ID: 650024

The Effect of Laminar Compared to Turbulent Airfoils on the Aeroelastic Assessment of a Long-Range Transport Aircraft Configuration

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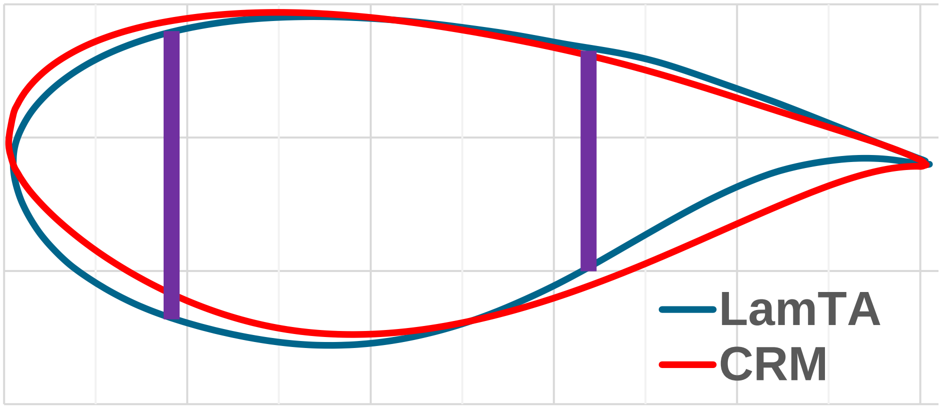
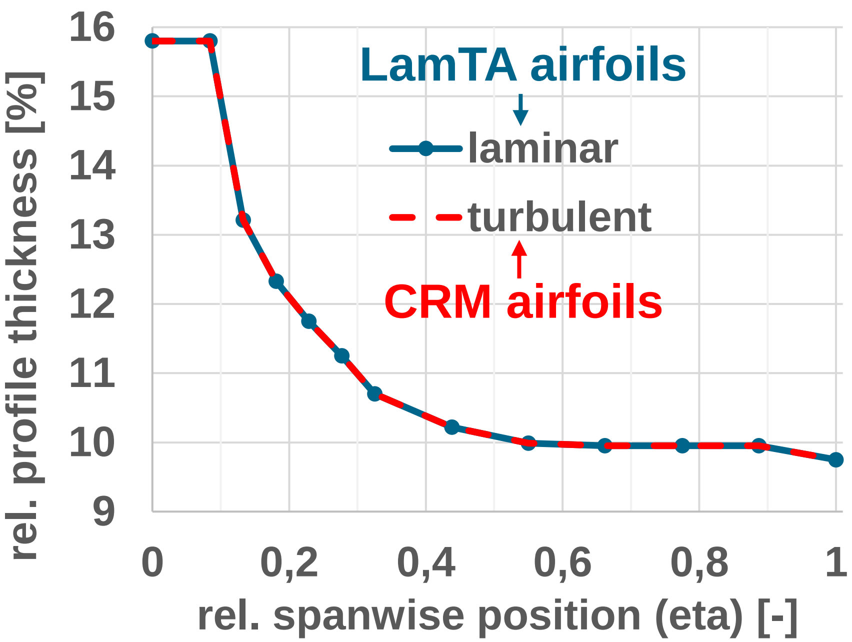
DLR project LamTA (Laminar Tailored Aircraft)

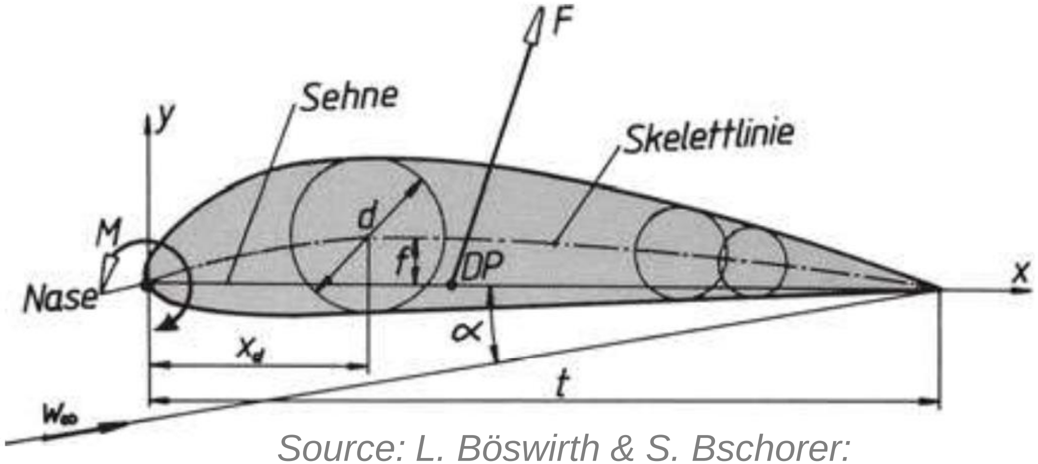
→ *Goal: „Quantify the potential of laminar flow in energy savings during flight"*



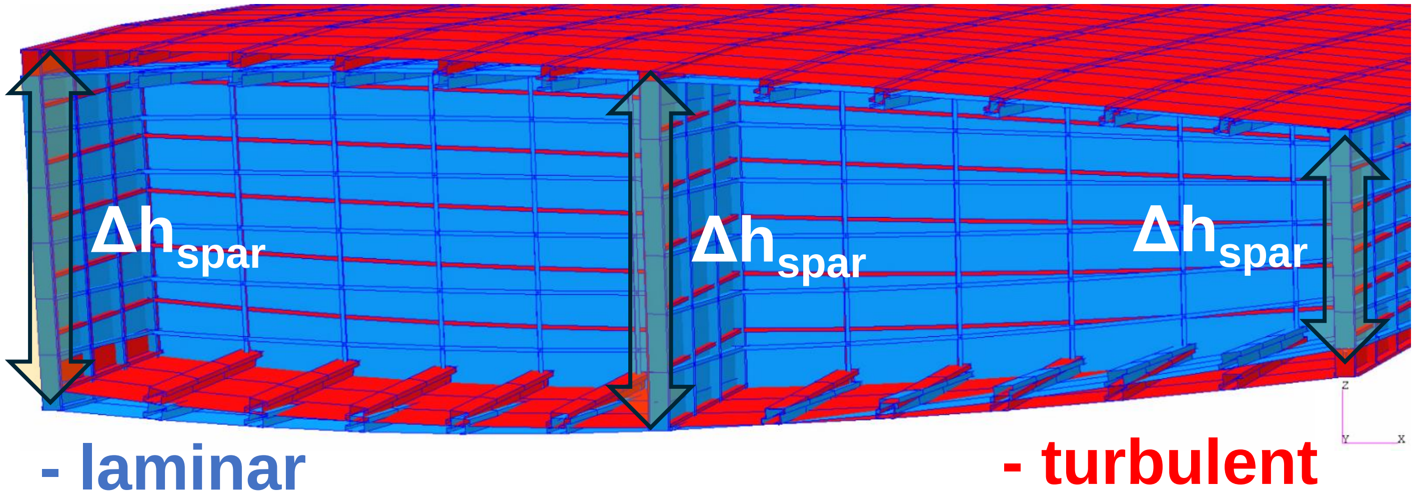


Two A/C with the same:
- TLARS
- Planform
- Rel. profile thickness distribution
- Flight-Twist

rel. profile thickness = *d/t*

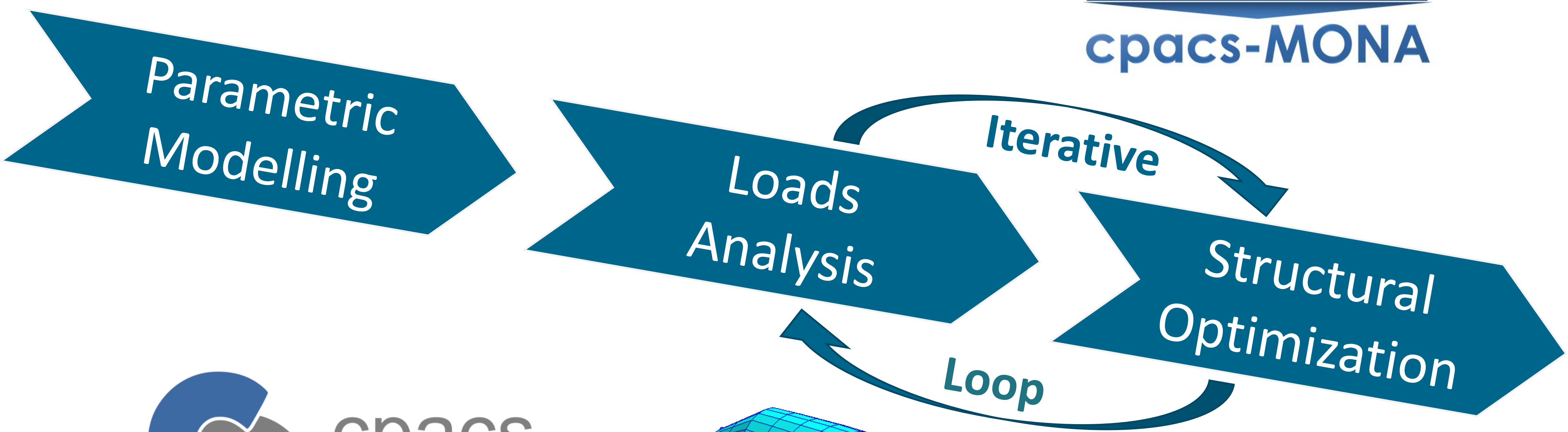


Source: L. Böswirth & S. Bschorer: „Technische Strömungslehre"



