Multifidelity Optimization with Transonic Flutter Constraints

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Background

- We have the ability to compute CFD-based aeroelastic response of wing structures
  - Static trim, flutter, gust
- We can also compute adjoint-based derivatives of this response with respect to shape and sizing design variables
- But the computational cost of design optimization is very high
  - Especially for dynamic aeroelastic constraints

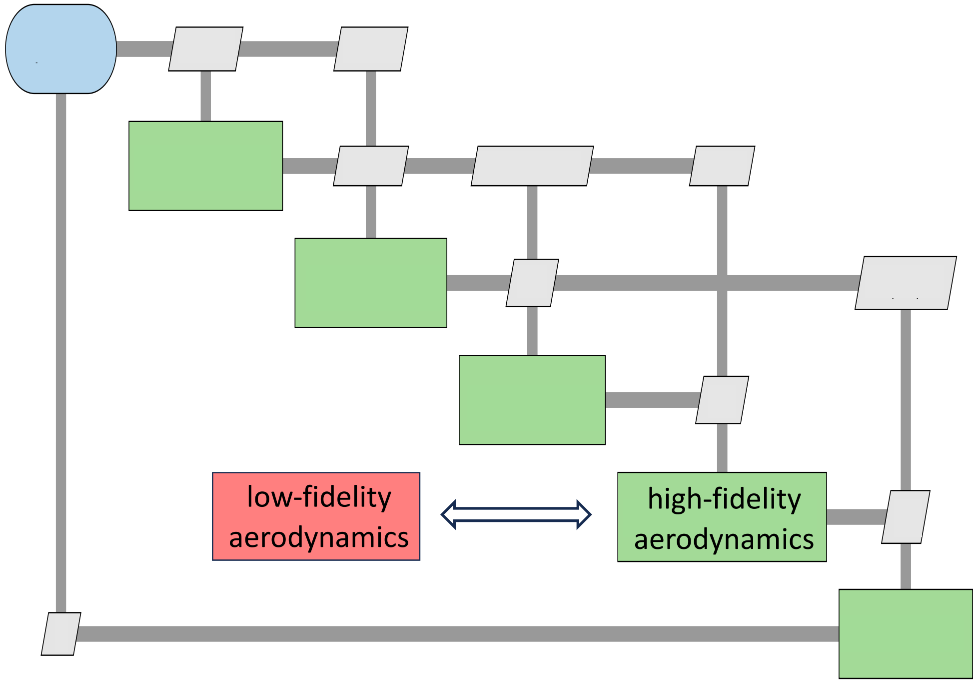
Goals

- Can we utilize multifidelity ideas to speed-up the gradient-based optimization?

- Only interested in multifidelity optimization methods that scale to large numbers of design variables
  - Trust Region Model Management (TRMM)
  - Alexandrov et al., J. Aircraft, 2001

- Only interested in exploring the aerodynamic fidelity, b/c this is most expensive part of our workflow
  - CFD vs. a linear panel code (DLM)

- Because we are using OpenMDAO and MPhys, it is relatively easy to swap out the aerodynamic solver, but leave everything else untouched



