Optimization of thermal structures: linear and nonlinear

Hayoung Chung, Carolina Jauregui, Hyunsun Alicia Kim

Structural Engineering Department

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

THERMOELASTIC STRUCTURES

Fig 1 Azhai suspension bridge in Jishou, Hunan, China. http://raredelights.com/top-25-longest-suspension-bridges-world/aizhai-bridge/

Fig 2 NASA artwork of space shuttle re-entry. https://www.nasa.gov/centers/ames/multimedia/images/2006/shuttlehistory.html

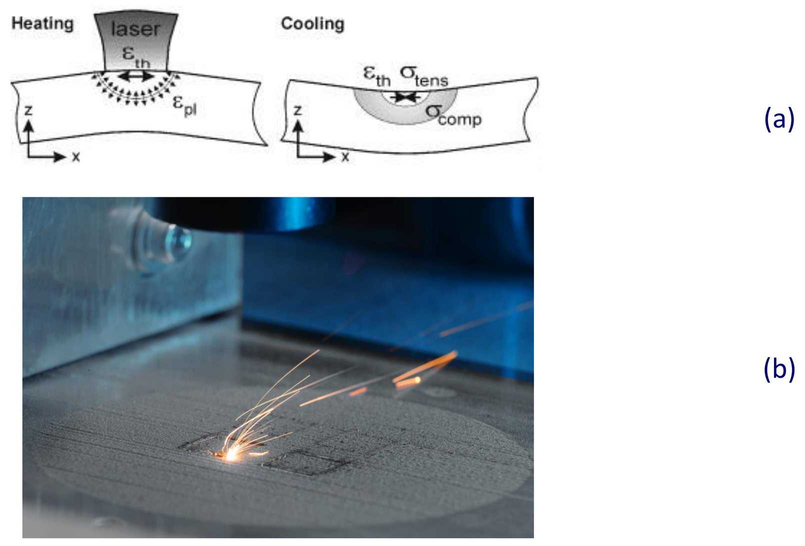


Fig 3 (a) Diagram of a laser forming forming mechanism which has a large temperature gradient (JP Kruth 2014). (b) Selective laser melting https://www.ilt.fraunhofer.de/en/press/press-releases/press-release-2016/press_release_20161107.html

CHALLENGES IN DESIGN

- Considering thermal effects in structures can be challenging when there are other physics that are in conflict with each other
- For thermal protection systems on space shuttles, designs that reduce thermal expansion also make them more susceptible to acoustic excitation
- Additively manufactured structures suffer from residual thermal stresses, which are difficult to intuitively design for
- Topology optimization is a design tool well suited to handling conflicting criteria and creating non-intuitive designs

TOPOLOGY OPTIMIZATION: INNOVATIVE DESIGNS

RESEARCH OBJECTIVES

LINEAR

Understand the implications of using the objective functions:

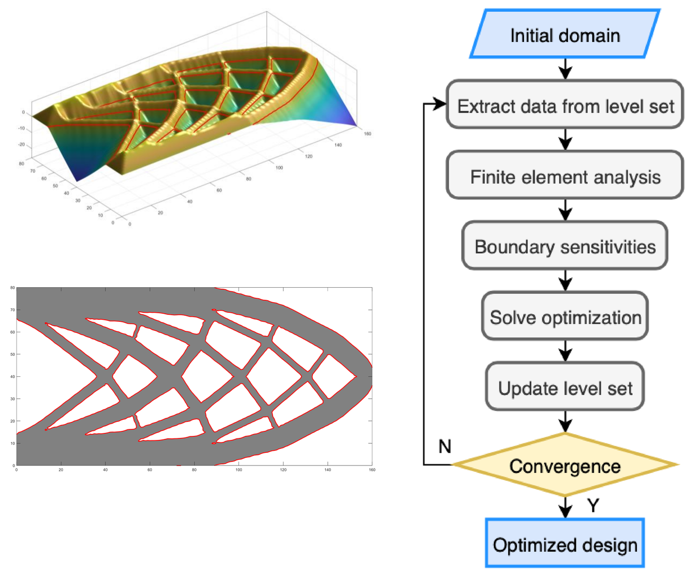
1. Minimize mean compliance, i.e. maximize stiffness
2. Minimize p-norm stress, an aggregation of all the stresses in the structure

NON-LINEAR

For structures that experience large mechanical loads with high temperature:

1. Investigate the effects of nonlinearity on the optimal designs
2. Provide a reasoning for such changes

LEVEL SET TOPOLOGY OPTIMIZATION



COMPLIANCE VS STRESS

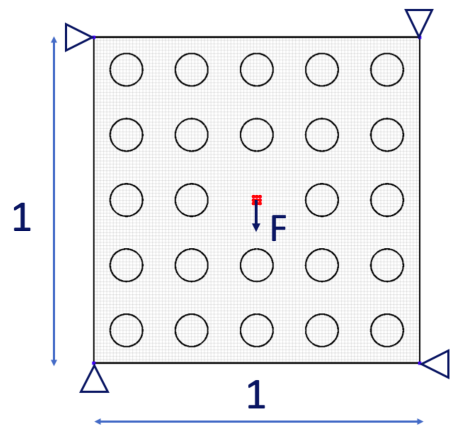


Fig 4 Plate with pinned corners. A load is applied in the center.