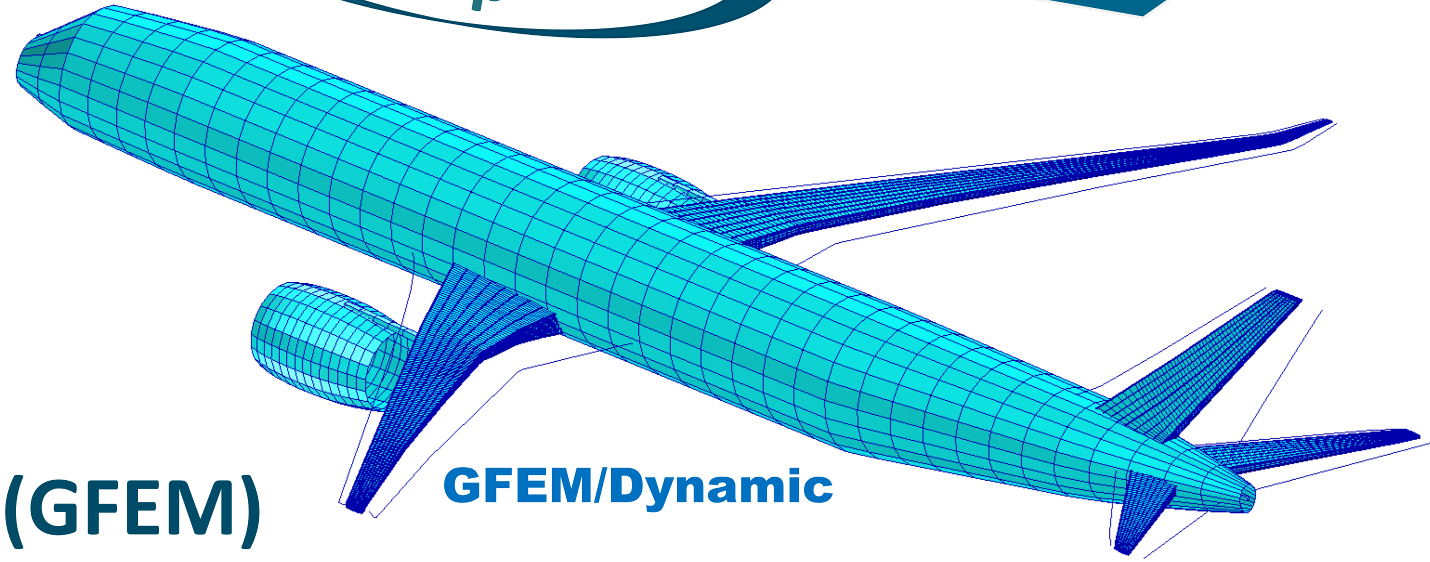
Aeroelastic Structural Design Tool

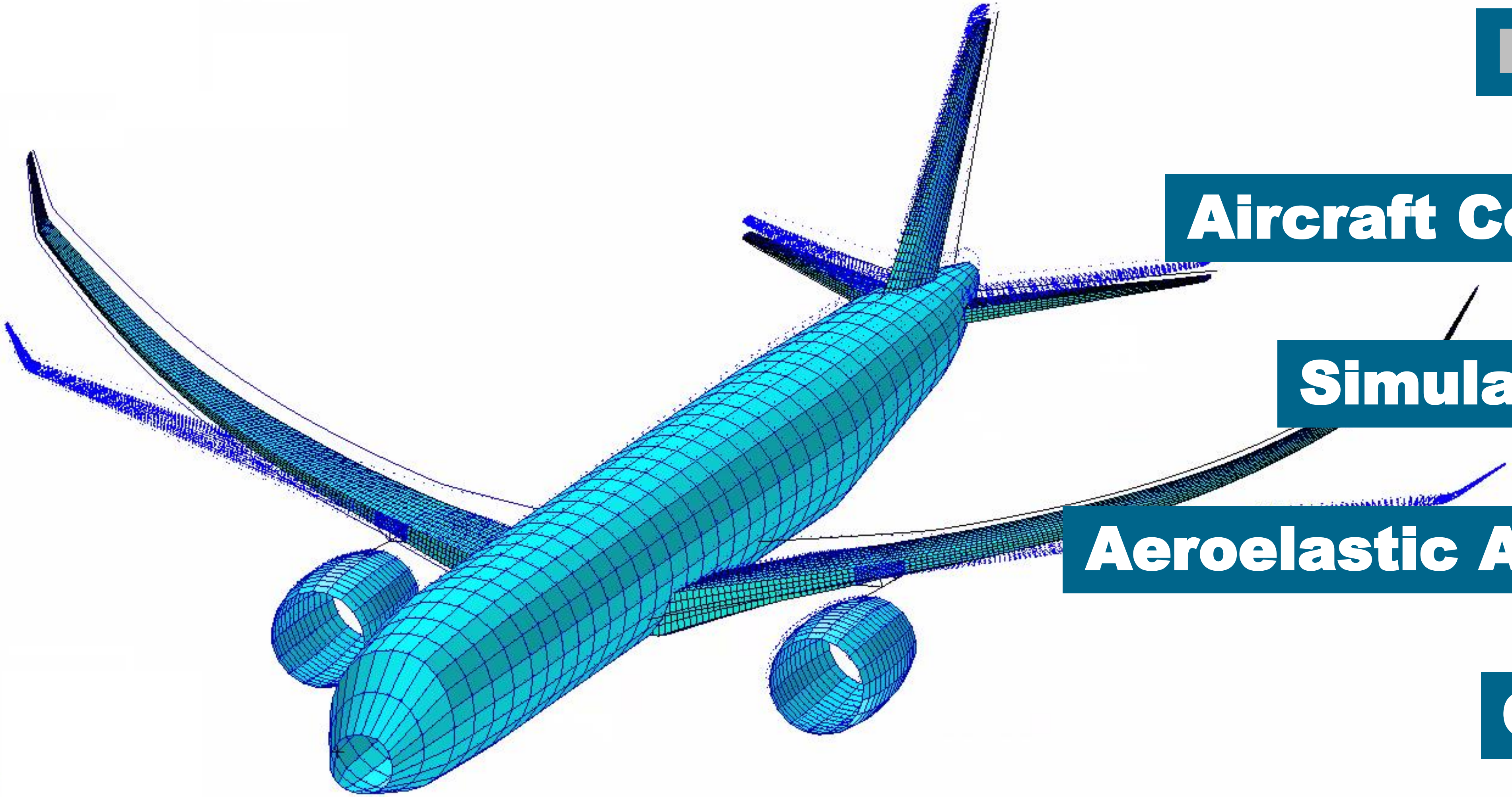
cpacs-MONA



cpacs
A Common Language for Aircraft Design

From a
CPACS-dataset
to the
Global Aircraft FEM (GFEM)

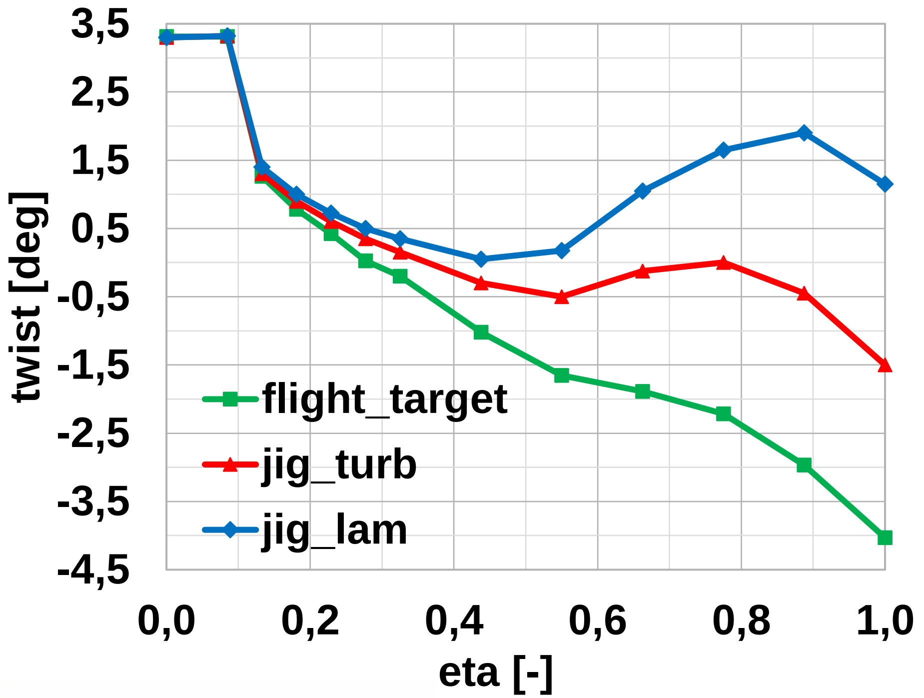

GFEM/Dynamic



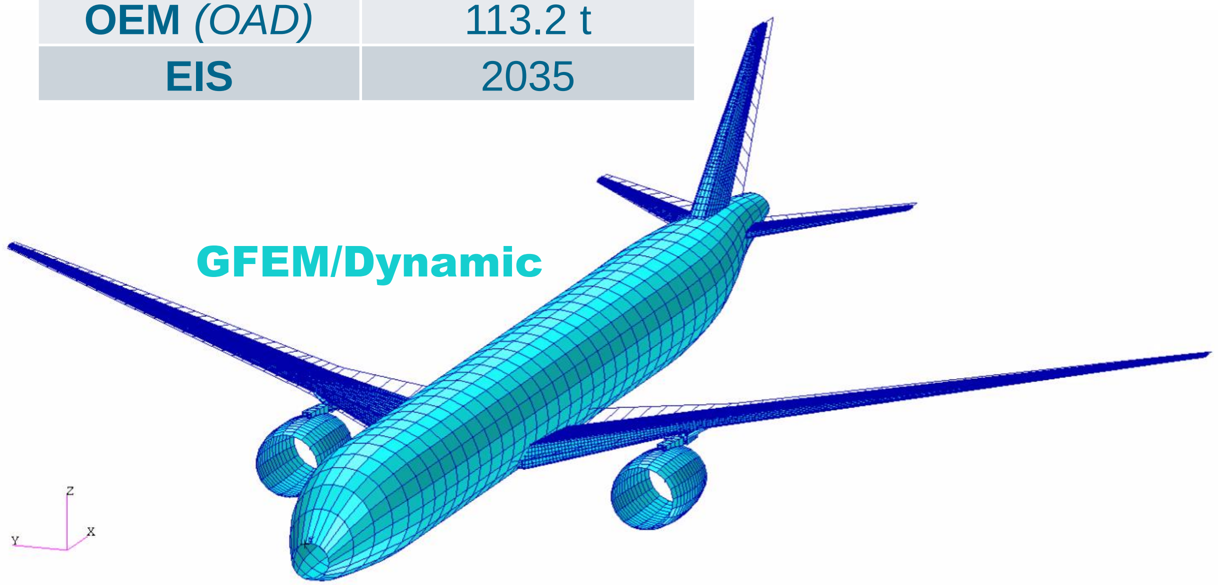
CONTENT

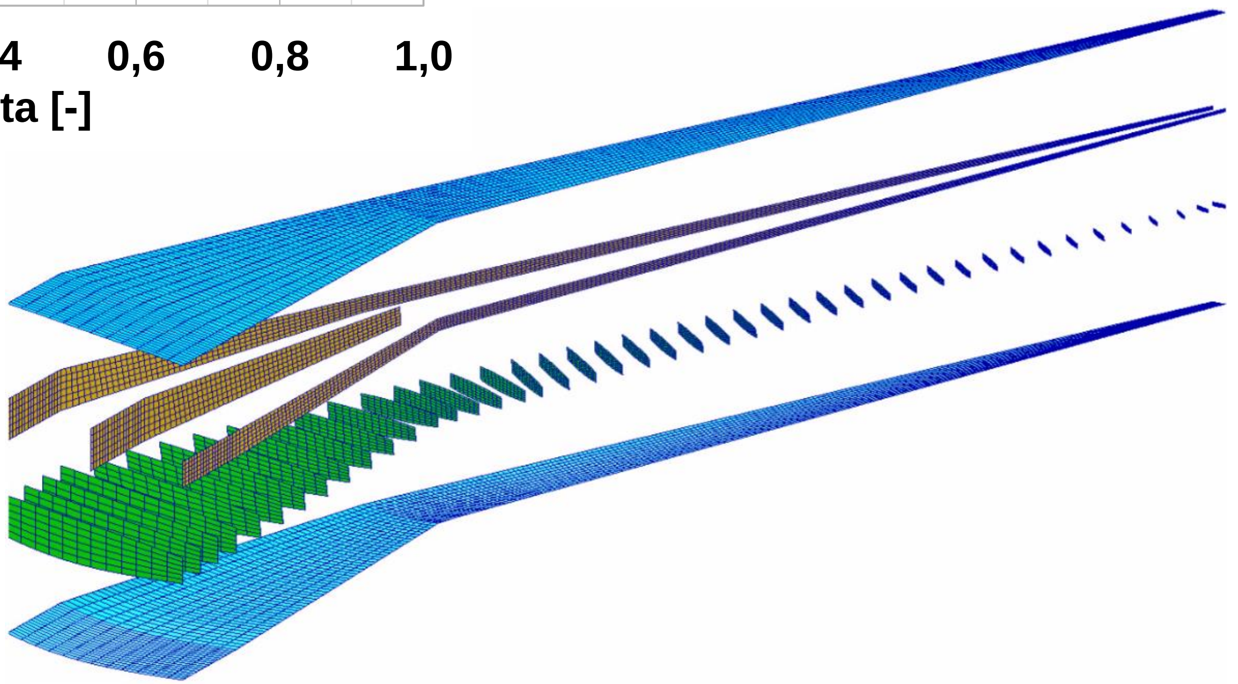
The LamTA Reference Aircraft Configuration

A/C Parameter	D315_lam_s5
Span	62.9 m
Wing area	324.2 m^2
Aspect ratio	12.6
MAC	6.32 m
Taper Ratio	0.125
PAX	315
V_{MO}	170 m/s
M_{MO}	0.86
MTOM	219.8 t
OEM *(OAD)*	113.2 t
EIS	2035



Structural Parameters	D315_lam_s5
Number of ribs	44
Number of spars	3
Material	CFRP
Engine diameter	3.8 m
Engine mass	7.9 t





Load Case Setup

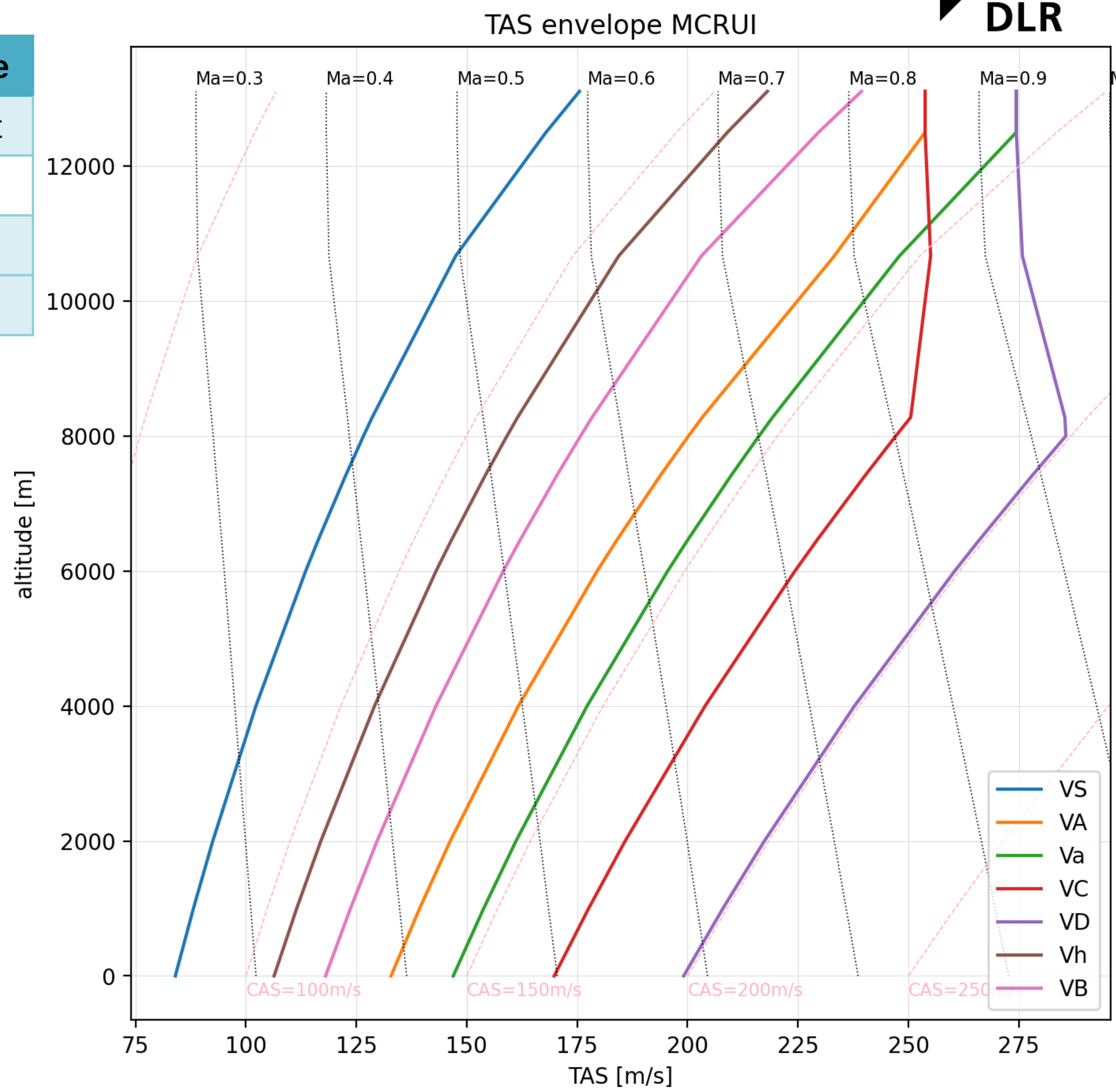
Loads Analysis
MSC Nastran SOL144 and SOL146

