MECH5930 Term-Project Proposal Presentation

Structural Sizing of an Aircraft Wing Structure

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Introduction: aircraft wing structure

- An aircraft wing structure must withstand various loads:
  - Aerodynamics
  - Self-weight
  - Operational loads (gust, maneuver, etc.)

- Main components:
  - **Outer skin**: transfer aero load
  - **Spars**: resist bending and shear
  - **Ribs**: maintain airfoil shapes
  - **Stringers**: handle torsions

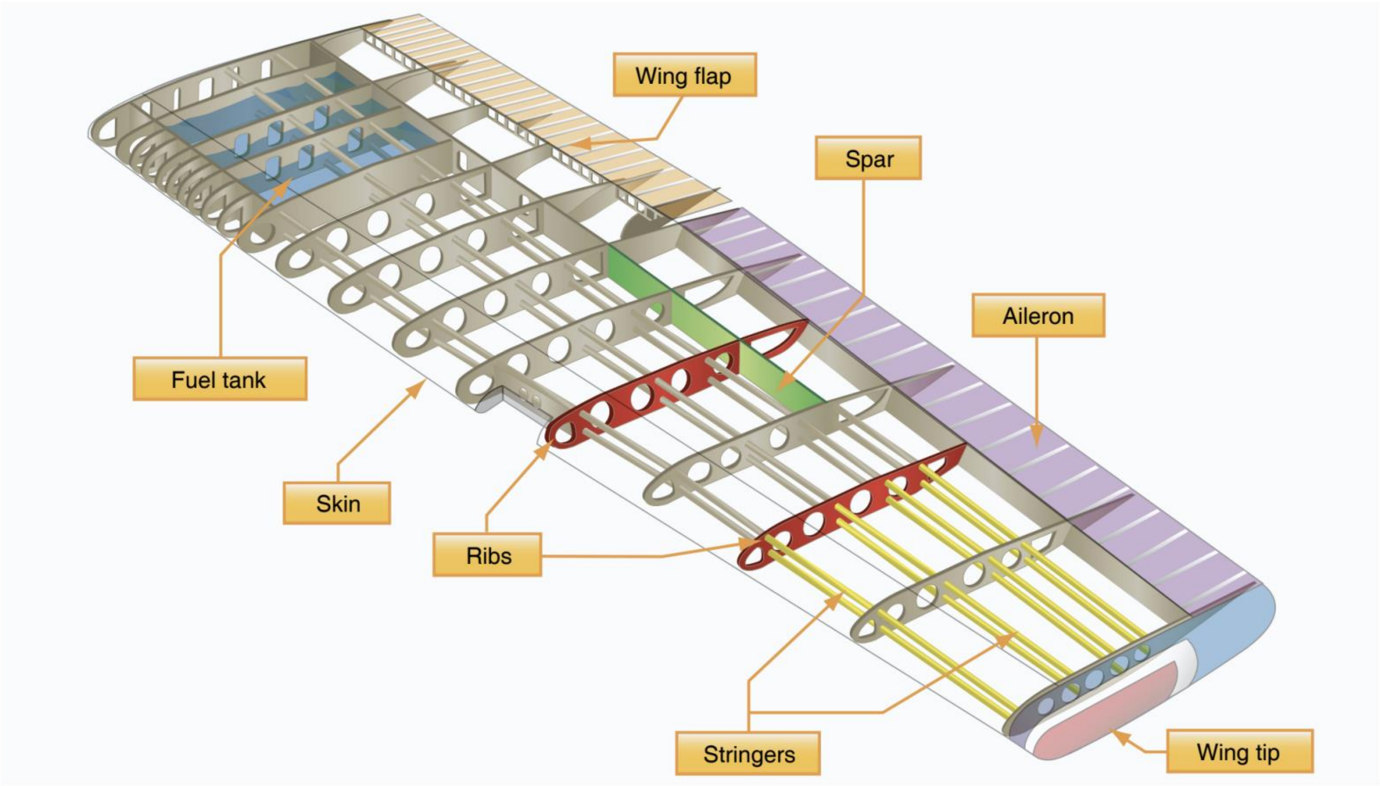
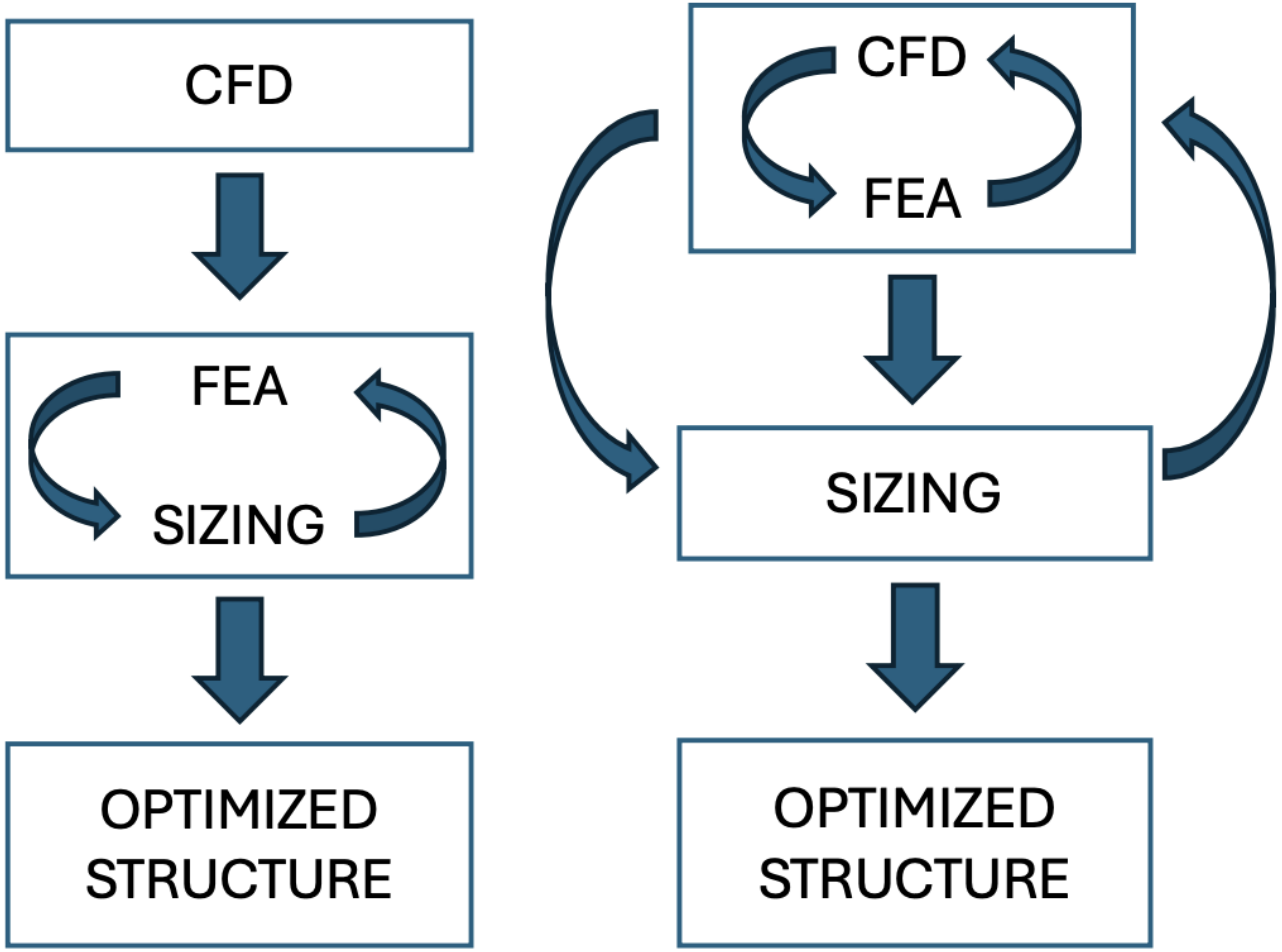


Figure 1: Primary components of an aircraft wing structure [1].

[1] Federal Aviation Administration, *"Pilot's Handbook of Aeronautical Knowledge,"* U.S. Department of Transportation, Federal Aviation Administration, Washington, DC, 2023.

