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Multiphysics Topology Optimization of Heat Transfer and Fluid Flow Systems

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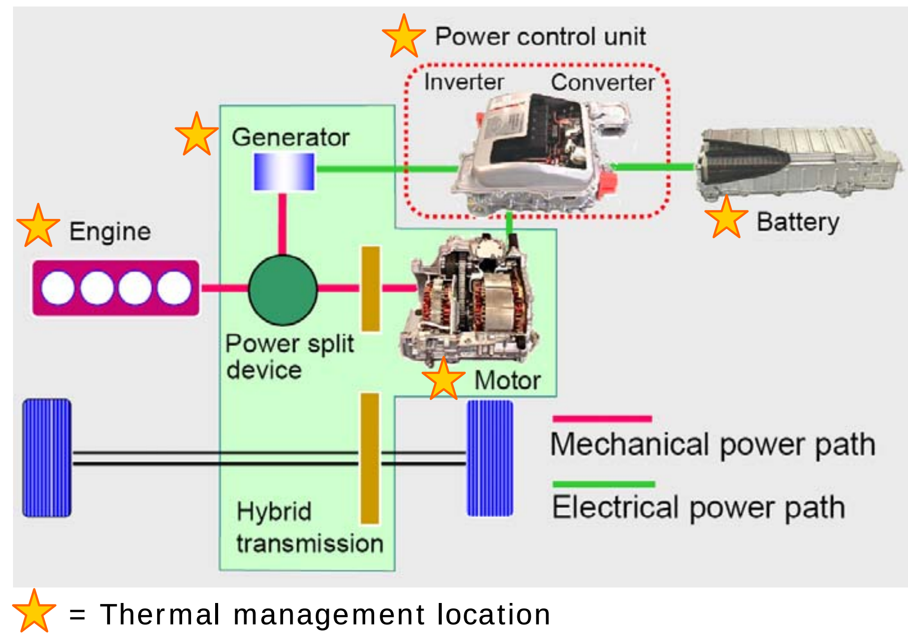
Overview

- Motivation
- Technical Approach
- Single Physics Example
- Multiphysics Example
- Conclusions

Motivation

- Advanced electrical machine design requires efficient thermal / fluid systems

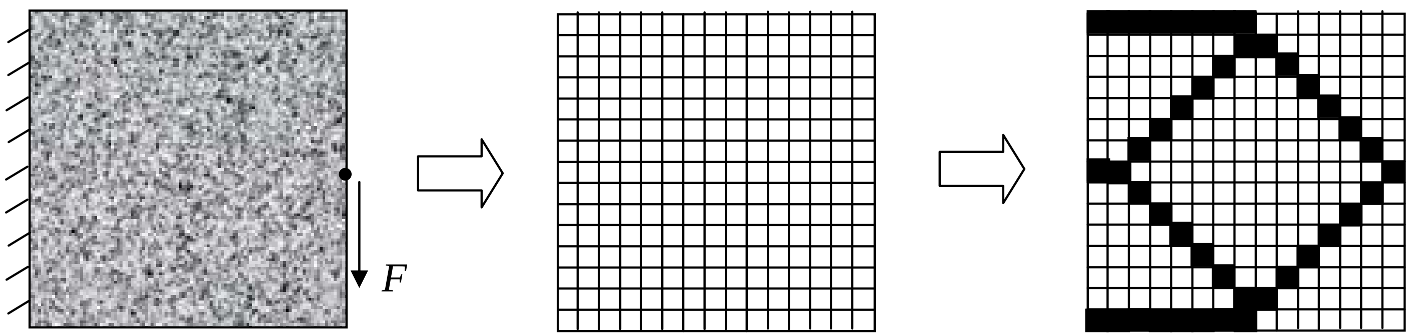
Toyota PRIUS



Toyota Hybrid System (THS) II

Technical Approach

- Topology optimization
  - Local control of density → 0 (void) and 1 (solid)



