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Towards cooperative high-fidelity aircraft MDO: comparison of Breguet and ODE evaluation of the cruise mission segment

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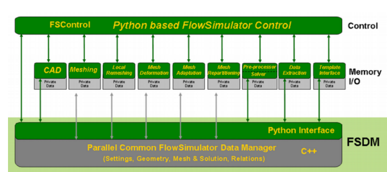
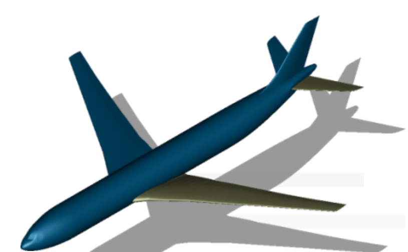
DLR project Digital-X

- Project highlights:
  - Computer-based aircraft design and virtual flight testing
  - Multiple disciplines (nine DLR institutes involved)
  - Multiple fidelity levels (from conceptual to PDE-based simulations)
- Work package MDO:
  - Use of established in-house and commercial tools
  - Further development of tools in support of MDO
  - Distributed process integration across institutes
  - Derivative-free and gradient-based optimization
  - Airbus research model XRF-1 as the baseline configuration



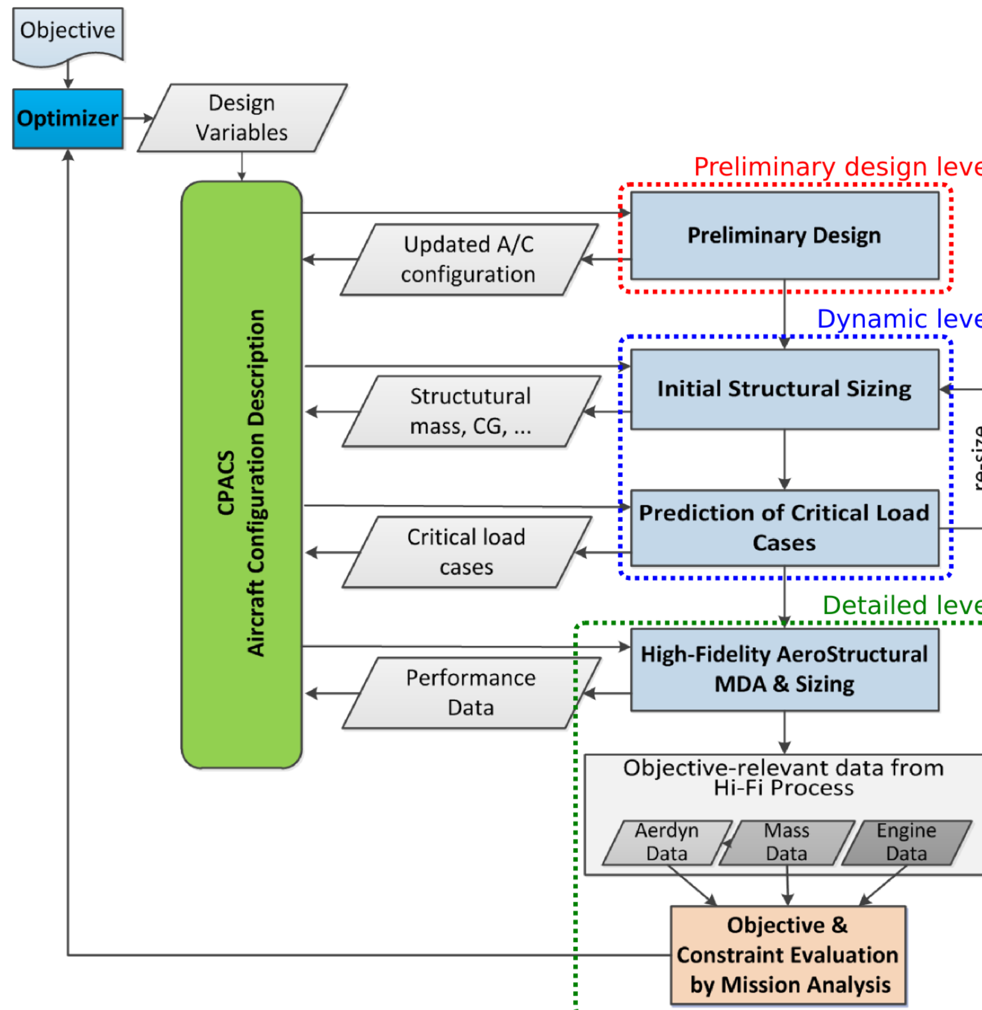

Airbus XRF-1

Issue of reusability of MDO processes

- Who and for how long should be able to use an MDO process?
- Typically so far:
  - Developed for the purpose of achieving a project goal
  - Tied particular computing platform, no documentation
  - Probably not usable any more after the project is finished
- Where we would like to go:
  - Longer-term maintainable processes and process components
  - Sufficiently portable and documented, working examples
  - Usable by experts who are not the initial developers
- In terms of *reuse-readiness levels* (RRLs, NASA ESDSWG):
  - Our processes currently at RRL is 1 or 2
  - We would like to reach RRL 4 or 5

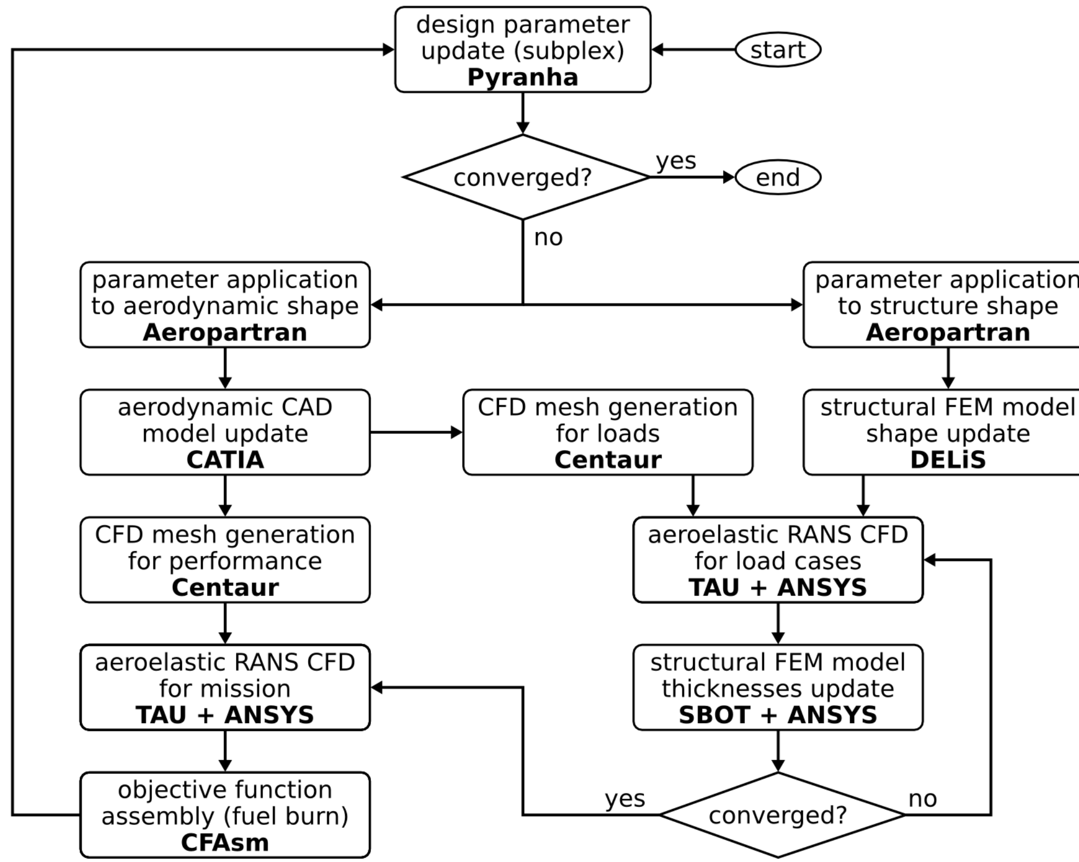
A multi-fidelity MDO process: conceptual view

