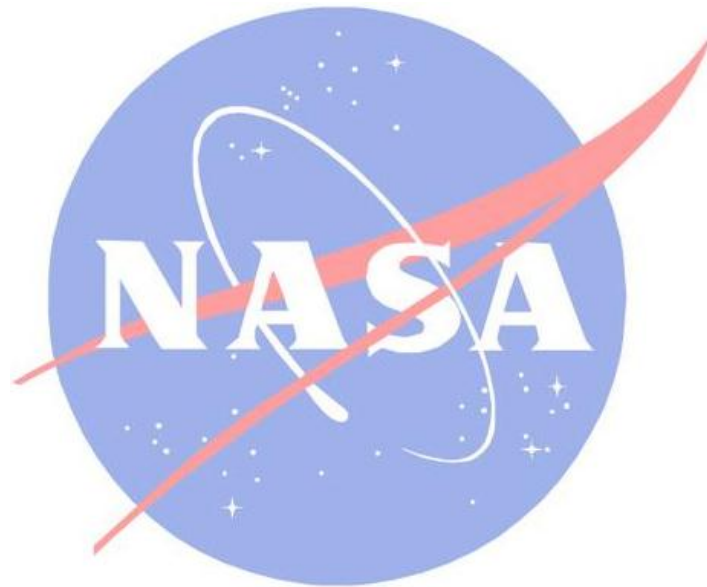


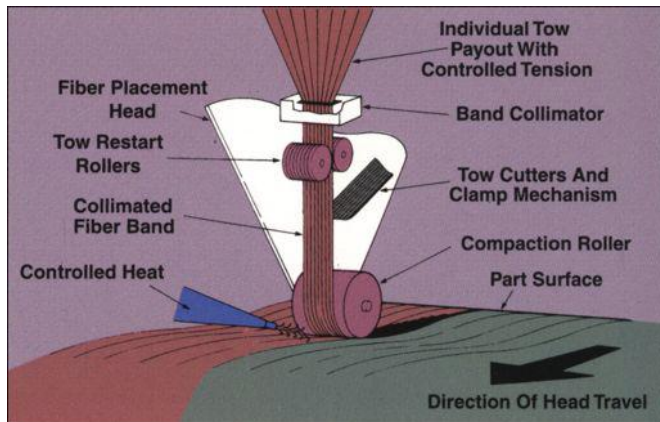
Ongoing Aeroelastic Optimization Research at NASA LaRC, Aeroelasticity Branch





1. Aeroelastic tailoring with tow-steered composites
2. Aeroelastic tailoring with functionally-graded metals
3. Wing box topology optimization
 - Curvilinear rib/spar/stiffener placement
 - Cellular-based stringer topologies
 - Optimal topology of lightening holes within ribs/spars
 - 3D level set methods

- ◆ Conventional laminates: all fibers in a ply are straight and parallel, with a given orientation
- ◆ Tow steering: fiber orientation within a ply can vary continuously throughout structure
 - Variable-stiffness, tailored load paths



Courtesy Cincinnati Machine



C. Wu: NASA LaRC

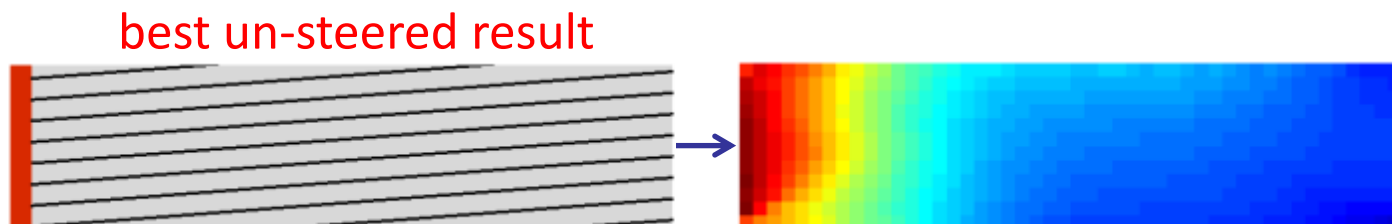
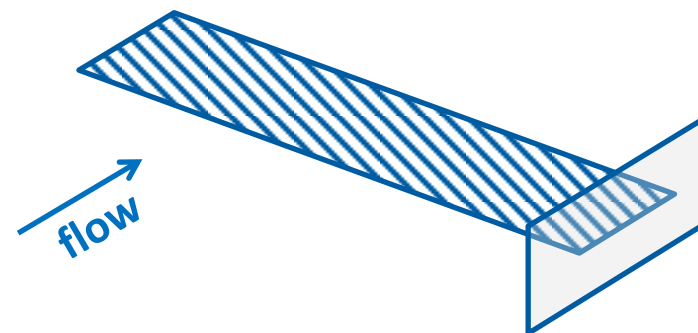
very little work has been done on tow steering for AE tailoring