Trust Region Model Management

- At a location in the design space, $\boldsymbol{x}_0$:
  - Compute the low-fidelity response and its gradients
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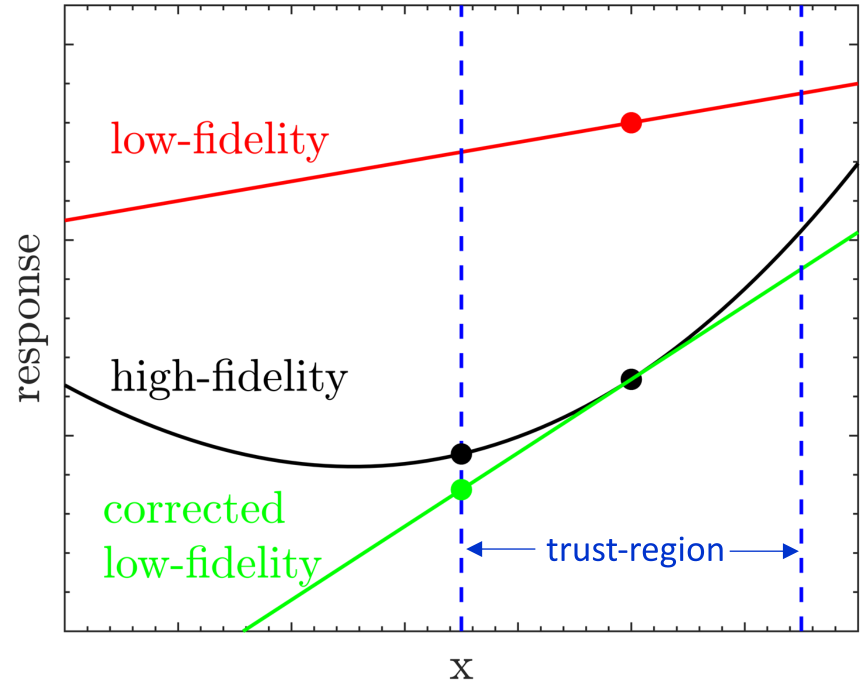
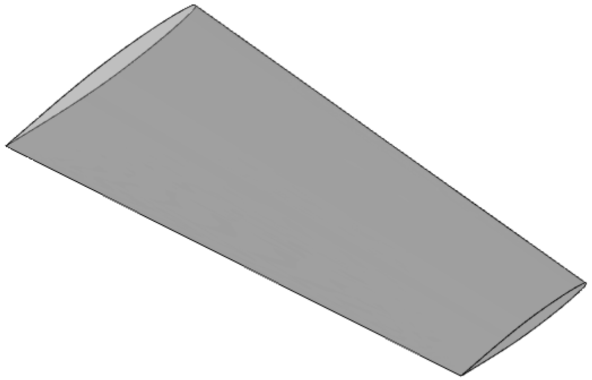
- Construct a <u>corrected low-fidelity</u> model:
  - Will equal the high-fidelity response and gradients at $\boldsymbol{x}_0$
- Optimize the corrected low-fidelity model over a trust-region Δ
  - Inexpensive
- Evaluate this new optimum with the high-fidelity code
  - Depending on the goodness of the high-fidelity result, we can accept or reject the new optima, grow or shrink Δ