- A derivative-free MDO process
- Discussions among discipline experts to reach the concept process
- Multiple fidelity levels
- MDF architecture
- CPACS aircraft data format for data exchange



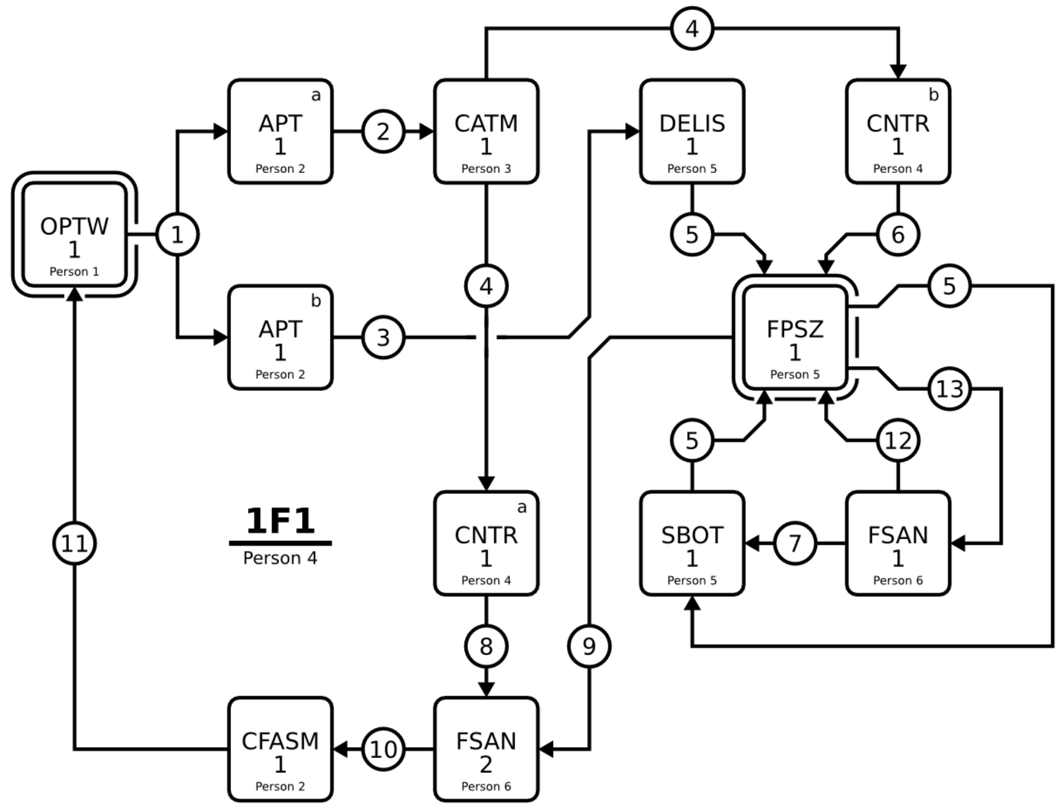
Detailed-level MDO process: algorithmic view

- To start, focus on the "detailed level"
- Make an actual algorithmic diagram
- Still not sufficient to kick-off implementation
- People from different institutes need to directly contribute



