TOWARDS AERO-STRUCTURAL OPTIMIZATION USING THE NEW CFD SOFTWARE BY ONERA, DLR, AIRBUS (CODA)

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DLR-AS-CASE, DLR-SP-SUM
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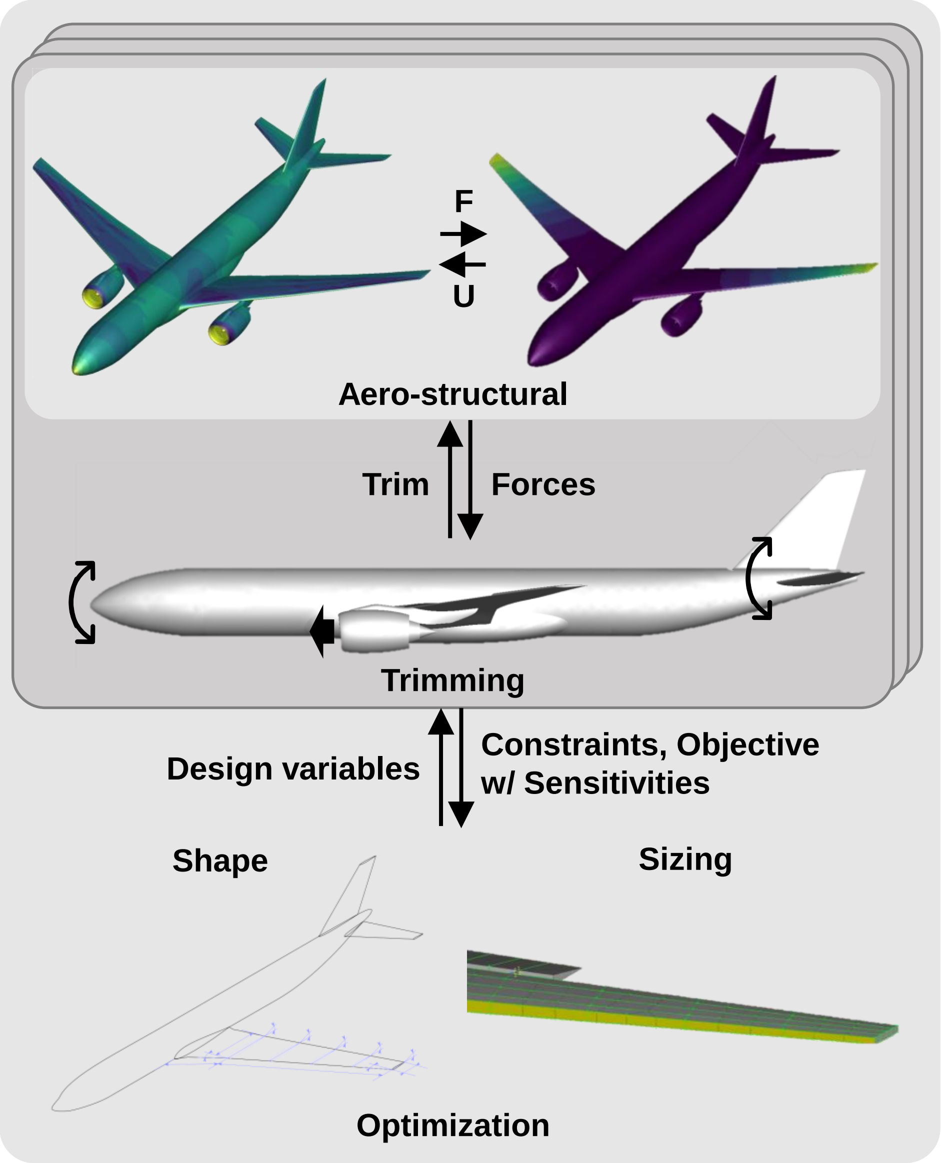
DLR

Motivation



Assess technological potential by fully coupled Aero-Structural design

- Long way to go
- Importance
  - **Efficiency**
  - **Accuracy**

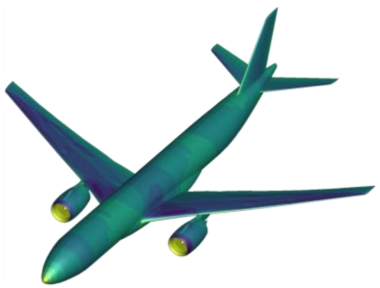
Gradient-based MDO

Main goal: Gradually introduce CODA beside DLR-TAU into existing MDO stream

- Both RANS solver suites

Tools

CFD
CODA



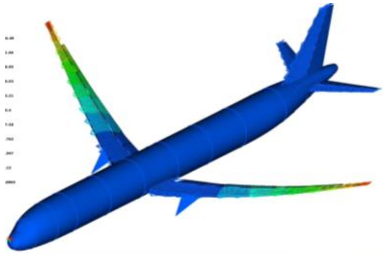
ONERA, DLR, Airbus

- FV + DG in one framework
- Hybrid parallelization (MPI + GASPI)
- Advanced turbulence modeling (e.g. RSM)
- Cell centred, Roe upwind
- **Adjoint capability**
  - **Automatic (Algorithmic) differentiation (AD)**

