Precise Control of Cure Processes During Repair

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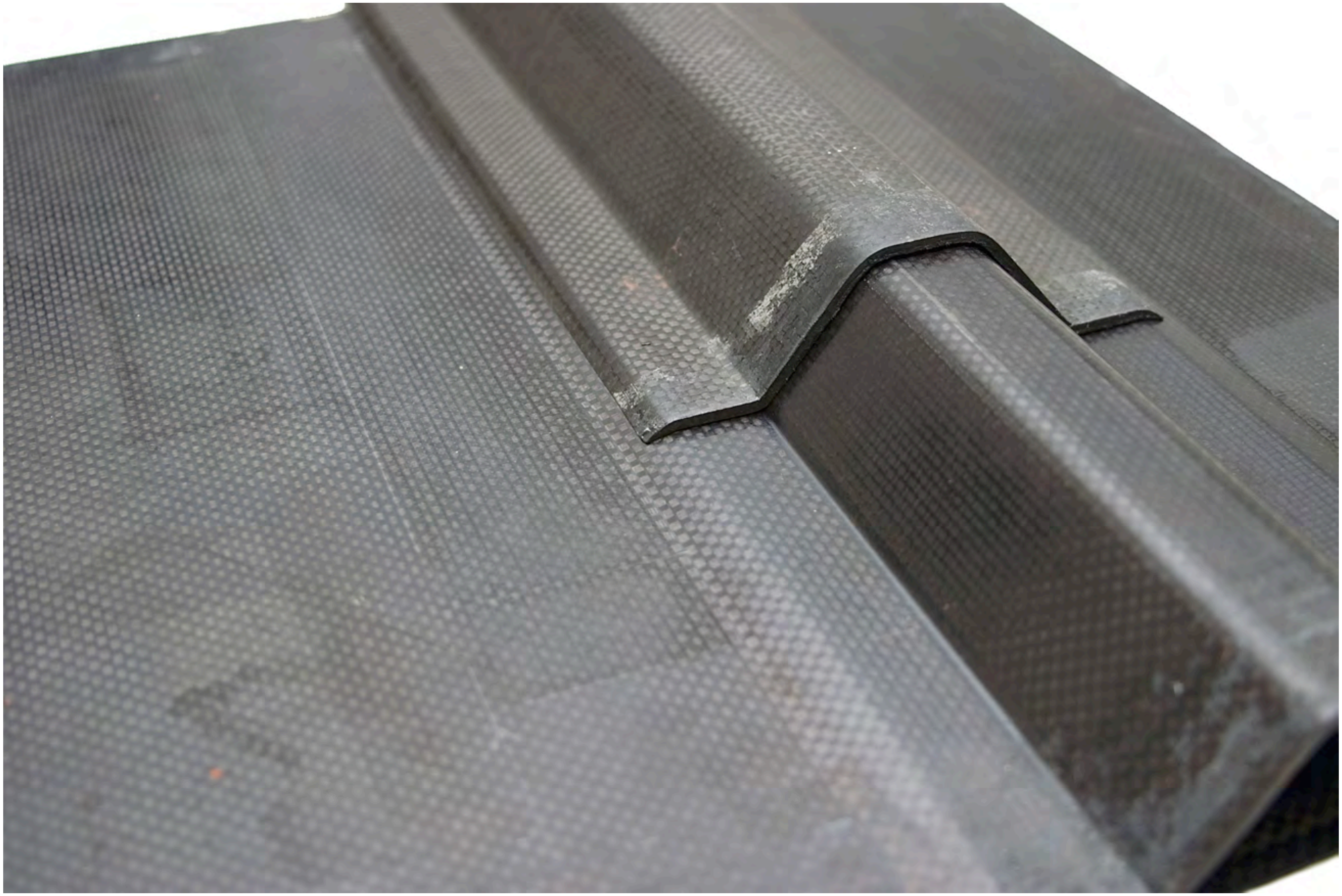
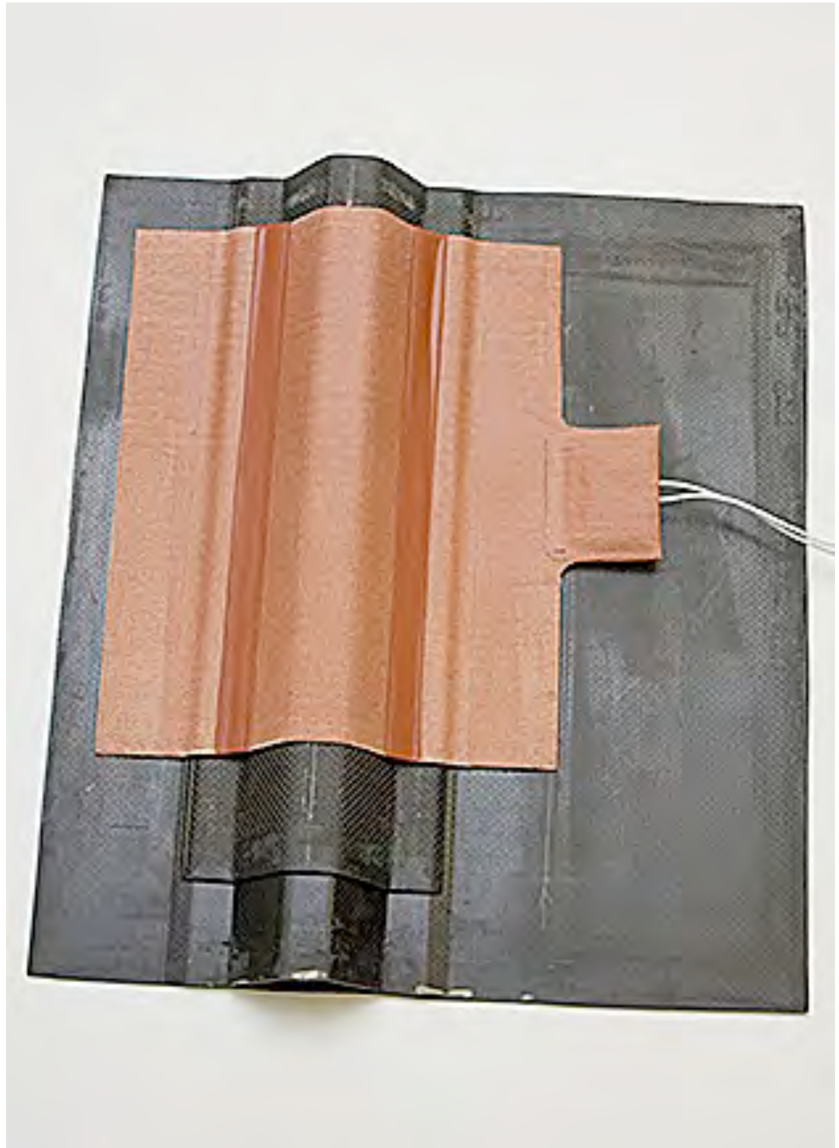