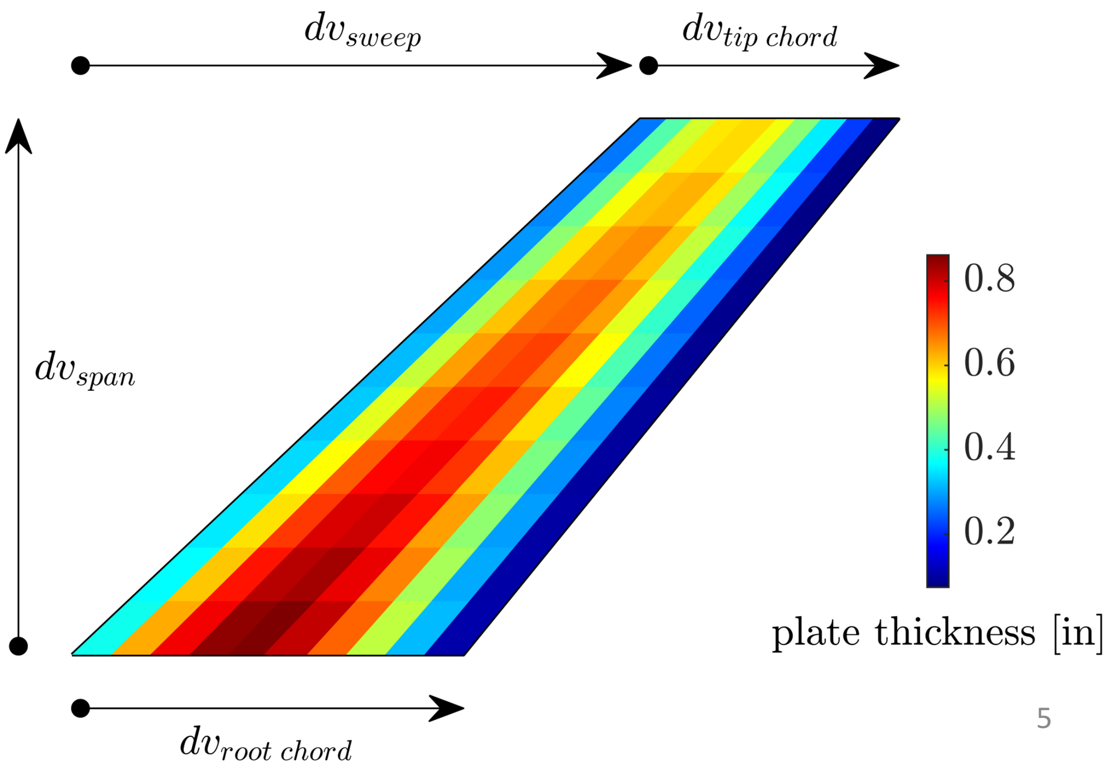
Optimization Demo Case



- AGARD 445.6: a popular aeroelastic validation case
  - We have reimagined this as an optimization test case

- Minimize structural mass, such that:
  1. The planform area stays the same
  2. The wing is trimmed (match C_L)
  3. The stresses at trim aren't too large
  4. The flutter-q is greater than some value

- Design variables:
  1. Four planform variables
  2. A thickness scaling variable
  3. Trim AoA



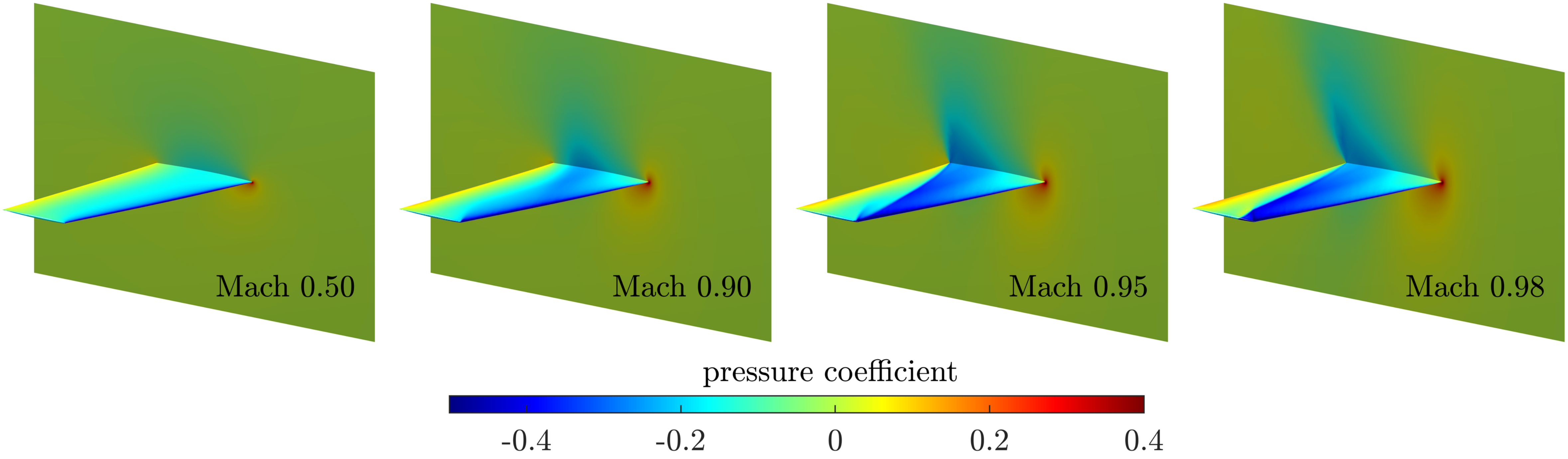
High-Fidelity vs. Low-Fidelity

- High-fidelity:
  - Inviscid Euler mesh with 200,000 nodes
  - On 400 Intel Skylake CPU cores, one function call (static aeroelastic trim + flutter) takes 95 minutes, and the derivative call takes 155 minutes

- Low-fidelity:
  - Planar DLM mesh with 128 quads
  - A complete low-fidelity (or corrected low-fidelity) optimization takes less than 5 minutes