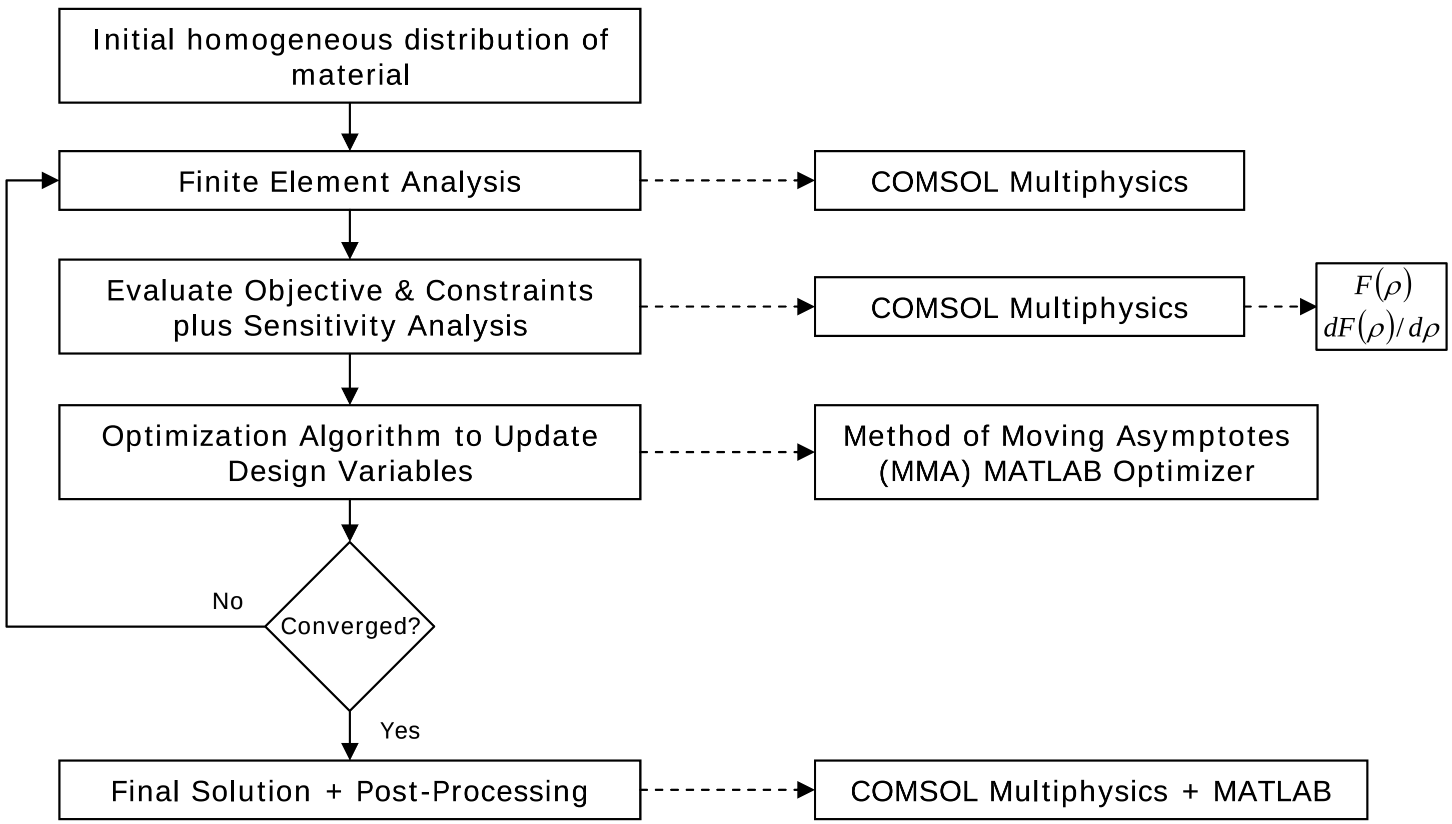
Design Domain + Loads & Boundary Conditions | Discretized Design Domain | Example Optimized Design Domain

$$
\begin{aligned}
&\text{Minimize} && F(\rho) \\
&\text{Subject to} && R(\rho) = 0 \\
& && \rho_{\min} < \rho < 1
\end{aligned}
$$