CFD
TAU

- Hybrid RANS/LES for unstructured hybrid grids
- Validated & actively used in European aerospace industry & academia
- Advanced turbulence modeling (e.g. RSM)
- Cell vertex, Central+matrixD
- **Adjoint capability**
  - **Analytic differentiation**

Structural solver
Lagrange

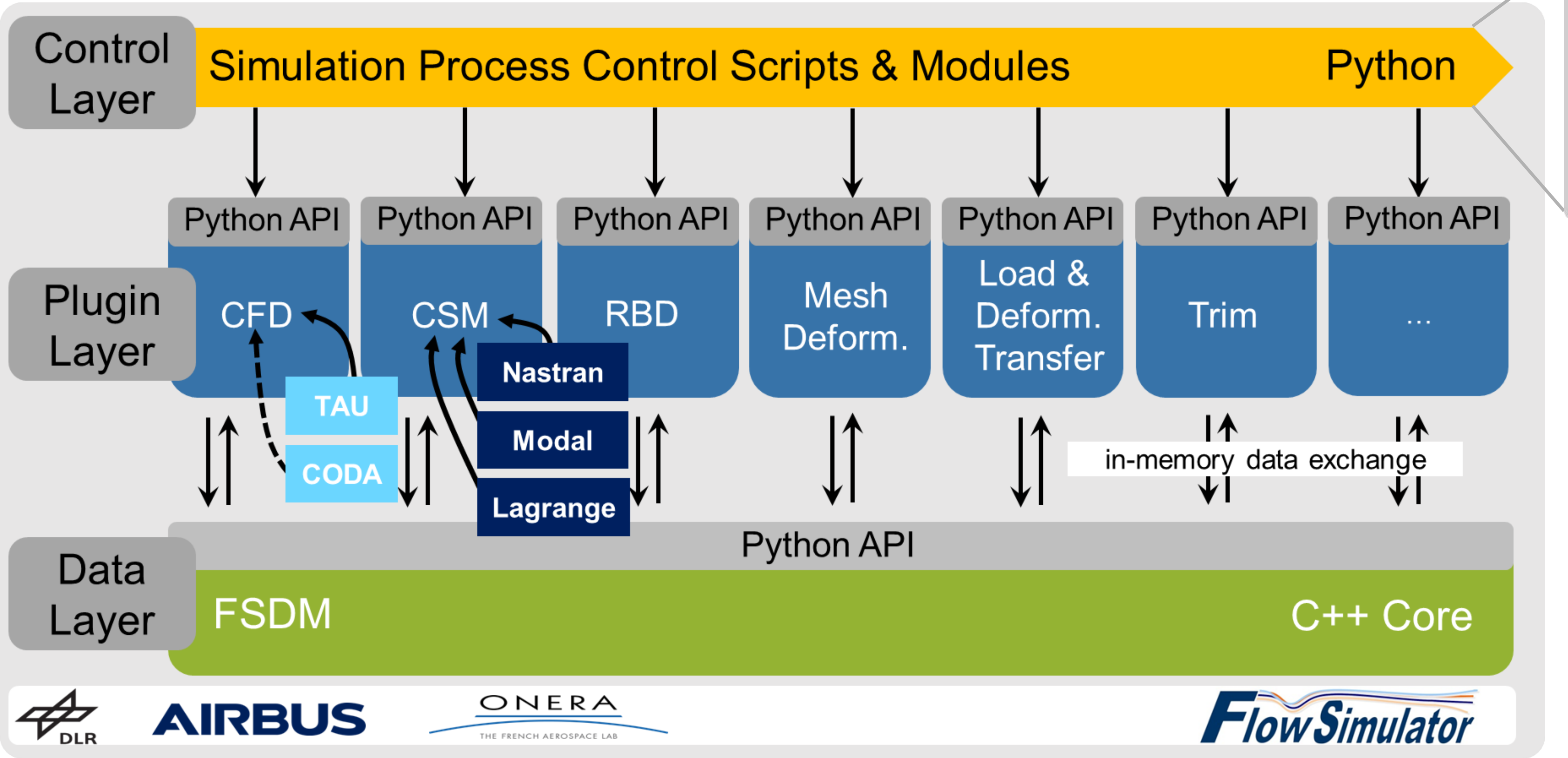


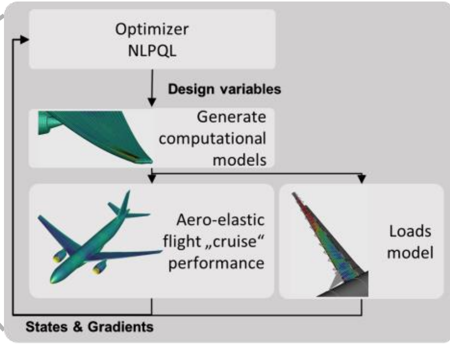
- Structural analysis and optimization software by Airbus Defence & Space
- Structural sizing methods specifically for aerospace application
- Full spectrum of element types
- Nastran syntax input file

