#ArchitectingAviation

Adjoint *CODA* & *FlowSimulator* for EXACT-2

Algorithmic Differentiation (AD) and integration of the new-generation CFD software *CODA* towards high-fidelity MDAO capabilities for electric aircraft design in EXACT-2

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Adjoint *CODA* for MDAO of Electric Flight

CODA is the new-generation computational fluid dynamics (CFD) software being developed as part of a collaboration between the French Aerospace Lab ONERA, the German Aerospace Center (DLR), Airbus, and their European research partners. Unlike other CFD software, *CODA* is a CFD library by design embedded into the *FlowSimulator* HPC ecosystem. This significantly enables a seamless and modular integration with MDAO frameworks and workflows.

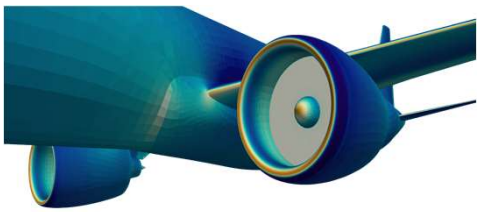
Key Targets in EXACT-2:

In order to enable *CODA* for EXACT-2 MDAO scenarios, we

(a) provide efficient adjoint MDAO capabilities in *CODA*
(b) develop efficient propeller modelling support for gradient-based MDAO of electric aircraft
(c) provide these capabilities behind a generalized and derivative-enabled framework API called *FSMDAO* to integrate *CODA* and other *FlowSimulator* plugins into mixed-fidelity workflows

Scalable Adjoint Computations with *CODA*

CODA uses reverse-mode algorithmic differentiation (AD) to compute sensitivities. Unlike forward AD, the performance of reverse AD does not depend on the number of input parameters. This enables scalable adjoint computations for large MDAO design spaces.



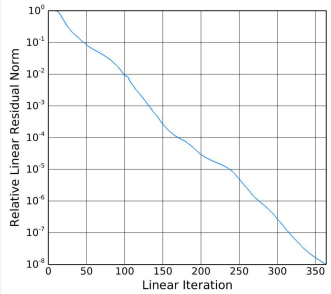
CODA adjoint enabled sensitivity analysis: F25 with powered engines

As a result of an optimized implementation, the run-time performance of the adjoint in CODA is close to the primal solver. In contrast to other CFD software relying on reverse AD, memory overhead is minimal.

Additionally, adjoint *CODA* is interoperable with different AD libraries, and shares the highly scalable software HPC infrastructure with the primal CFD solver.

DLR-F25 (2.5 M)	Fwd	Rev (*Eigen*)	Rev (*ADOL-C*)
Time [min]	23.9	29	186.6
Ratio over fwd	1.0	1.2	7.8

Hexa Mesh (125k)	Fwd	Rev (*Eigen*)	Rev (*ADOL-C*)
Memory [MB]	298.7	298.3	297.0
Ratio over fwd	1.0	0.999	0.994

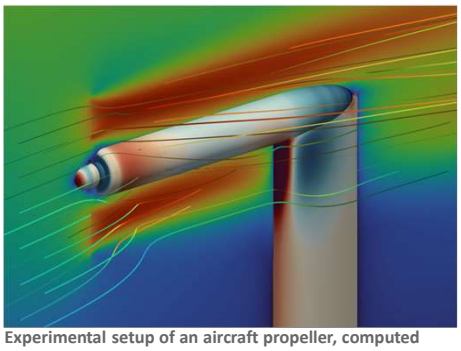


Robust convergence of adjoint problems (left) with minimal runtime and memory consumption (top)

HPC cluster CARA, for large-scale MDAO applications with *CODA* for EXACT-2

Towards Integration of Efficient Propeller Models

CODA infrastructure is being developed to couple efficient propeller models such as body-force or actuator disk approaches with the adjoint *CODA* approach via the *FlowSimulator* ecosystem for electric aircraft design.



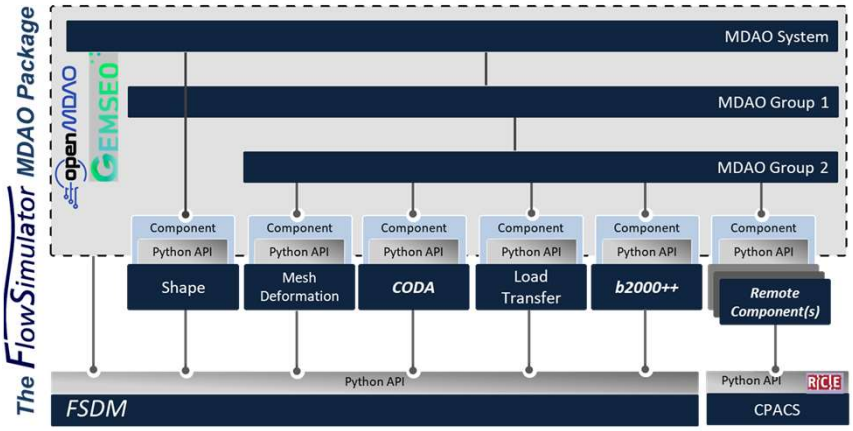
Experimental setup of an aircraft propeller, computed with a virtual blade model in *CODA*

FSMDAO Integration for Gradient-Based, Mixed-Fidelity Workflows

The derivative-enabled *FlowSimulator* interface *FSMDAO* is systematically applied to offer *CODA* MDAO capabilities for high- and mixed-fidelity design optimizations of electric aircraft configurations in EXACT-2.

Beyond *CODA* we intend to showcase the usability of further *FlowSimulator* plugins like the *b2000++* structure mechanics FE solver to overcome scalability bottlenecks in EXACT-2 design analysis and optimization tasks.

Moreover, we provide a link to established low- to mid-fidelity electric aircraft design workflows running on the RCE network coupled to the high-fidelity tools (e.g. CODA) via CPACS models.



HPC MDAO framework *FlowSimulator* with gradient-enabled integration of *CODA* and other plugins for MDAO challenges in EXACT-2

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