Allow density design variables to vary continuously for gradient-based optimization

Technical Approach

- Topology optimization
  - COMSOL + MMA in MATLAB environment



Technical Approach

- Governing equations

  - Heat transfer

Eq.1 $-\nabla \cdot (k(\rho)\nabla T) = Q$ => Pure Heat Conduction

Eq. 2 $\rho C(\mathbf{u} \cdot \nabla T) = \nabla \cdot (k(\rho)\nabla T) + Q$ => Convection - Diffusion

  - Fluid mechanics

Eq. 3 $\nabla \cdot \mathbf{u} = 0$ => Fluid Incompressibility

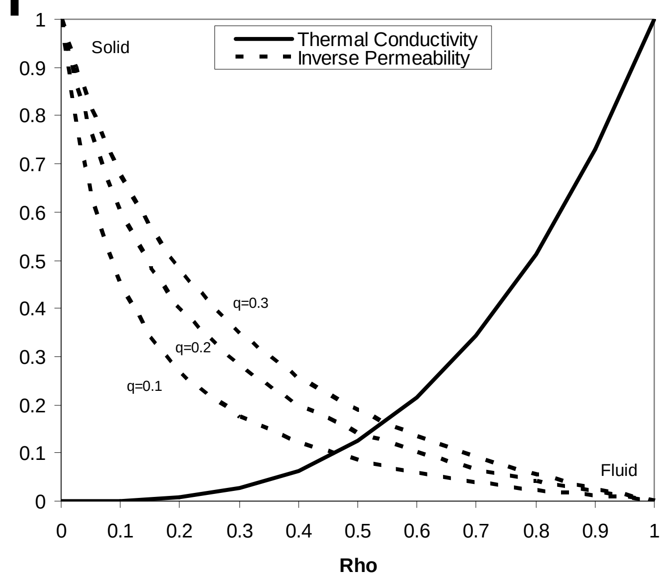
Eq. 4 $\rho(\mathbf{u} \cdot \nabla \mathbf{u}) = -\nabla P + \eta \nabla^2 \mathbf{u} - \alpha(\rho)\mathbf{u}$ => Brinkman - type Equation

Technical Approach

- Design variable interpolation
  - Thermal conductivity

Eq. 5 $$k(\rho) = \left(0.001 + 0.999 * \rho^{p}\right) * k_{\max}$$

=> SIMP (ref. Bendsoe and Sigmund, 2004)



  - Inverse permeability

Eq. 6 $$\alpha(\rho) = \alpha_{\min} + \left(\alpha_{\max} - \alpha_{\min}\right) * \left(\frac{q * (1-\rho)}{(q+\rho)}\right)$$

=> RAMP (ref. Olesen et al., 2006)

- Thermal / fluid objective function

Eq. 7 $$F(\rho) = w_1 B(\rho) + w_2 C(\rho)$$

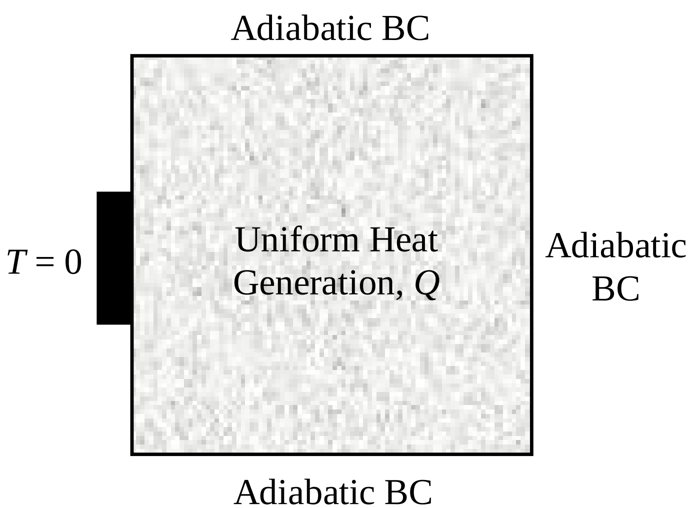
Related to total fluid power dissipated in porous medium