Introduction: structural sizing

- **Structural sizing**: an optimization process determining the optimal dimensions for the structures (e.g., skin thickness, spar cross-sections, rib placement)
- **FSI**: fluid structure interaction
- **One-way FSI**: FEA and CFD ***are not coupled***, sizing iteration is only with FEA
- **Two-way FSI**: FEA and CFD *are coupled*, sizing iteration is with both CFD and FEA

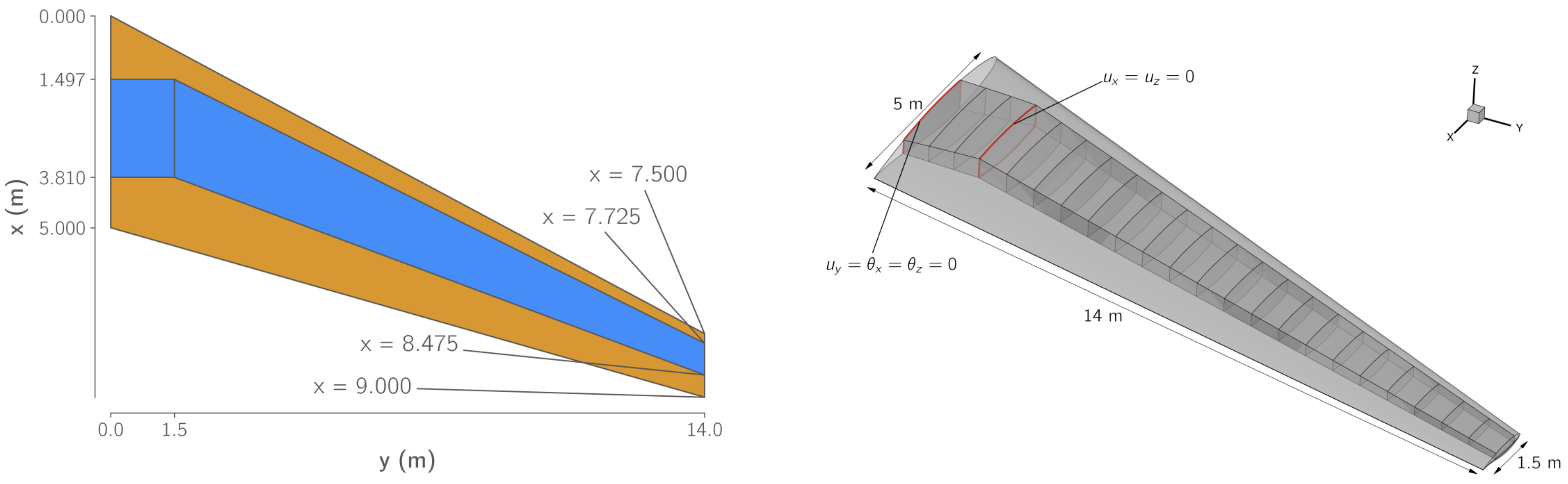


(a) One-way FSI (b) Two-way FSI.

Figure 2: Conceptual workflows for structural sizing via one-way and two-way FSI.

Problem description

The wing geometry **has not been finalized**. The following is just for illustration purposes (from MDO Benchmark case, based on Boeing 717 wings). Only skins, ribs, and spars will be modelled. Stringers are not modelled.



(a) Wing planform.

(b) Wing OML and wingbox structure.

Figure 3: The wing planform and wing OML and wingbox structure [3, 4].

https://mdobenchmarks.github.io/MDOAeroelasticBenchmark/

Governing Equations and Boundary Conditions

FEA: Linear Elasticity

$$\boldsymbol{\varepsilon}(\boldsymbol{u}) = \frac{1}{2}\left(\nabla \boldsymbol{u} + \nabla \boldsymbol{u}^{\mathsf{T}}\right)$$

$$\boldsymbol{\sigma} = \mathbb{C} : \boldsymbol{\varepsilon}$$

$$\boldsymbol{\sigma} = 2G\,\boldsymbol{\varepsilon} + \lambda\,\mathrm{tr}(\boldsymbol{\varepsilon})\,\mathbf{I}$$

$$G = \frac{E}{2(1+\nu)}, \qquad \lambda = \frac{E\nu}{(1+\nu)(1-2\nu)}$$

$$\nabla \cdot \boldsymbol{\sigma} + \boldsymbol{b} = \mathbf{0} \quad \text{in } \Omega_s$$

$$(G+\lambda)\nabla(\nabla \cdot \boldsymbol{u}) + G\nabla^2 \boldsymbol{u} + \boldsymbol{b} = \mathbf{0}$$