Composite Flat Plates, Low-Speed Flow

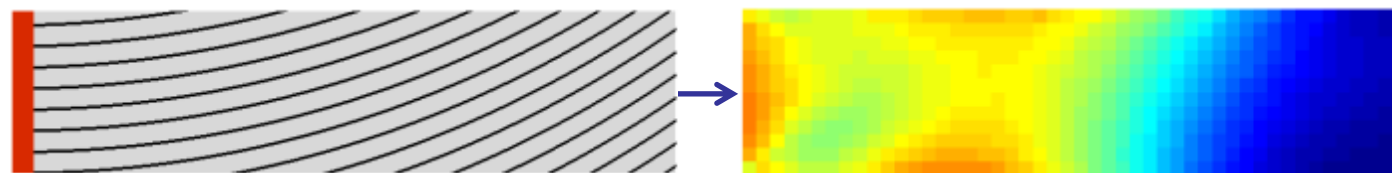


static aeroelastic deformations:



fiber path of outer layer

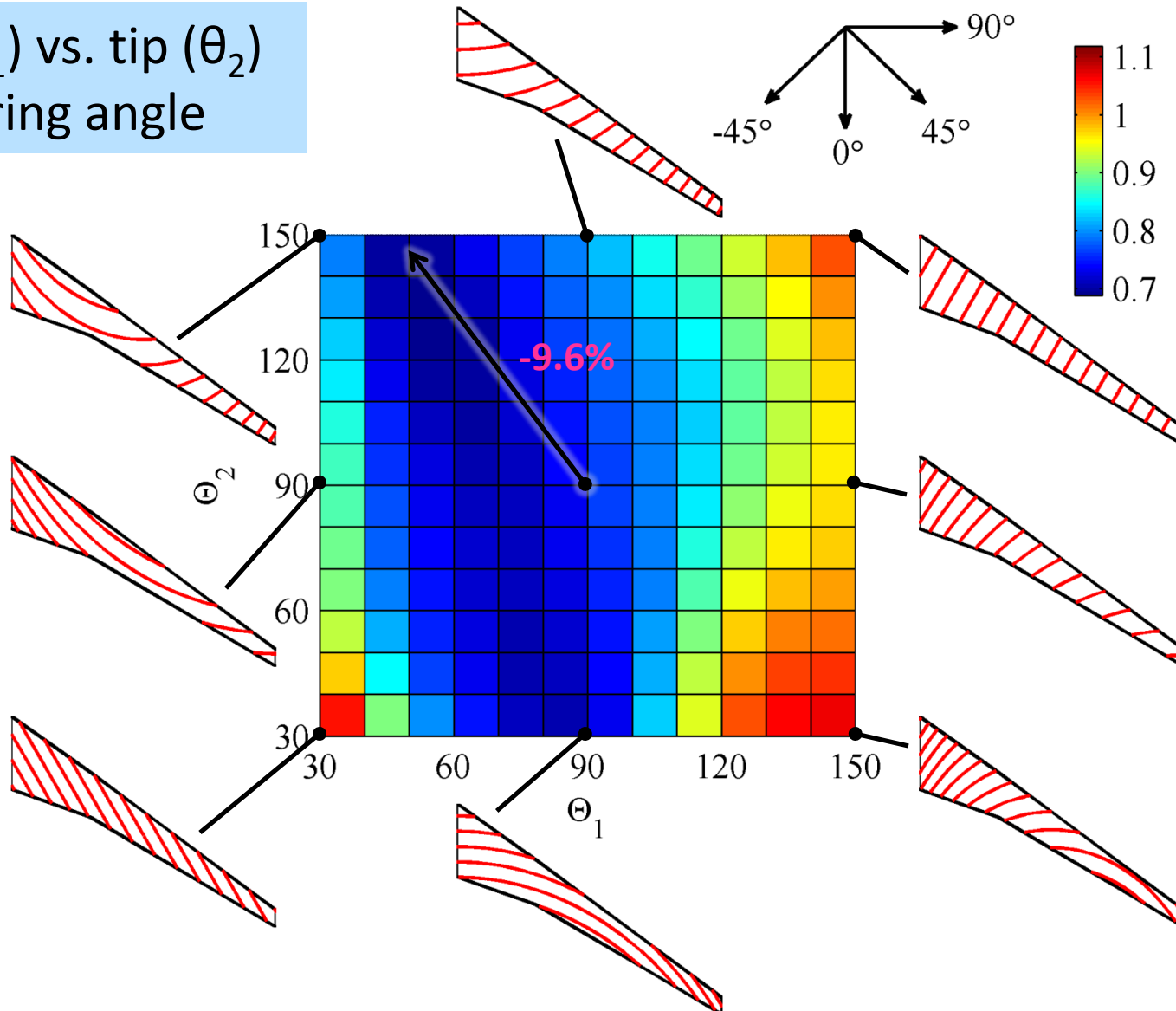
Tsai-Wu failure metrics



best steered result

stresses spread over more of wing, drop in peak stress: ***no mass added***

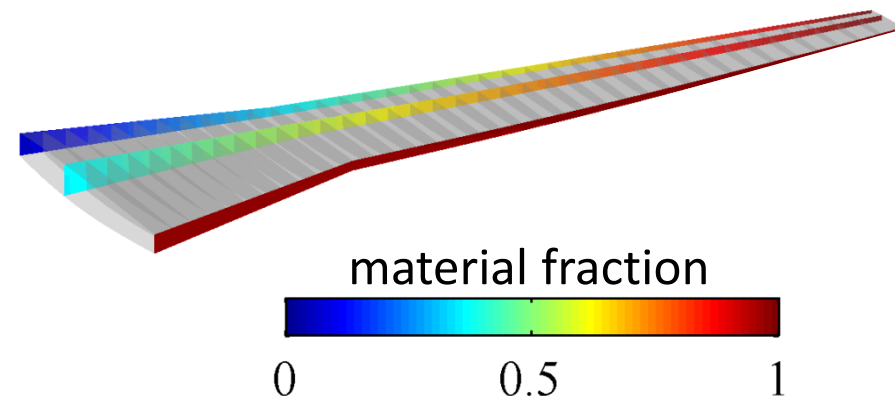
root (θ_1) vs. tip (θ_2)
steering angle



peak Tsai-
Wu failure
index

- ◆ FGM: spatially vary the distribution of 2 metals in a structure
 - Continuously-varying properties
 - Enabled by EBF³
 - Any benefit for non-thermal (subsonic) applications?
- ◆ Aluminum alloy and aluminum w/silicon carbide particulates
 - Same density, AlSiC has 45% higher modulus
 - Ability to change local stiffness without changing mass

