U.S. AIR FORCE

USSF

AFRL

Utilization of ESP and CAPS in high-fidelity aeroelastic design optimization

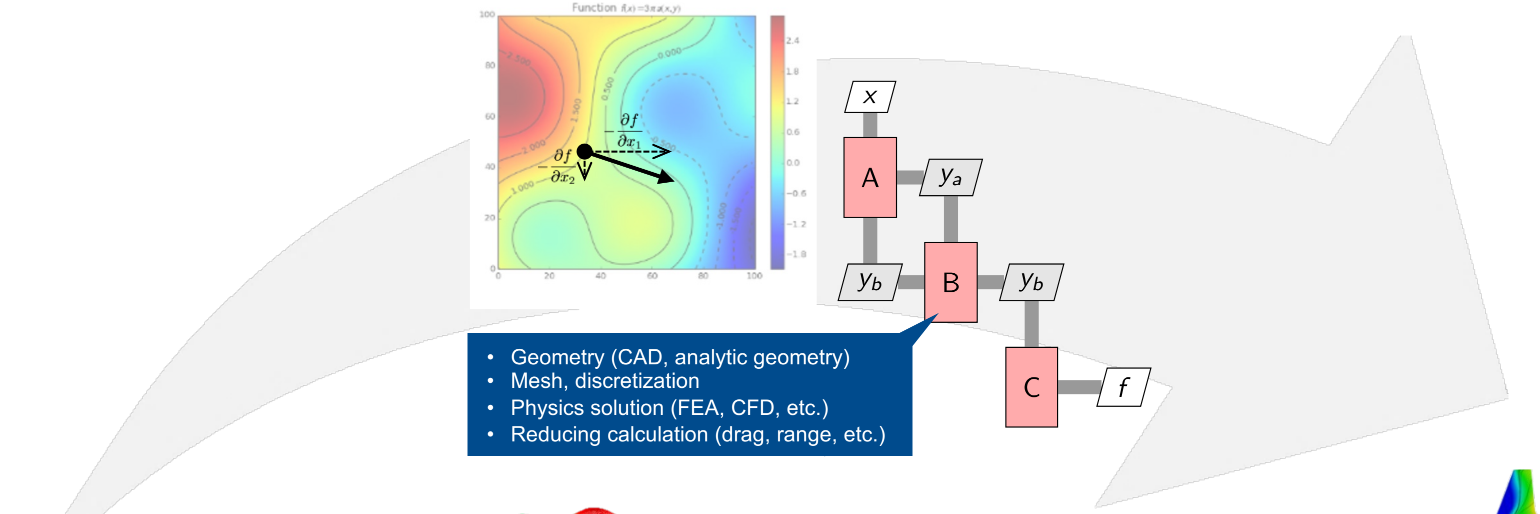
NATHAN A. WUKIE | RESEARCH AEROSPACE ENGINEER | AIR FORCE RESEARCH LABORATORY

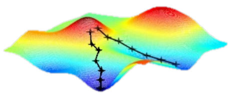
NEAL NOVOTNY | AEROSPACE ENGINEER | UNIVERSITY OF DAYTON RESEARCH INSTITUTE

DAVID SANDLER | AEROSPACE ENGINEER | UNIVERSITY OF DAYTON RESEARCH INSTITUTE

AIAA SciTech 2024

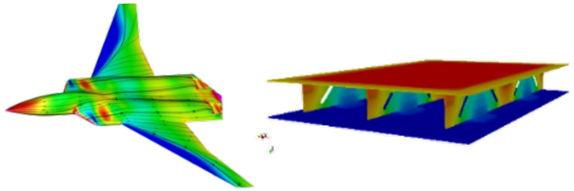
Vehicle MDO Vision





$$\frac{df}{dx} = \frac{\partial f}{\partial y_b}\frac{\partial y_b}{\partial y_a}\frac{\partial y_a}{\partial x} + \frac{\partial f}{\partial y_b}\frac{dy_b}{dx} + \frac{\partial f}{\partial y_a}\frac{dy_a}{dx}$$

Coupled Multidisciplinary Sensitivity Analysis (SA)