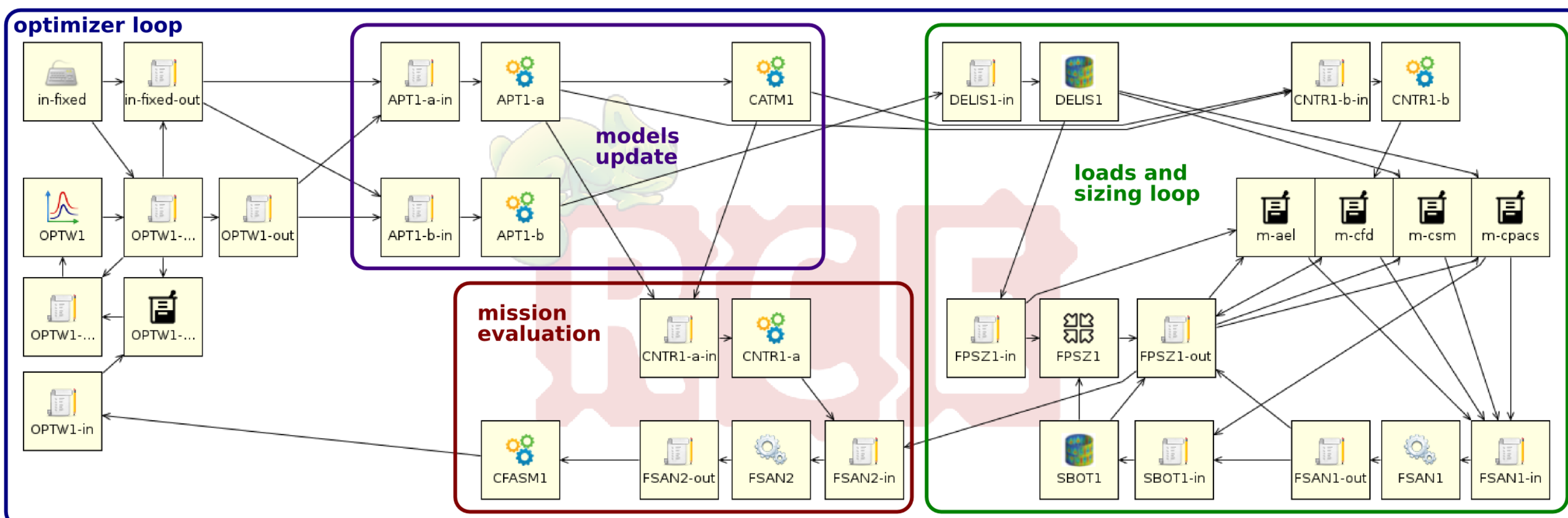
Detailed-level MDO process: “blueprint” view

- Introduce a “blueprint” notation
- Every component a piece of software
- Algorithmic loops as components
- Data transferred through links specified in accompanying table
- Constant data specified in another table
- Process and each component has a “maintainer”



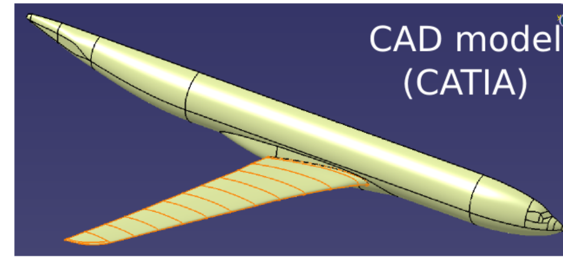
Process implementation infrastructure

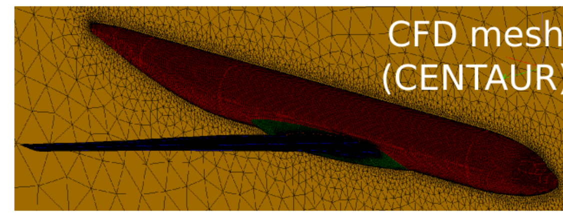
- Remote Component Environment (RCE)
- Graphical workflow environment
- Distributed component execution, support for HPC resources
- Communication across machines and operating systems
- Developed by DLR, open-source license

