0$



LoadLoop 03

132 critical LCs identified

2045 elements with $RF_{tot} \leq 1.0$

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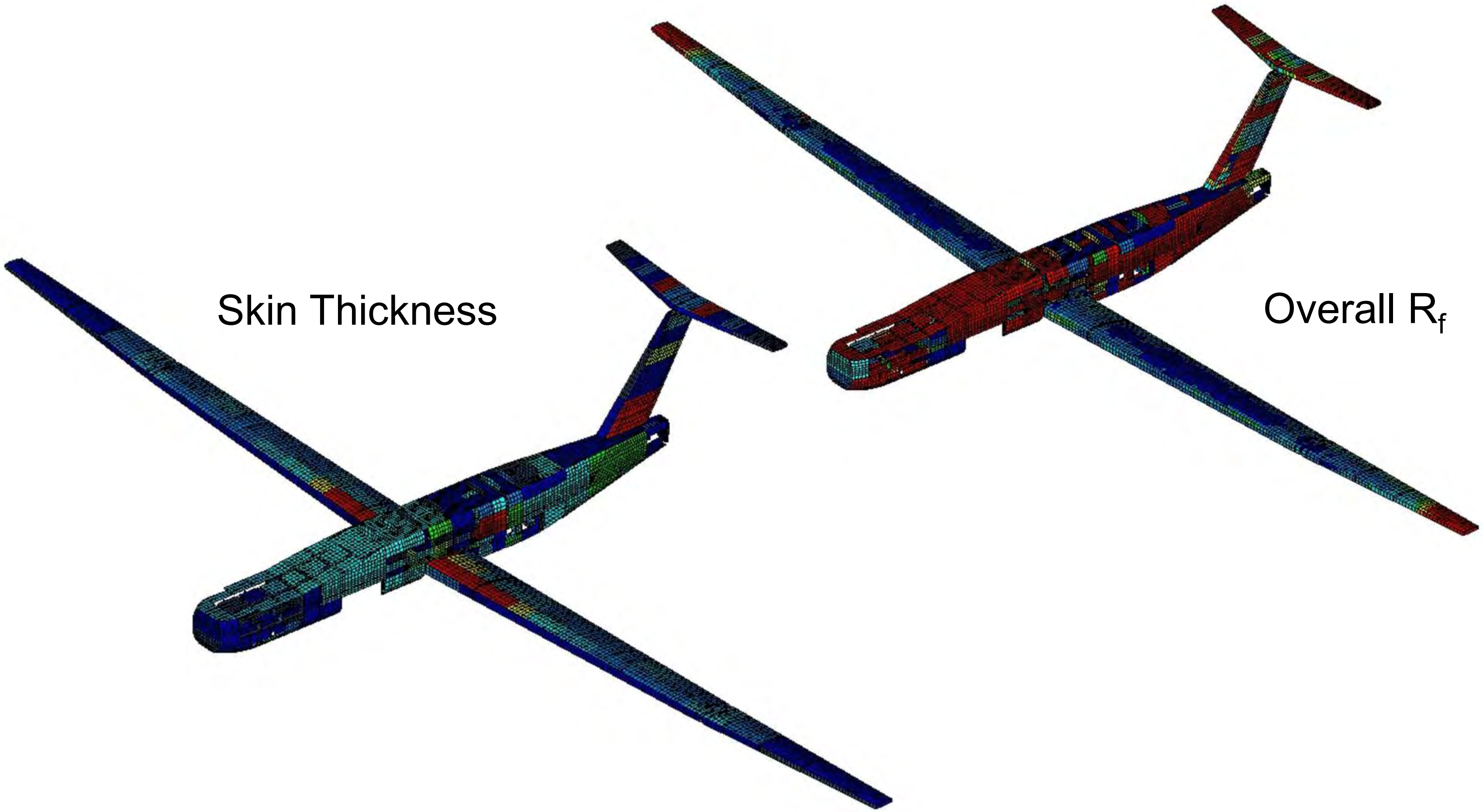
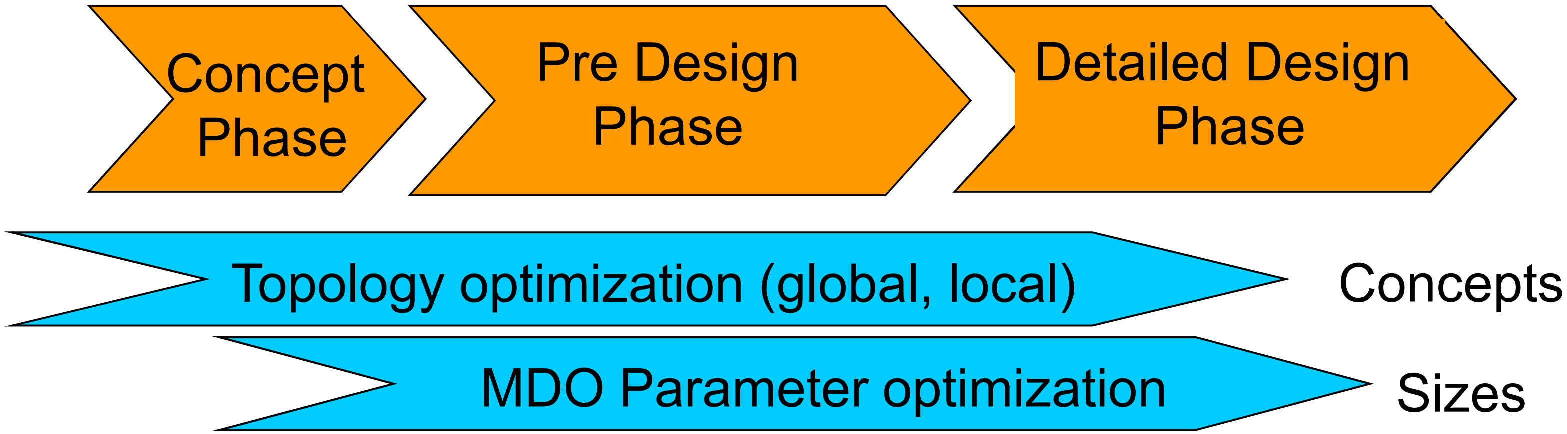
Skin Thickness Distribution and Min. Reservefactors

- Interims Results -> Sizing Loop ongoing.



Contents

Benefits of the Automated Airframe Design Process



- Determination of ***weight optimum*** concepts, shapes and sizes
- Optimum performance of very advanced products requiring the consideration of complex, multidisciplinary relations and interactions
- **Reduced effort, time & cost** by avoiding late concept changes
- **Reduced effort, time & cost by the automation** of the design process (loads and sizing loop) => Tremendous amount of saving for Talarion expected !
- Very important: Optimization process has to be an **integral part of the design process. It does not make sense to start it at the end !!!**

Summary

- The optimization assisted airframe design process has been established and applied within all design phases of a broad range of A/C projects (civil and military applications; components, large assemblies & full A/C).
- The multidisciplinary design optimisation with **LAGRANGE** leads to a feasible airframe design which satisfies the requirements of all relevant disciplines with **minimum weight.**
- **The automation** of both loops: structural sizing and loads loop results in an **tremendous reduction** of **development time and effort**.
- The strategic decision for an continued development of the in-house MDO tool LAGRANGE is due to the specific aerospace design criteria on one hand (no Commercial Of The Shelf tool available) and the tremendous benefits and competitive advantages on the other hand.
- The in-house software availability allows the fast adaption to advanced analysis methods as well as to new technological product and customer requirements.
- **Further Applications and Co-Operations are welcome !**

Thank you for your attention!

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