Current State-of-the-Art Vehicle/System-level MDO

Design Parameters: **<25**

Constraints: **10-100's**

Discipline Fidelity Level: **1-2**

Future MSTC MDO Goals

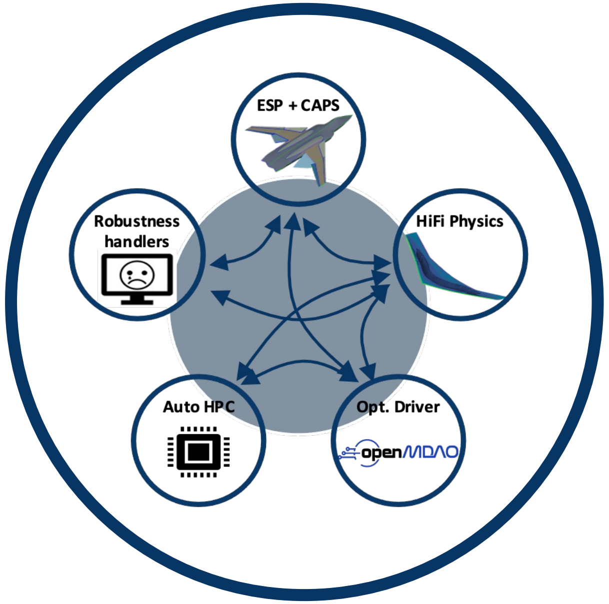
Design Parameters: **10,000+**

Constraints: **1000+**

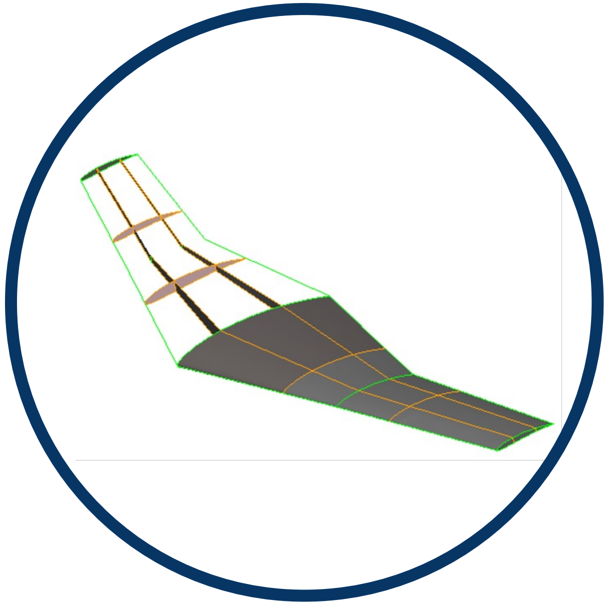
Discipline Fidelity Level: **1-3+**

Topics

Software infrastructures



Test-bed parameterized model



Optimization studies

Sensitivity Analysis for Multidisciplinary Systems (SAMS-II)

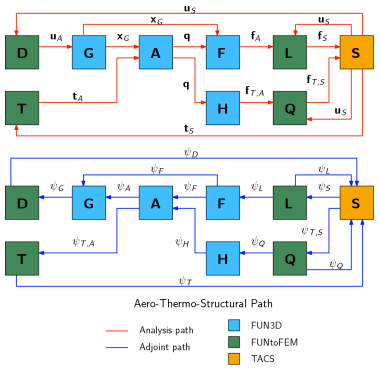
Steady + transient high-fidelity sensitivity analysis (SA) methods > 2 physics – aerothermoelasticity

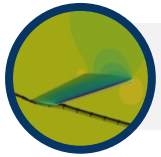
SAMS-II → Aero*thermo*elasticity

- Georgia Tech + AFRL
- Enhancements supporting nonlinear aerothermoelasticity with sensitivities in MELD, FUNtoFEM, FUN3D, TACS

FUNtoFEM

Coupling for transient, forward + adjoint aerothermoelasticity

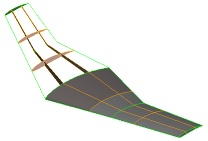




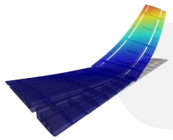
Fun3D

↓ **Python** ↑

FUNtoFEM ← **Python** → **ESP + CAPS**



↓ **Python** ↑



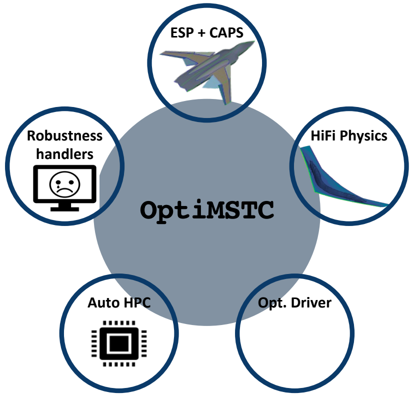
TACS

ESP + CAPS integrated with FUNtoFEM processes for computing total aerothermoelastic sensitivities (special thanks to Marshall Galbraith, MIT)

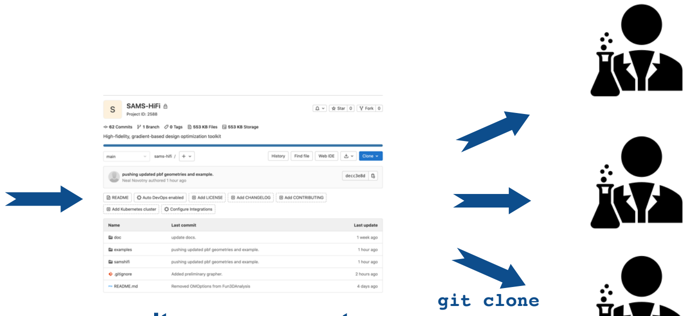
Software infrastructures

OptiMSTC

AFRL ecosystem for HiFi, multidisc. gradient-based design opt.



Encapsulate common requirements and patterns

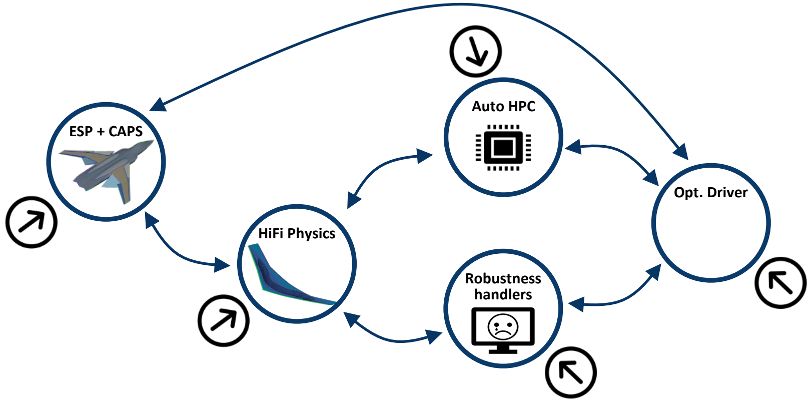


git management

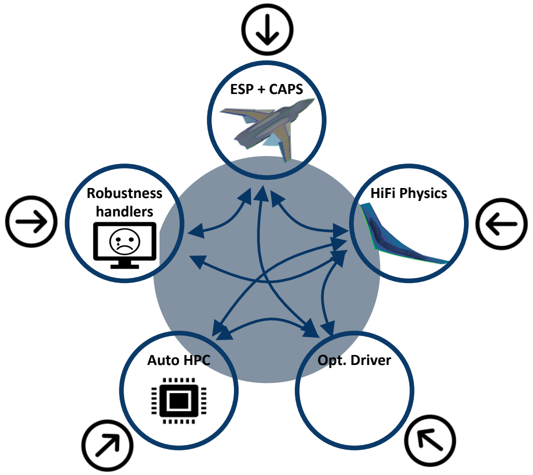
discovery

Persistent, documented, sustainable software capabilities for high-fidelity, multidisc. design opt.