Tools

FlowSimulator

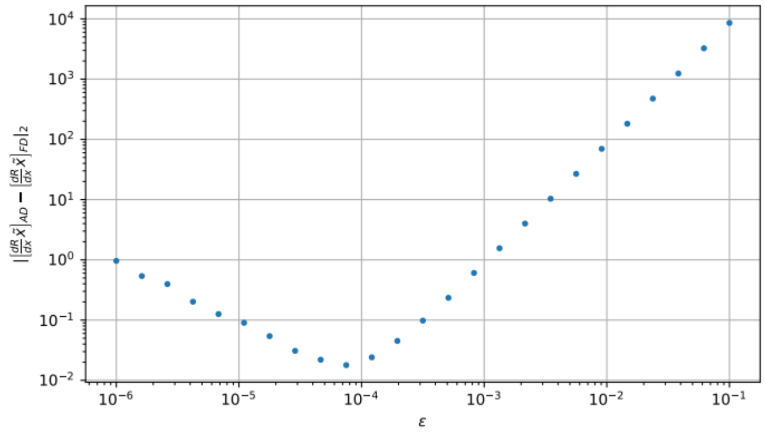
HPC-enabled multidisciplinary simulation capability



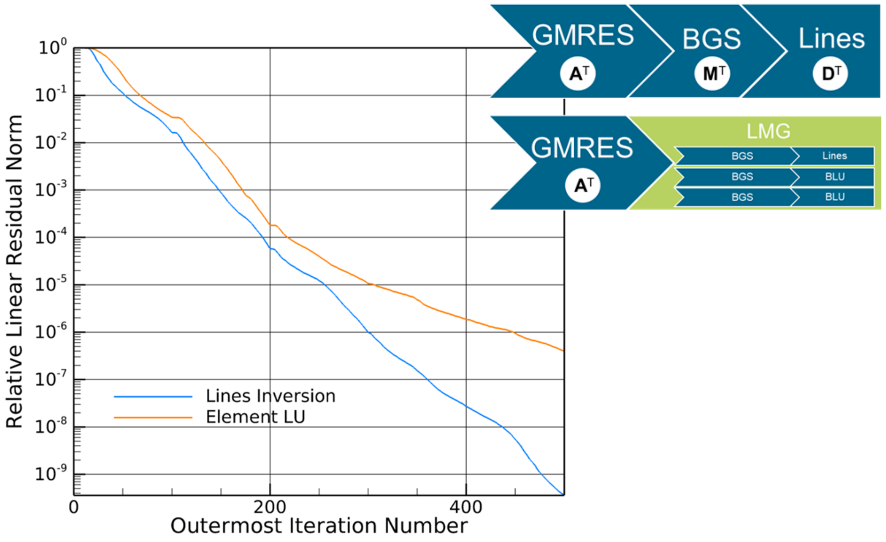


Algorithmic Differentiation (AD) of *CODA*

- Scalable forward and reverse AD of full residual and integral quantities in *CODA* with near-optimal run time (~2x) and memory (<2x) requirements
- Advanced linear solver capabilities supporting nested matrix-free and matrix-based solver stacks for robust convergence of stiff linear systems
- Hybrid-parallel capabilities of HPC-optimized primal CFD solver retained, supporting overlapping communication and computation