DLR

laminar	MCRUI	MFOeF	MOOee	MTOAa	MTOfF	MZOAe
Mass	176.4 t	189.2 t	118.1 t	199.8 t	199.8 t	172.1 t
Payload	75 %	0 %	0 %	100 %	40 %	100 %
Fuel	25 %	100 %	0 %	20 %	100 %	0 %
%MAC CG	30 %	35 %	20 %	15 %	35 %	15 %

- 6 different **mass cases**
- Various **flight points** (altitude and airspeed)
- Static **Maneuvers**
  - 2.5g pull-up
  - -1g push-down
  - 1g flight
  - Yaw
  - Roll
- Dynamic **1-cos gust** encounters
- Conceptual **landing/ground** cases

over 1.000 load cases per A/C



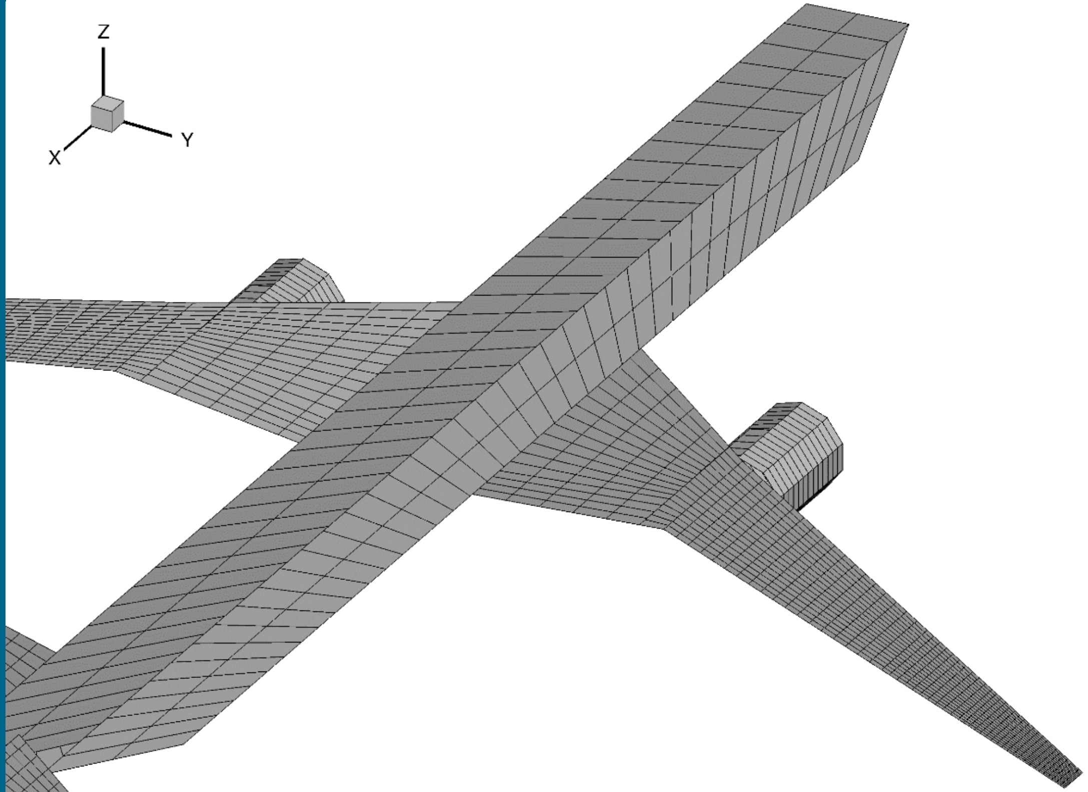
Aerodynamic Model

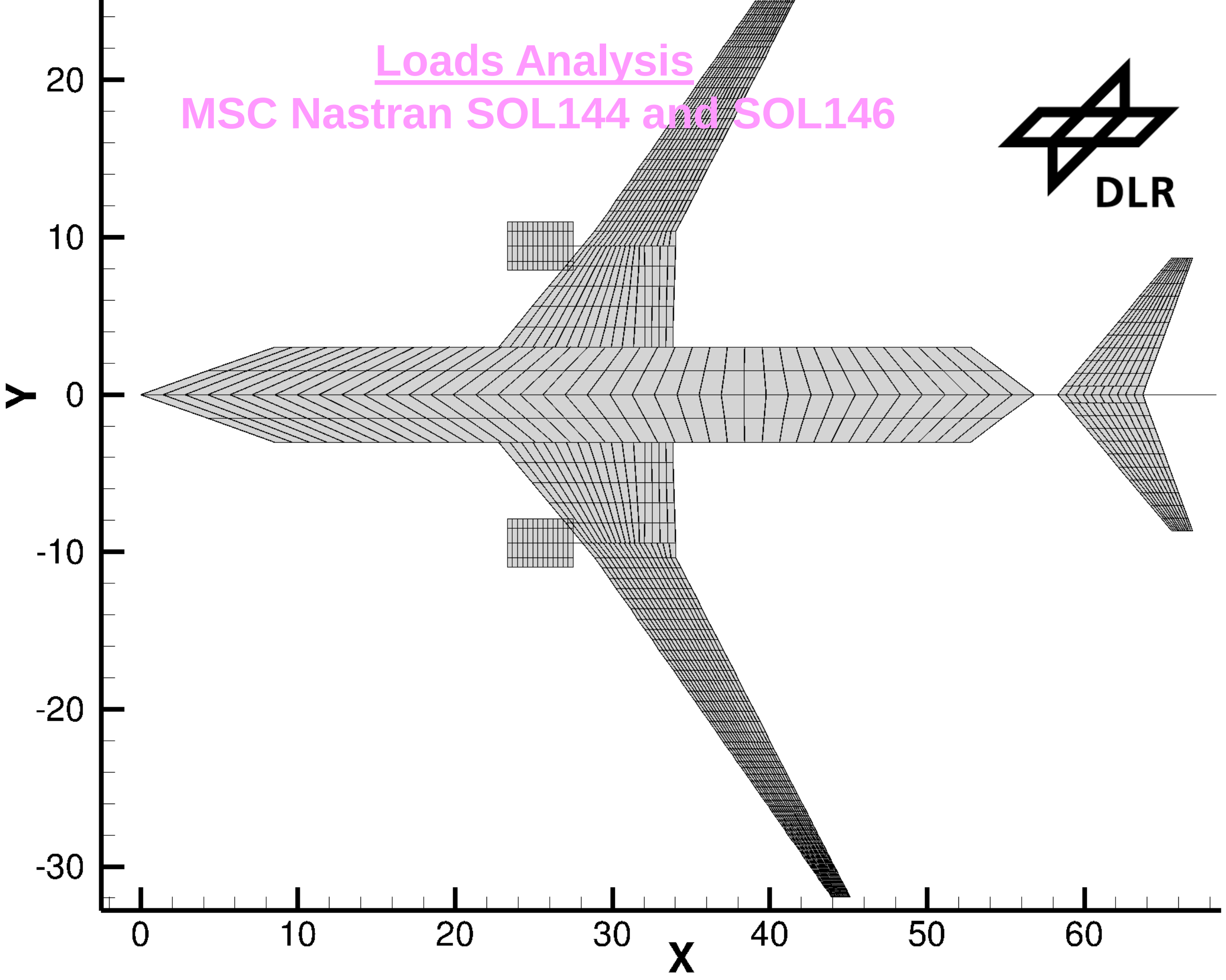
Nastran VLM/DLM Modell:

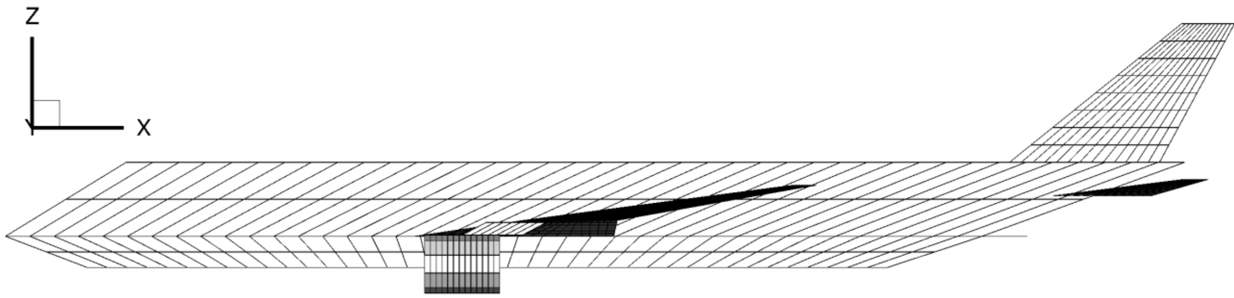
- Cross-Fuselage
- Nastran CAERO1 panels
- Aerodynamic corrections for camber and twist (W2GJ), no CFD corrections
- Various control surfaces
- Maneuver load alleviation (MLA) @ 2.5g