One-off optimization script



OptiMSTC performs assembly and management

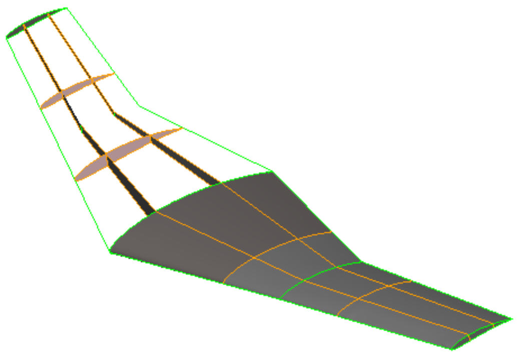


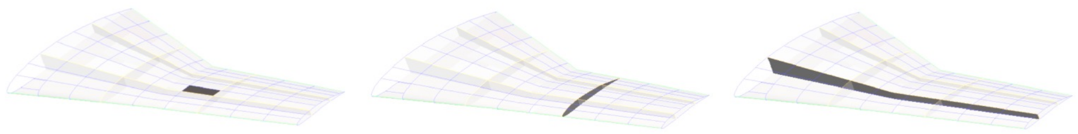
Test-bed ESP model

1. Aerodynamic and structural parameterized wing model

2. Parameterized numbers of structural sections, airfoil sections, and planform sections.

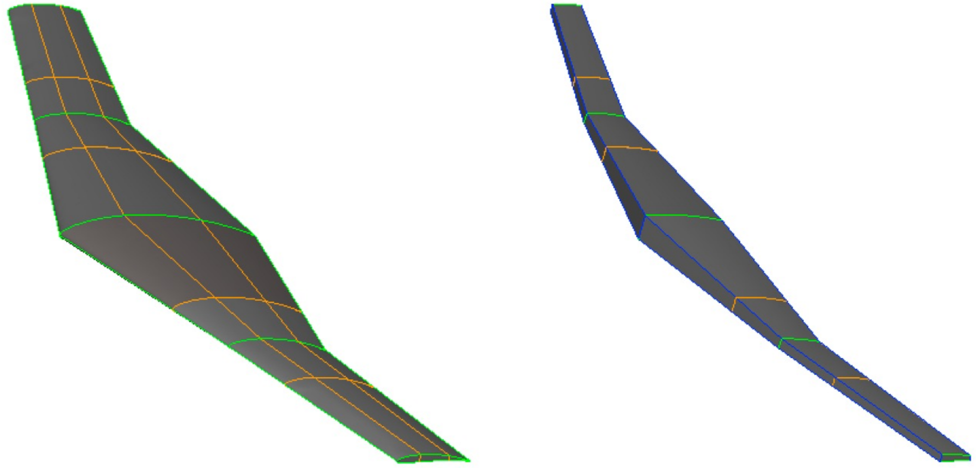
3. Attribution for fine-grained meshing control as well as for driving aerodynamic and structural modeling.





(a) wingSkinTopGroup_3_5 (b) Individual spanwise divisions (c) wingSparGroup_1

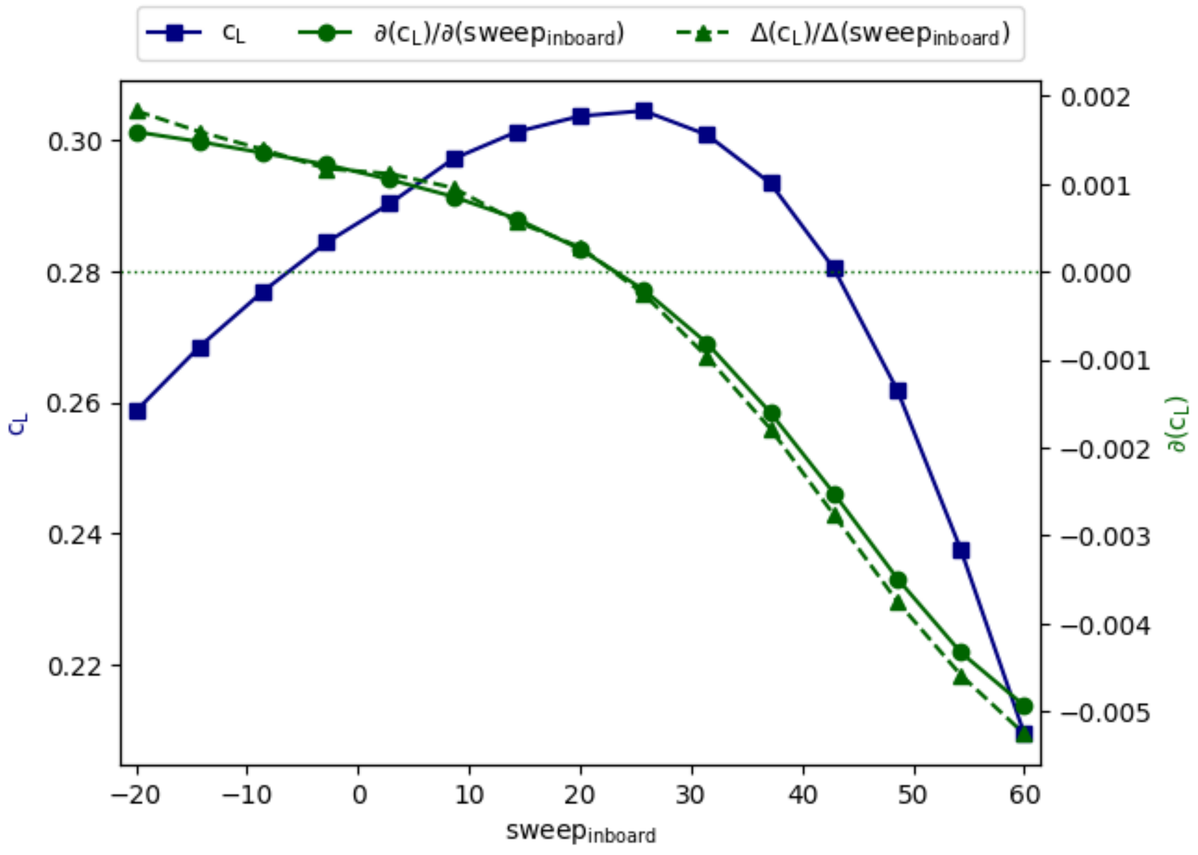
Fine-grained CAPS group control for structural modeling