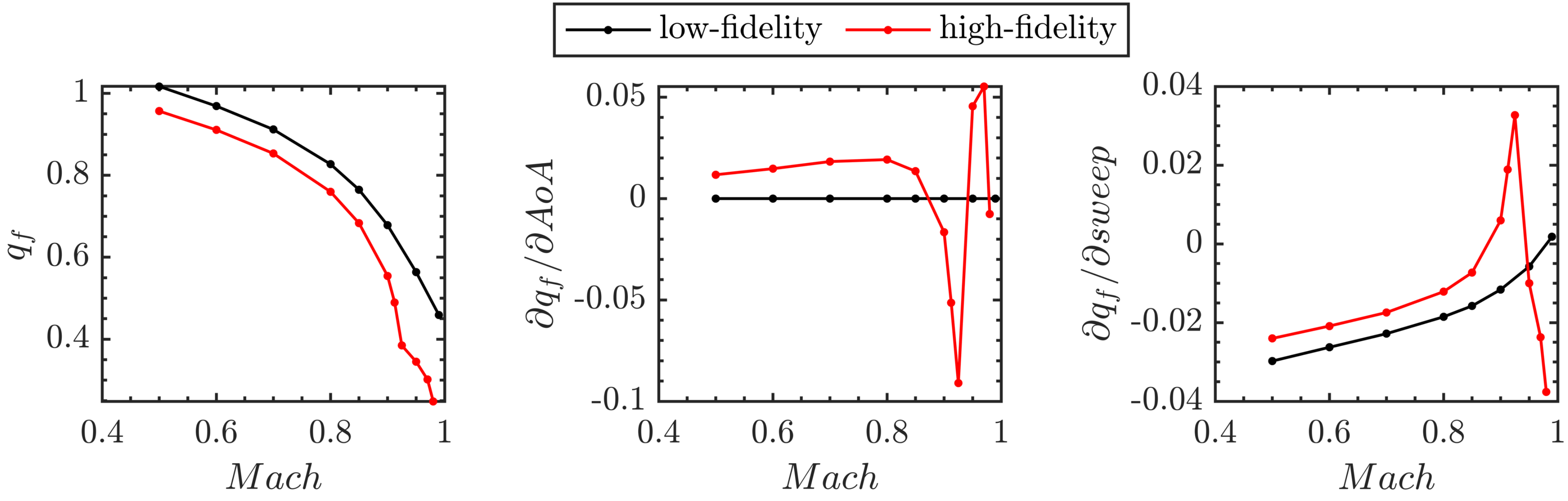
- We will study the numerical response, and also the TRMM performance, for increased Mach number
  - For transonic flows, low- and high-fidelity response will show larger differences

High-Fidelity Static Aeroelastic Behavior



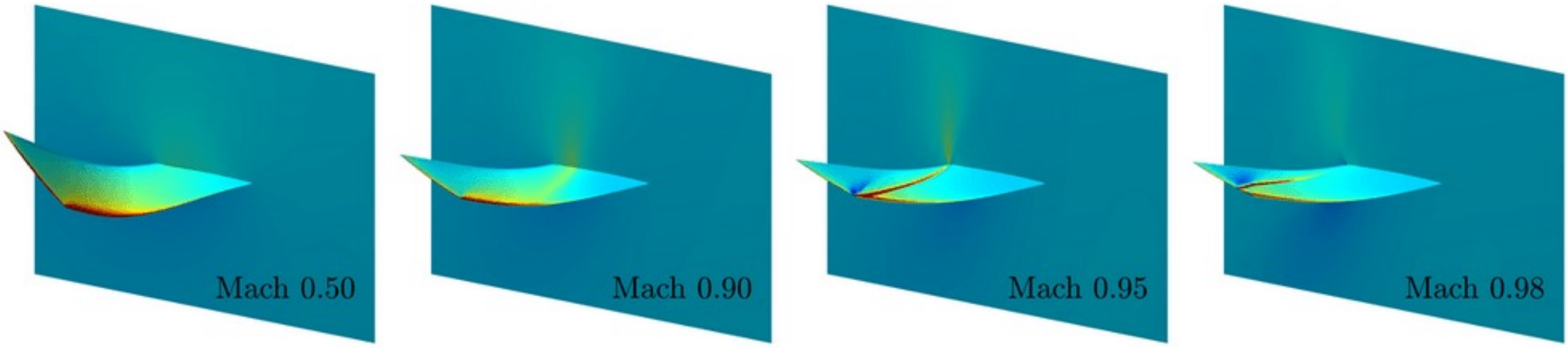
- No optimization here, just looking at the response of the baseline design
- AoA = 1 deg. for all cases