Loads Analysis

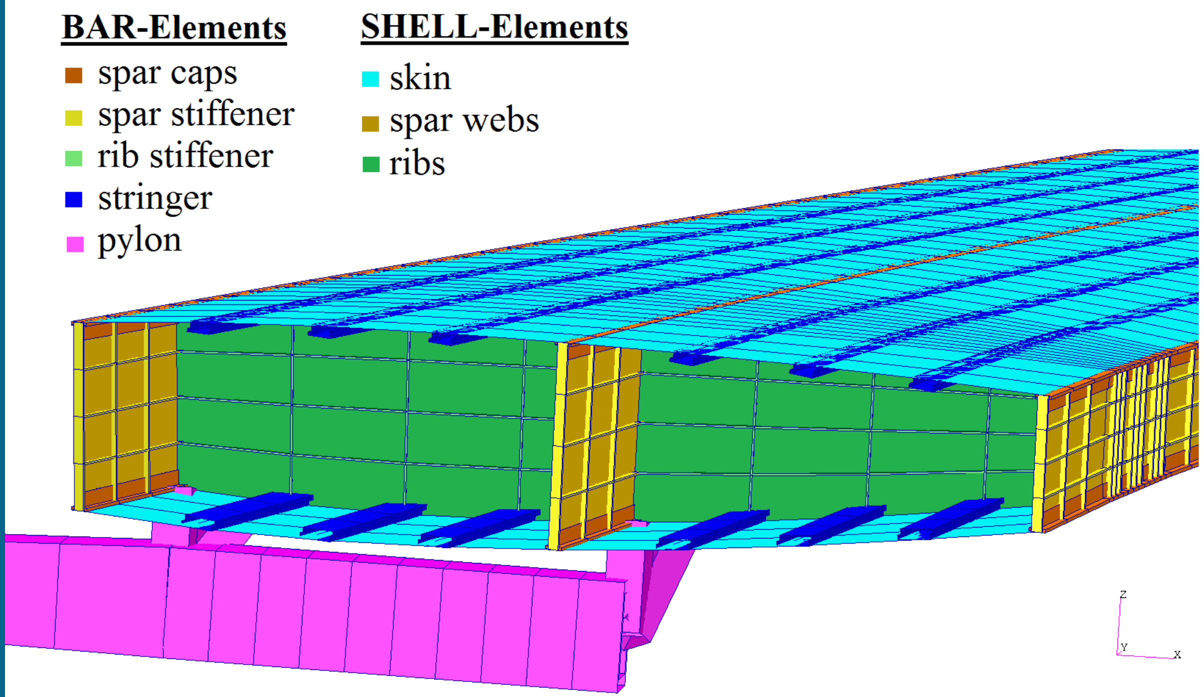
MSC Nastran SOL144 and SOL146







Structural Model and Optimization Model

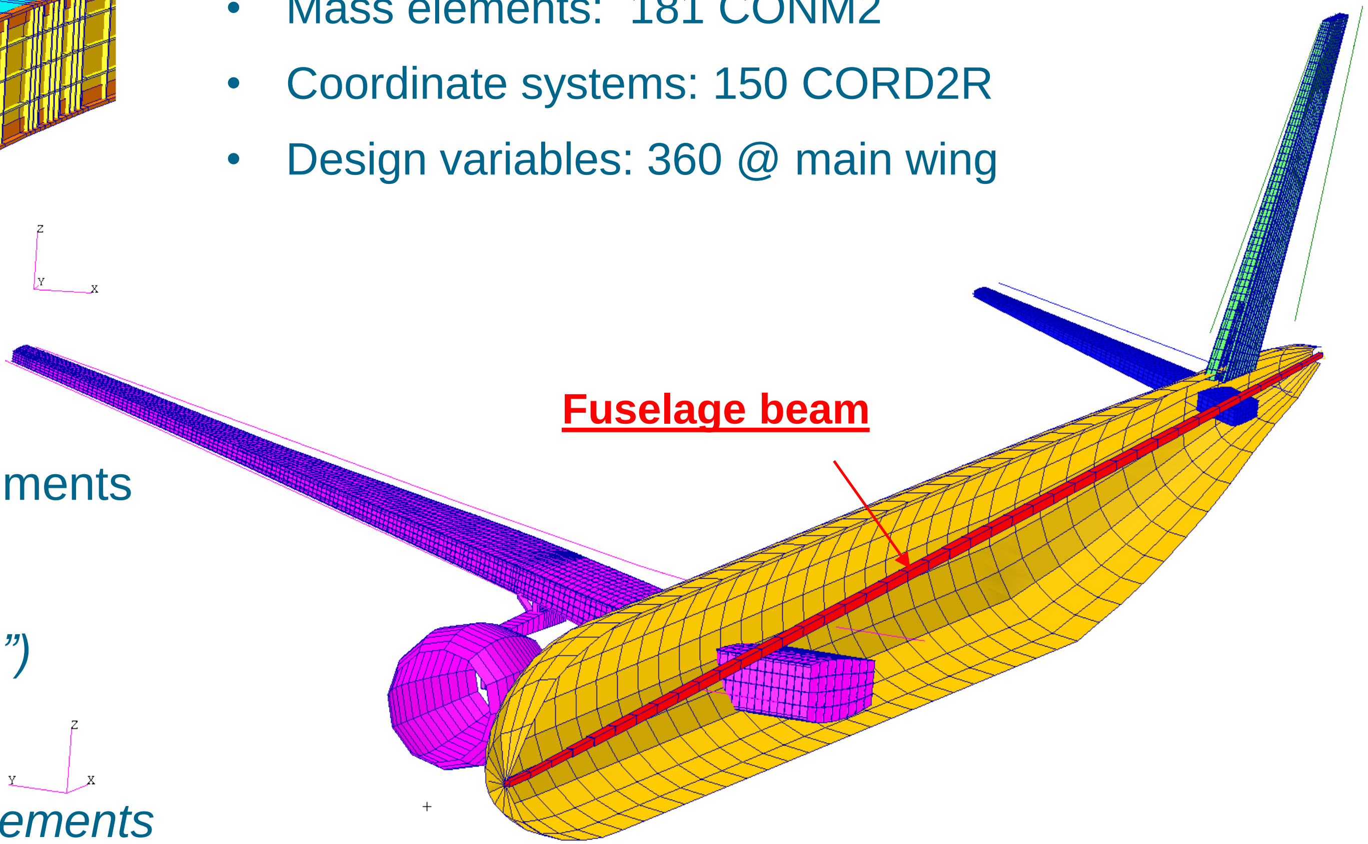


Structural Model

- Nodes: ~ 31.000 GRID
- Shell elements: ~ 34.000 CQUAD4
- Beam elements: ~ 45.000 CBAR
- Mass elements: 181 CONM2
- Coordinate systems: 150 CORD2R
- Design variables: 360 @ main wing

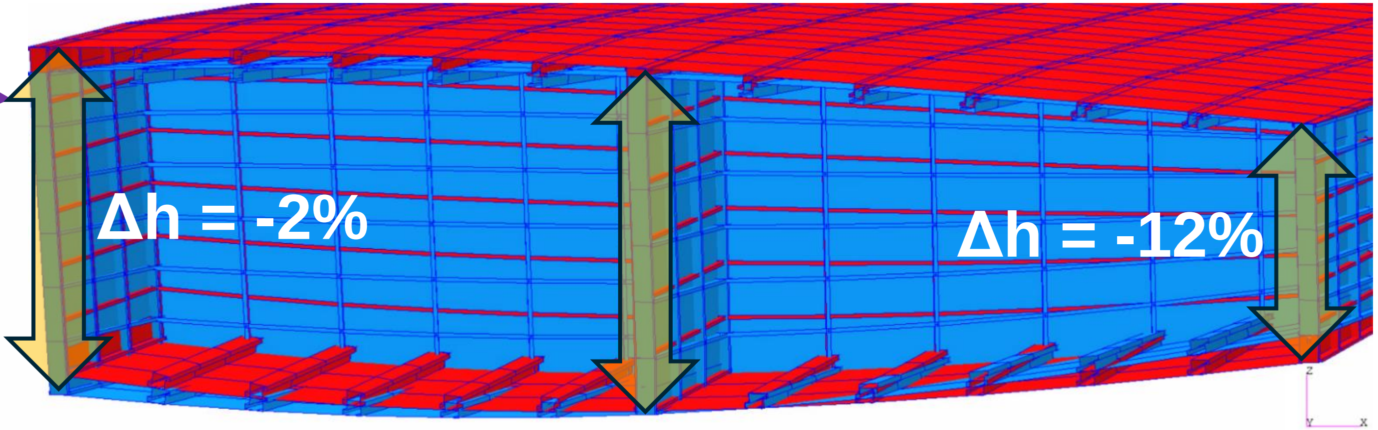
Optimization Model

- Design variables: Thickness of the SHELL-elements
- Constraints: Strains (max./min./shear)
- Controlsurface efficiency optimization *("on top")*
- Objective: Minimum weight of the wingbox
- *Preliminary cross-section sizing of the BAR-elements*