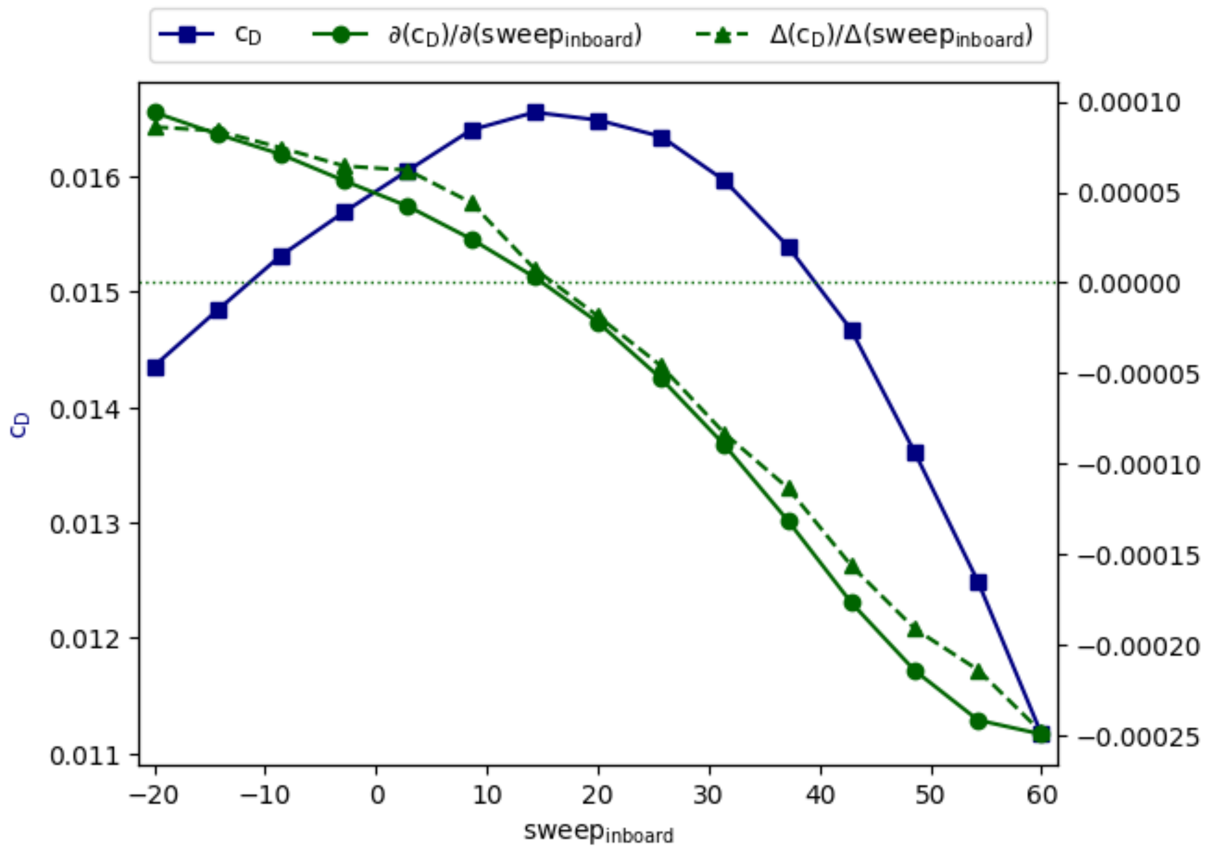


(a) Full skin (b) Wingbox only

Full skin and wingbox options for structural modeling

Accuracy tests for sensitivities

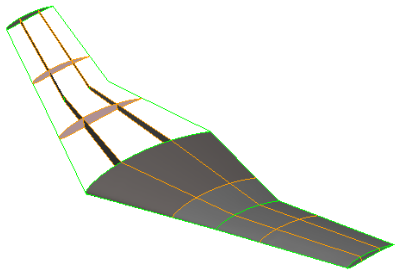


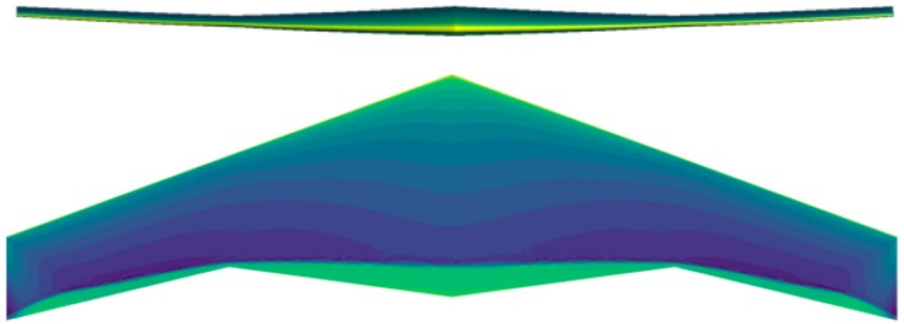


Successful verification of total aeroelastic shape sensitivities with ESP + CAPS

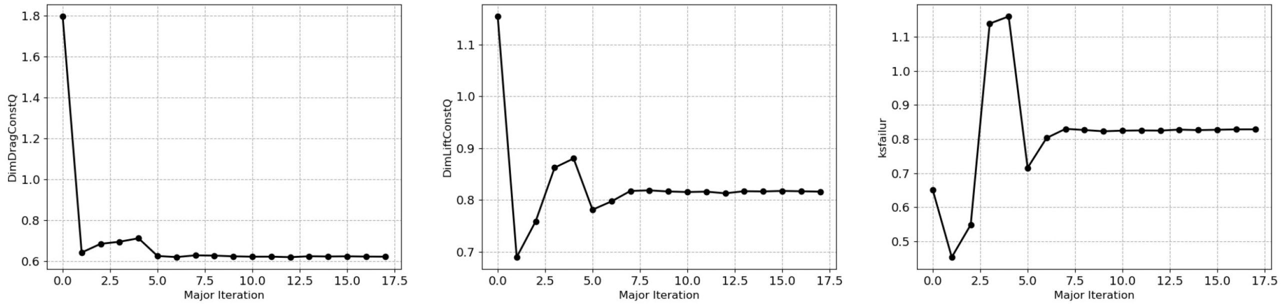
Aeroelastic Shape Optimization: thickness + camber

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & D(x) \\ \text{subject to} \quad & L(x) \geq L_{\text{min}} \\ & \text{KS}_{\text{failure}}(x) < 1 \end{aligned}$$



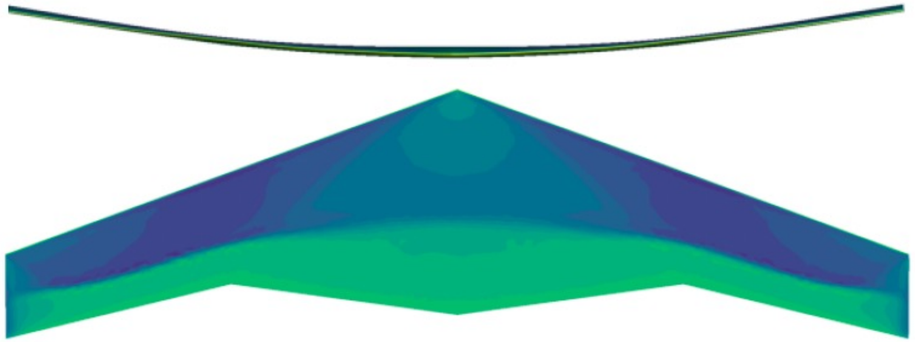