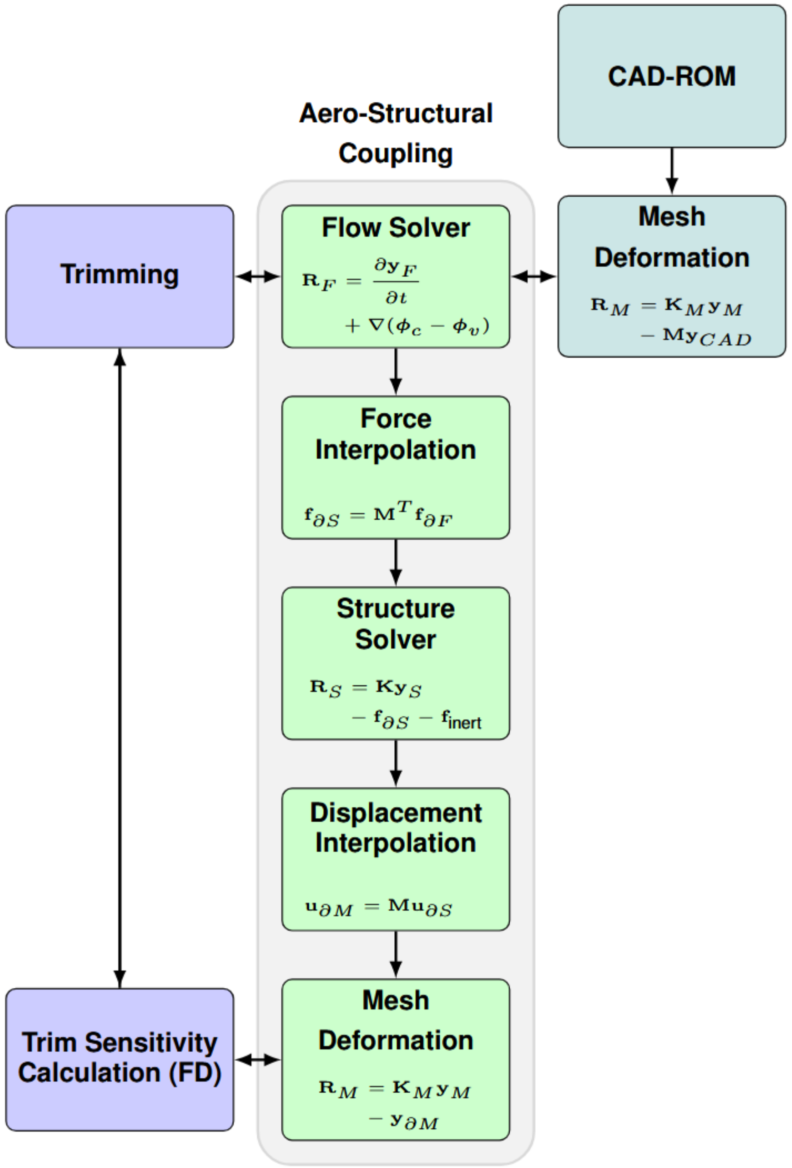


(a) $\frac{\partial R}{\partial X}\delta X$: AD vs. FD over step size



(b) Linear solver convergence

Lagrange MDO



$$
\begin{aligned}
\boldsymbol{y}_F^{(i+1)} &= CFD\left(\boldsymbol{y}_M^{(i)}\right) \\
\boldsymbol{y}_S^{(i+1)} &= \boldsymbol{K}^{-1}\left(\boldsymbol{f}_{inert} + \boldsymbol{M}^T \boldsymbol{F}_F \boldsymbol{y}_F^{(i+1)}\right) \\
\boldsymbol{y}_M^{(i+1)} &= \boldsymbol{K}_M^{-1} \boldsymbol{M} \boldsymbol{y}_S^{(i+1)}.
\end{aligned}
$$

- Mesh Deformation, aerodynamic and structural solver
- ***yF*** , the fluid state in the volume CFD mesh,
- ***yM***, the CFD mesh coordinates and
- ***yS***, the structural displacements.
- The stiffness matrix is ***K***
- ***FF*,** aerodynamic state variables
- ***M*,** multi-component moving least squares (MLS)

- Surface Parameterization: CAD-ROM
- Mesh Deformation: Elastic Analogy (linear)

Gradient Verification

Wing Twist CODA	section1	section2	section3
CL – FD 0.1	0.025303675648	0.032950708471	0.017177927138
CL – FD 0.01	0.025303768387	0.032950725378	0.017177891019
CL – FD 0.001	0.025303768387	0.032950725378	0.017177891019
CL – Sensitivity	0.02529**9826929**	0.03294**8466372**	0.01717**5410327**
CD – FD 0.1	0.000798513222	0.000964471261	0.000629095281
CD – FD 0.01	0.000798513104	0.000964470045	0.000629092971
CD – FD 0.001	0.000798513104	0.000964470045	0.000629092971
CD – Sensitivity	0.000798**714810**	0.000964**599265**	0.000629**255590**

Cost Function Sensitivities

$$\boldsymbol{y}_{\boldsymbol{F}}^{(i+1)} = CFD\left(\boldsymbol{y}_{\boldsymbol{M}}^{(i)}\right)$$

$$\left(\frac{\partial T}{\partial X}\right)^{T} \hat{\Lambda} = -\left(\frac{\partial I}{\partial X}\right)^{T} - \left(\frac{\partial R}{\partial X}\right)^{T} \Lambda$$

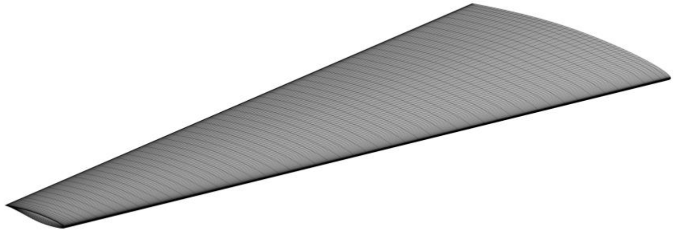
Right-hand side:

CODA Adjoint AD +

CODA Forward AD

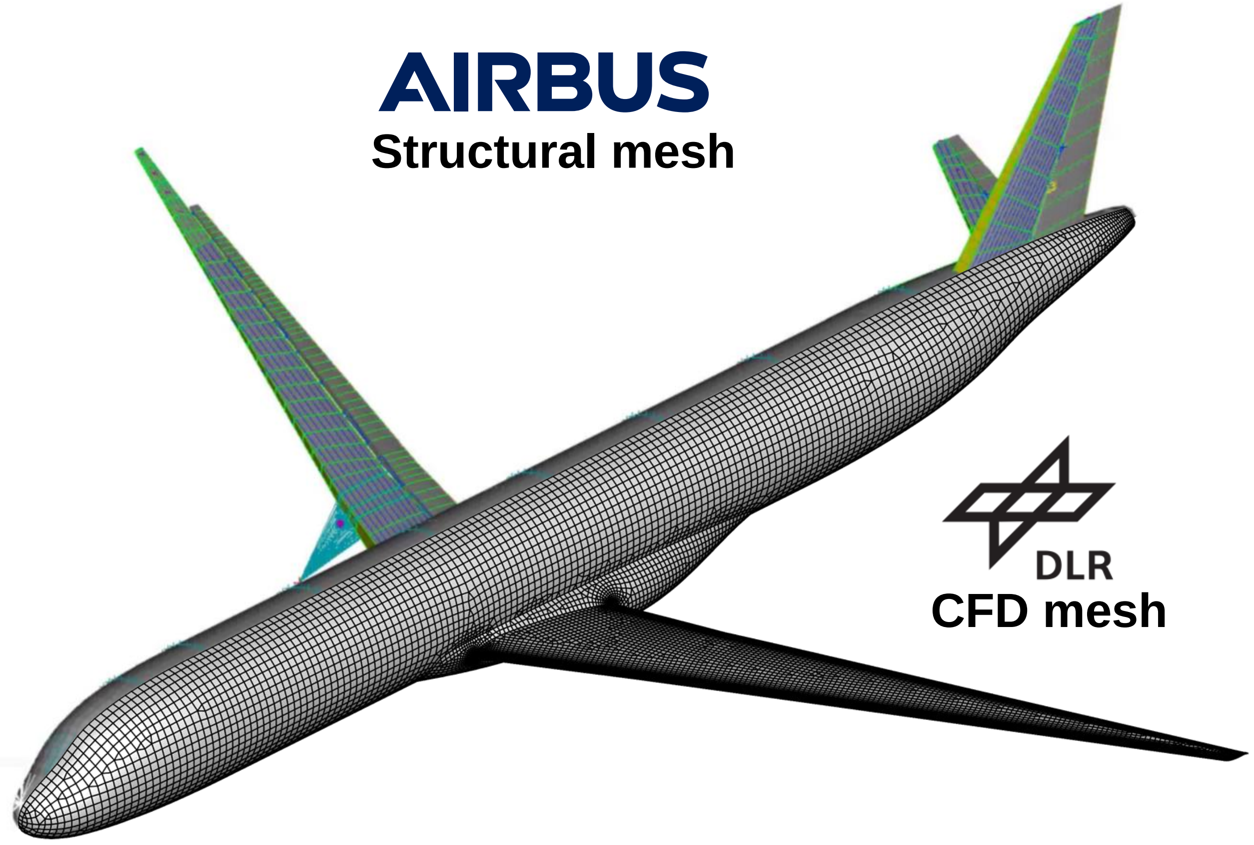
Testscase:

Simple Transonic Wing



OPTIMIZATION - DLR-F25

Design Task | DLR-F25
Optimisation of L/D



Structural and CFD meshes

Ma	0.78	[m]
Re	22 M	[-]
Flight level	10,363	[m]
F_z, M_y	0.	[N;Nm]
Span	45.0	[m]
Aspect ratio	15.5	[-]
Structure	CFRP	
# Nodes CFD	1,030,000	[-]
# DOF structure	75,000	[-]

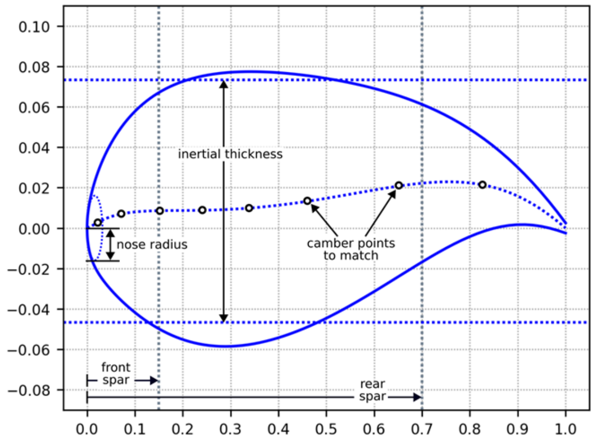
DLR-F25 is a conceptual design of an advanced short-to-medium range airliner.