E = 1 F = 1

v = 0.3 Mesh = 100x100

α = 0.01 $^1/_\circ$

COMPLIANCE

$\Delta T = 0°$

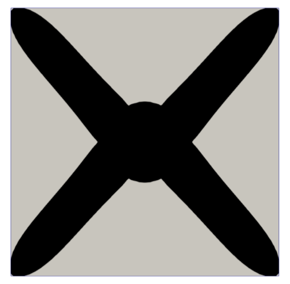


Fig 5 Final solution for minimizing compliance at ΔT = 0°. Final values: C = 2.995, σ_{PN} = 4.650.

$\Delta T = ?°$

Fig 6 Final solution for minimizing compliance at ΔT = ?°. Final values: C = , σ_{PN} =

STRESS

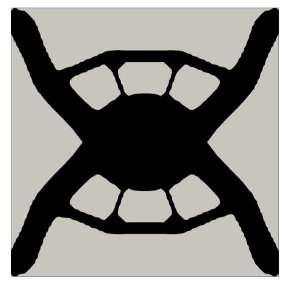
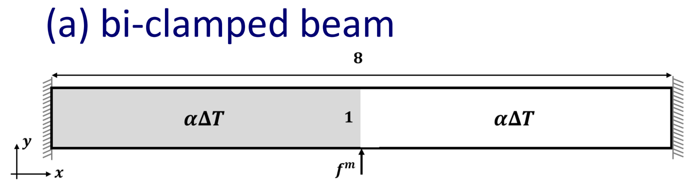


Fig 7 Final solution for minimizing p-norm stress at ΔT = 0°. Final values: C = 3.653, σ_{PN} = 4.335.

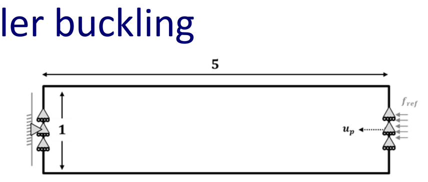
Fig 8 Final solution for minimizing p-norm stress at ΔT = ?°. Final values: C = , σ_{PN} =

APPLYING HIGH LOADS AND TEMPERATURE EFFECTS

(a) bi-clamped beam



(b) Euler buckling



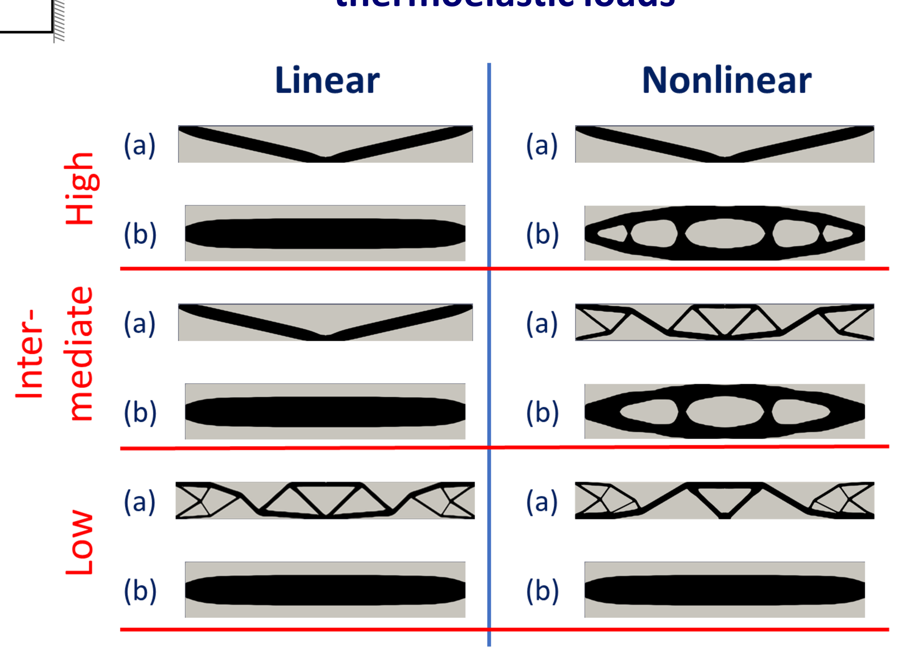
Material nonlinearity
Hyperelastic (neo-Hookean) material
$E = 1.0, \nu = 0.3$