Initial



(a) Drag (b) Lift ($L_{\text{min}} = .82$) (c) KS failure (Failure max $= 1$)

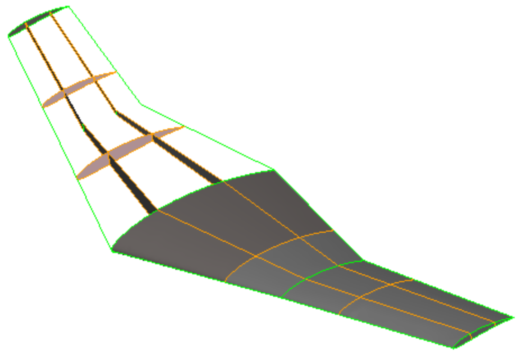
Optimization histories



Optimized

ESP + CAPS critical part of successful aeroelastic shape optimization process

Aeroelastic Structural Sizing Optimization

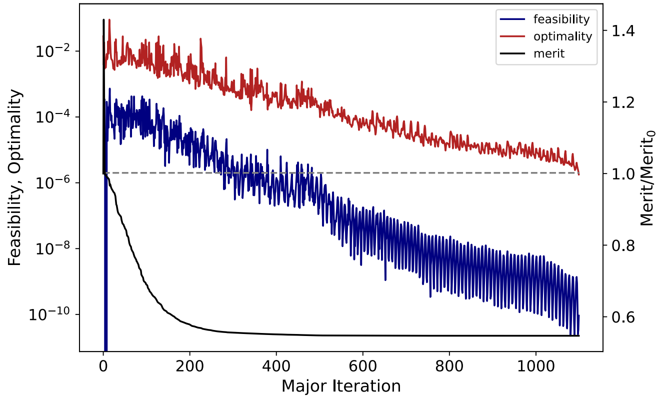


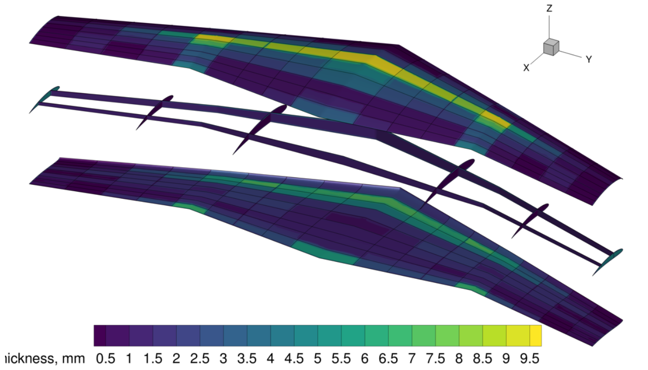
$$\begin{array}{lll} \underset{x}{\text{minimize}} & \text{mass}(x) & \\ \text{subject to} & \text{KS}_{\text{failure}}(x) < .35 & \\ \text{wrt} & x & \text{(where } x \text{ are panel thickness parameters)} \end{array}$$

