Precise Control of Cure Processes During Repair

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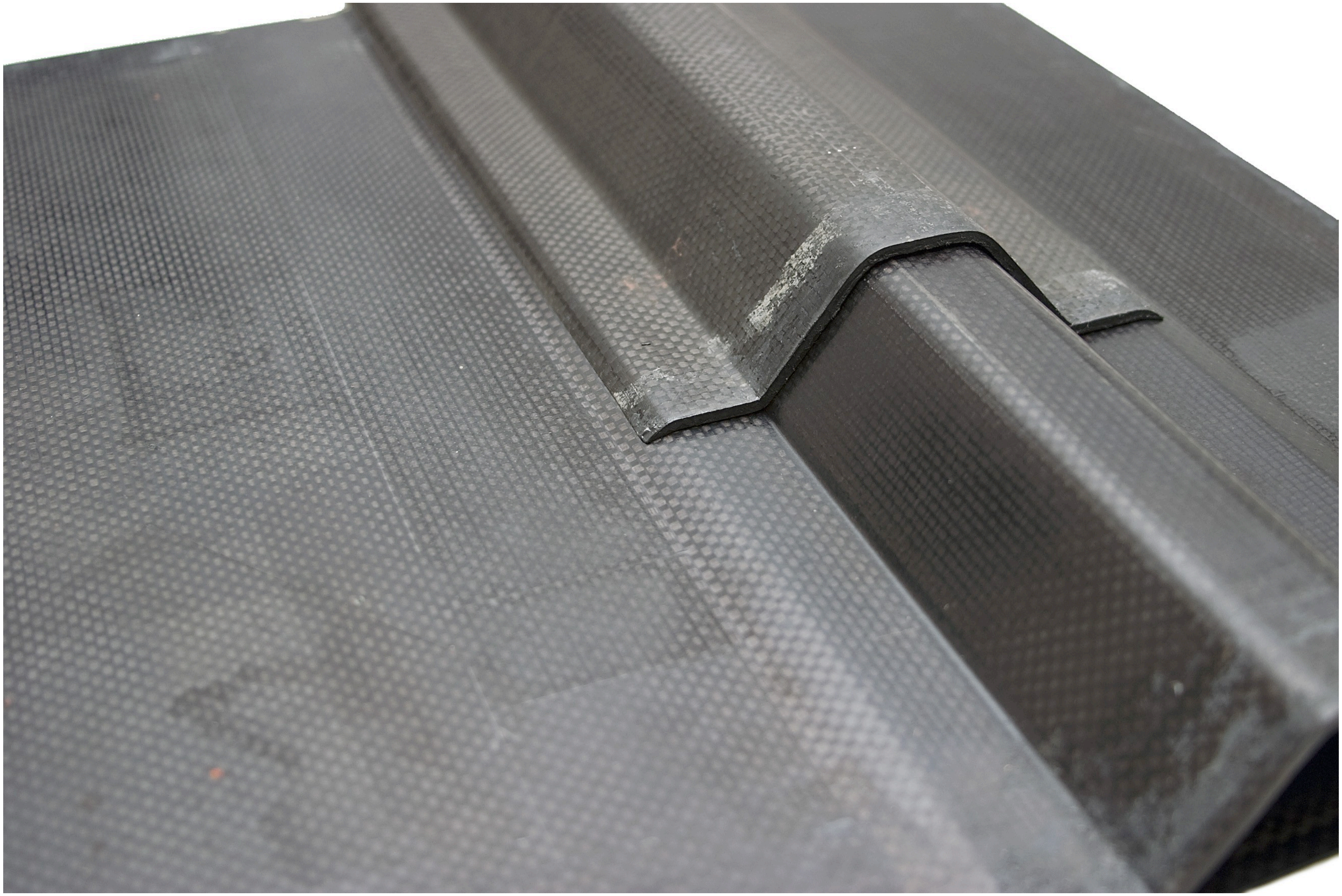
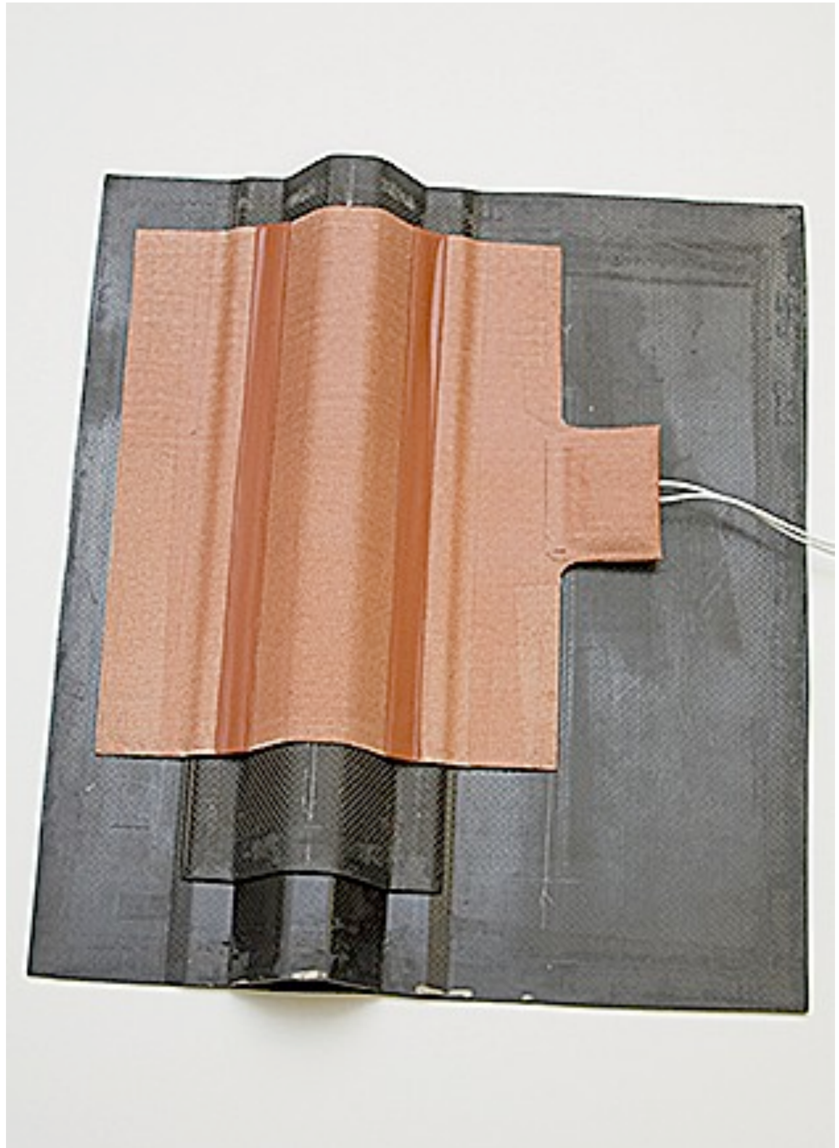