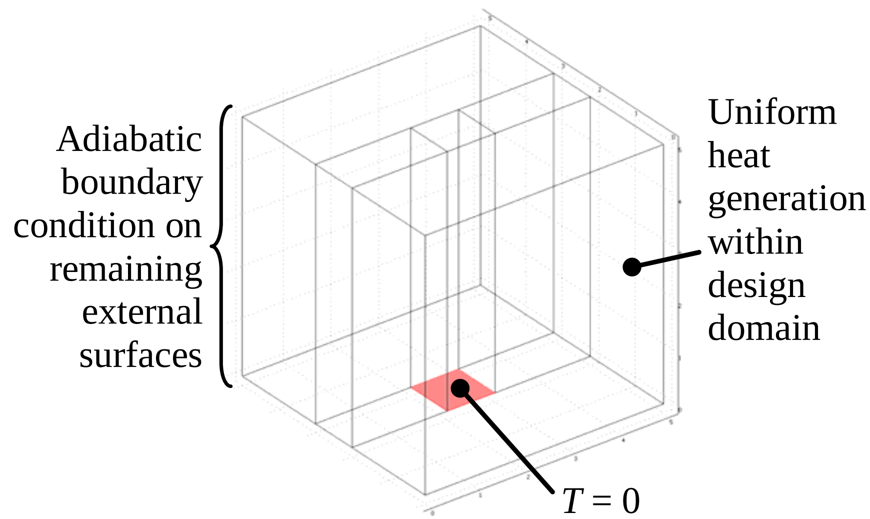
Related to mean temperature of domain

Weighting values (2X)