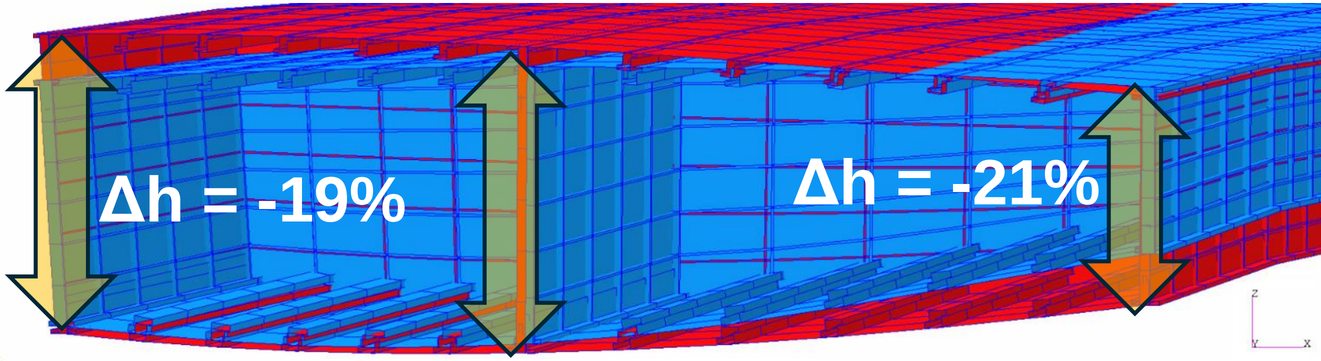


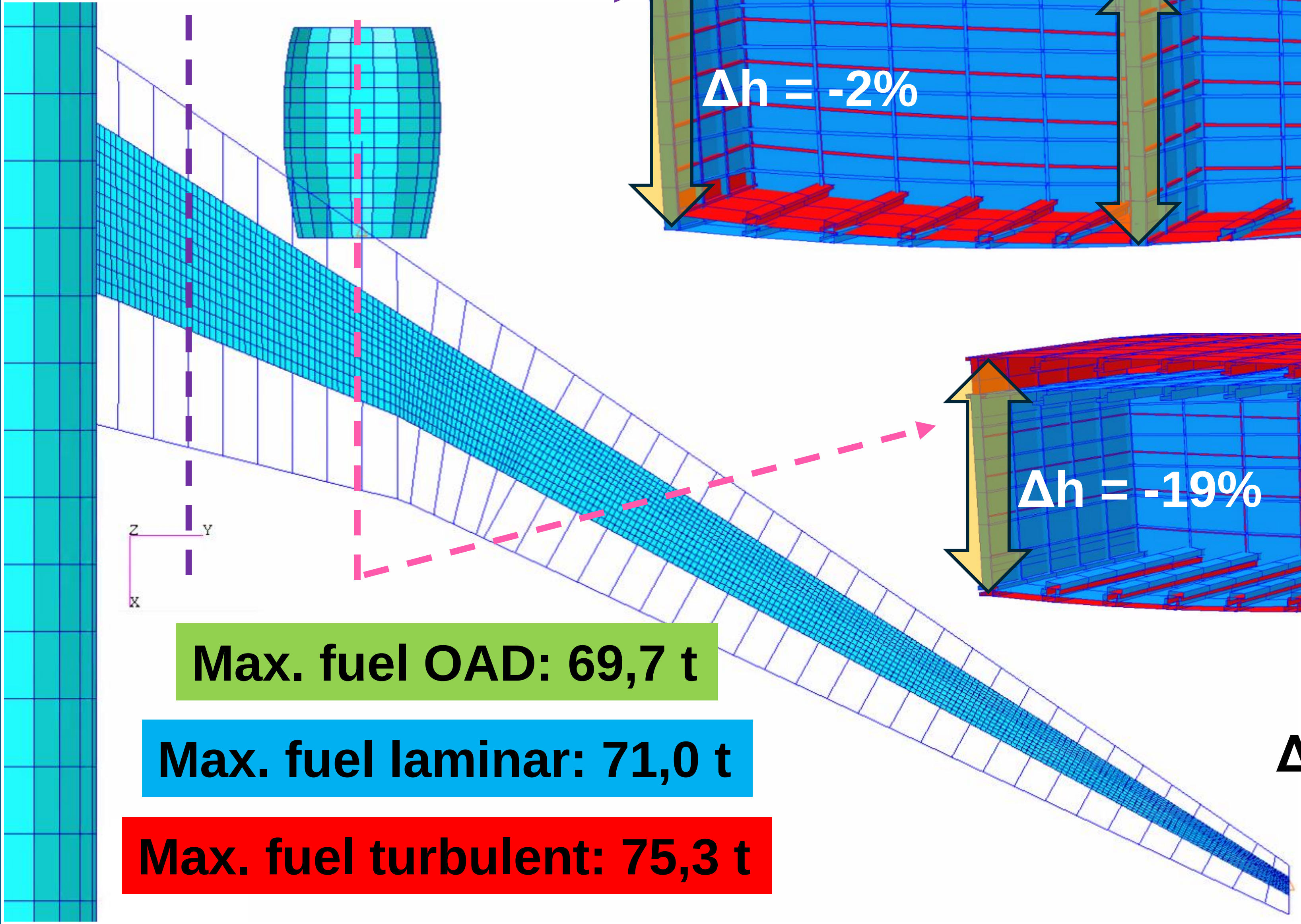
Wingbox Comparison

@Landing gear attachment



@Engine attachment





Max. fuel OAD: 69,7 t

Max. fuel laminar: 71,0 t

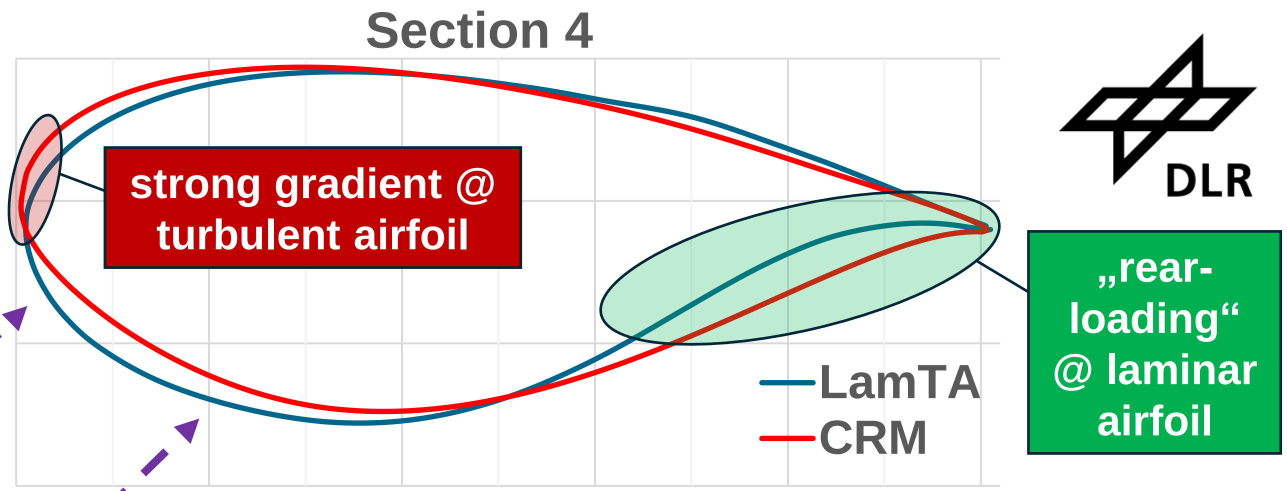
Max. fuel turbulent: 75,3 t

$$\Delta h = \frac{h_{laminar} - h_{turbulent}}{h_{turbulent}}$$

- turbulent
- laminar

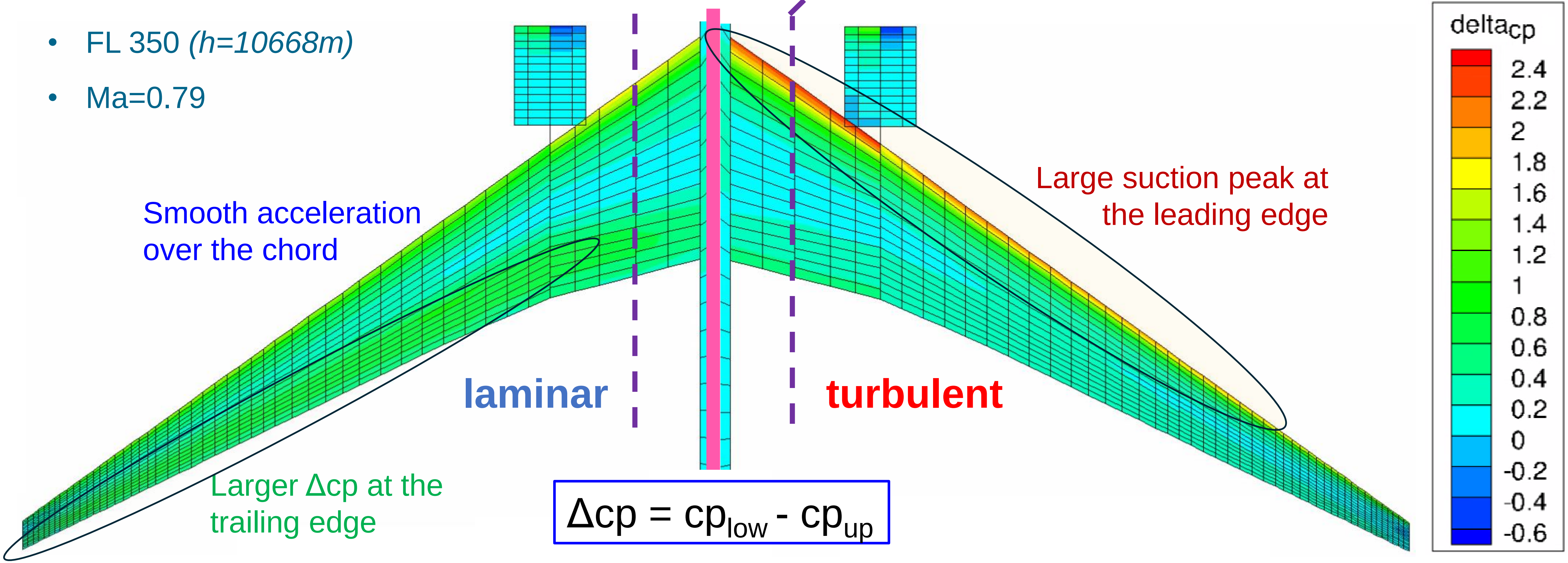
Pressure Distribution (VLM)

Pure Effect of Camber and Twist



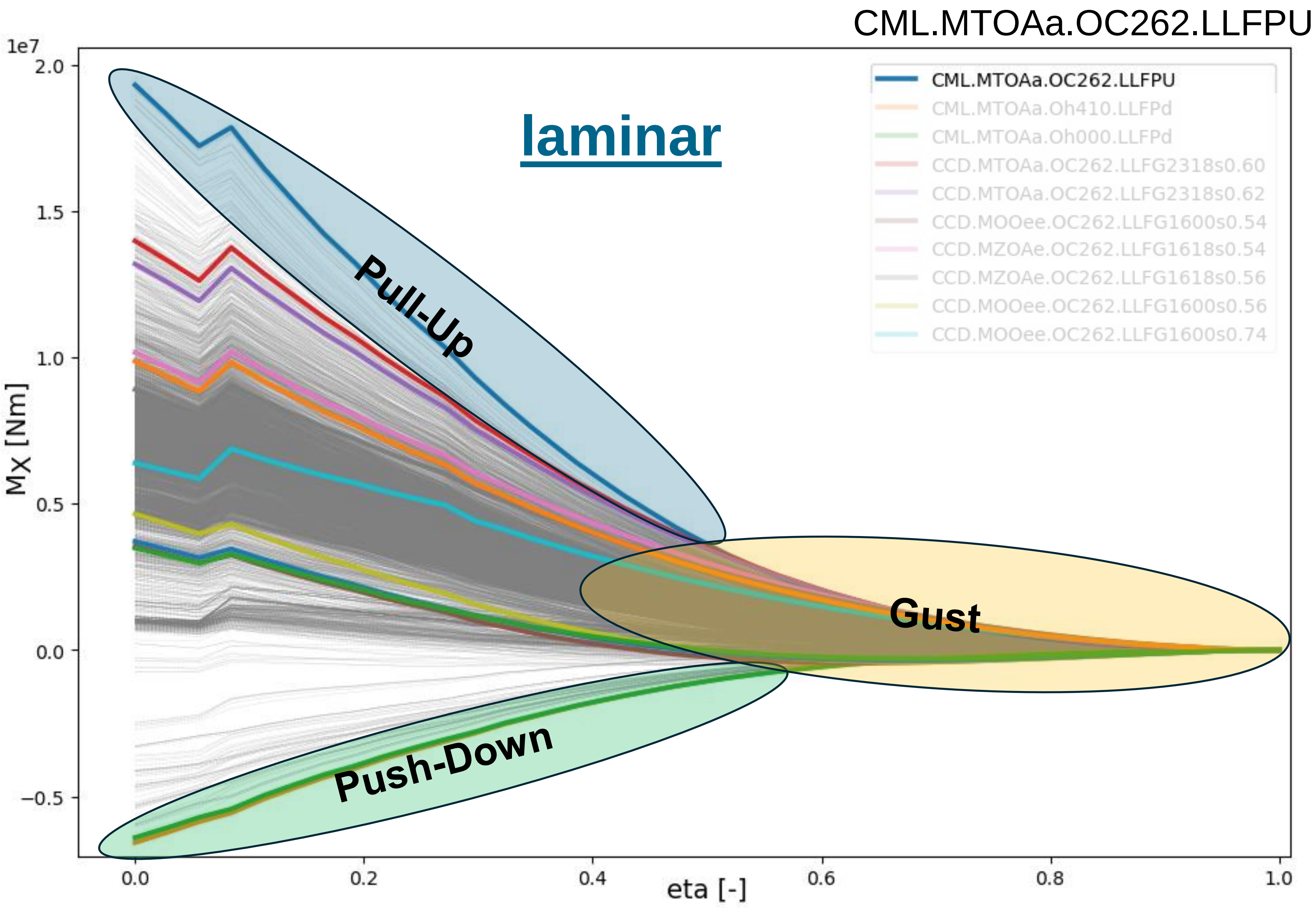
1g level flight:

- Clean Configuration
- Cruise Mass Case
- FL 350 *(h=10668m)*
- Ma=0.79



$\Delta cp = cp_{low} - cp_{up}$

Wing Bending Cutting Moment (M_x)



Max. wing root bending moment:

- 2.5g pull-up maneuver
- MTOM *(forward CG)*
- FL 262 *(h=8000m)*
- Vc *(Ma=0.84)*
- *MLA*

Maximum

- Pull-up from root to 50%
- Gust from 50% to the tip

Minimum (max. negative)

- Push-down from root to 60%
- Gust from 60% to the tip

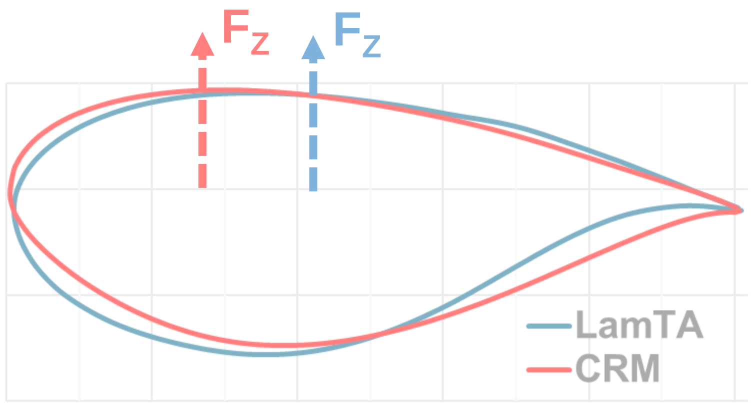
Maximum Cutting Moments – Bending (M_x) and Torsion (M_y)

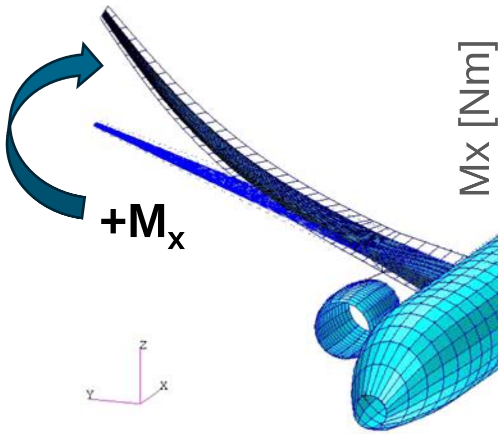
Bending Moment (M_x):

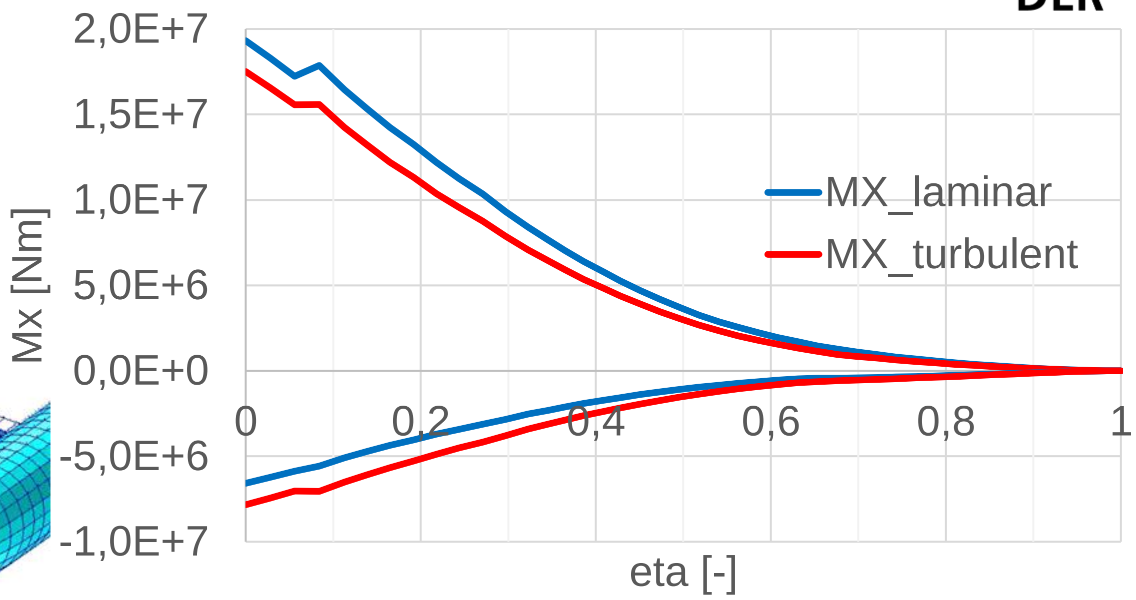
- **Laminar** wing:
  higher max. moment
- **Turbulent** wing:
  higher negative moment

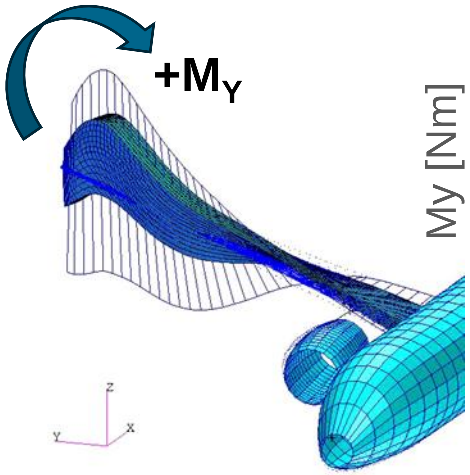
Torsional Moment (M_y):

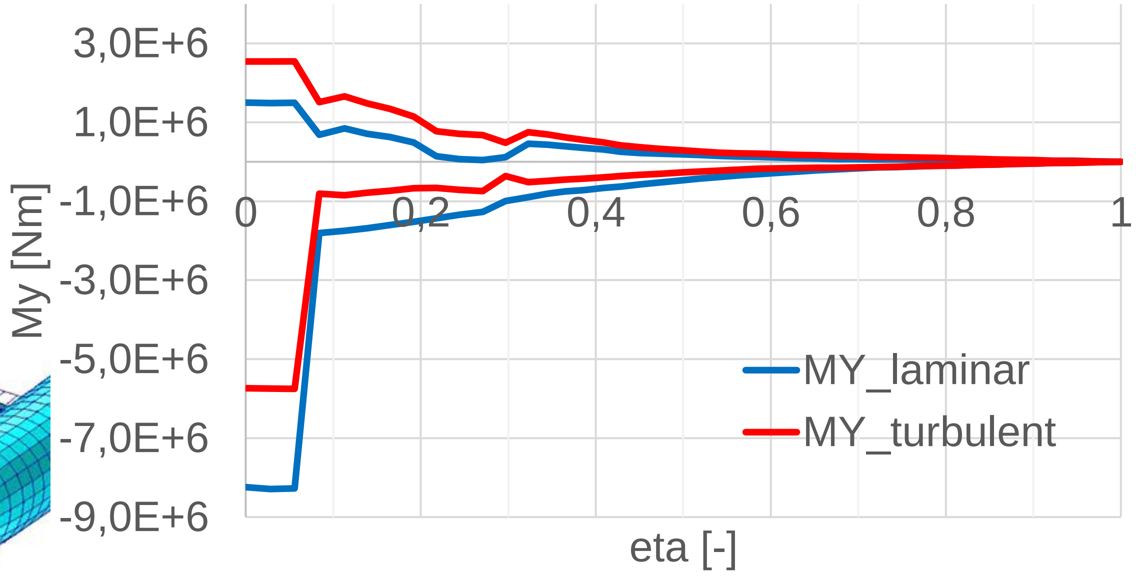
- **Laminar** wing:
  higher negative (nose down) moment (rear-loading)
- **Turbulent** wing:
  higher max. (nose up) moment (suction peak at the nose)