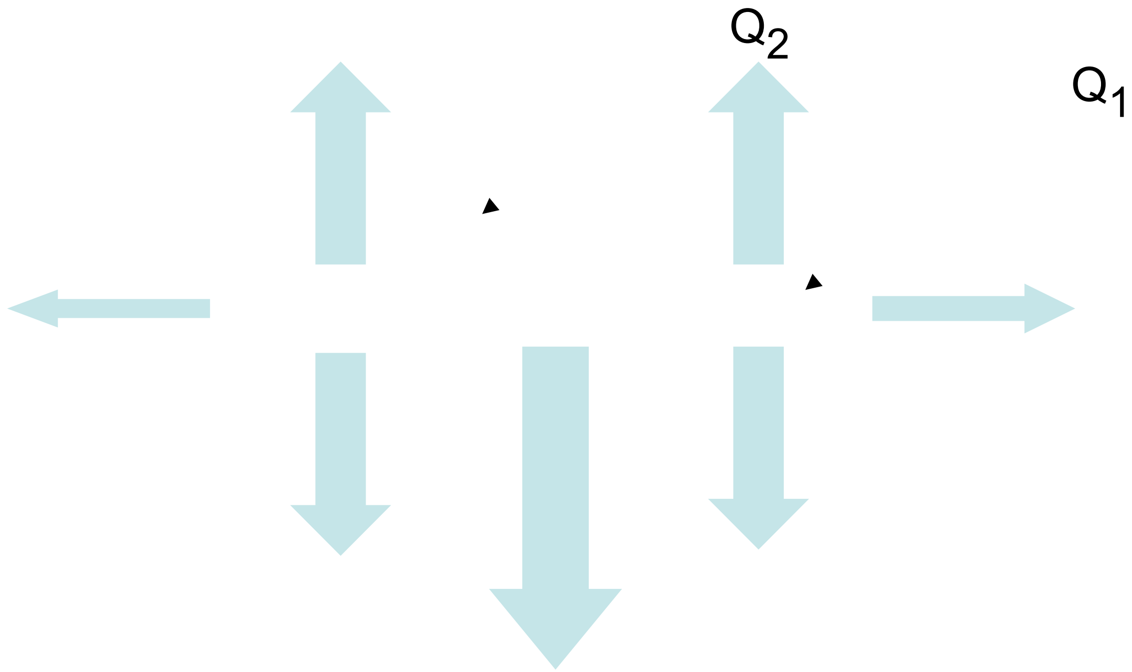
Optimization of Composite Repairs

GOAL: **Produce a Spatially Uniform Temperature at the Repair Site for a Specified Time**

APPROACH: **Custom Design a Heating Blanket or Heating Source with Spatially Varying Heating Density**