graded stiffeners

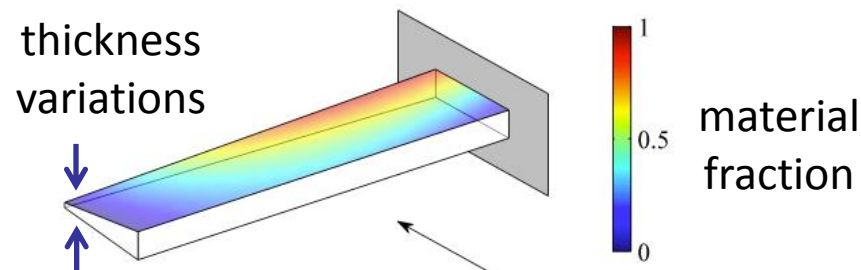




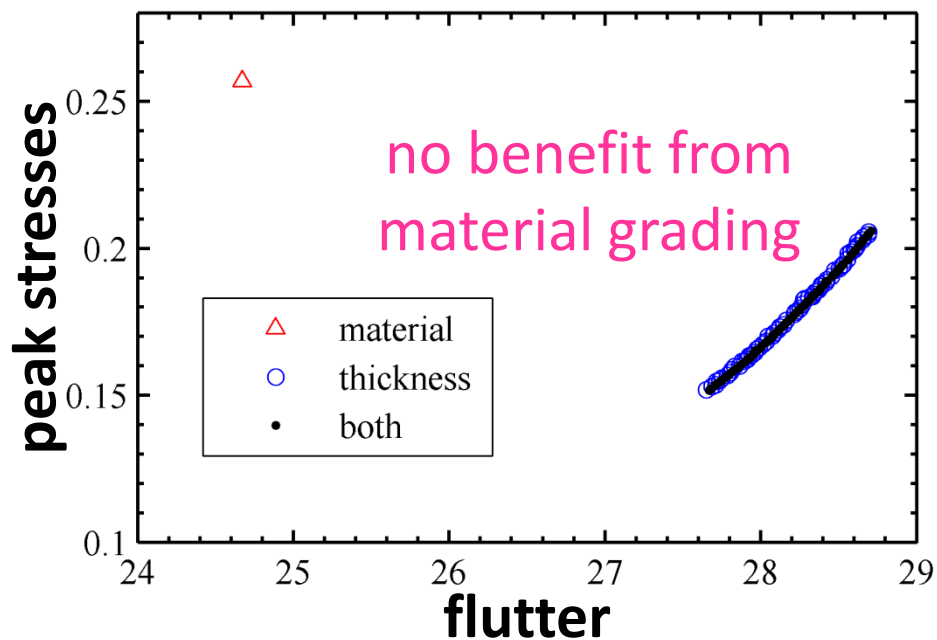
Thickness vs. Material Grading



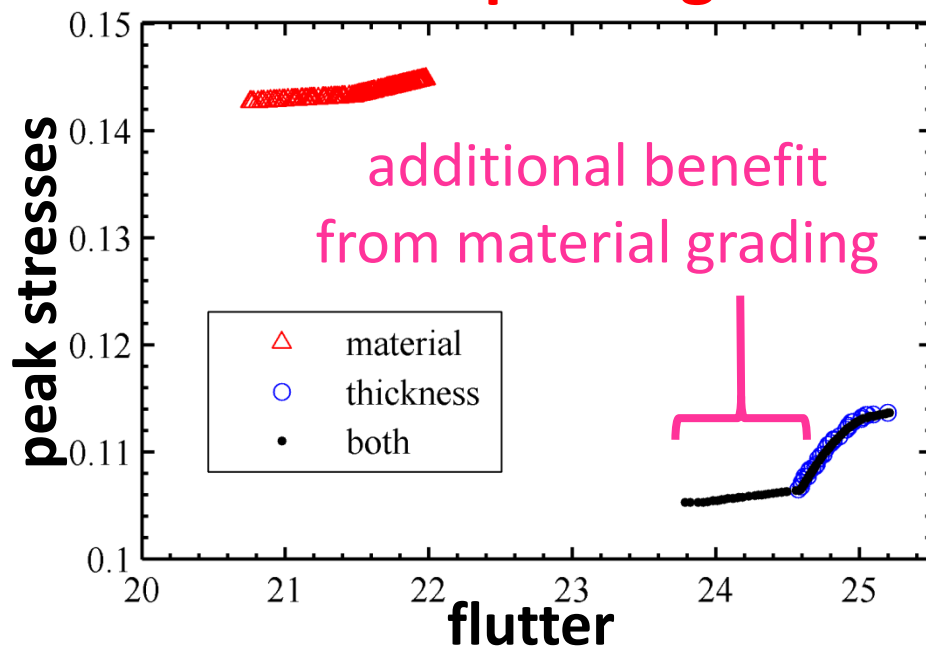
optimal trade-off
curves for different
tailoring strategies



straight wing



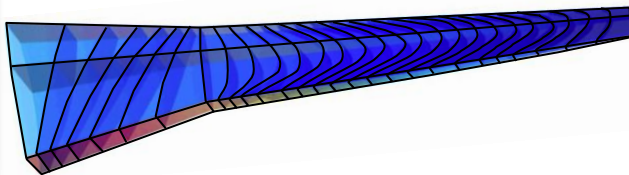
swept wing



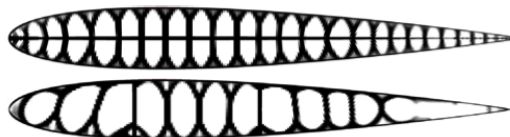
- ◆ Identify optimal distribution of support material within a wing box (topology)
 - Passively control trade-off between weight and aeroelastic performance

three topology optimization activities:

location, orientation, connectivity,