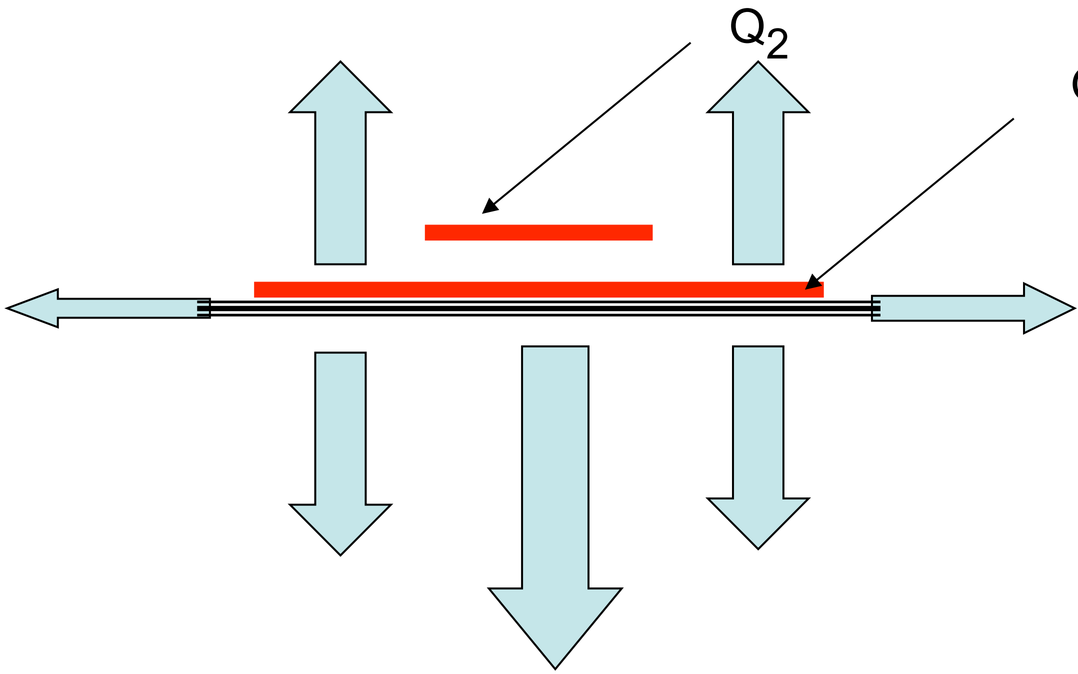
Optimization of Composite Repairs

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**

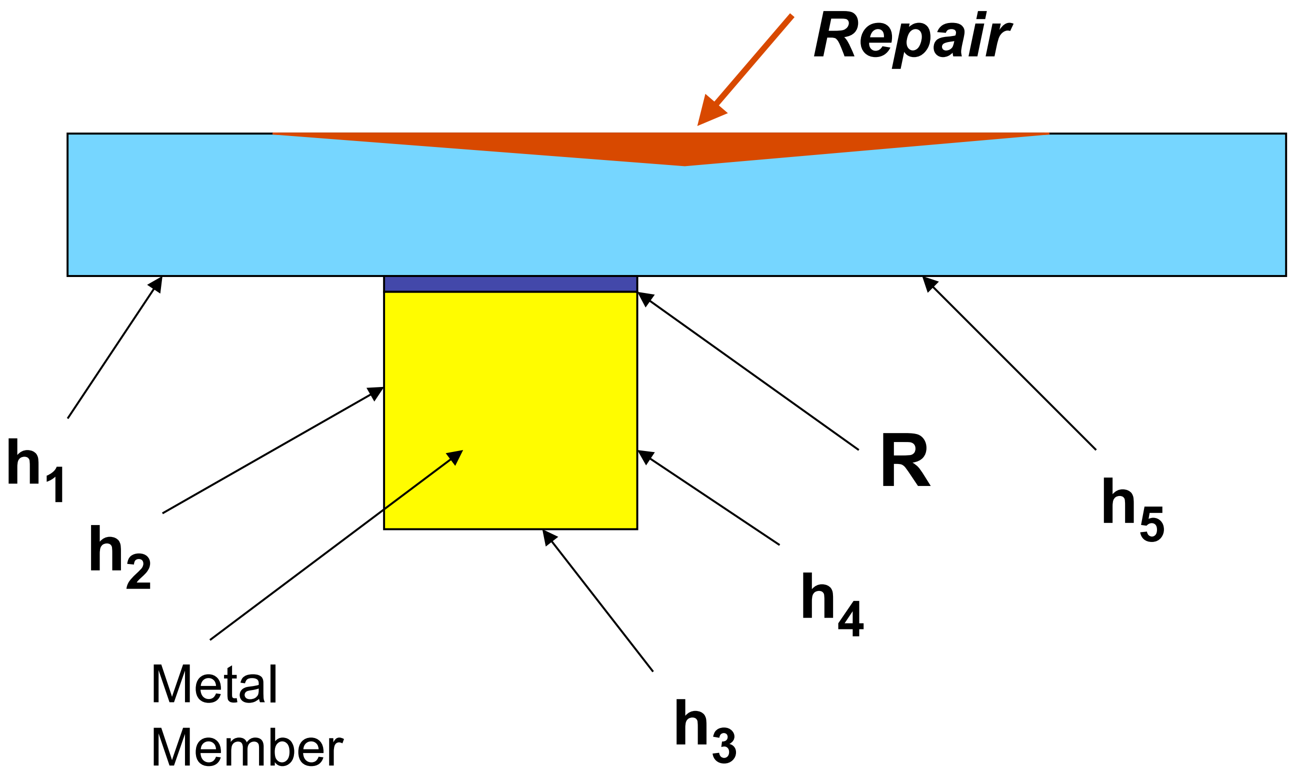
PROBLEM: **How to Determine the Needed Distribution of Heat**