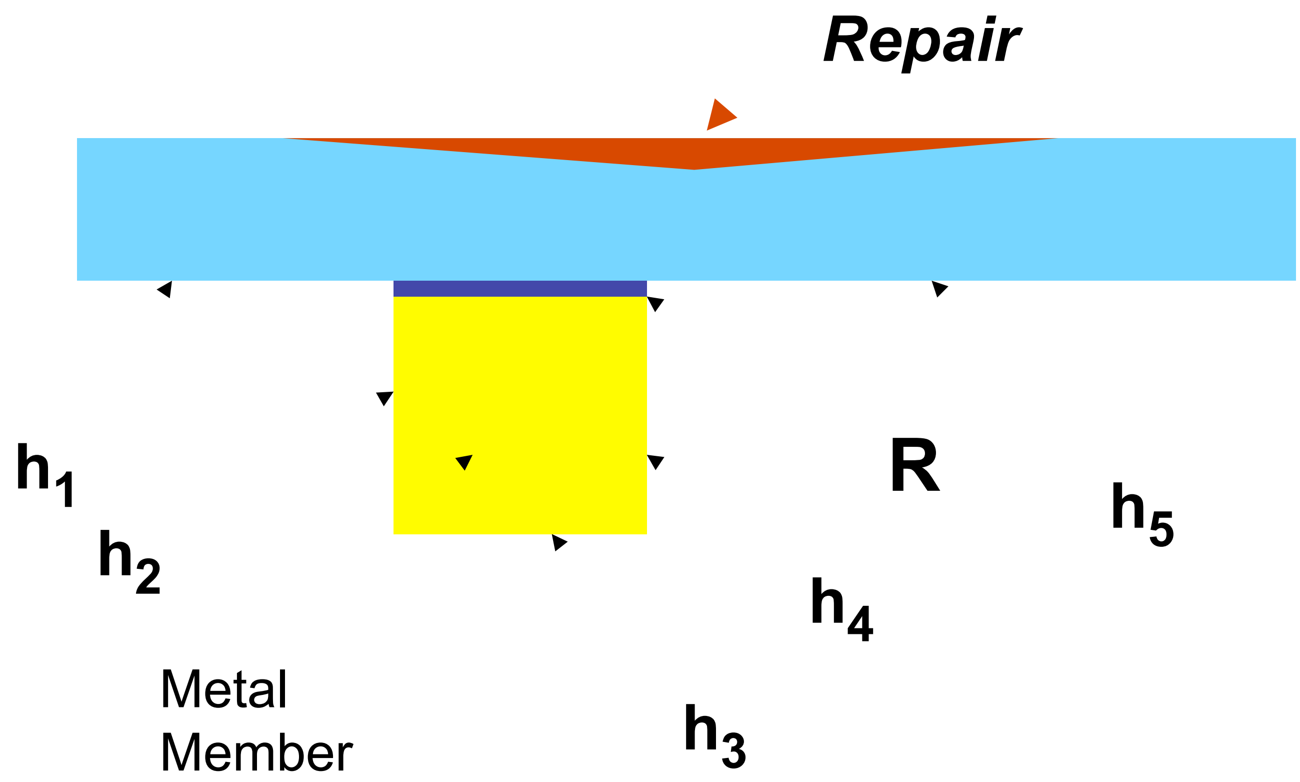
PROBLEM: **How to Determine the Needed Distribution of Heat**

Schematic of Heat Loss



What are Q_1 and Q_2

Required: The Thermal Characteristics of the Repair Site

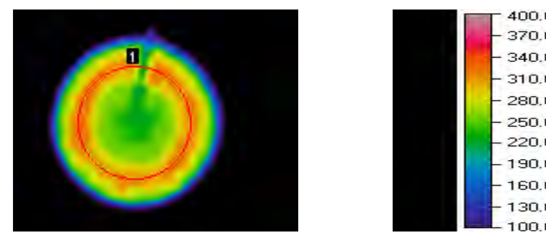


Proposed: Heat the system using a Thermal Blanket with Constant Heating Density and Measure Temperatures—Estimate Thermal Characteristics

TC

Blanket

System



System

Inverse Method

Using measured temperatures estimate the characteristics, P_i

$T(t) = M(x,y,z,t,P_1,P_2,\ldots P_n)$ by choosing values of P_i until the model gives a good fit to the data

$$\begin{Bmatrix} \Delta P_1 \\ \Delta P_2 \\ \Delta P_n \end{Bmatrix} = (A^T A)^{-1} A^T \{T - M(P_0)\}$$

where $$A = \left[\frac{\partial\{M\}}{\partial P_1} \quad \frac{\partial\{M\}}{\partial P_2} \quad \frac{\partial\{M\}}{\partial P_n} \right]$$