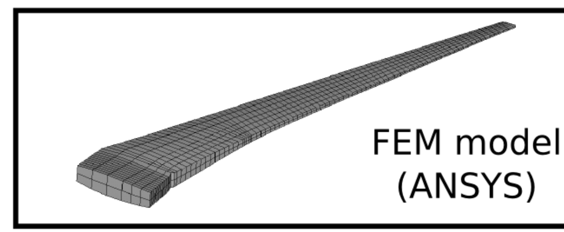


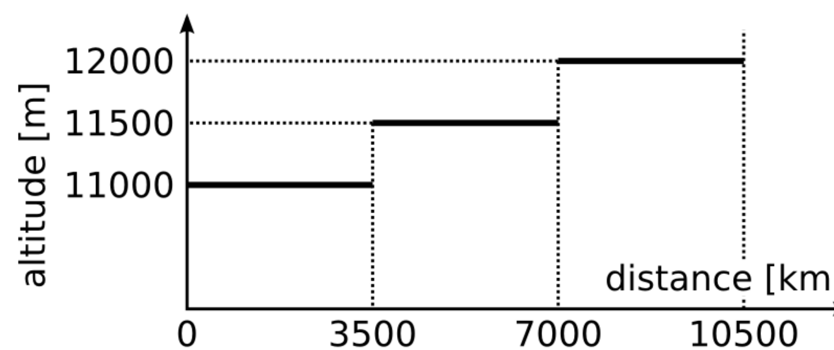
Example optimization case

- Large twin-engine airliner (~250 t MTOW)
- Minimize mission fuel burn
- Coupled aero-structural analysis (RANS+FEM)
- Wing-fuselage configuration:
  - Wing planform shape, five design parameters visible to optimizer
  - Wing structure element thicknesses by fully-stressed design
- Subplex optimization algorithm
- Two load cases: 2.5 g, -1 g
- Cruise Mach 0.83, range 10500 km, three altitude segments
- Fuel burn evaluated using
  - Breguet range equation
  - ODE integration (RK-3)