Schematic of Heat Loss

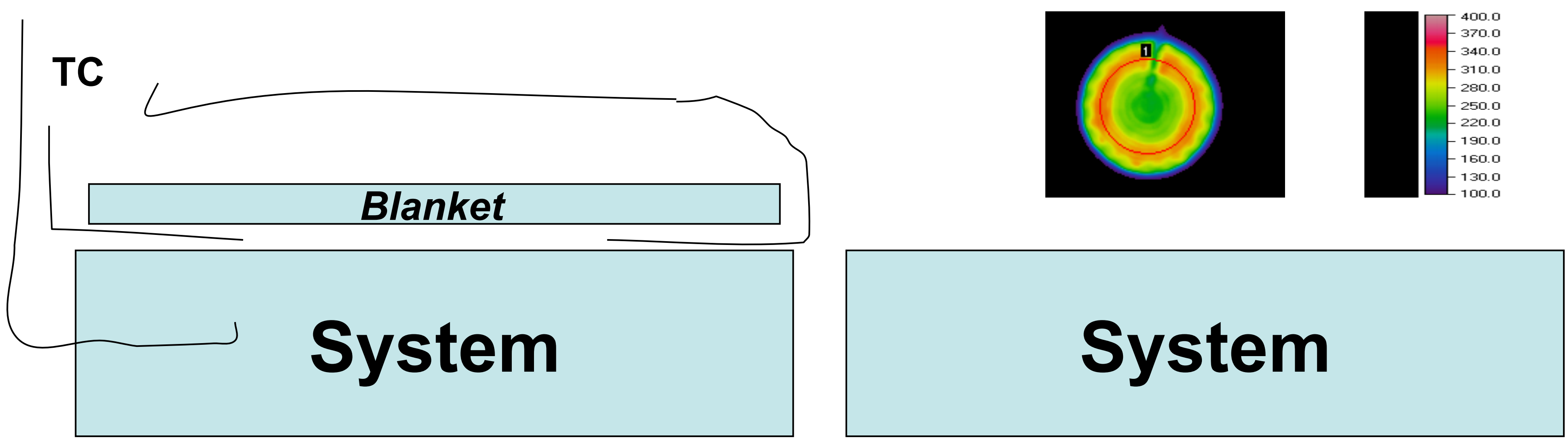


What are Q_1 and Q_2

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



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