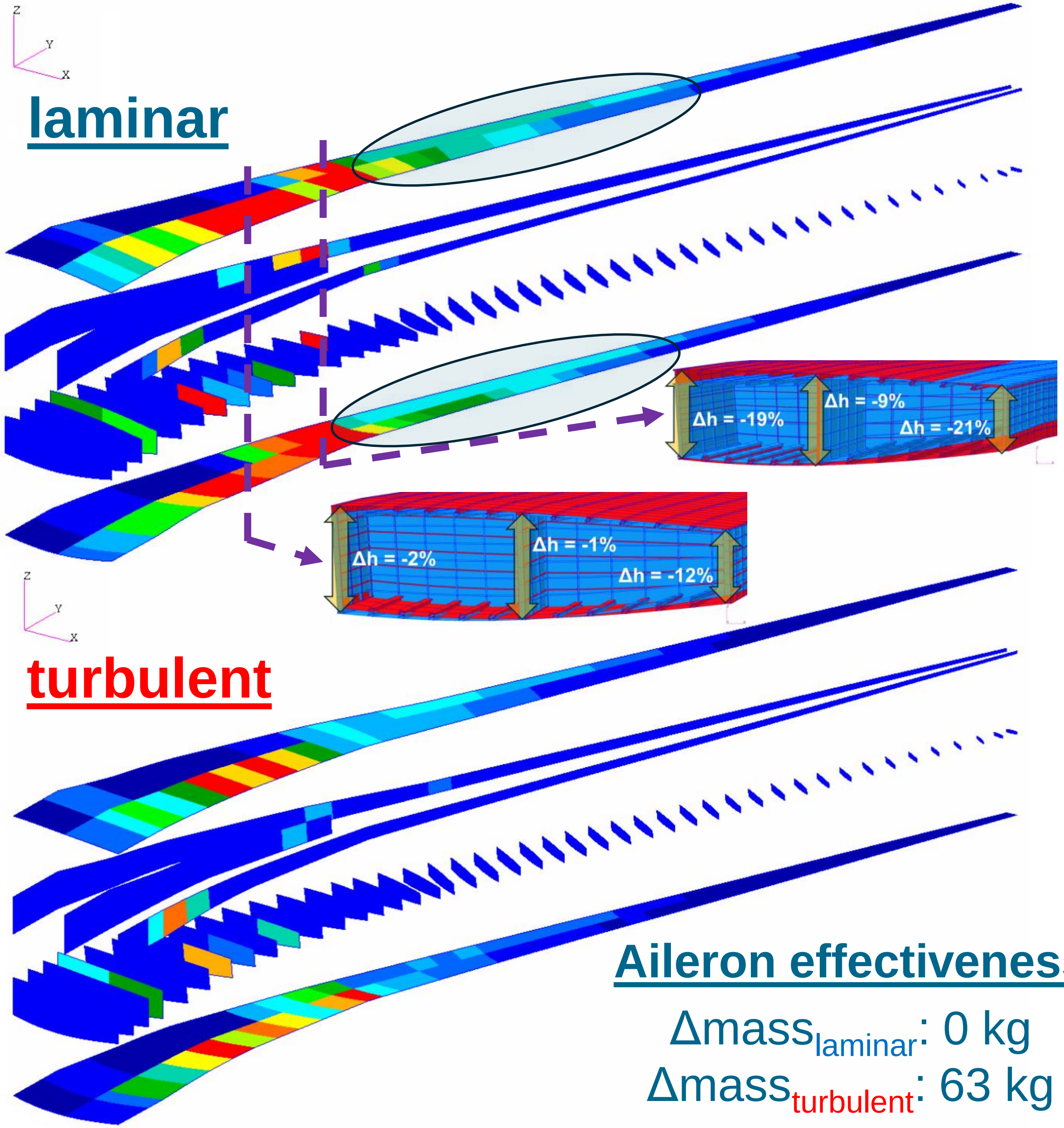






Aeroelastic Assesment

Influence on the Wing Primary Mass



Aileron effectiveness

$\Delta mass_{laminar}$: 0 kg
$\Delta mass_{turbulent}$: 63 kg

Laminar Wing

More material at the **landing gear** and **pylon attachment** region

Higher skin thickness at **mid section**

Component	laminar	turbulent	delta
Skin (lower)	1.781 kg	1.228 kg	-31 %
Skin (upper)	1.746 kg	1.213 kg	-31 %
Stringer	1.250 kg	1.155 kg	-8 %
Ribs	803 kg	735 kg	-8 %
Rib stiff.	169 kg	149 kg	-12 %
Spar webs	609 kg	613kg	+1 %
Spar caps	372 kg	345 kg	-7 %
Spar stiff.	253 kg	216 kg	-15 %
Titanium	278 kg	309 kg	-11 %
Overall	**7.261 kg**	**5.963 kg**	**-18 %**

intermediate

Eigenmodes Analysis

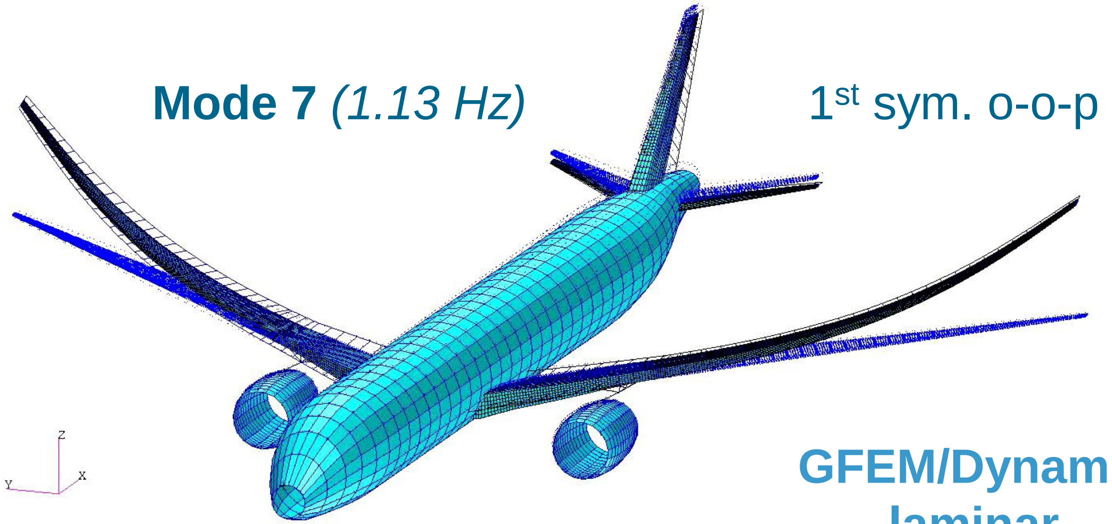
Eigenmodes Analysis
MSC Nastran SOL103

Mode Nr.	MCRUI	MFOeF	MOOee	MTOAa	MTOfF	MZOAe
7	1.06 Hz	0.94 Hz	1.13 Hz	1.03 Hz	0.94 Hz	1.11 Hz

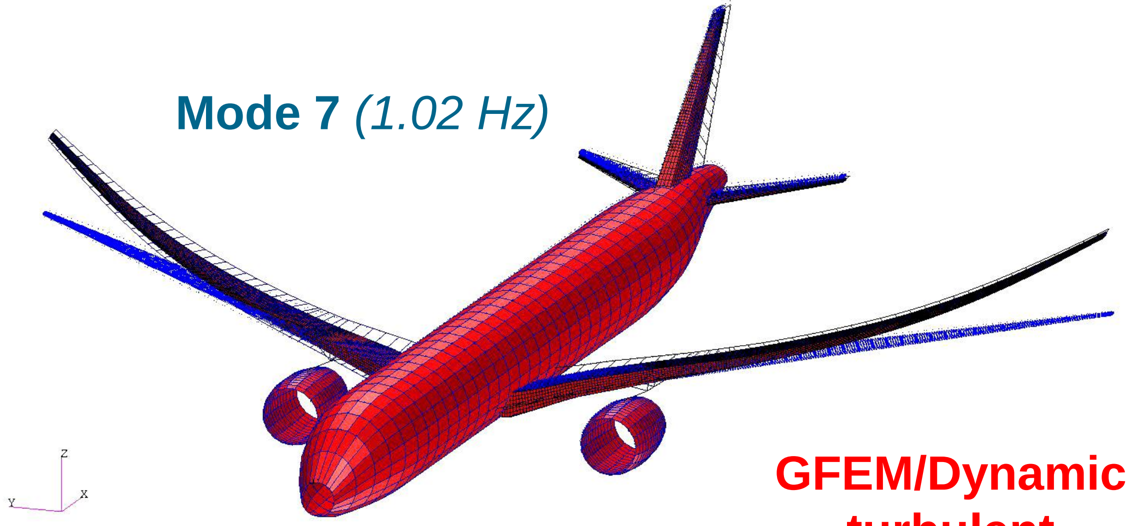
MCRUI	MFOeF	MOOee	MTOAa	MTOfF	MZOAe
0.94 Hz	0.81 Hz	1.02 Hz	0.90 Hz	0.81 Hz	1.00 Hz