Aeroelastically deformed model

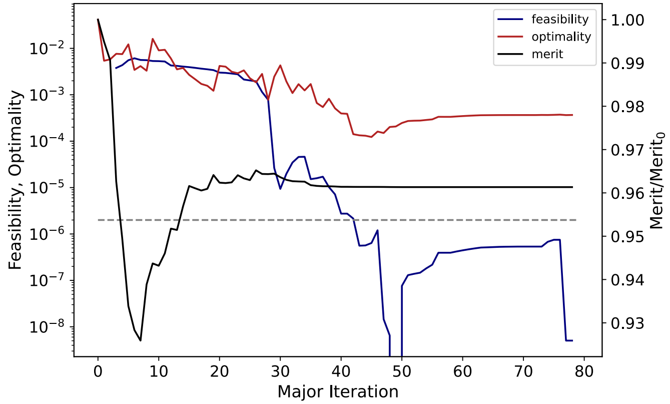
Jig shape

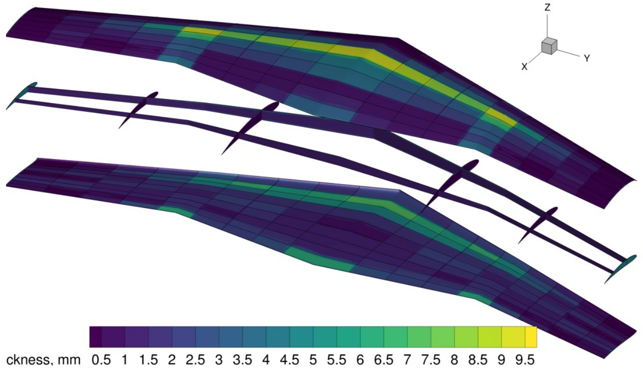
One-way coupled structural sizing optimization





Two-way coupled aeroelastic structural sizing optimization



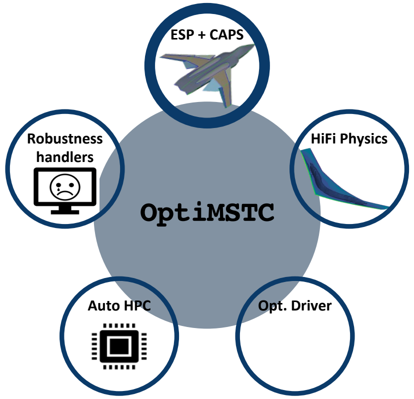


ESP + CAPS utilized for partitioning skin panels into groups for thickness optimization

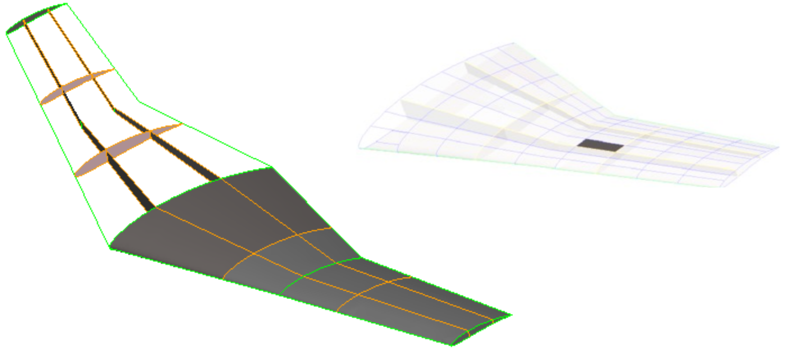
Summary

ESP + CAPS critical components of AFRL high-fidelity, multidisciplinary design optimization infrastructure.

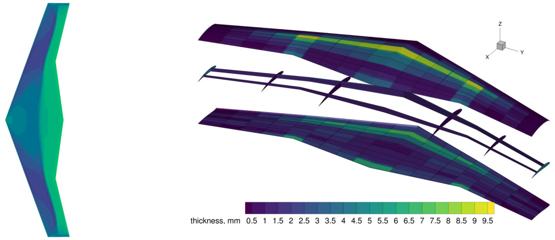
- ESP → geometric sensitivities for gradient-based optimization
- CAPS → process management and interactions between discipline solver components



Testbed ESP model supporting demonstration aeroelastic design optimization capabilities



Integrations of ESP + CAPS with FUNtoFEM demonstrate aeroelastic shape, sizing optimization



QUESTIONS?