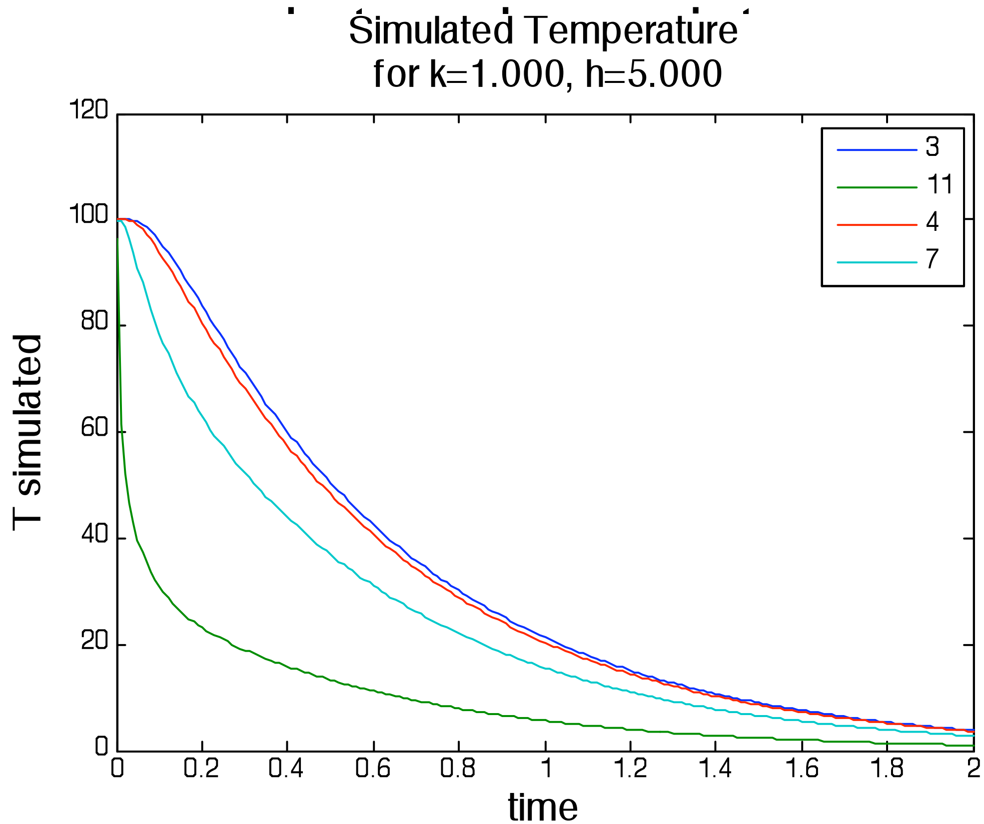
T(x,0)=100

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

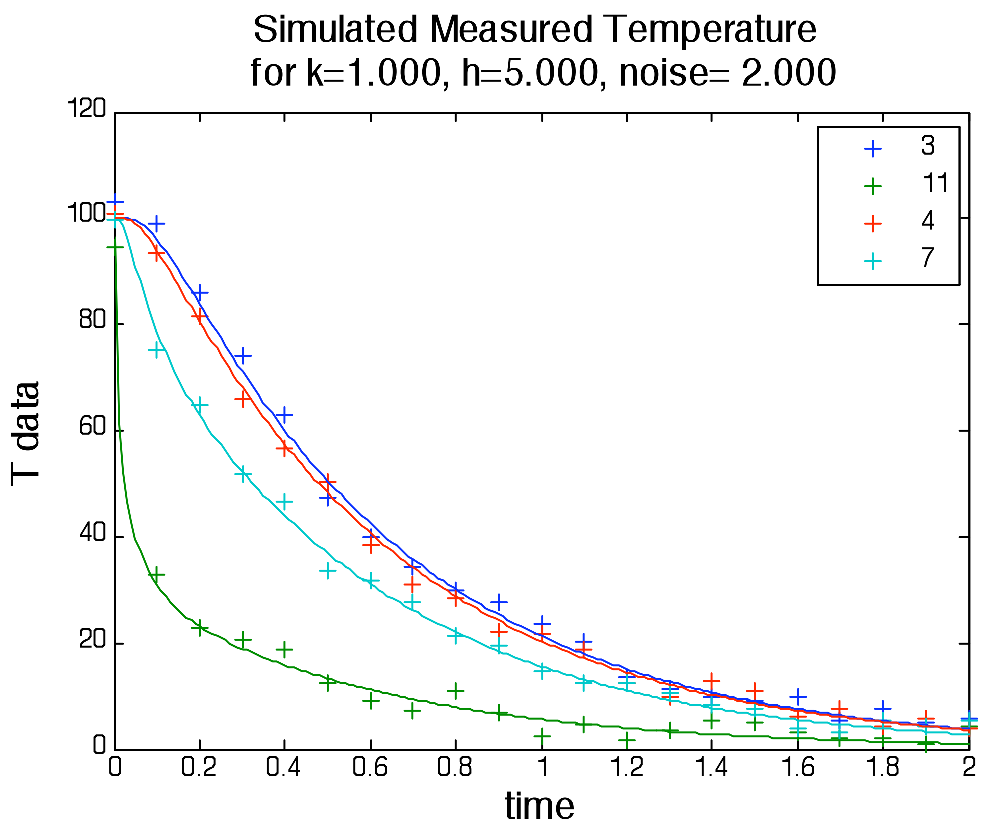
Estimate conductivity (k) and heat transfer coefficient (h) using