Mode 7 *(1.13 Hz)*

1st sym. o-o-p bending



Mode 7 *(1.02 Hz)*

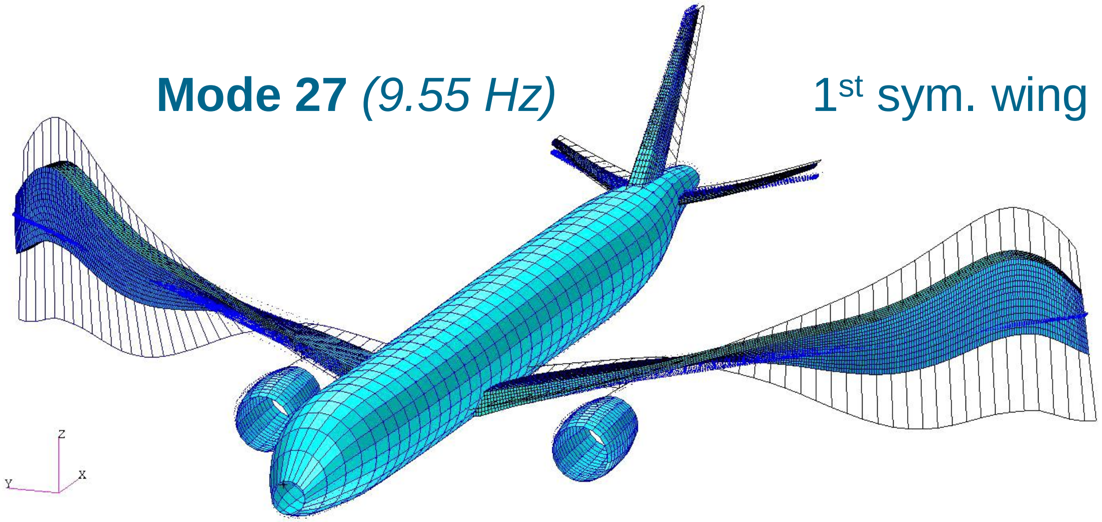


GFEM/Dynamic laminar

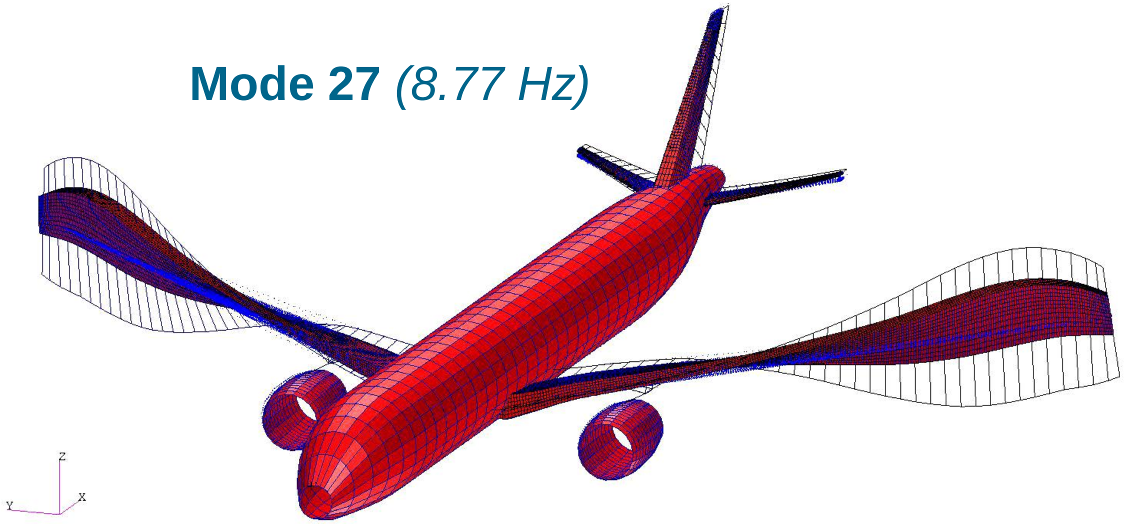
GFEM/Dynamic turbulent

Mode 27 *(9.55 Hz)*

1st sym. wing torsion



Mode 27 *(8.77 Hz)*

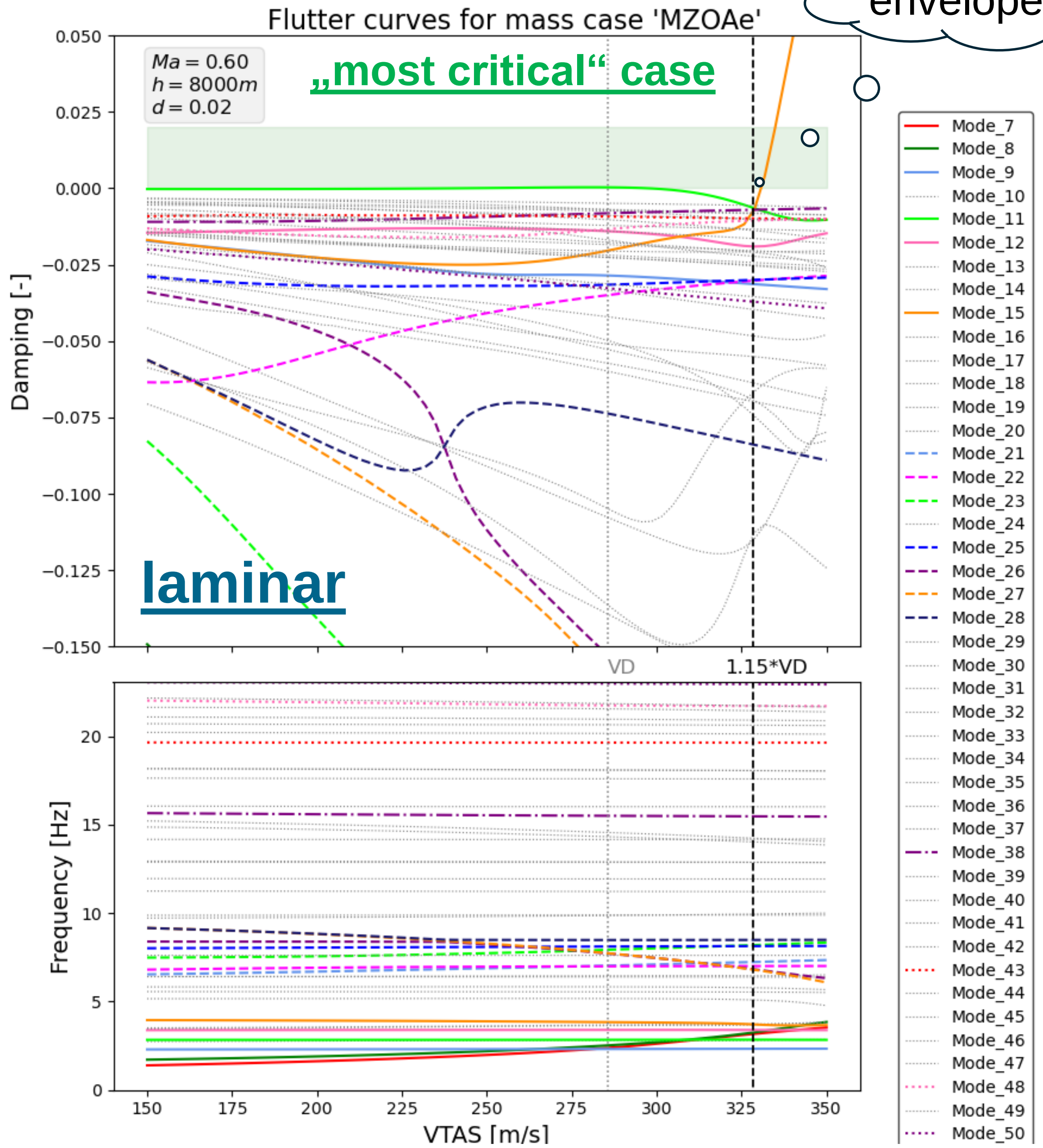


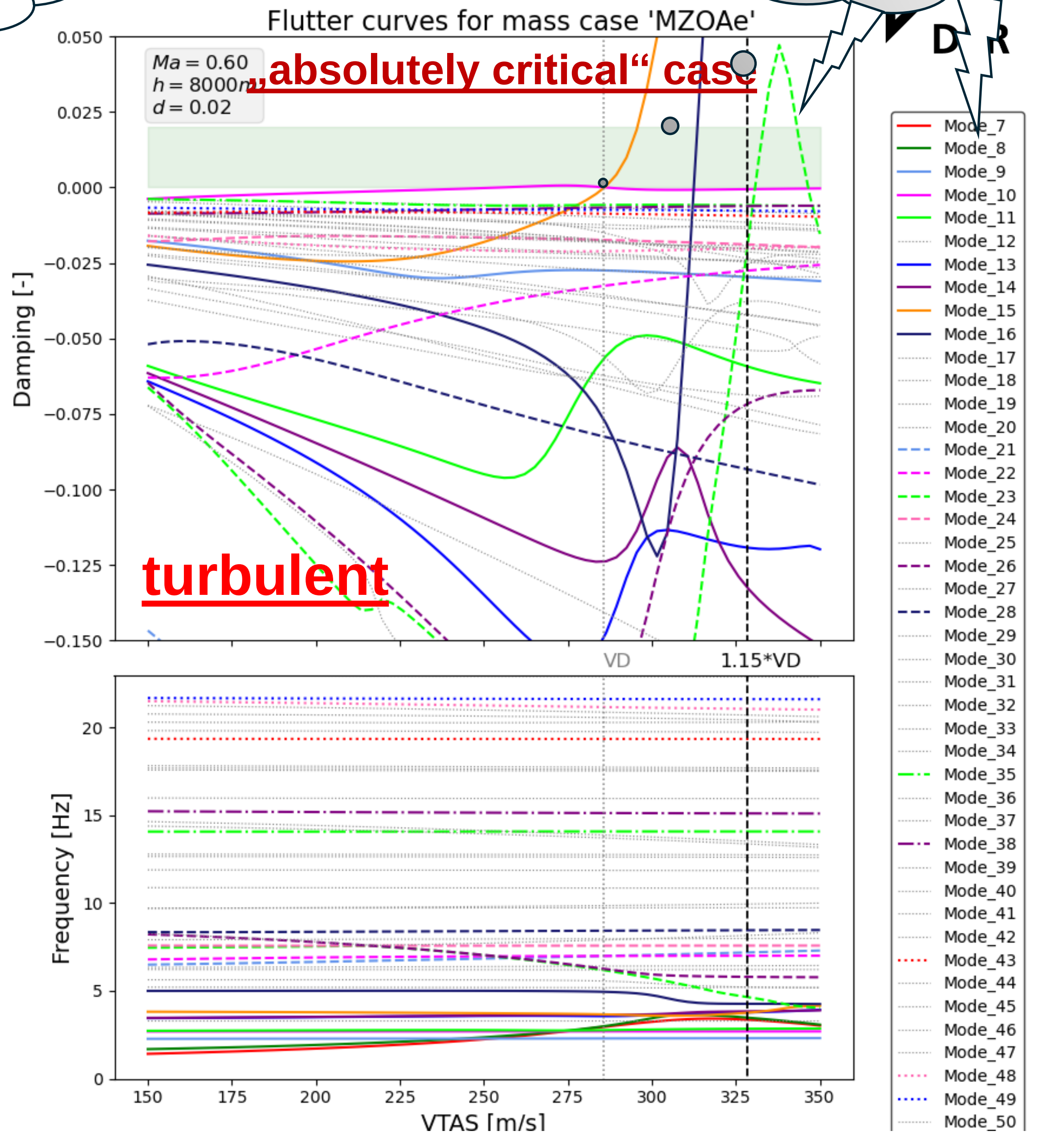
Subsonic Flutter-Check

Outside the envelope ☺

Flutter Analysis
MSC Nastran SOL145

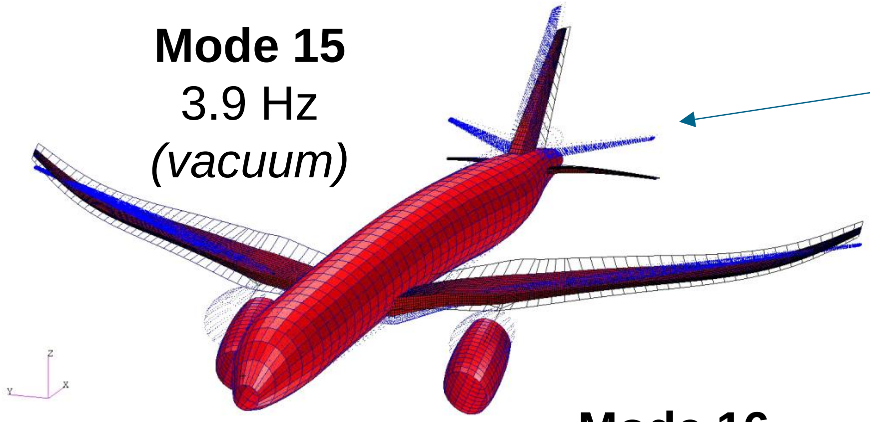
Inside the envelope ☹



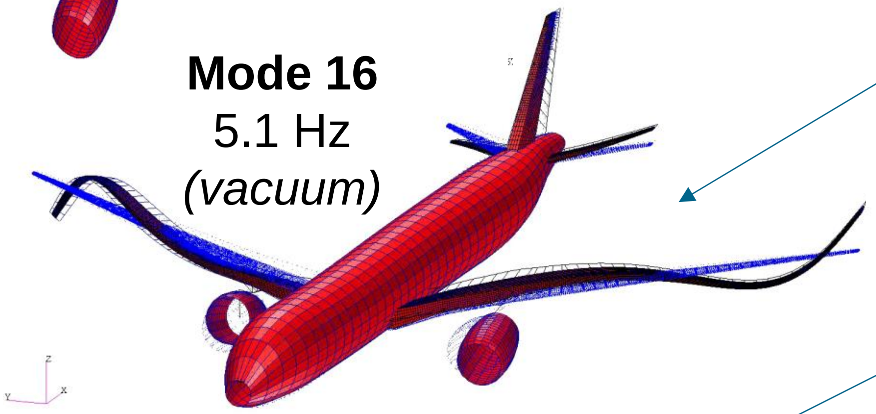


Critical Eigenmodes Turbulent

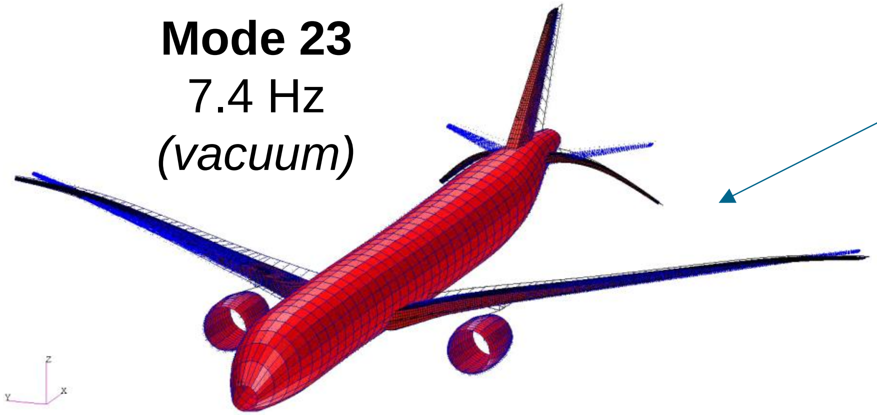
Mode 15
3.9 Hz
(vacuum)