Flutter Dependence on Fidelity



- No optimization here, just looking at the response of the baseline design
- There is a transonic flutter dip that increases the gap between low- and high-fidelity
- The low-fidelity trim and shape flutter derivatives become much less useful in the transonic regime

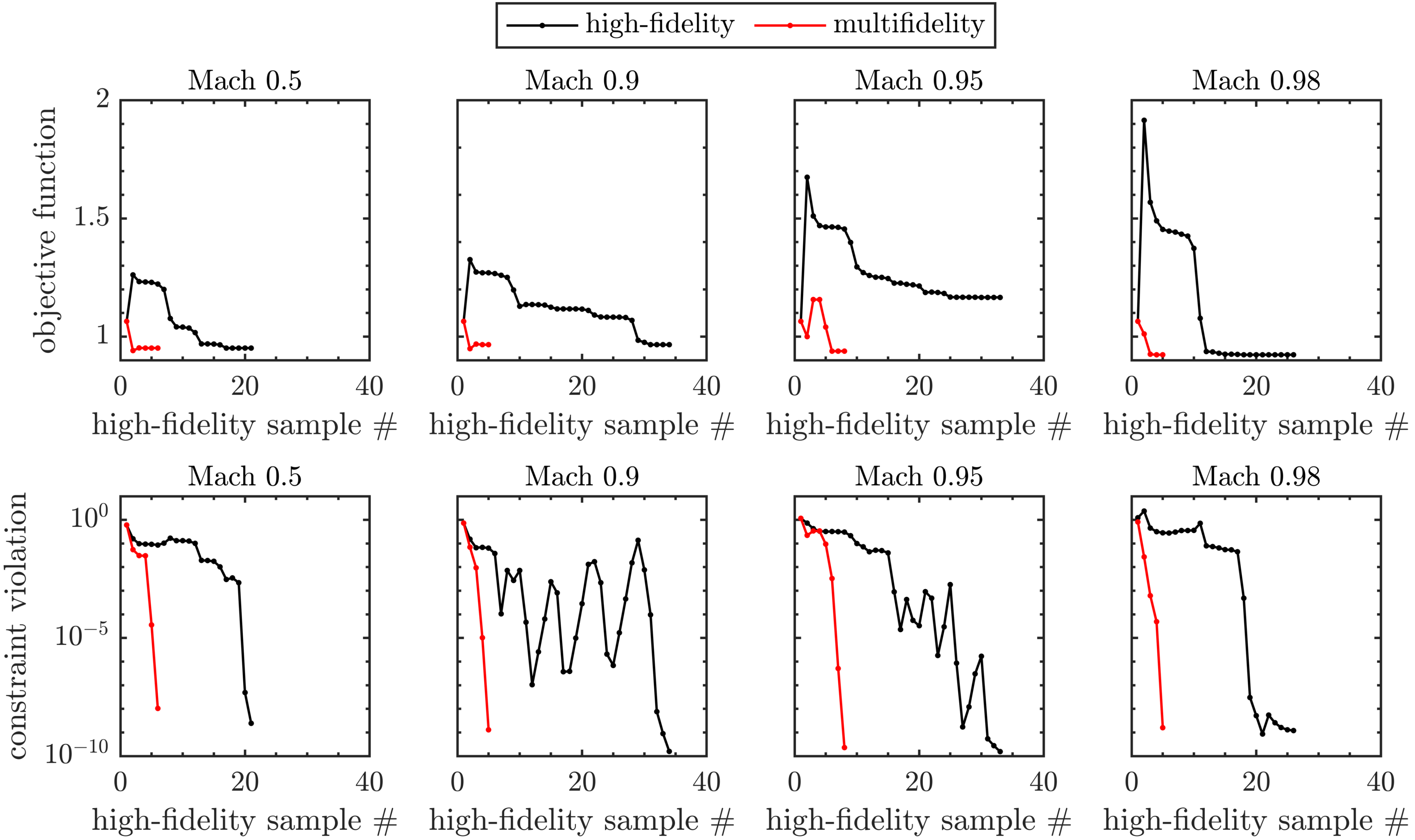
High-Fidelity Flutter Behavior



Oscillatory Flow Pressures

- No optimization here, just looking at the response of the baseline design
- Transonic flutter mechanisms tend have less coupling between the first and second modes