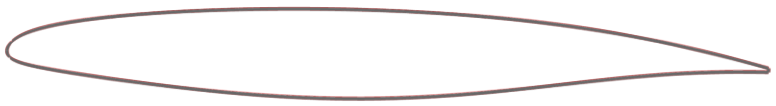
Development of DLR-F25 was funded by the German Federal Ministry for Economic Affairs and Climate Action.
Thanks to Sebastian Deinert (Airbus D&S) for the structure model & Achyuth Attravanam for the CFD mesh.

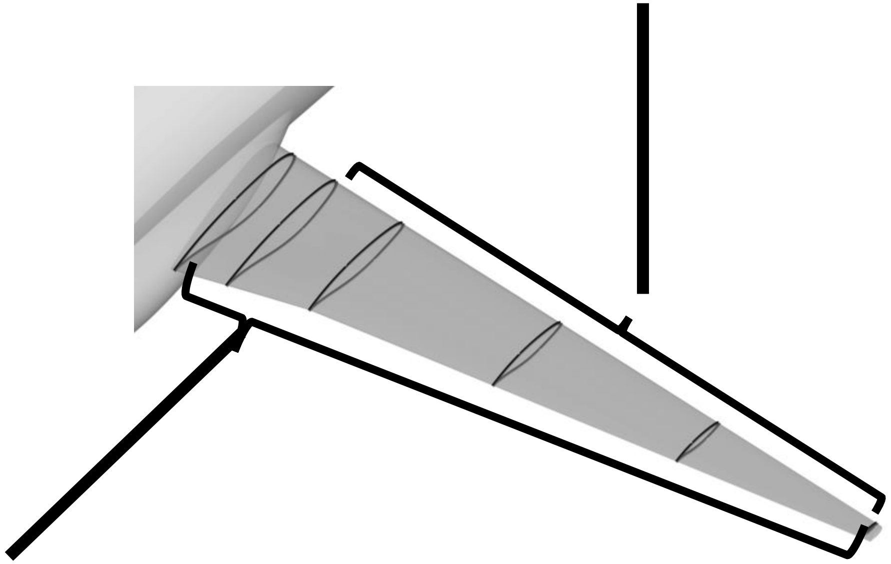
Design Task | Design variables

Shape

Camber	Twist
8 Positions @ 6 Sections	5 Sections