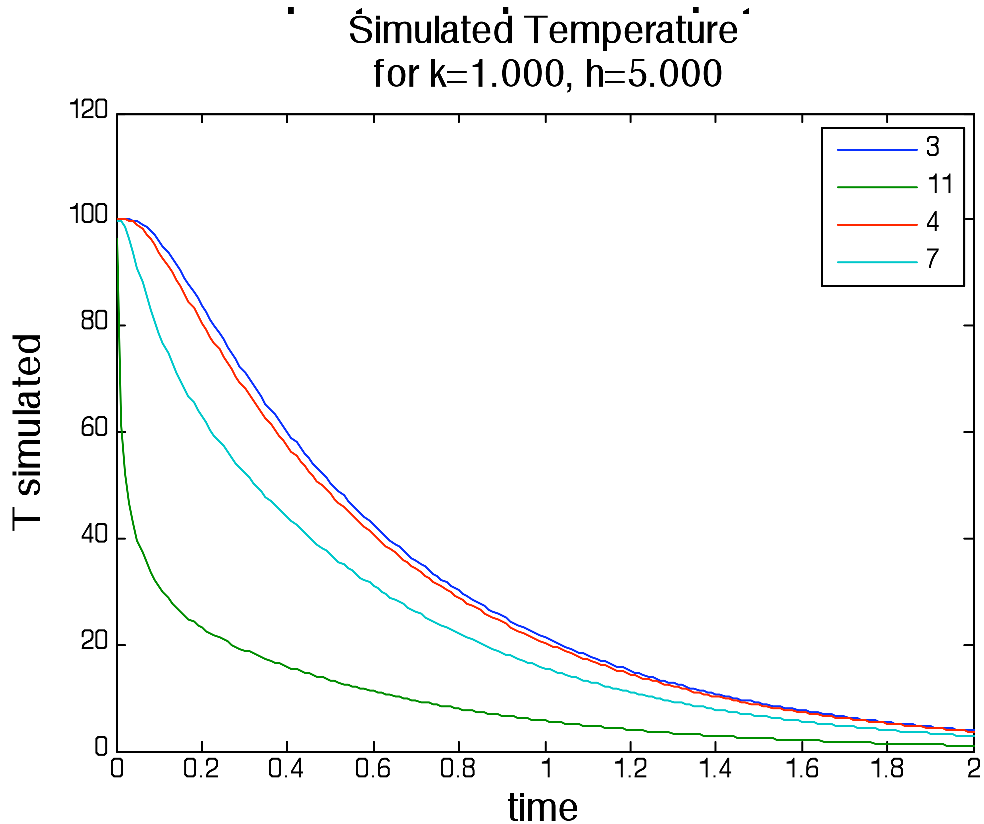
Example

T(x,0)=100

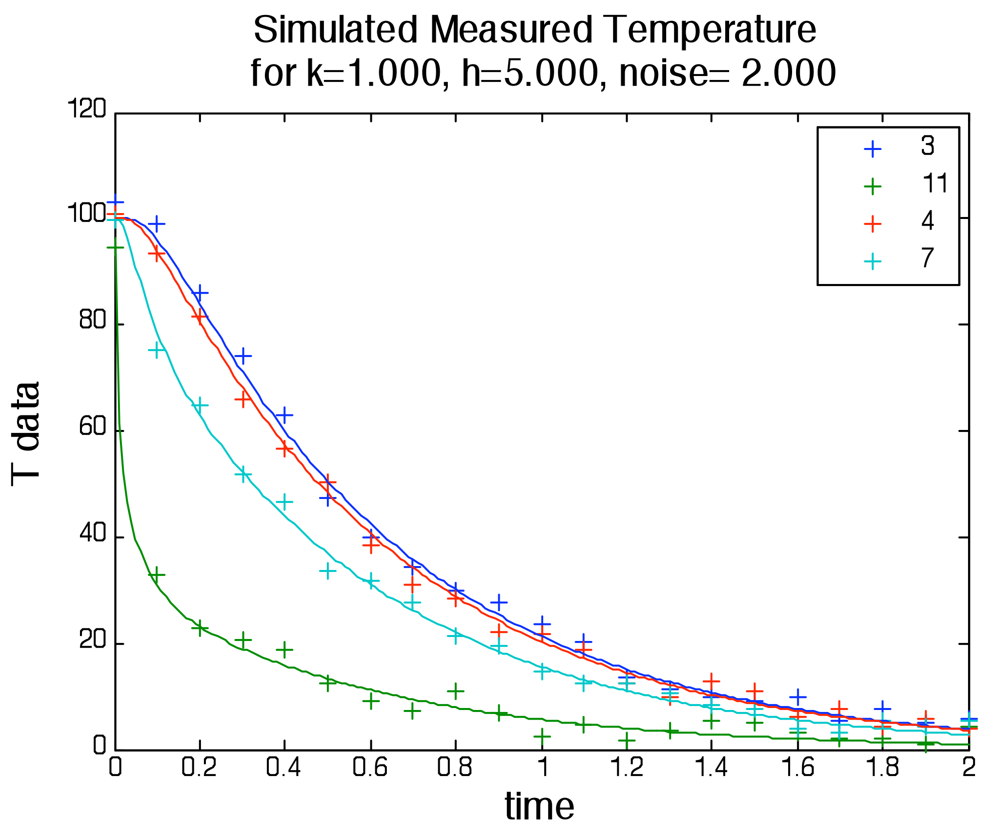
$$q = h(T(L,t) - T_\infty)$$

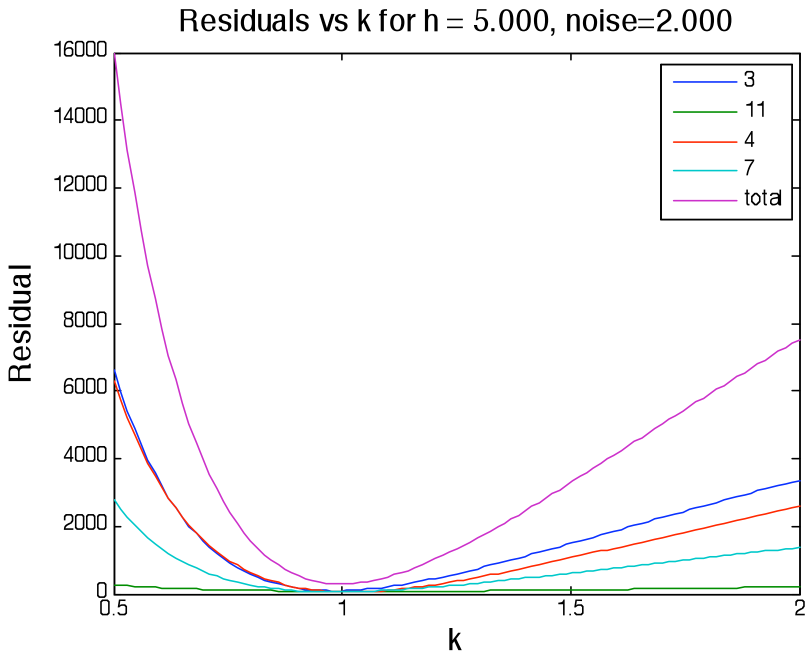
Estimate conductivity (k) and heat transfer coefficient (h) using Temperature