CFD: Compressible Navier-Stokes

$$\frac{\partial \mathbf{U}}{\partial t} + \nabla \cdot \mathbf{F}_c(\mathbf{U}) - \nabla \cdot \mathbf{F}_v(\mathbf{U}, \nabla \mathbf{U}) = \mathbf{Q}(\mathbf{U}) \quad \text{in } \Omega_f$$

Reynolds-Averaged Navier Stokes

Boundary Conditions

Fixed support at wing root, and pressure from CFD, $p(\mathbf{x})$, is applied to the wing skin.

$$\boldsymbol{u} = \mathbf{0} \quad \text{on } \Gamma_{\text{root}},$$

$$\boldsymbol{\sigma}\,\boldsymbol{n} = -p(\boldsymbol{x})\,\boldsymbol{n} \quad \text{on } \Gamma_{\text{skin}}.$$

Proposed plans

- **The project only covers** one-way FSI with manual sizing process. If time permits, two-way FSI with numerical optimization algorithm will be pursued.

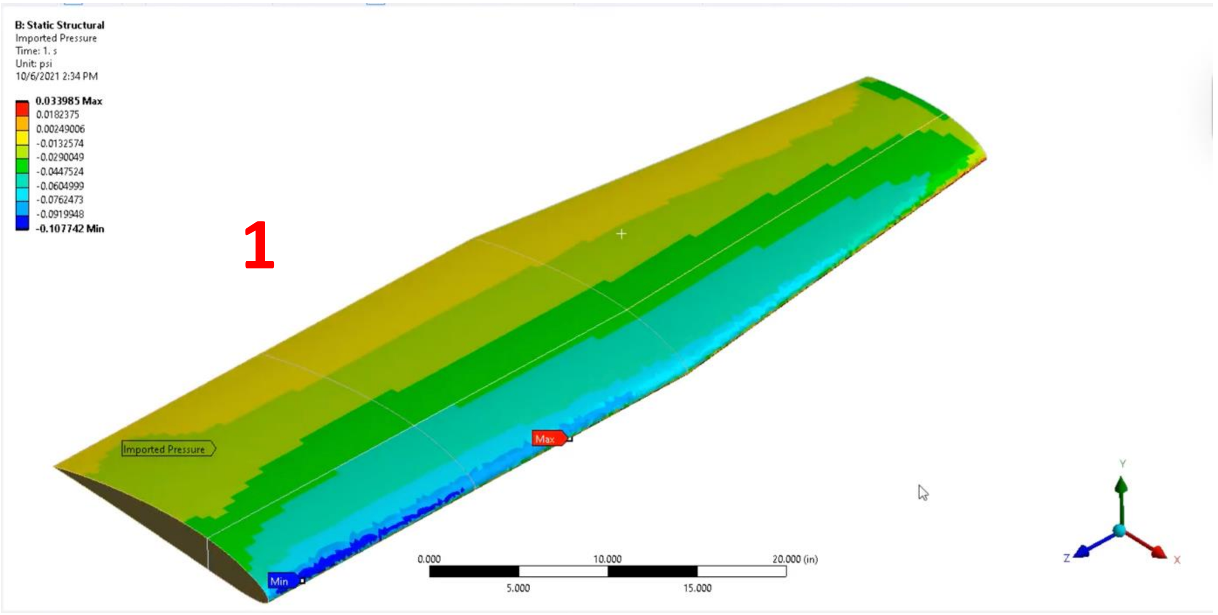
- Tools
  - **CFD**: Ansys Fluent
  - **FEA**: Ansys Mechanical