curvilinearity of ribs/spars/stringers?

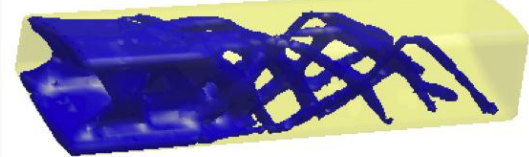


distribution of material
within the shell structures?



Oktay et al., 2011

distribution of 3D material
within the wing box?



K. James, U of T

simultaneous or sequential
optimization

- ◆ Parameterize number, location, and curvilinearity of ribs and spars within each wing box section
- ◆ Basic code developed by R. Kapania's group at VPI
 - Aeroelasticity added to framework by LaRC



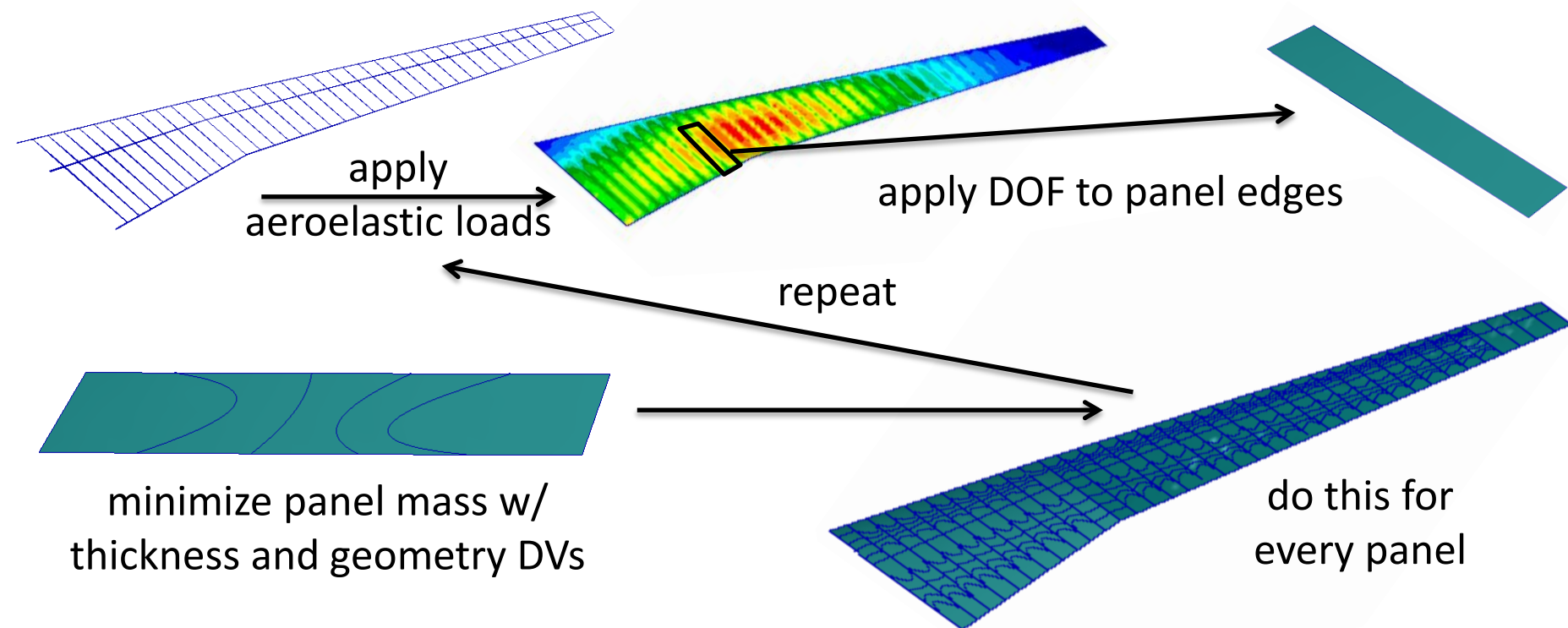
- ◆ Difficult design space
- ◆ Anything gained from curvilinearity?
 - Enabled by EBF³