at several va



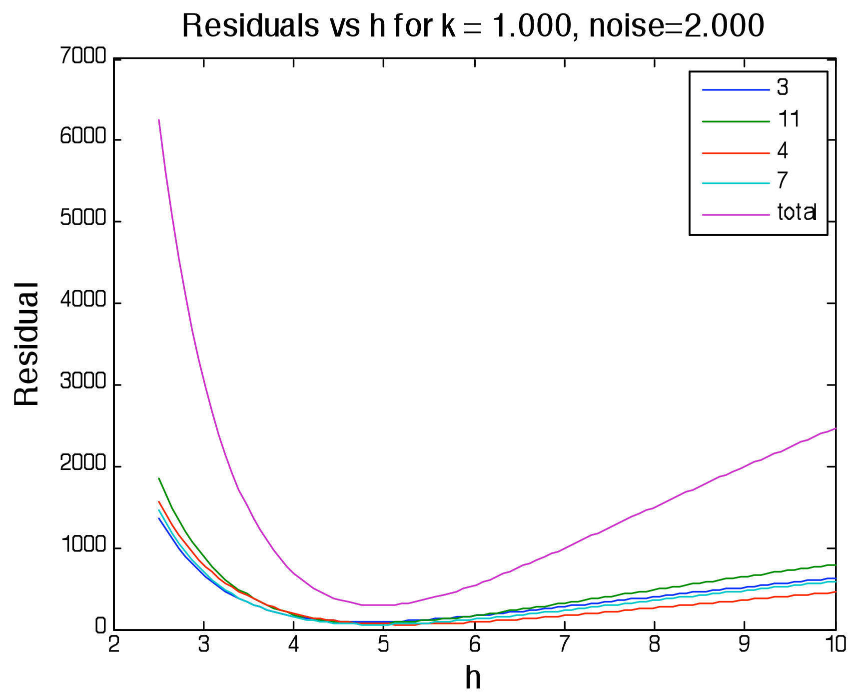
The Measured Temperatures are noisy



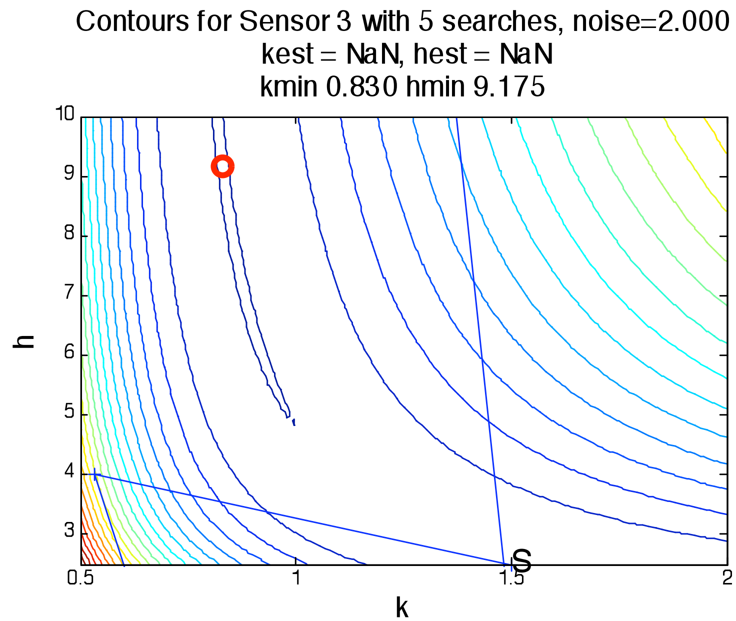


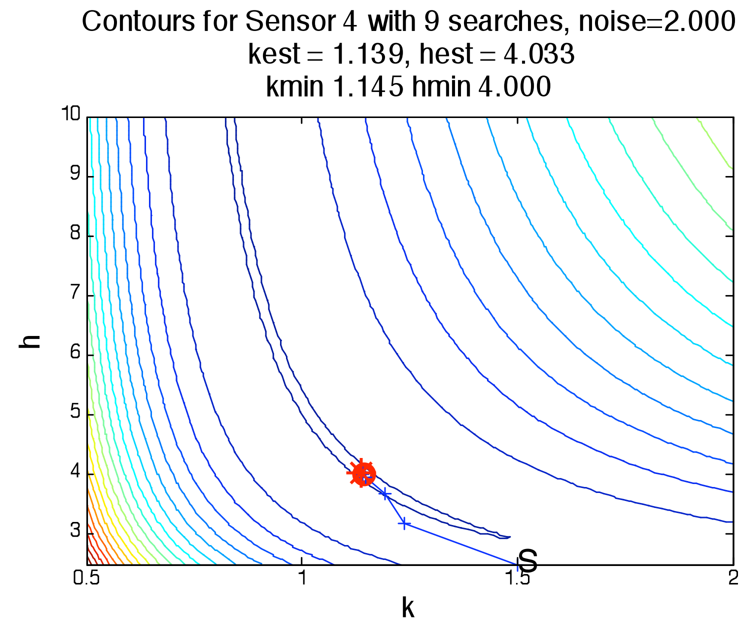
Can we estimate k by itself?