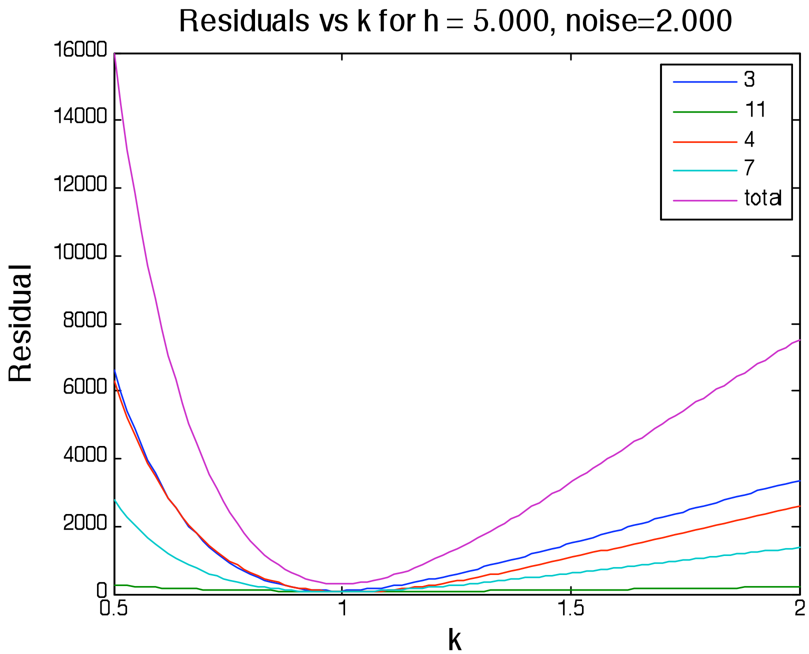
Temperature

at several va



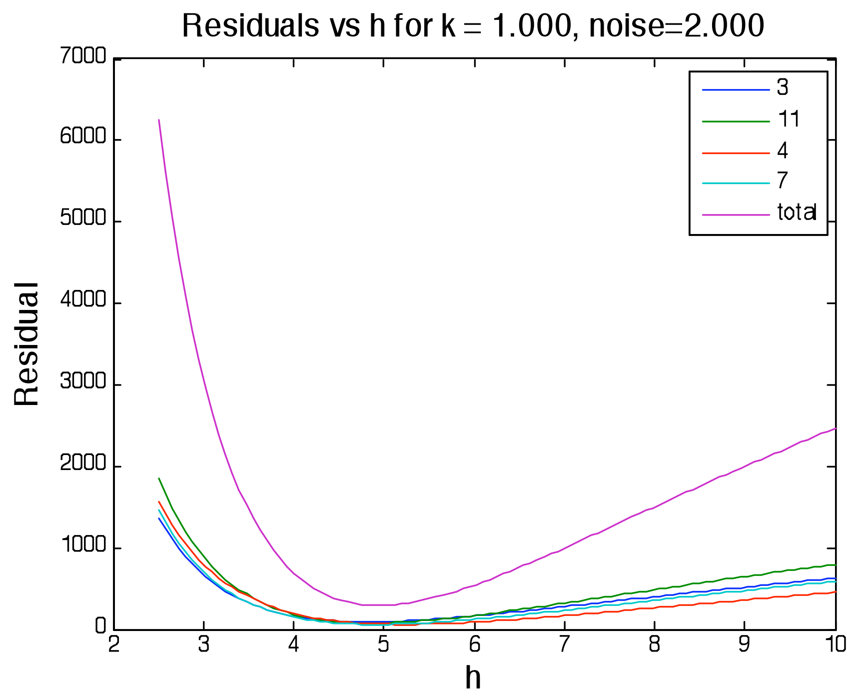
The Measured Temperatures are noisy





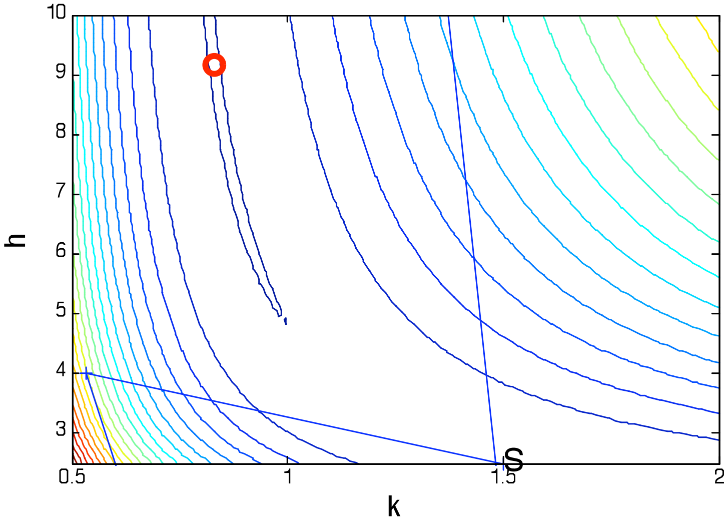
Can we estimate k by itself?