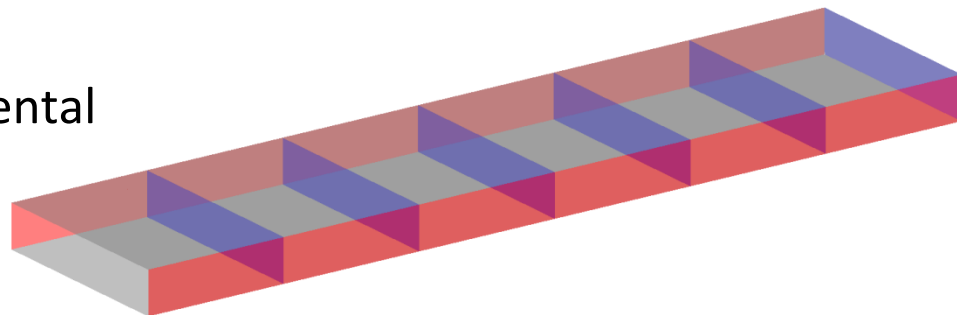
Curvilinear Panel Stiffeners



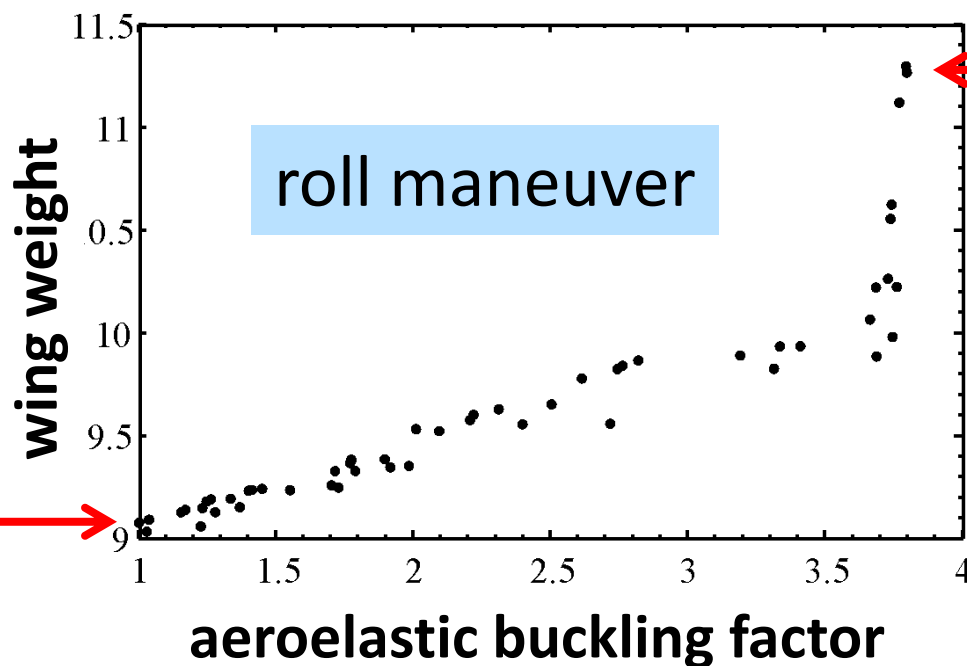
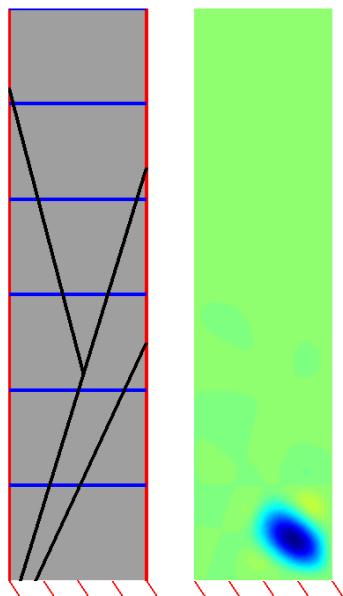
- ♦ Optimal curvilinear stiffener placement for minimum-mass panel strength/buckling/cripling (VPI code)
 - Extend to entire wing?