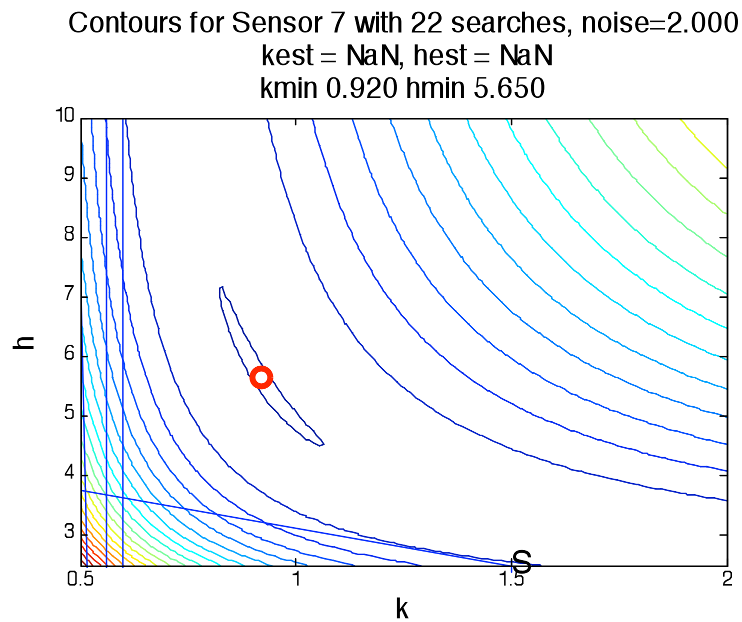
Can we estimate h by itself?