Multifidelity Optimization

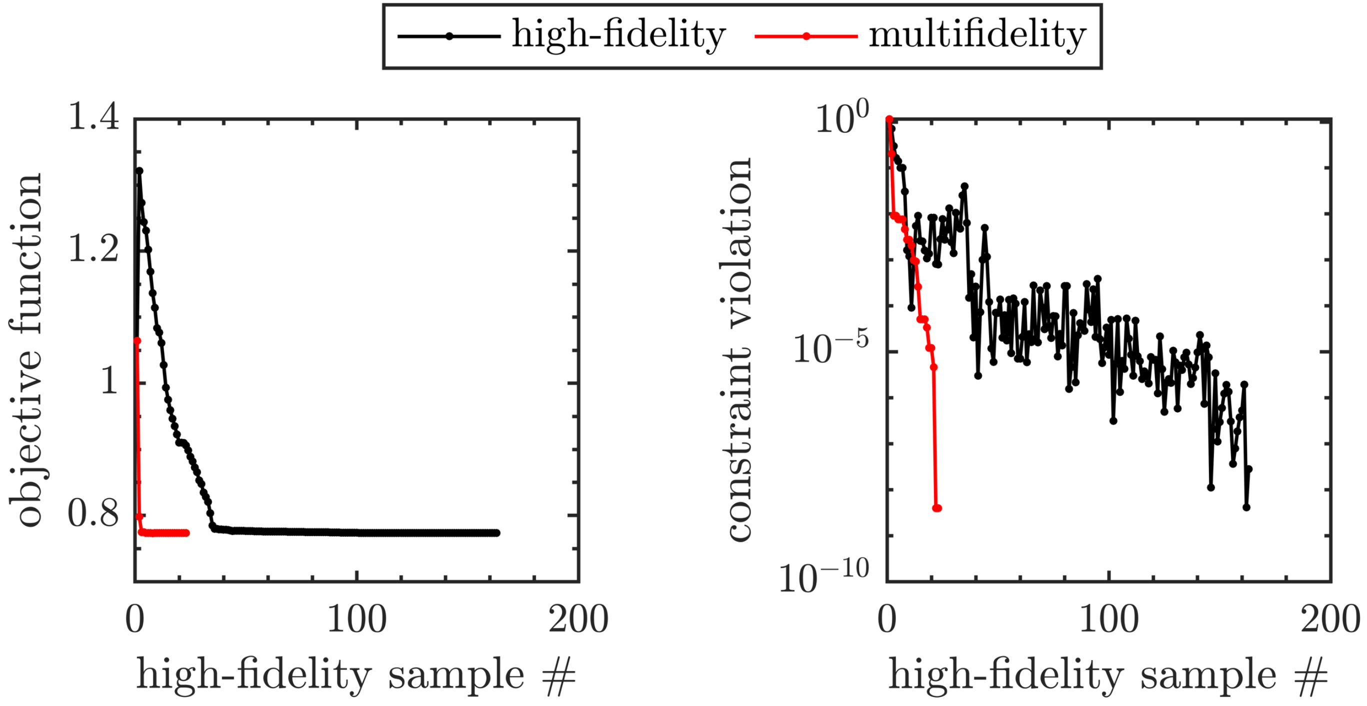


Larger Design Spaces

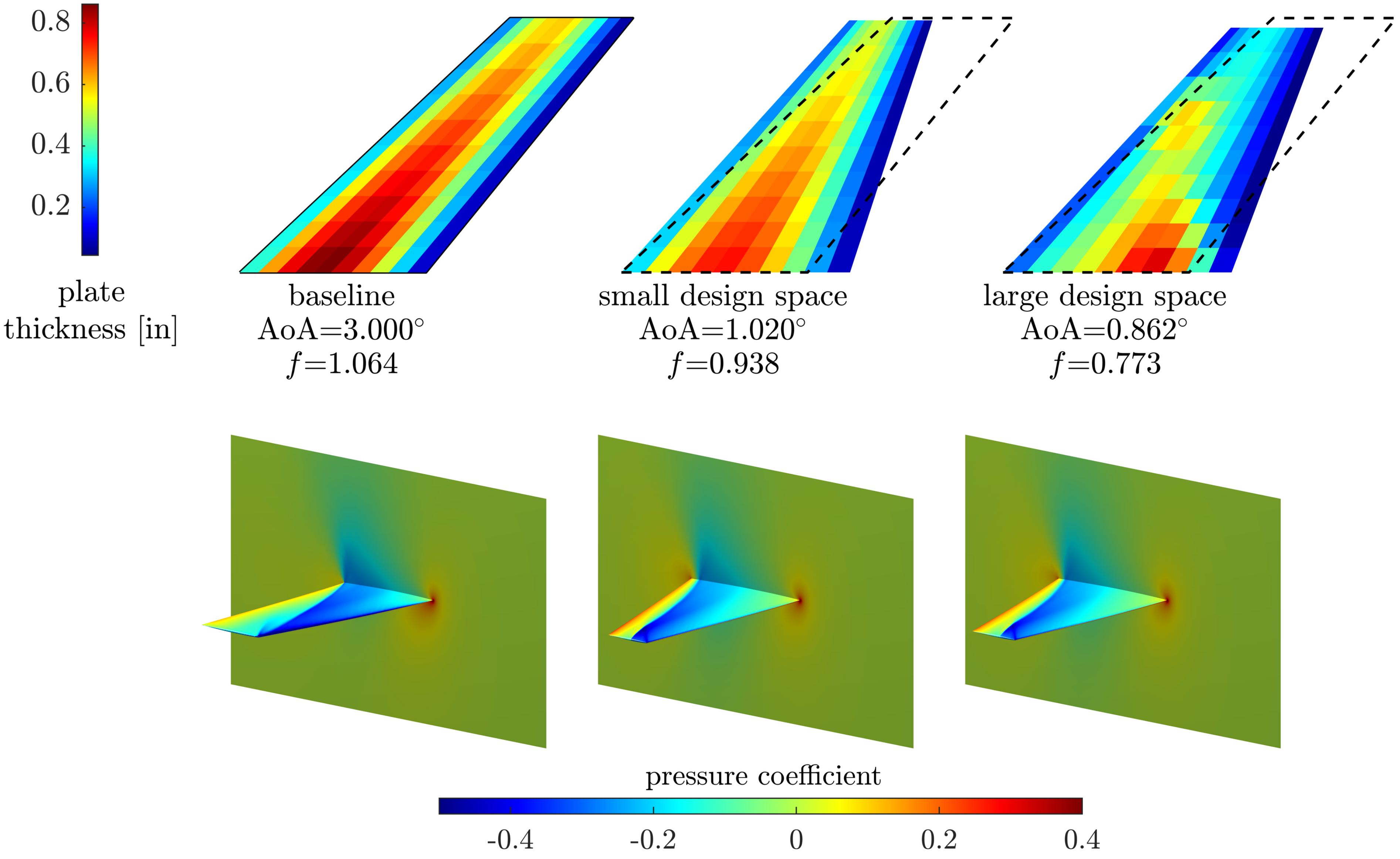
- Rather than just a single thickness-scaling DV for the entire plate-wing, we can individually optimize the thickness of every finite element:

- So now, the design variables are:
  1. Four planform variables
  2. 100 thickness scaling variables
  3. Trim AoA

- Only run at Mach 0.95



Larger Design Spaces (2)



Conclusions

- Sizing and shape CFD-based aeroelastic optimization with static trim and flutter constraints
- Multifidelity TRMM optimization gave speed-ups of ~5-8 over single/high-fidelity optimization, for the various cases considered
  - Subsonic and transonic flows
  - Smaller and larger design spaces
- Multifidelity speed-up did not obviously degrade for transonic flows
  - This is true even though the low-fidelity DLM solver is providing inaccurate derivatives, especially for the flutter constraint

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