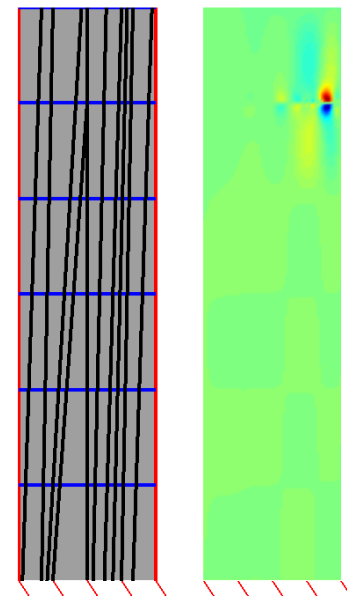
- ◆ Stringer topologies based on cellular mechanics
- ◆ Cell structures form in stages
 - Process controlled by a developmental program (optimization variables)
 - Cell walls become skin stringers
 - M. Kobayashi, U. Hawaii



min. weight



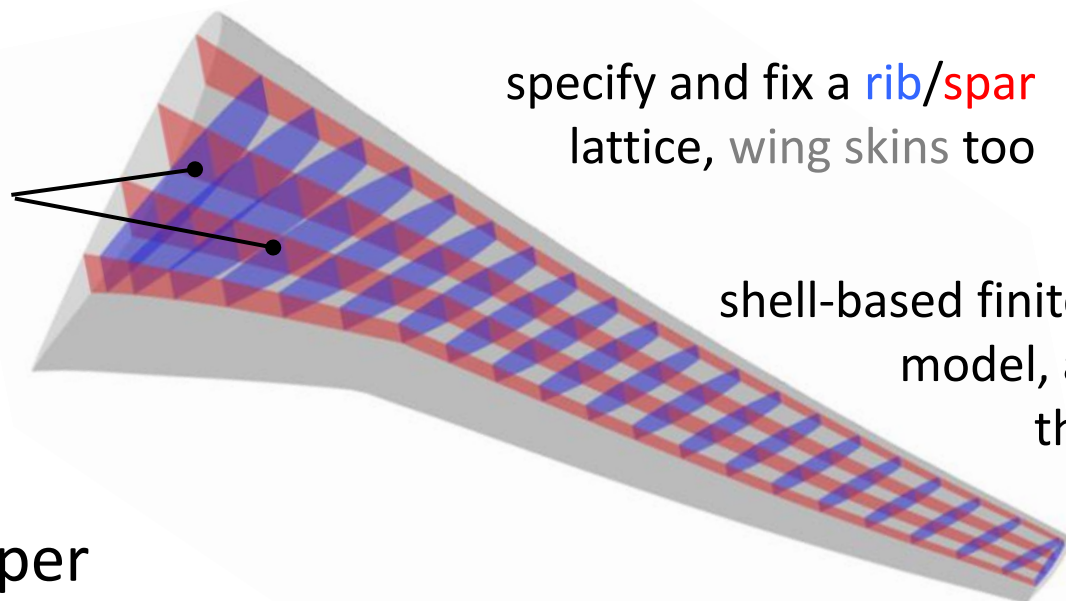
max. buckling



Conduct topology optimization within the **rib** and **spar** shell structure

specify and fix a **rib**/**spar** lattice, wing skins too

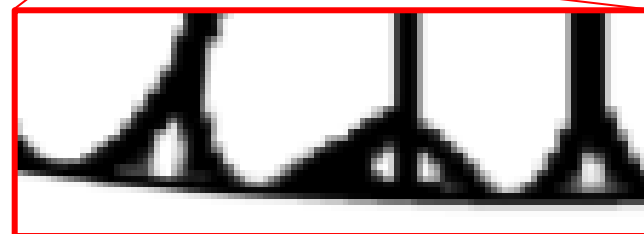
shell-based finite element model, aluminum throughout