Final optimization response outputs

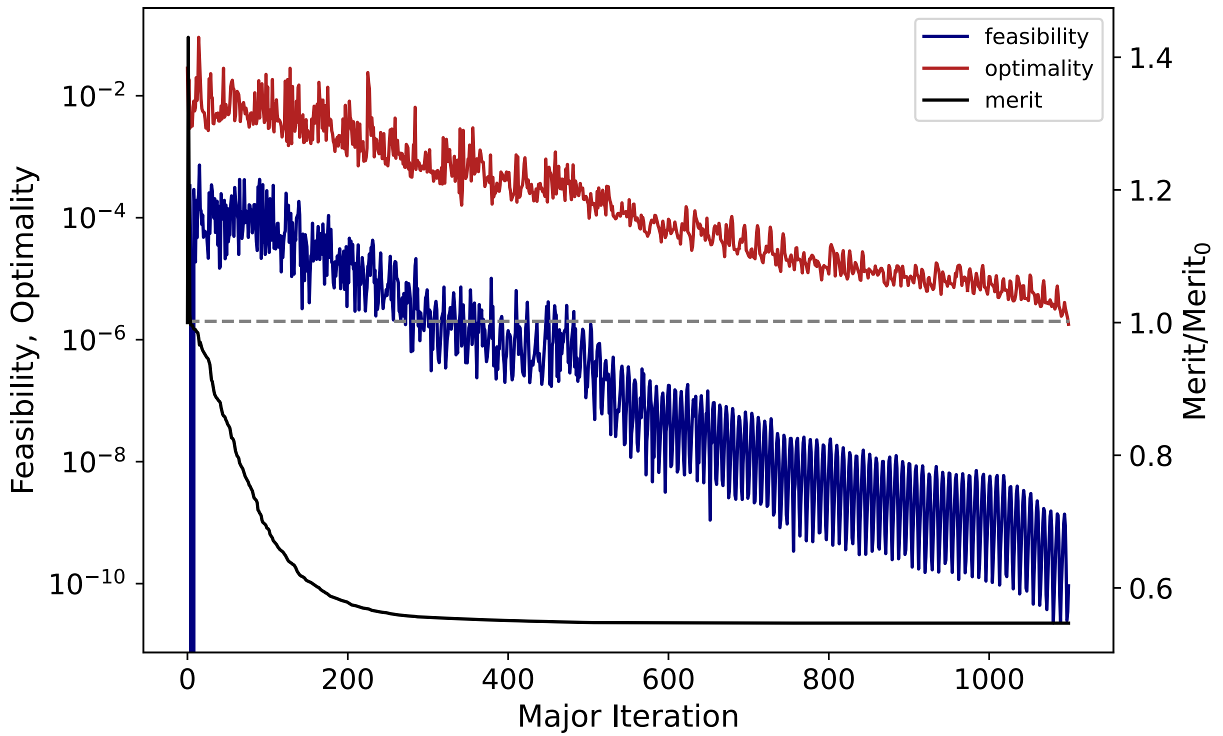
Case	KS Failure	Structural Mass, kg
Initial	0.30398549261043206	290.476
One Way Basic Structural Sizing	0.35000000714491925	221.414
One Way Detailed Structural Sizing	0.35000000125153630	127.613
Two Way Structural Sizing	0.35000004747774810	124.896

Problem Statement

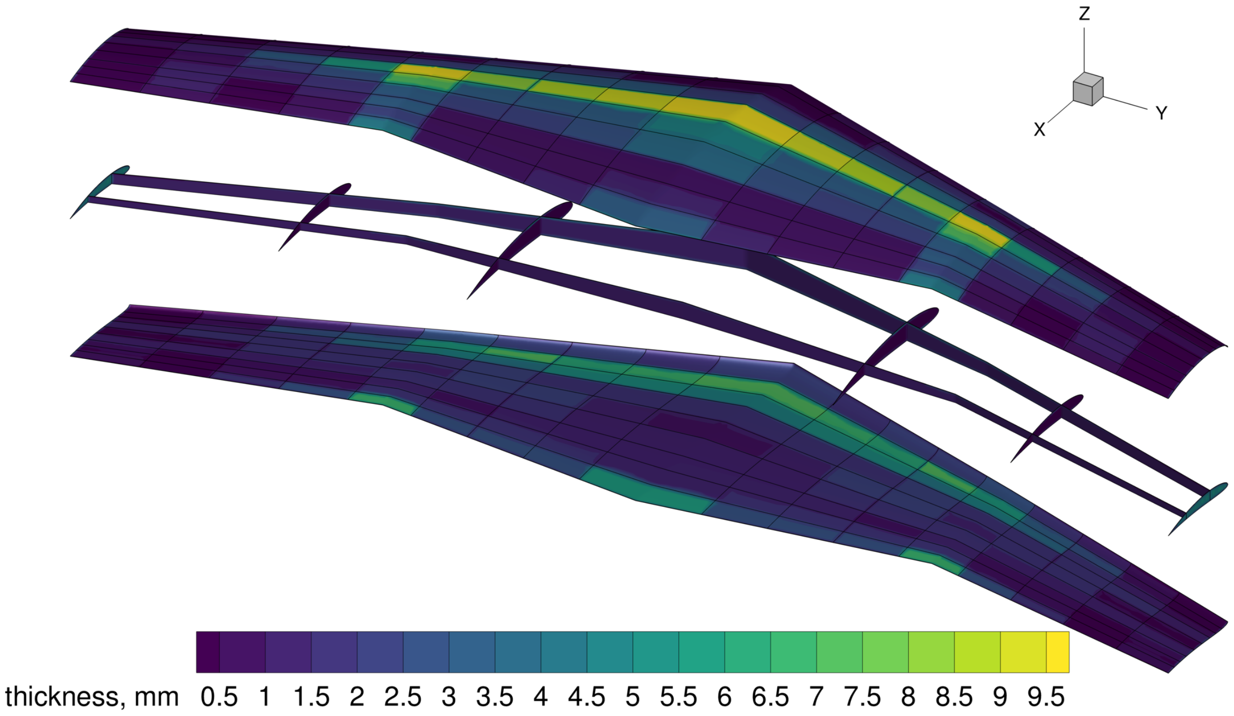
- Minimize structural mass subject to KS-Failure constraint
- With respect to structural sizing variables
- Optimization is conducted in multiple stages to prime increasingly complicated cases with a simpler result
- Inviscid aerodynamics, linear structures
- Material - standard aluminum