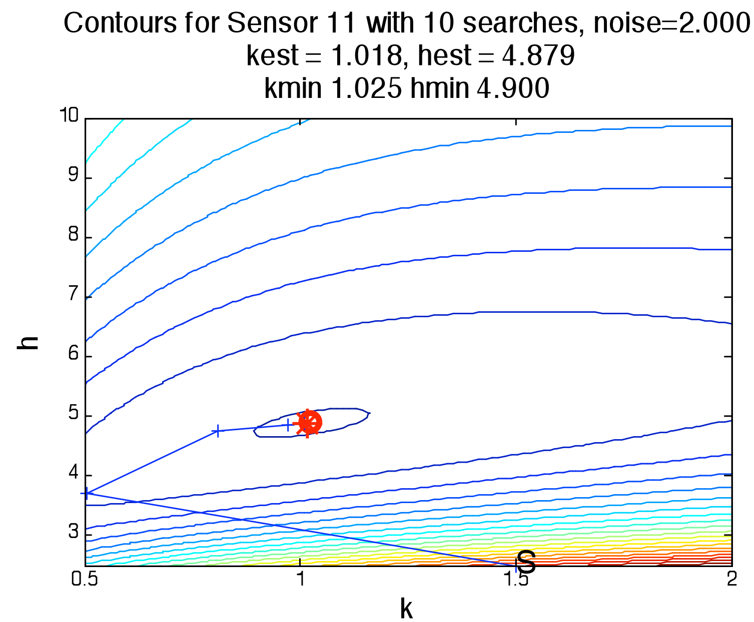


Estimating k and h simultaneously

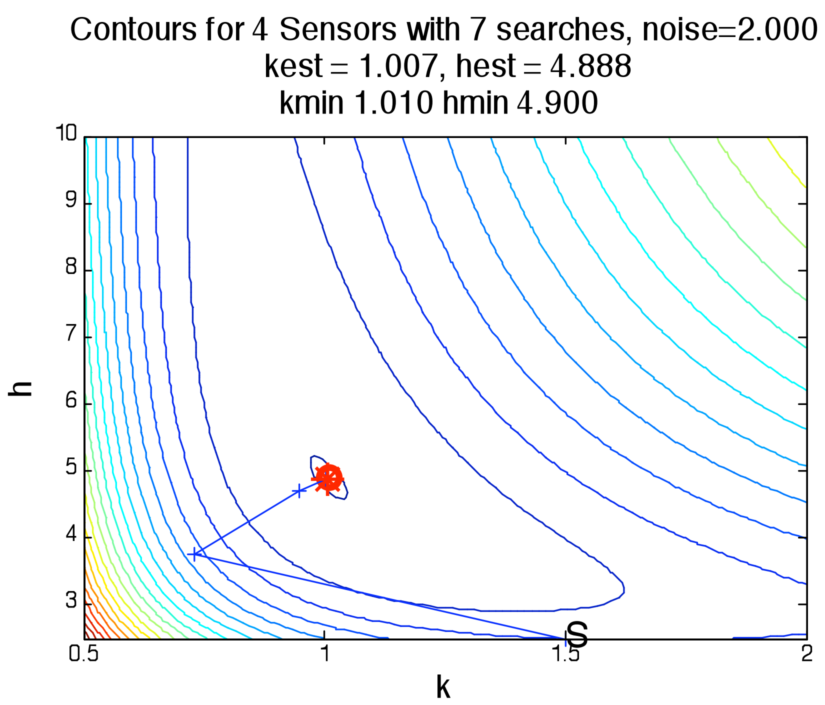


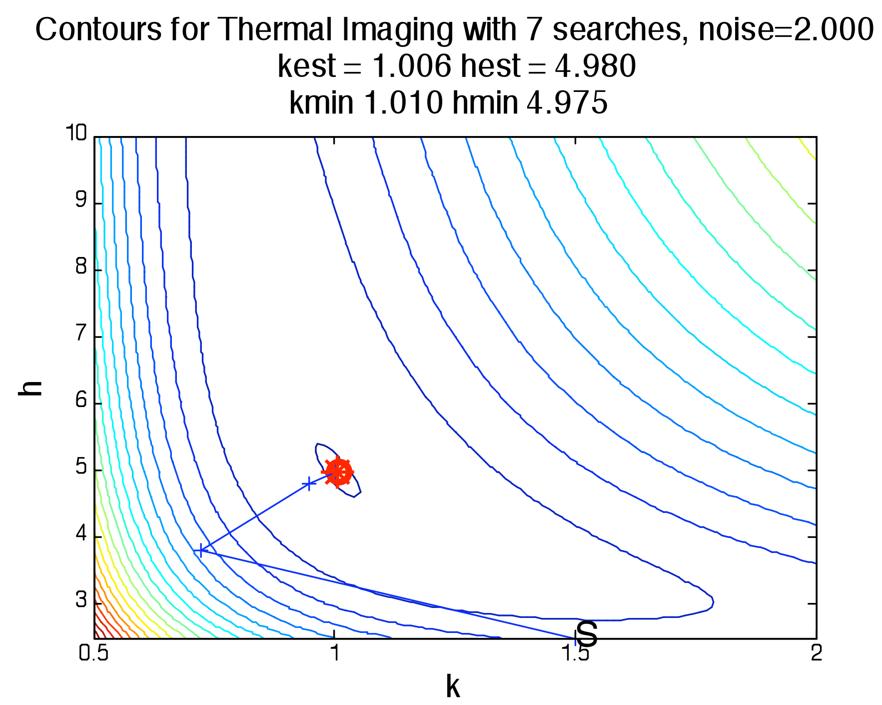






Estimating k and h with multiple sensors





The Problem is that each search requires 4 calculations of the temperatures

Using a Reduced Model

Why?

		Assembly	Solving
1D	N~30	1	1
2D	N~900	30	$27\ 10^3$
3D	N~27000	900	$700\ 10^6$

Process:

1) Compute the Model response for a range of Parameters

2) Extract a set of patterns that accurately reflect the response

3) Expand the solution in terms of these patterns

POD Proper Orthogonal Decomposition

1) Each pattern is a vector of nodal values of the Temperature
2) Each pattern vector is orthogonal to all others
3) Each subsequent pattern contains less information
4) The solution is a linear combination of the pattern vectors

Difficulties

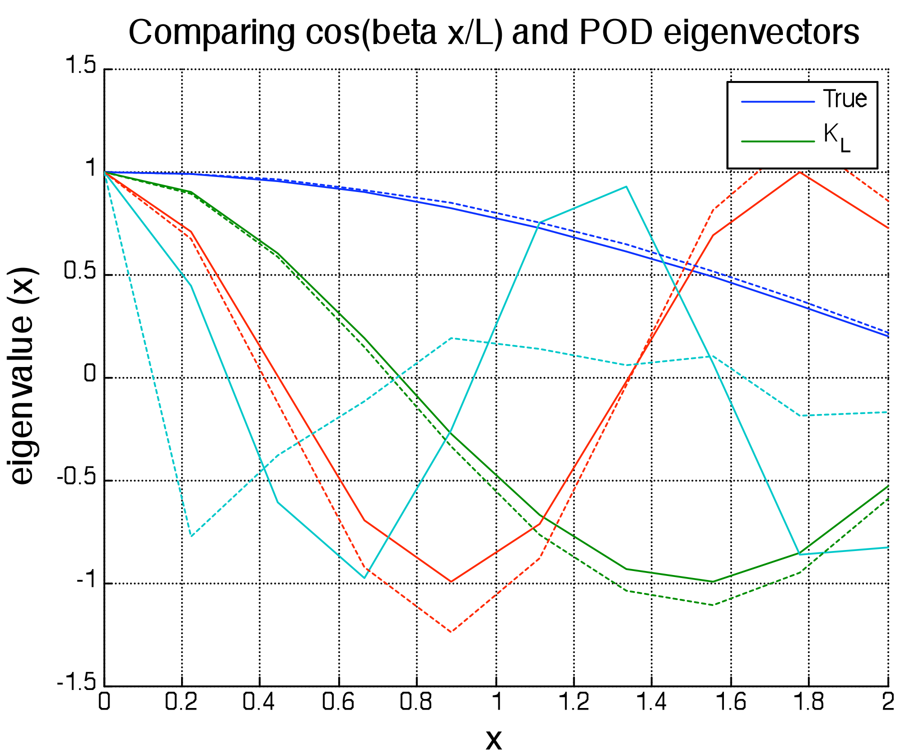
1) No proof that the solution using a reduced model approaches the true response
2) Solutions can be obtained only for parameters within the range of the sampled responses