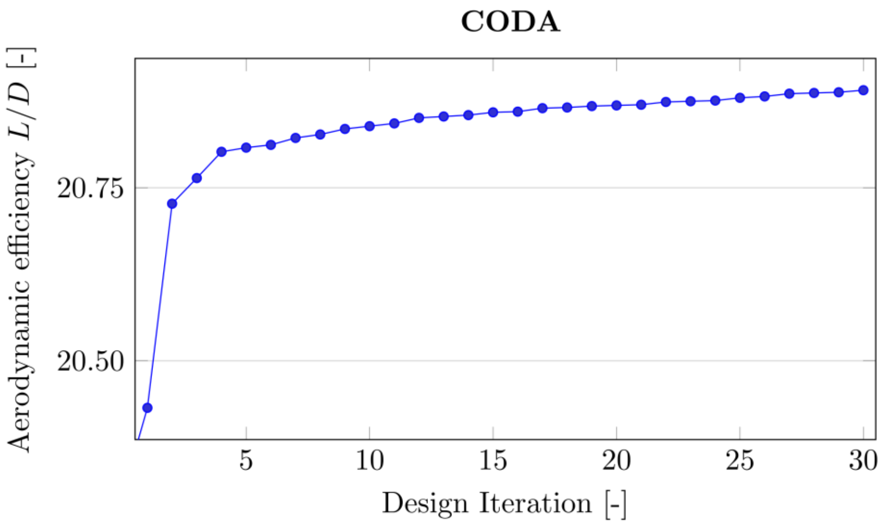


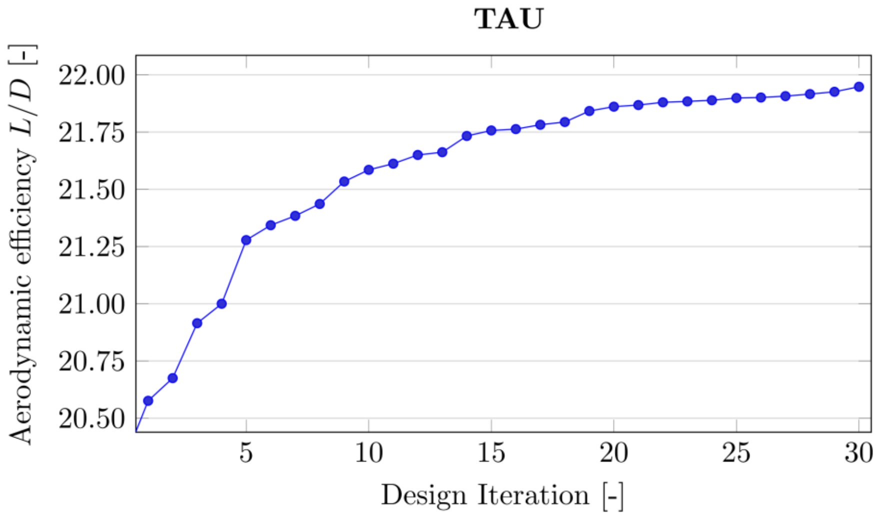




→ 53 Shape design variables

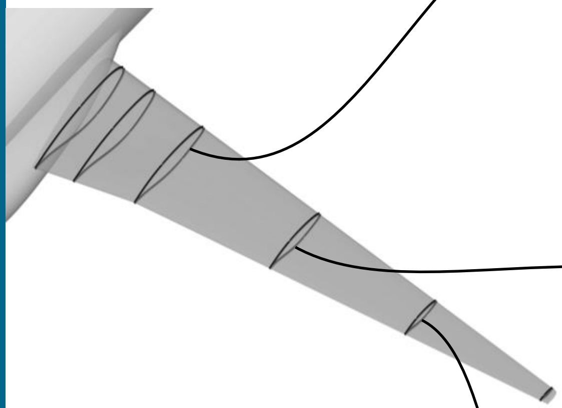
Design Task | Convergence



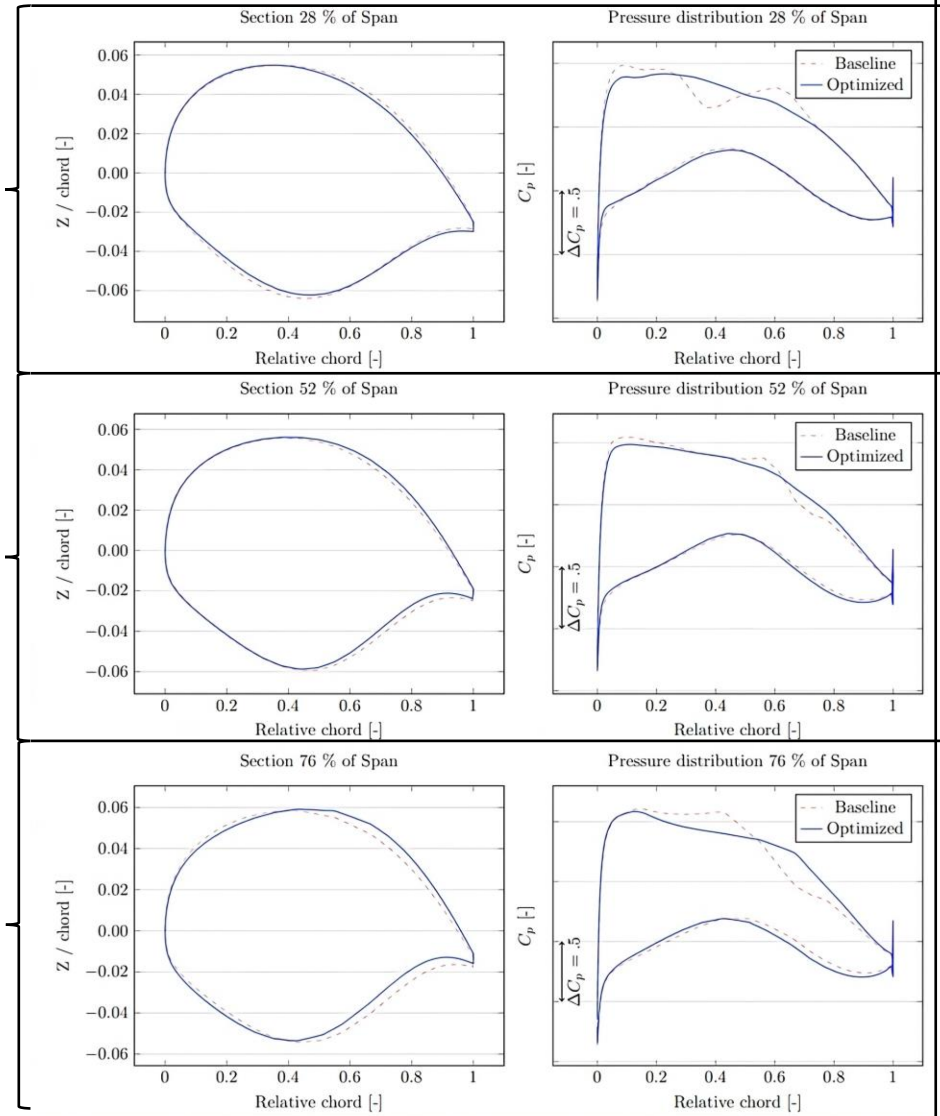


- L/D optimisation
  - Constant lift = 0.59
- Very different behaviour!
- Note! CODA and TAU use different numerical strategies