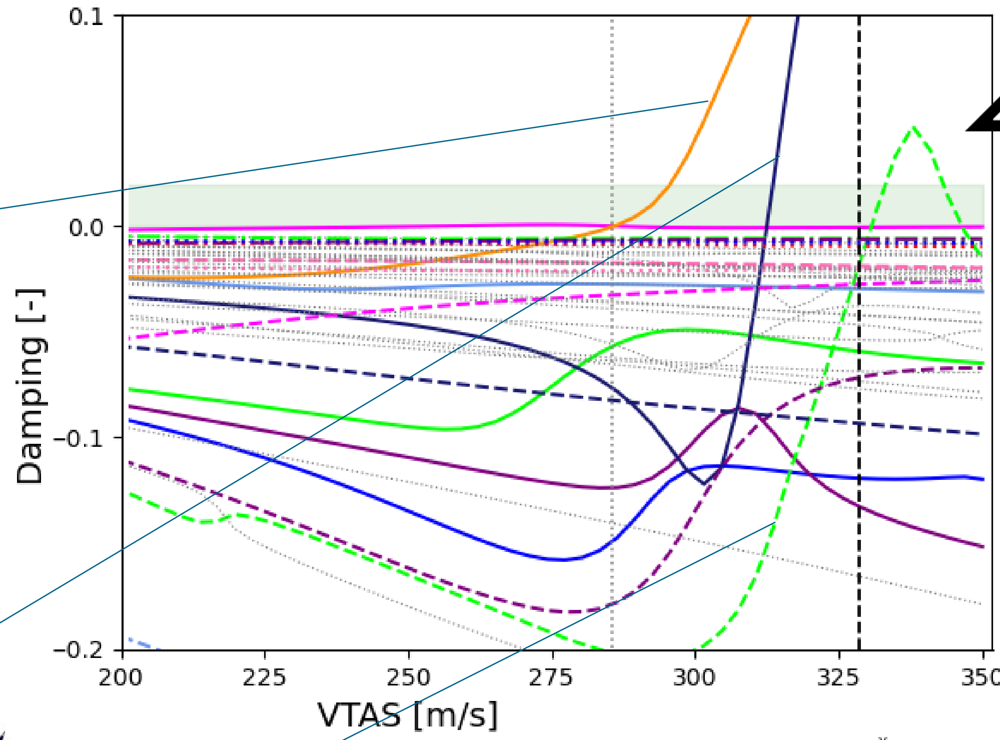


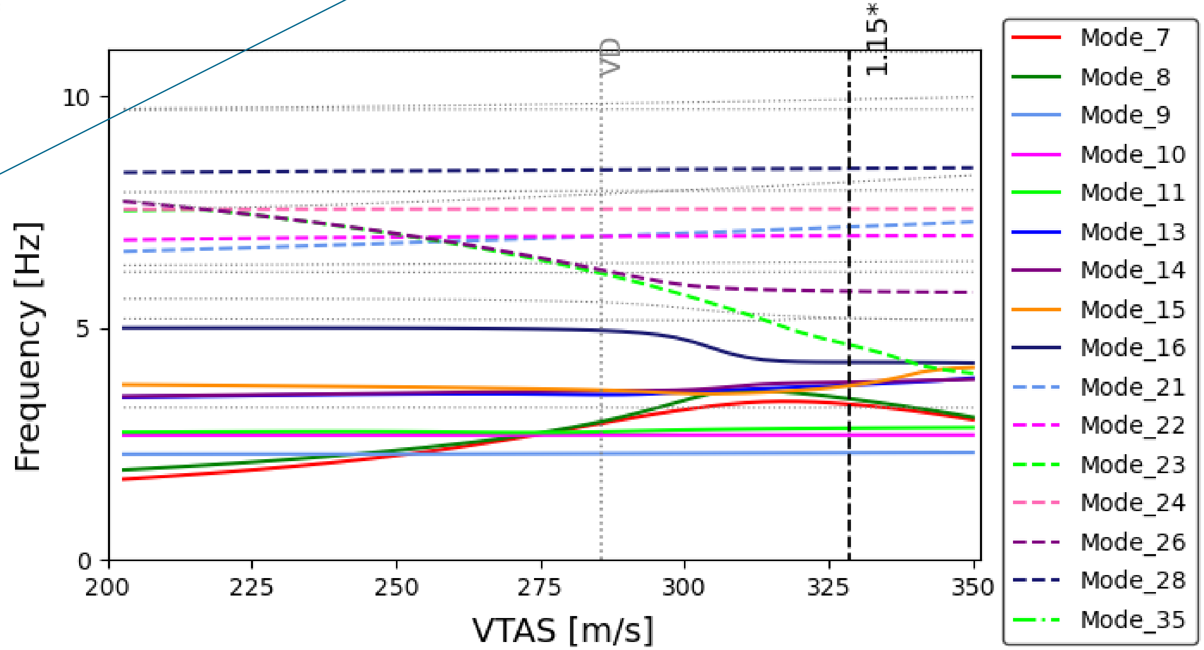
Mode 16
5.1 Hz
(vacuum)



Mode 23
7.4 Hz
(vacuum)







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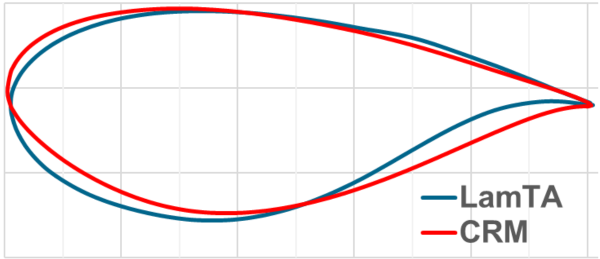
Aeroelastic Assesment

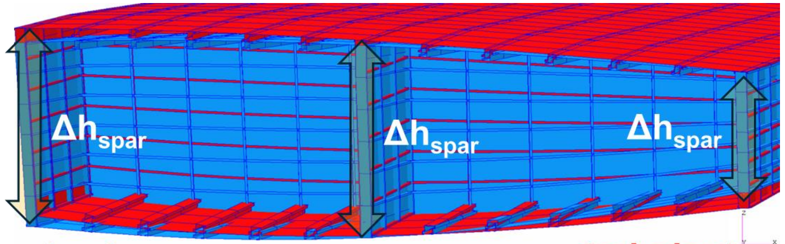
Summary

M. Schulze & J. Ruberte Beilo: “The Effect of Laminar Compared to Turbulent Airfoils on the Aeroelastic Assessment of a Long-Range Transport Aircraft Configuration”

The **shape of the airfoils** has a **strong effect** on the…

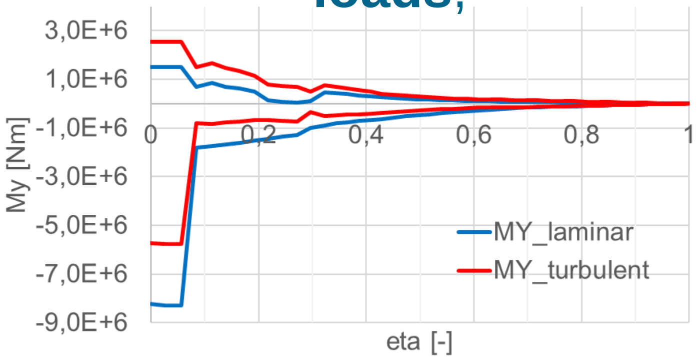


structure,

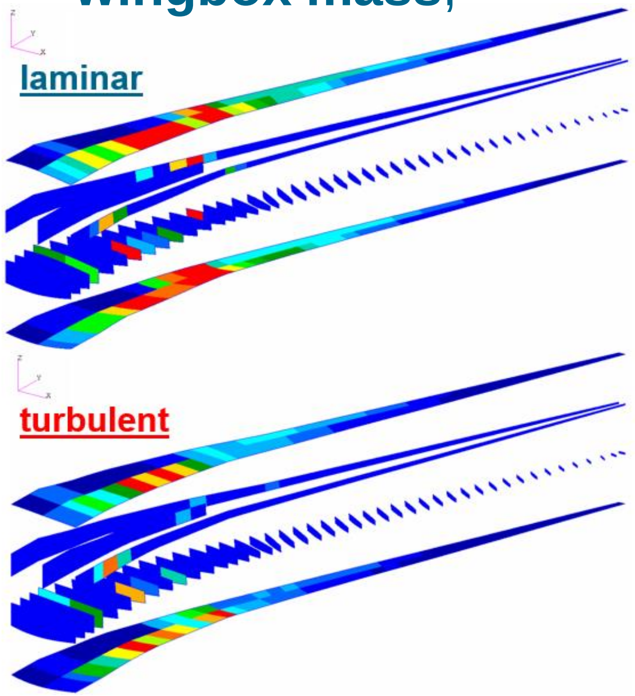


- laminar **- turbulent**

loads,



wingbox mass,



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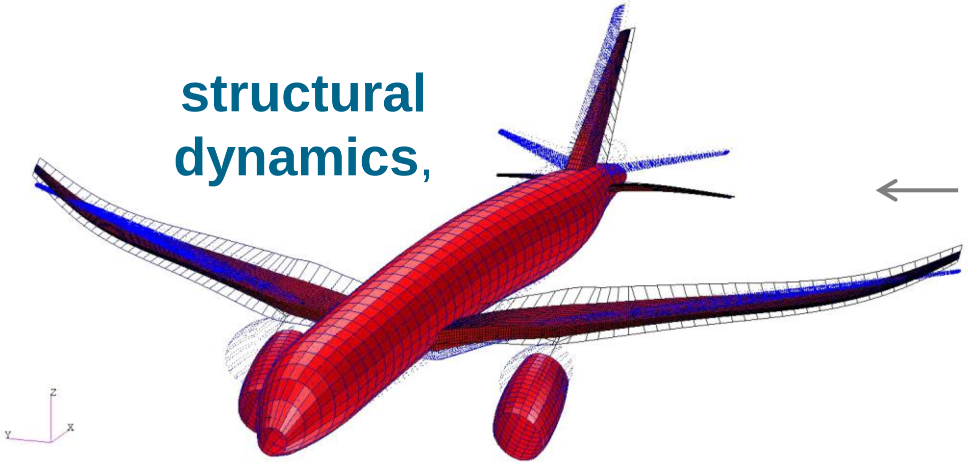
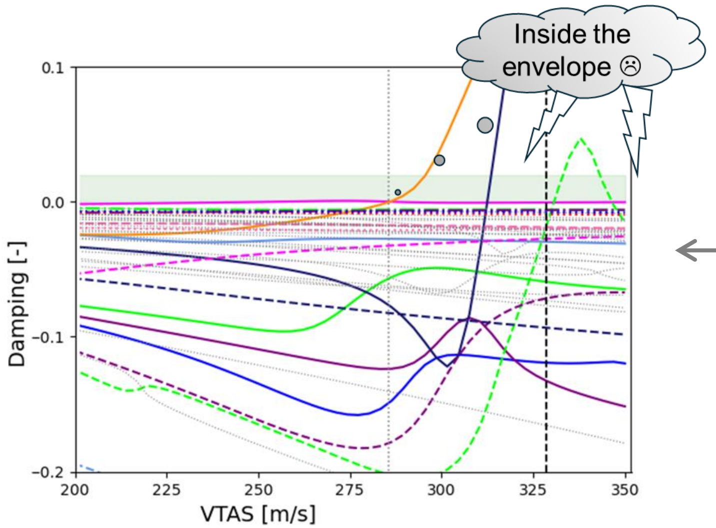
structural dynamics,



aeroelastic stability.



ID 650024

Thank you for your attention!

Questions?

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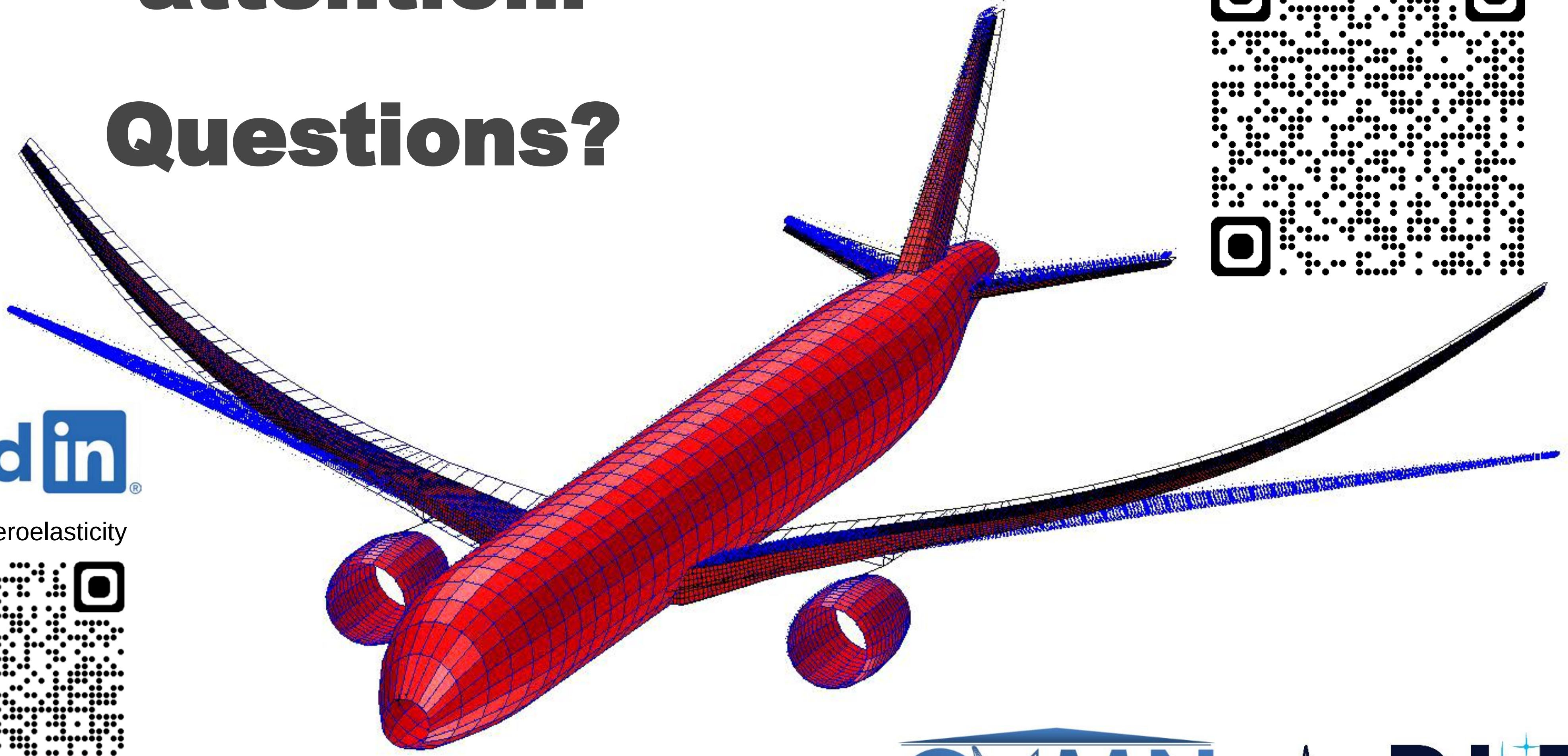

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