Single Physics Example

- Optimization for pure heat conduction
  - Model descriptions



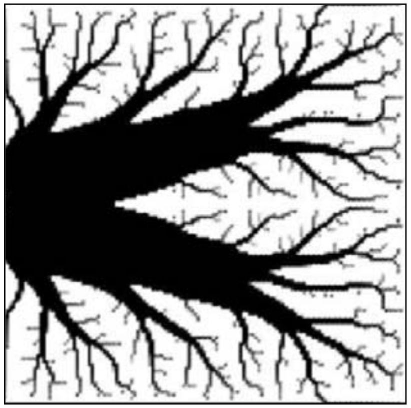


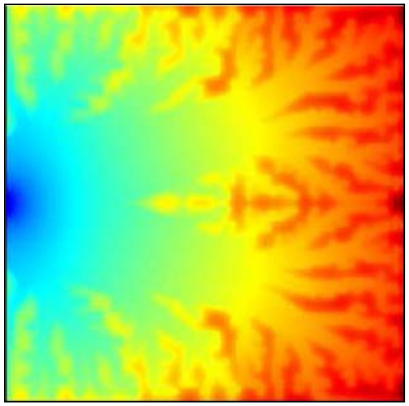
<u>2-D Domain</u>

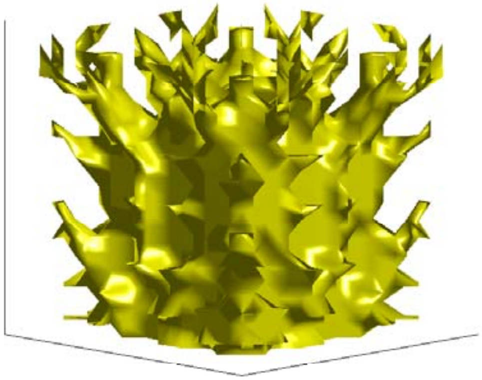
<u>3-D Domain</u>

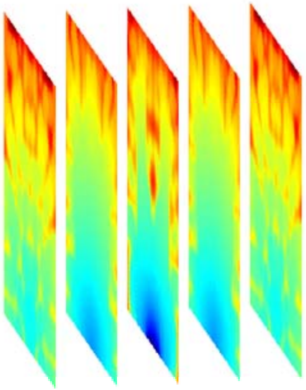
Single Physics Example

- Optimization for pure heat conduction
  - Results


Optimal Topology


Temperature Distribution


Optimal Topology

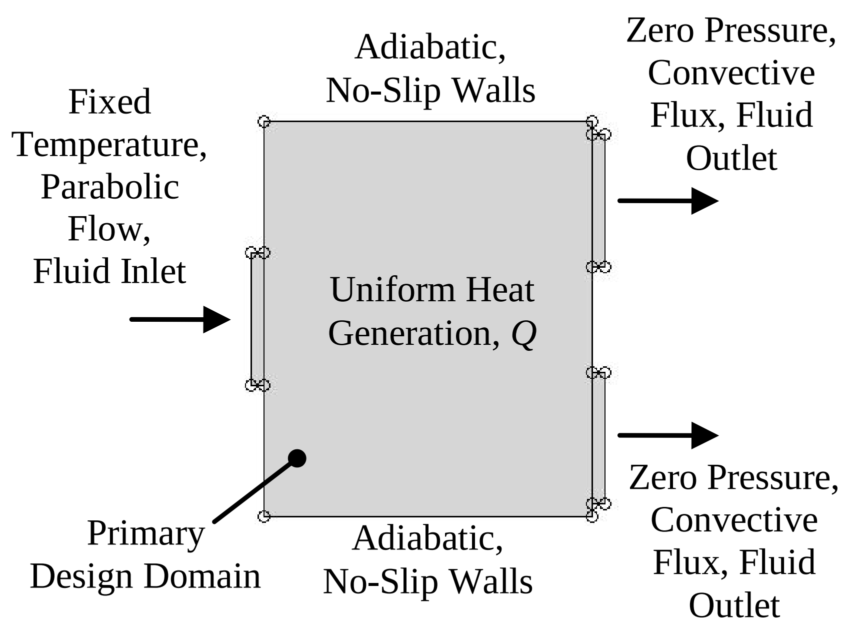

Temperature Distribution

<u>2-D Domain</u>

<u>3-D Domain</u>

Multiphysics Example

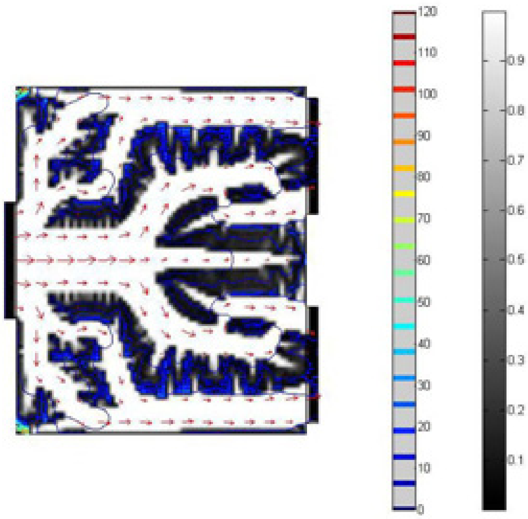
- Optimization for heat transfer & fluid flow
  - Model description – three terminal device