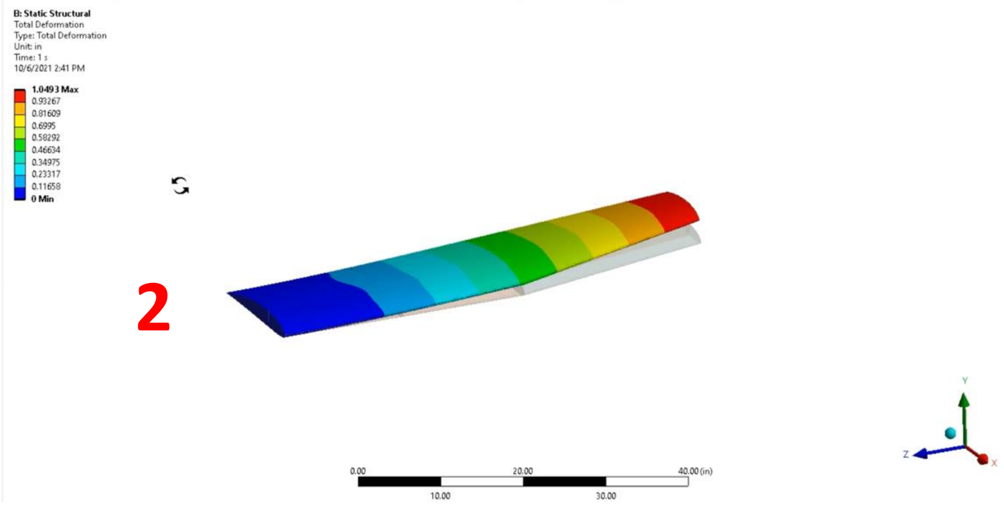
- Assumptions
  - **Load case:** only one design condition, i.e., at cruise flight condition
  - **Element types**: SHELL181 (4-node, linear) or SHELL281 (8-node-quadratic)
  - **Materials**: aerospace-grade aluminum alloy

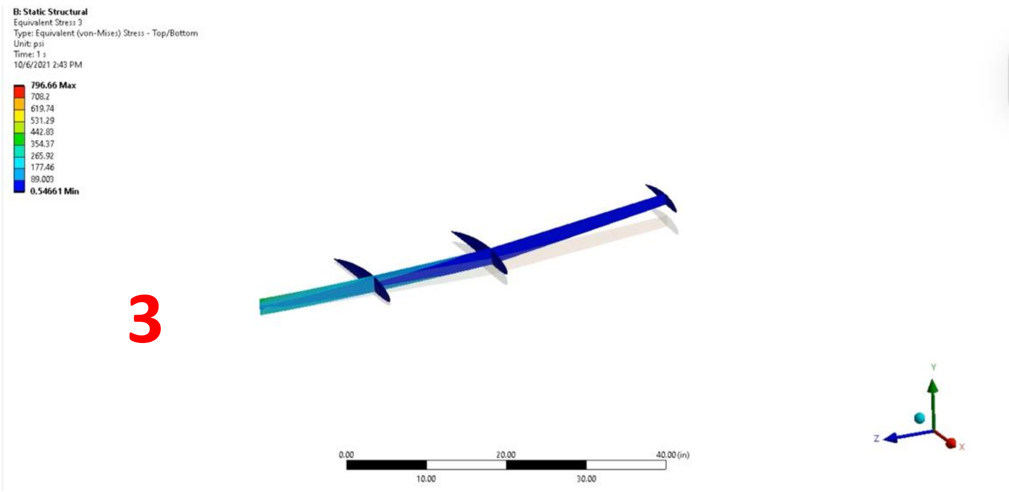
- Metrics of interest
  - Structural mass m_{struct}, wing tip deflection δ_{tip}, maximum von Mises stress $\sigma_{\mathrm{vM,max}}$
  - Factor of Safety: $FOS = S_y/\sigma_{\mathrm{vM,max}}$, where S_y is the material yield strength
  - Strength-to-weight ratio: $SFW = FOS/m_{\mathrm{struct}}$

The sizing process will maximize this SFW ratio.

Tutorials from Ansys







1. Pressure loads imported from CFD
2. Wing deflection
3. Von Mises stress on the spar and ribs

https://www.youtube.com/watch?v=yiTA2AiswEQ