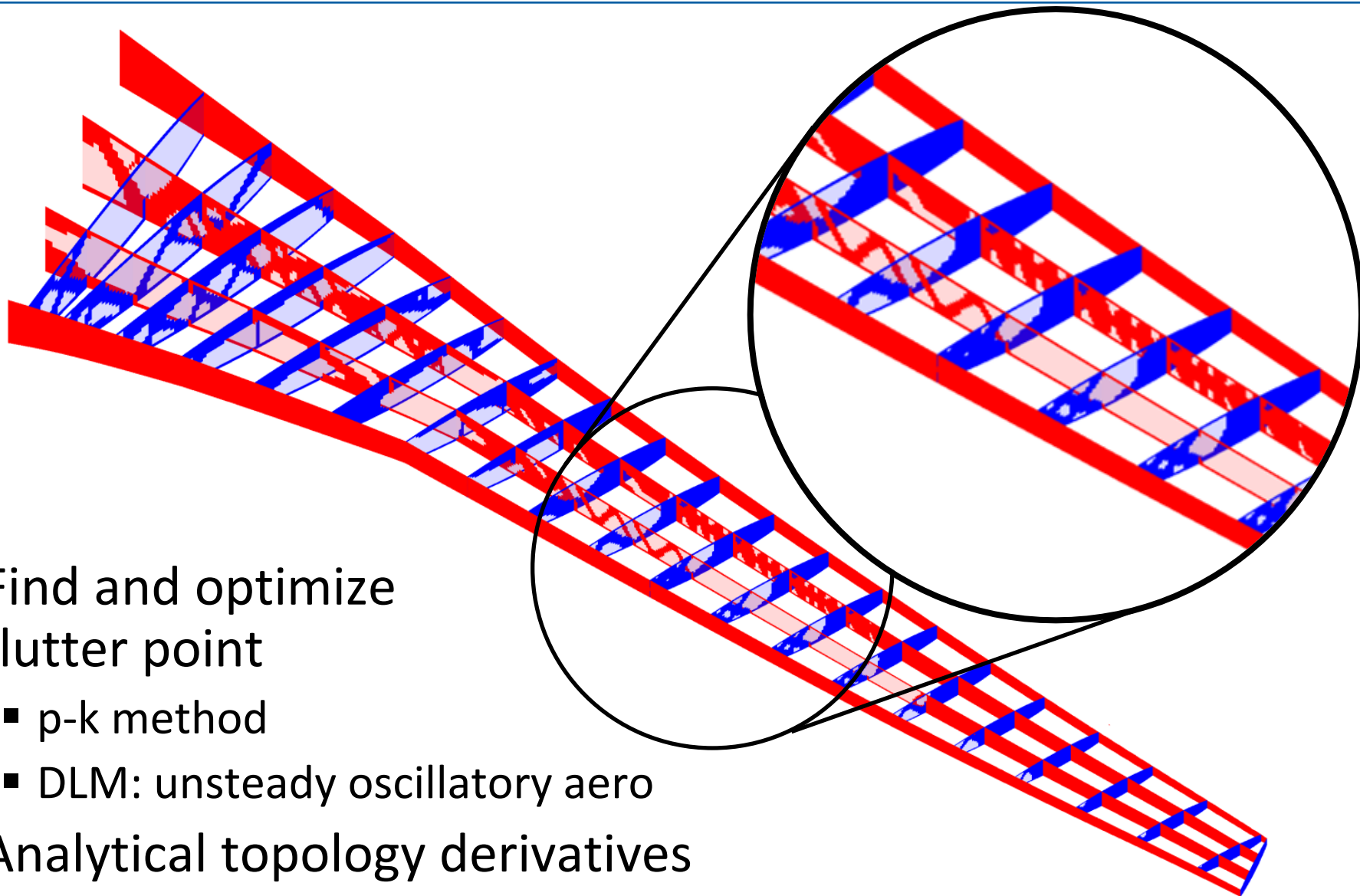


- ◆ One density DV per shell finite element
 - 0 (void) to 1 (solid)
 - Continuous design variables
 - Implicit penalty on intermediate densities