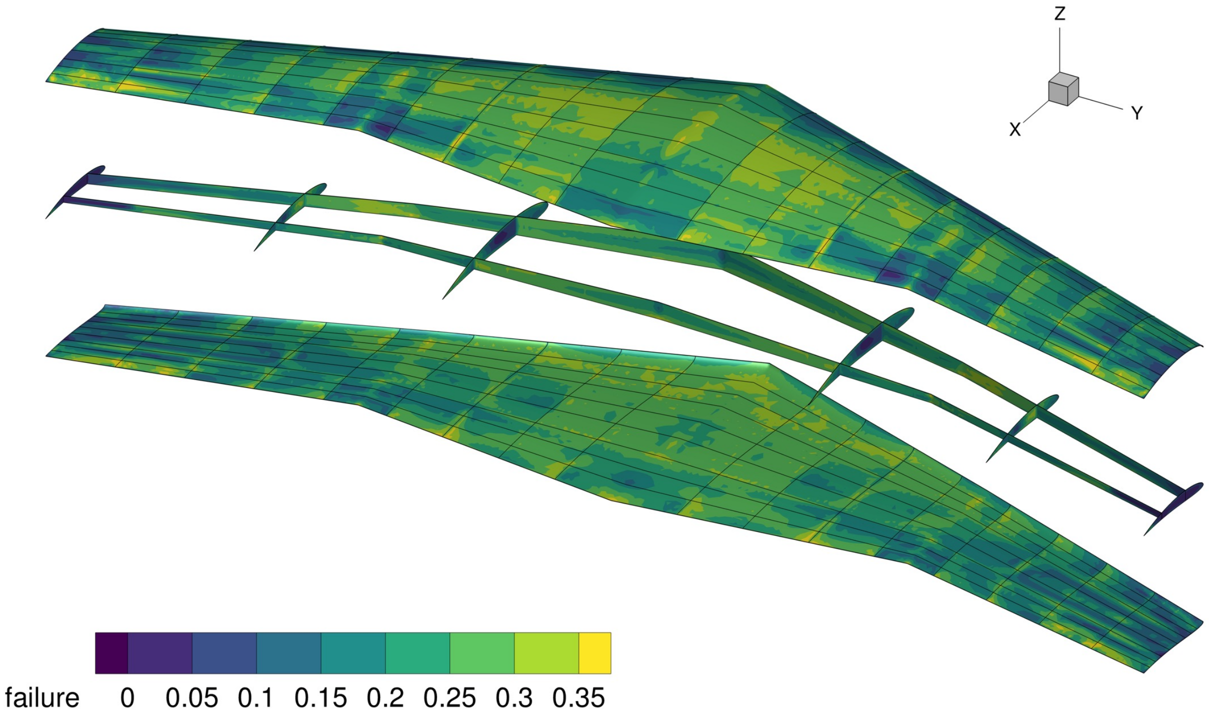
One-Way Structural Sizing – Detailed Sizing

- One-way sizing is continued from previous one-way result
- Design variables increased from 6 to 166 thickness design variables
    - 2 rib, 2 spar, 162 skin thicknesses
- Structural mass is reduced from 221 kg to 128 kg
- Feasibility and optimality convergence tolerances are satisfied (2E-6)



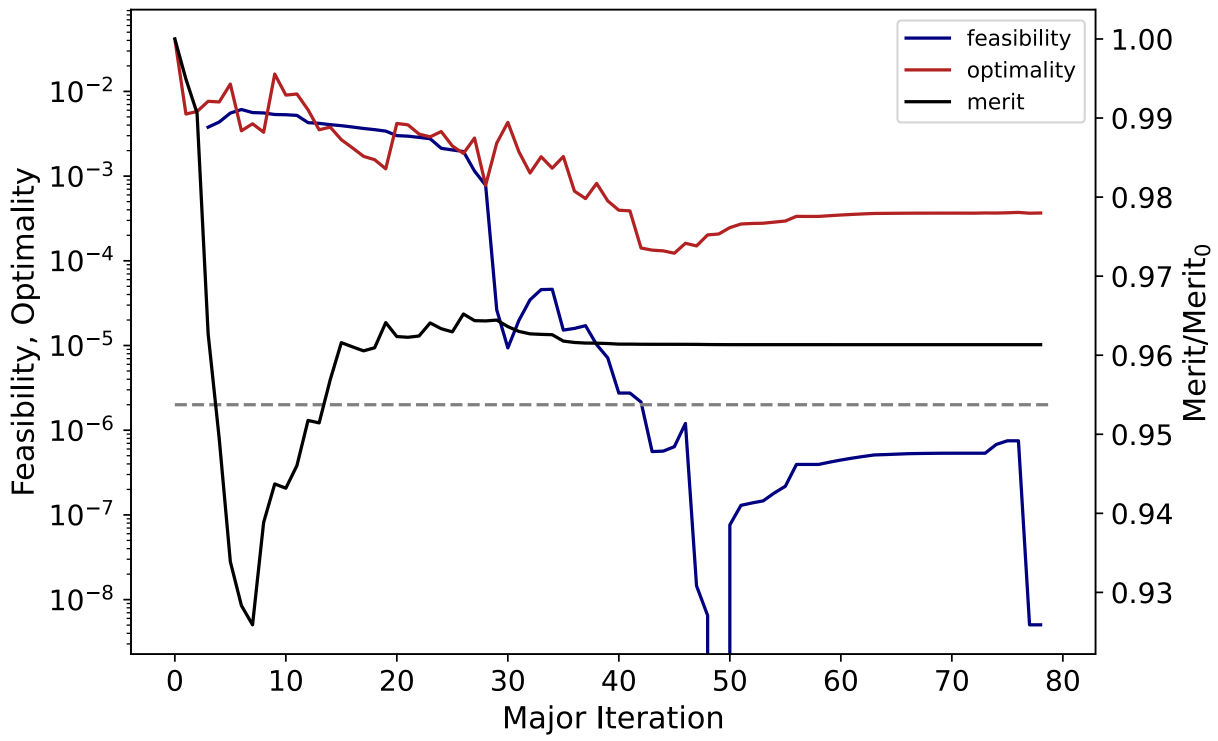
One-Way Structural Sizing Thickness and Failure Contours





Coupled Aeroelastic Structural Sizing

- Fully coupled aeroelastic structural sizing initialized from one-way sizing
- Enables “proper” aerodynamic loads for a given structural sizing
- Mass is further decreased from 128 kg to 125 kg
- Feasibility is satisfied to tolerance but optimality is reduced ~2 orders of magnitude
  - Attributed to noise from KS constraint



Coupled Aeroelastic Structural Sizing