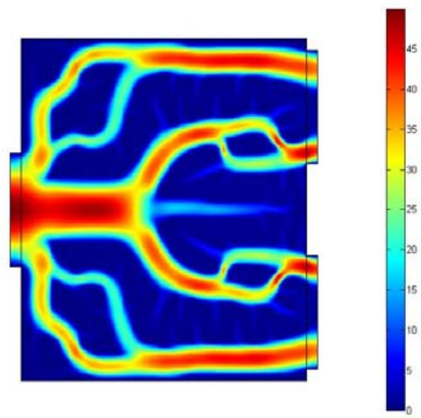
2-D Domain

Multiphysics Example

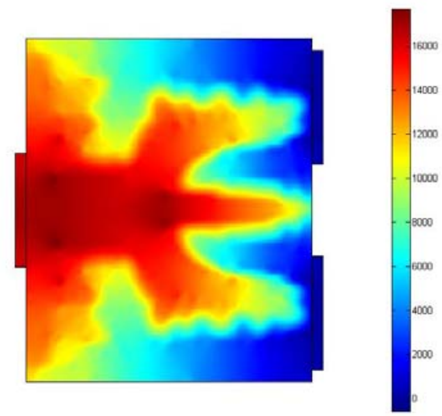
- Optimization for heat transfer & fluid flow
  - Results for $w_1 >> w_2$ in objective function



Optimal Topology, fluid velocity arrows, and temperature contours



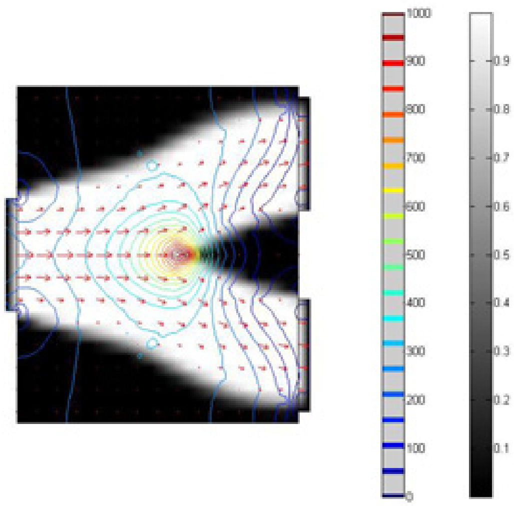
Fluid velocity contours



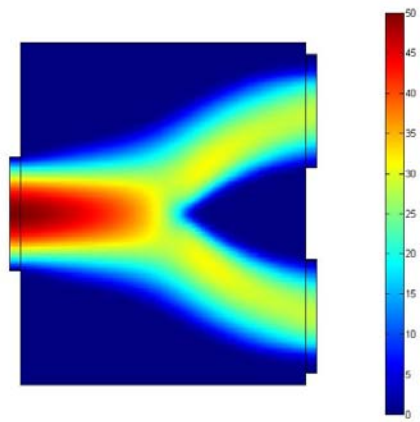
Fluid pressure contours

Multiphysics Example

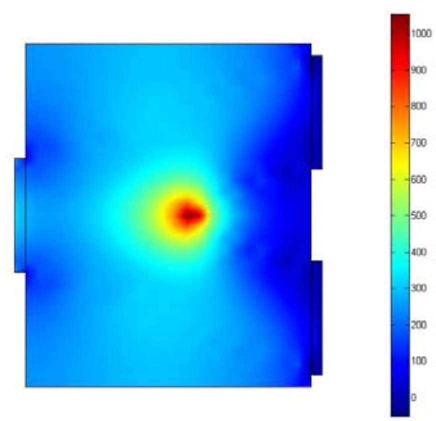
- Optimization for heat transfer & fluid flow
  - Results for $w_2 >> w_1$ in objective function



Optimal Topology, fluid velocity arrows, and temperature contours



Fluid velocity contours



Fluid pressure contours

Conclusions

- Multiphysics topology optimization demonstrated
  - COMSOL + MMA in MATLAB environment
  - Heat transfer and fluid flow objectives
- Ongoing work
  - Evaluation of interpolation schemes for oscillation suppression during solution
  - Efficient methods for determining weighting values
  - Novel applications to 3-D thermal / fluid heat transfer systems

Questions?

Thank you!