Oktay et al., 2011





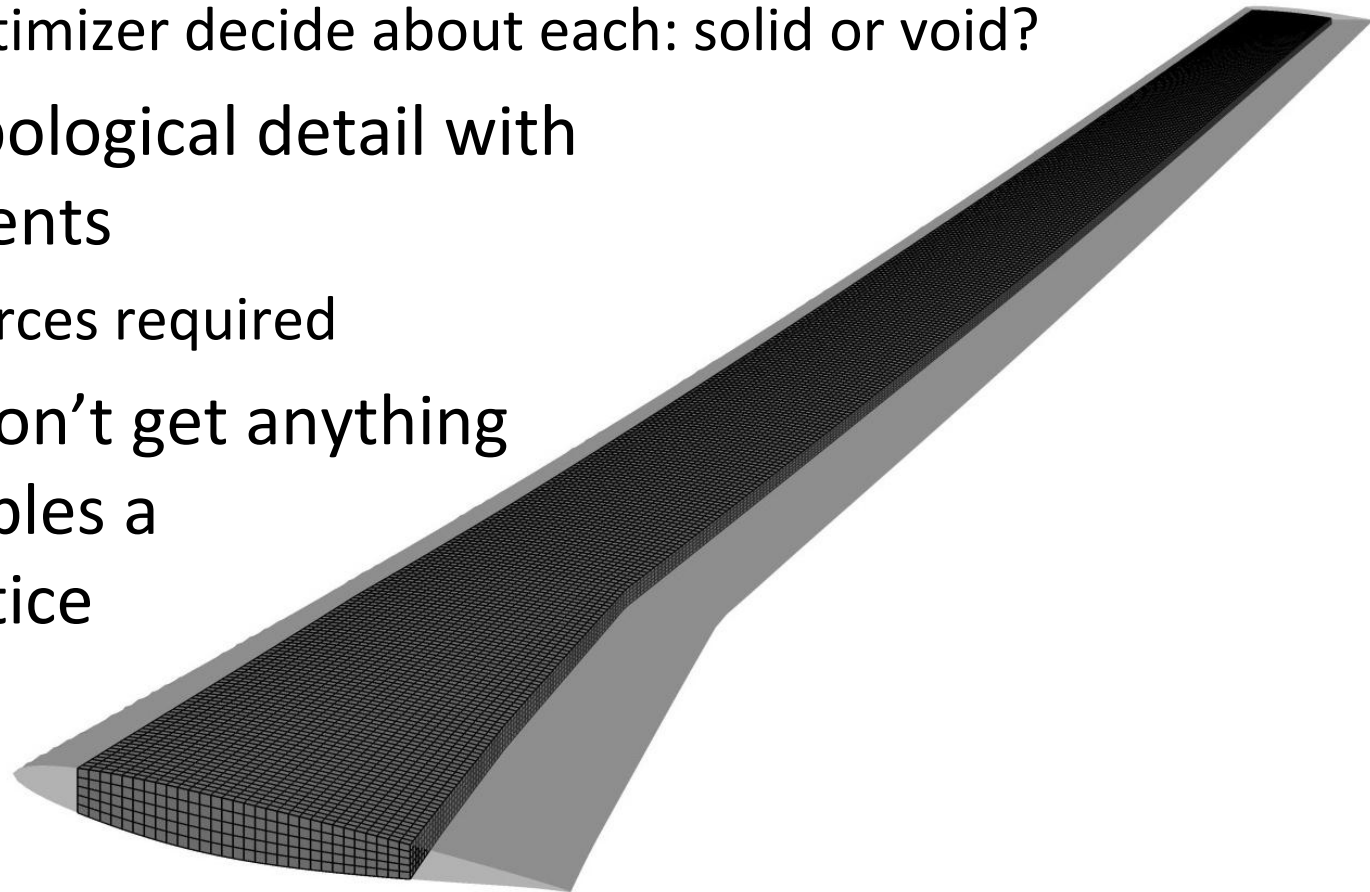
- ◆ Find and optimize flutter point
 - p-k method
 - DLM: unsteady oscillatory aero
- ◆ Analytical topology derivatives



Three-Dimensional Topologies

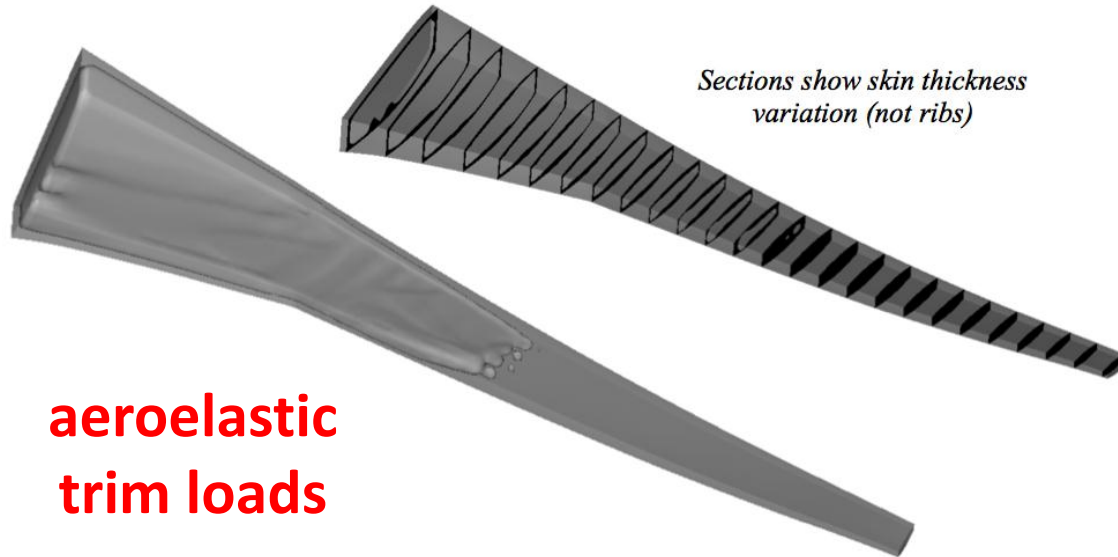


- ◆ Remove the underlying spar-rib concept
- ◆ Fill the wing box with tiny brick elements
 - Let the optimizer decide about each: solid or void?
- ◆ Greater topological detail with more elements
 - HPC resources required
- ◆ Probably won't get anything that resembles a spar-rib lattice
 - Why?





Aeroelastic Trim Compliance



3D level-set methods
to obtain optimal
topology

**aeroelastic
trim loads**