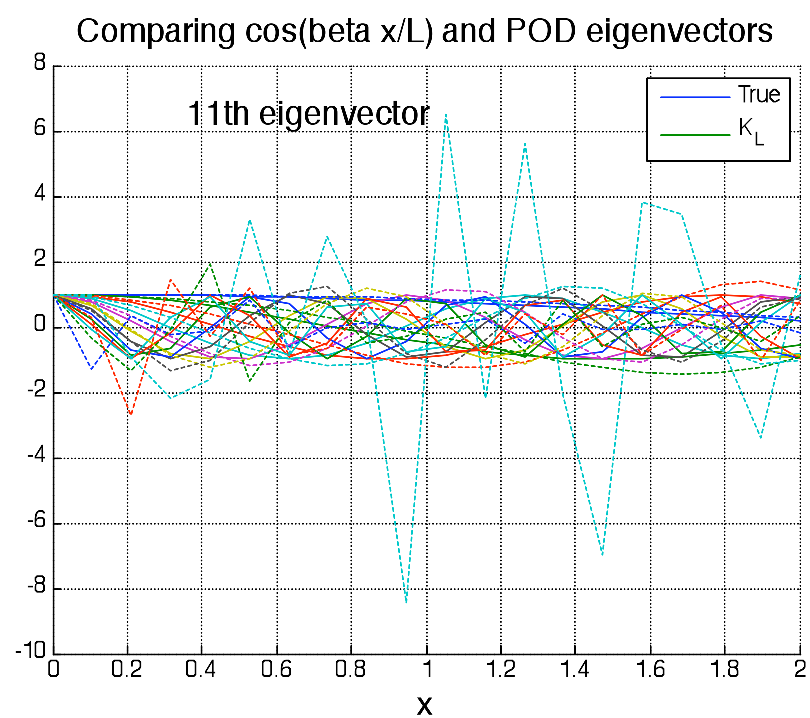
Advantage

1) If M patterns are used, the problem is equivalent to N=M
2) For nonlinear problems, FEM matrices must be inverted for each choice of parameter, but again N=M

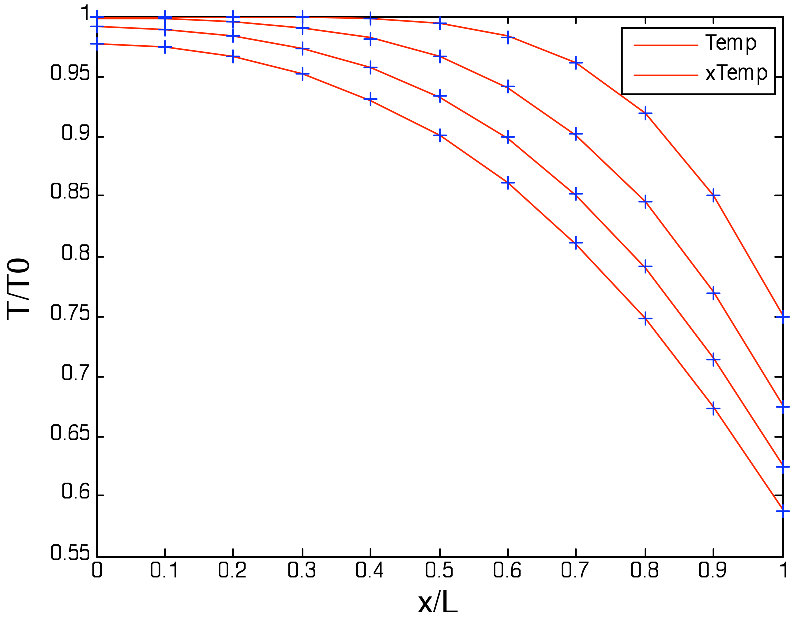
Fourier Series Solution

$$T(x,t) = \sum_{\beta} f(x,\beta) e^{-\beta^2 kt/\rho c}$$

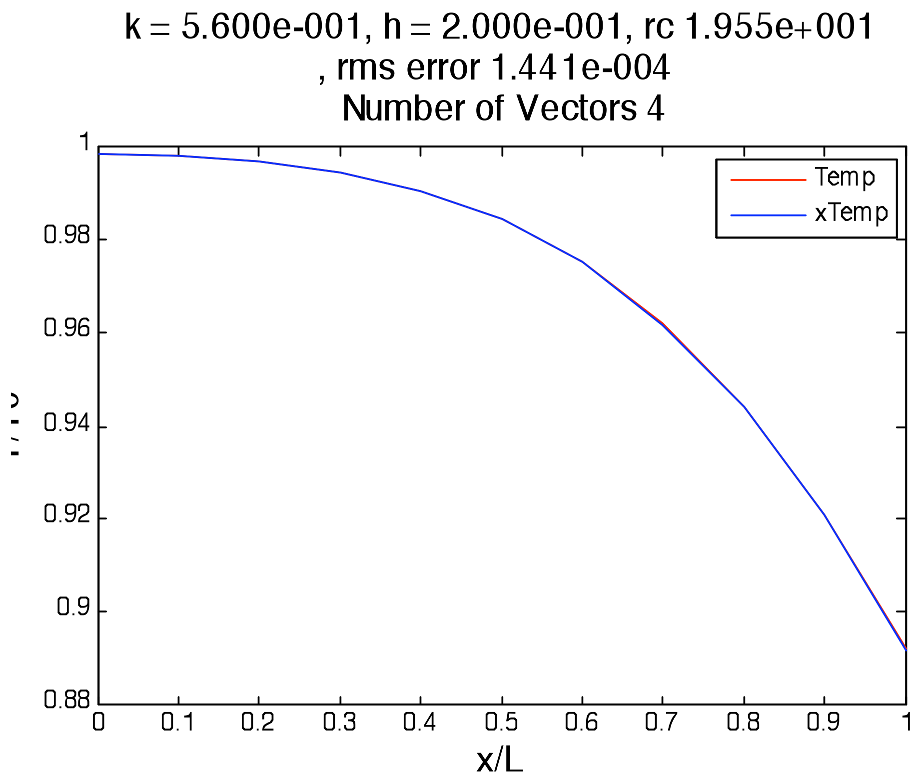




Reproducing the Exact Solution with POD



Interpolating for k, h, and rho c



Final Procedure

1) Run 3D FEM for ranges of all parameters to be estimated

2) Extract Patterns

3) Generate Sensitivities from the Reduced Model

4) Estimate Parameters

5) Predict Heat Losses from Repair Site

6) Design Heating Blanket