Geometric nonlinearity
High-order strain is used

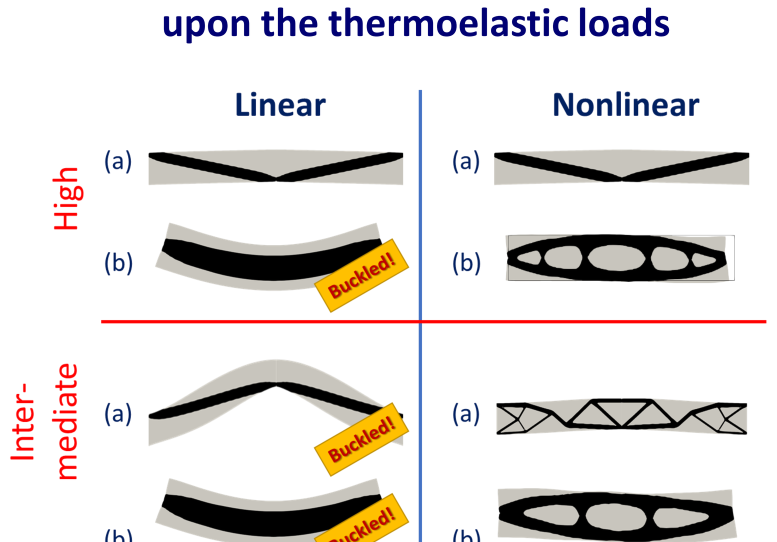
Problem definition

$$\min(u^T f^m)$$
$$\textit{subject to } Vol \leq Vol^*$$

Optimal layouts for given degree of thermoelastic loads



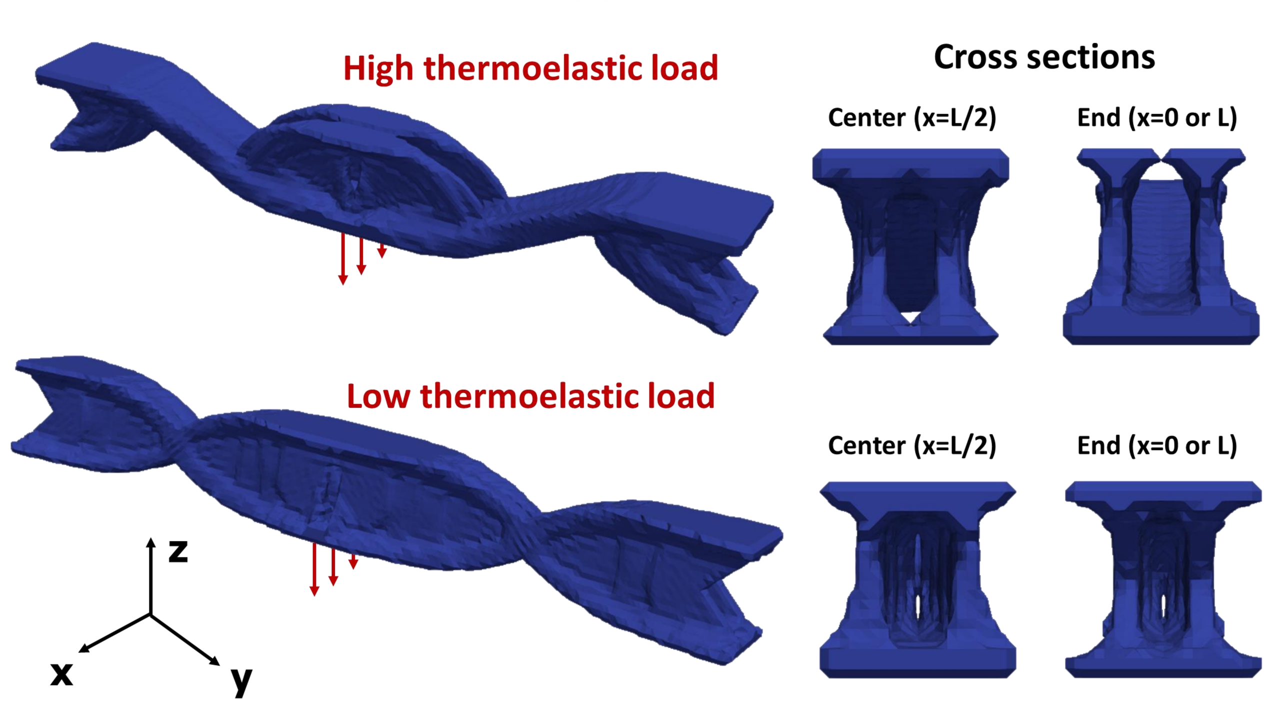
Structural responses upon the thermoelastic loads



Conclusion:
Upon combined load, it is *recommended* to employ nonlinear TopOpt, even with the computational burden.

APPLICATIONS: ADDITIVE MANUFACTURING

3D solution (Directly printable to 3D structure)



ACKNOWLEDGEMENTS

The authors would like to acknowledge support from DARPA and NASA Transformation Tools and Technology Project