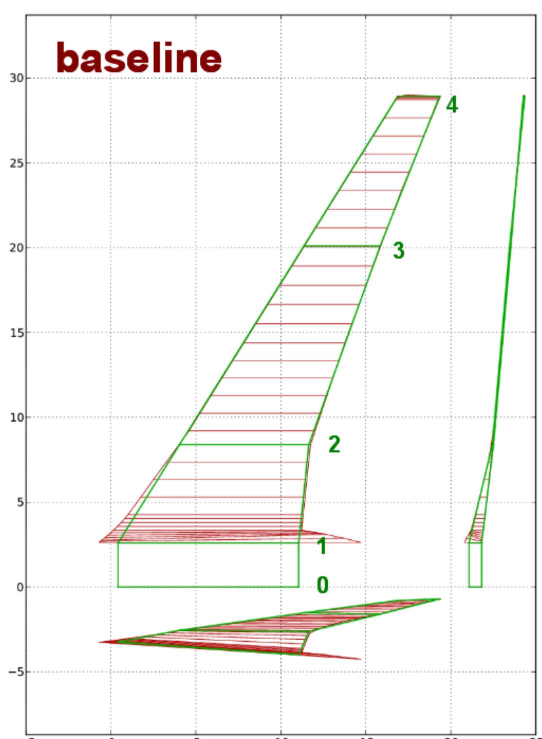


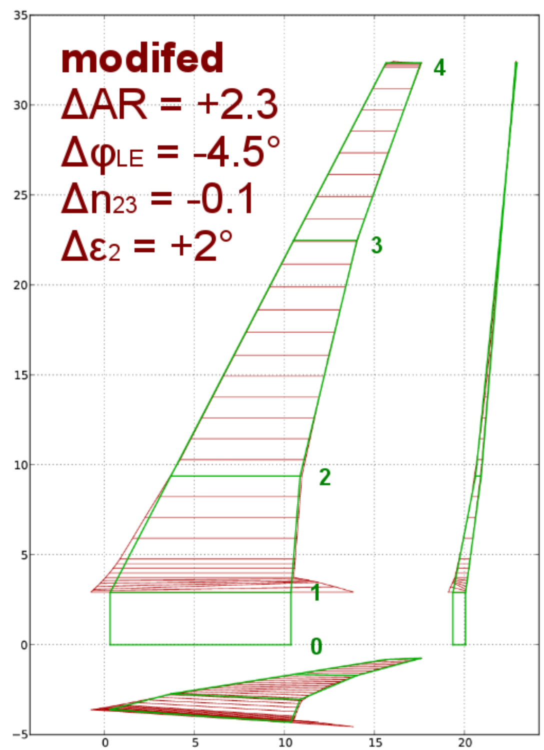


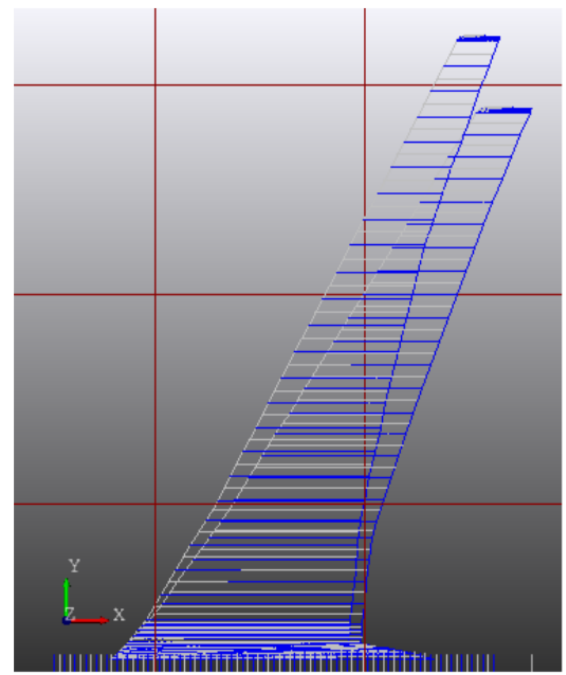
DLR

Aerodynamic shape parametrization

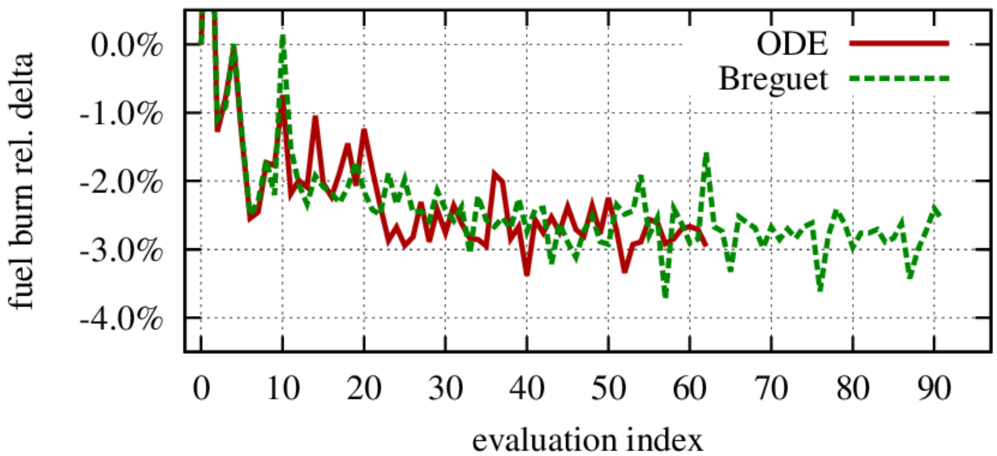
- Input wing geometry defined by large number of airfoil sections and their relative positioning → not suitable as design parametrization
- Define “design planform”, use it to deform the low-level parametrization