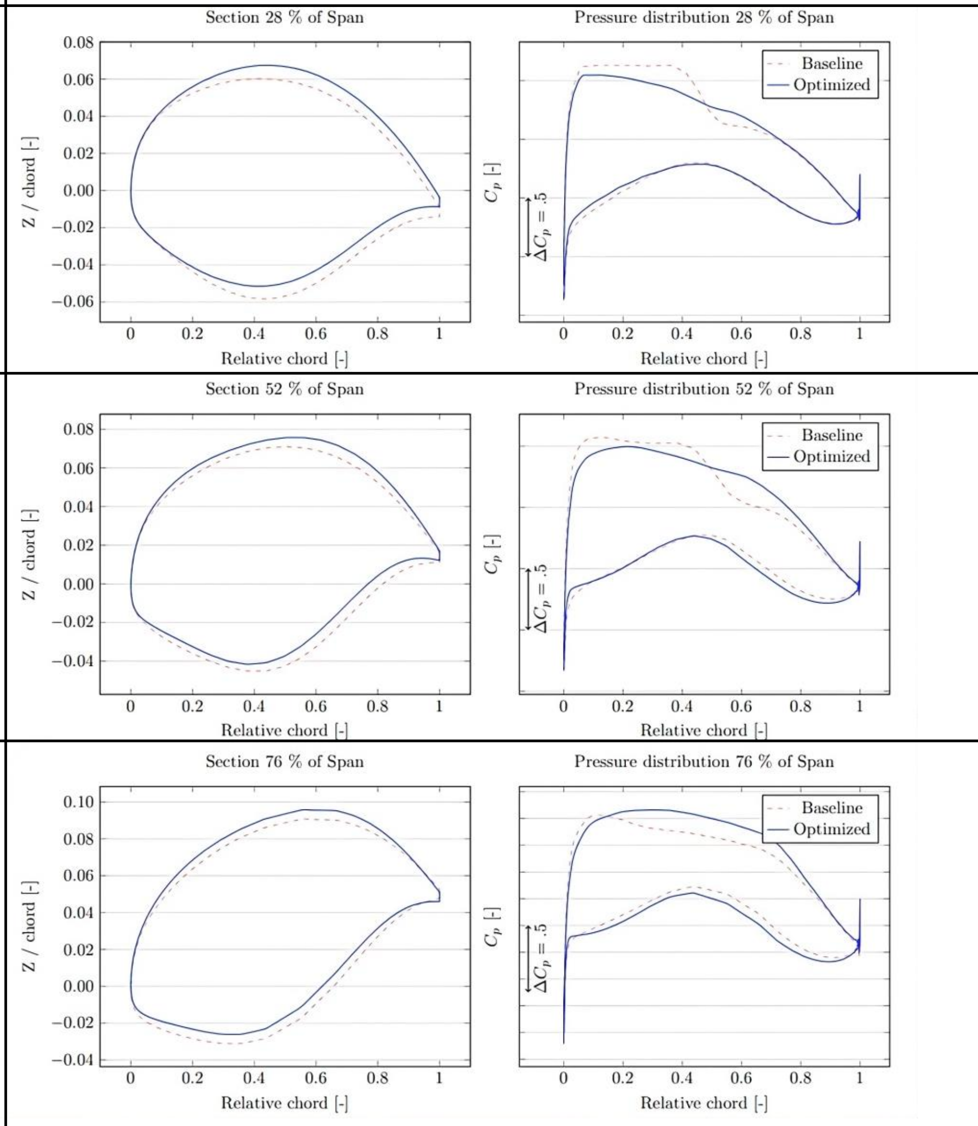
DLR-F25 | Shape optimization



CODA



TAU



Benchmark Data
DLR-F25

Simulation	CODA (128)	TAU (128)
Flow simulation	14 min (R=1e-10)	13 min (R=1e-10)
Flow adjoint	2 x 7.6 min (GMRes)	2 x 11.5 min (MG)
Forward AD (53), dC/dD	4.3 min	-
Memory Access	40 GB	20 GB
Total time (30 cycles)	16 hours	20 hours

CODA Adjoint AD: Efficient performance

CODA Forward AD: 53 design variables

Fazit and Future Activities

CODA

- Flow Adjoint convergences excellent – AD technique, thanks to compact approach
- No issues with robustness – can be futher enhanced with *GCRO–dynamic* for linear solver
- Effort for Forward AD linearisation for one design parameter is negligable
  - Replacement with full adjoint chain (flow + mesh) is currently under development

Future Steps

- In-depth investigation of CODA vs TAU behaviour regarding optimization task
- Follow on to complete Aero-Structure coupled optimization

Impressum

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