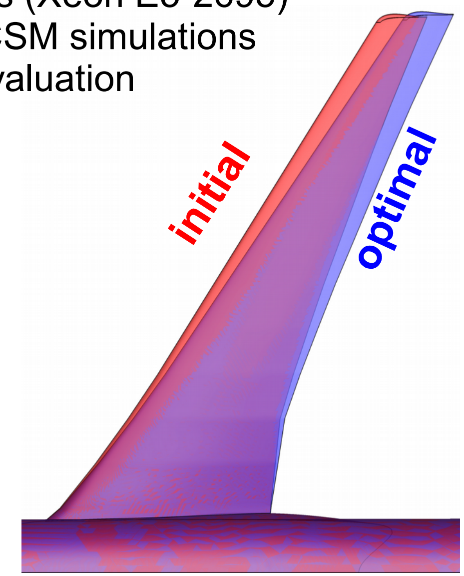




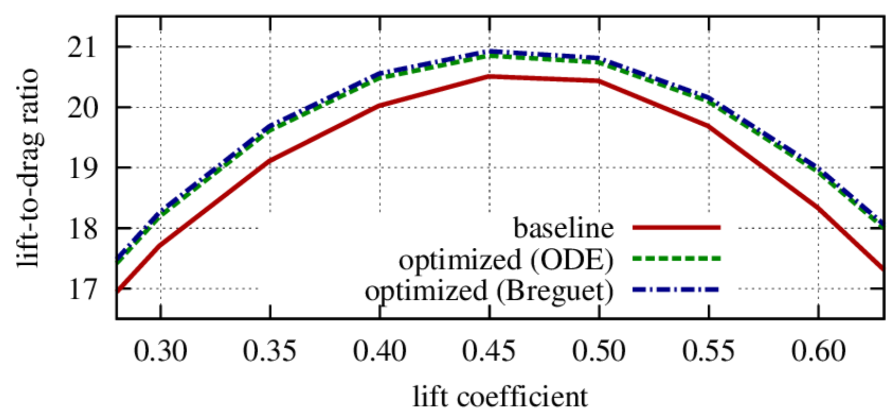
Optimization results



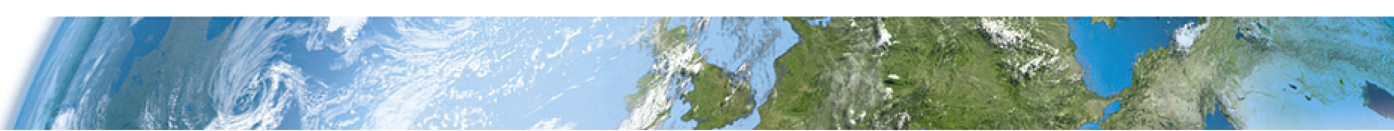
Run time 45 days (effective)
96 CPU cores (Xeon E5-2695)
12-20 CFD-CSM simulations per design evaluation



-	baseline	opt. (ODE)	opt. (Brg.)
aspect ratio	9.2	9.252	9.254
sweep [°]	32	34.52	34.34
twist 1 [°]	0.5	-0.051	0.022
twist 2 [°]	1.0	0.199	0.241
twist 3 [°]	-2.0	-1.432	-1.358
wing mass [t]	29.89	28.73	28.69
fuel burn δ	-	-3.4%	-3.6%



- ODE- and Breguet-based optimized designs practically identical



Conclusions and outlook

- Organizational and technical approach to process assembly presented
  - Enables cross-institute cooperation among discipline experts
  - Increases chances for reusability of processes and components
- An example optimization based on this approach demonstrated
  - Airliner wing optimized for minimum fuel burn
  - Although high-fidelity aerostructural analysis used throughout, Breguet-based fuel burn evaluation appears to be still sufficient...
  - ...but this should be re-checked with large number of design parameters (adjoint gradient-based process)

- Future work:
  - Derivative-free processes with more complex analysis (all fidelity levels, more critical load cases, more design constraints)
  - Adjoint gradient-based processes (much larger number of design parameters possible)

Thank you for your attention!