Can we estimate h by itself?

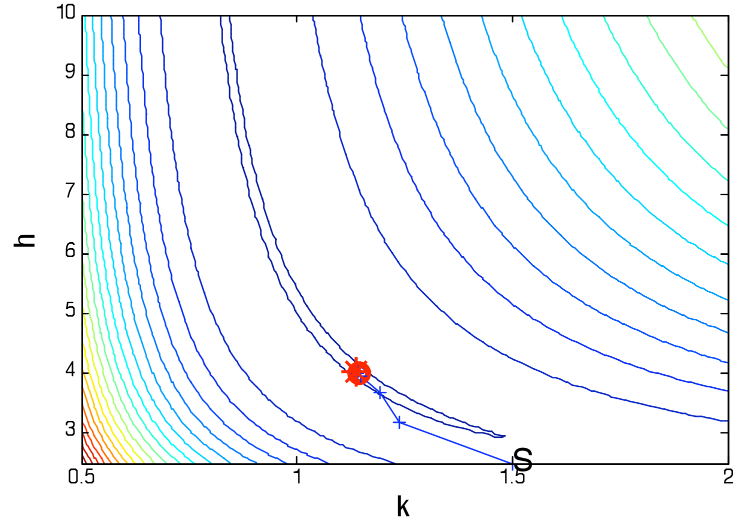


Estimating k and h simultaneously

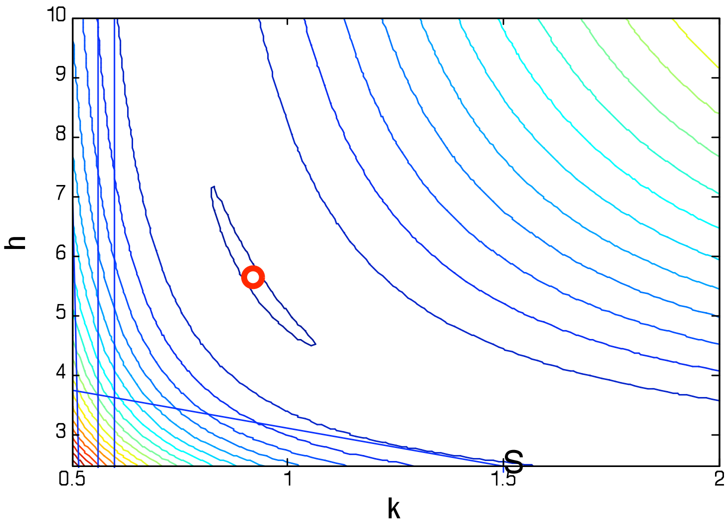
Contours for Sensor 3 with 5 searches, noise=2.000
kest = NaN, hest = NaN
kmin 0.830 hmin 9.175



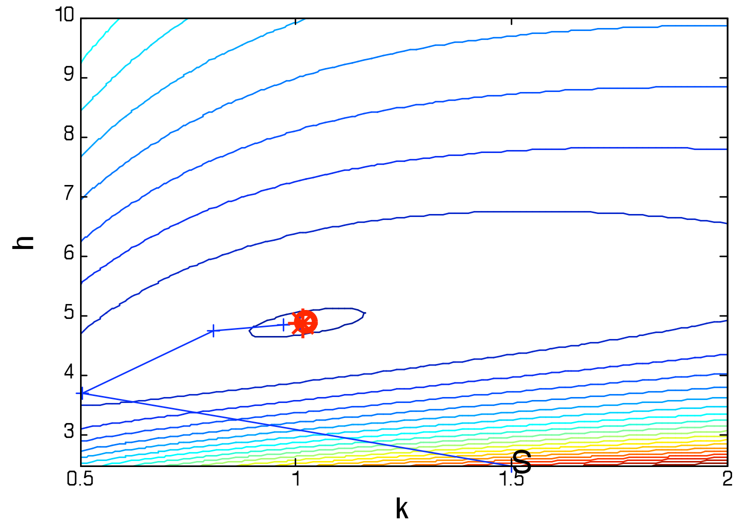
Contours for Sensor 4 with 9 searches, noise=2.000
kest = 1.139, hest = 4.033
kmin 1.145 hmin 4.000



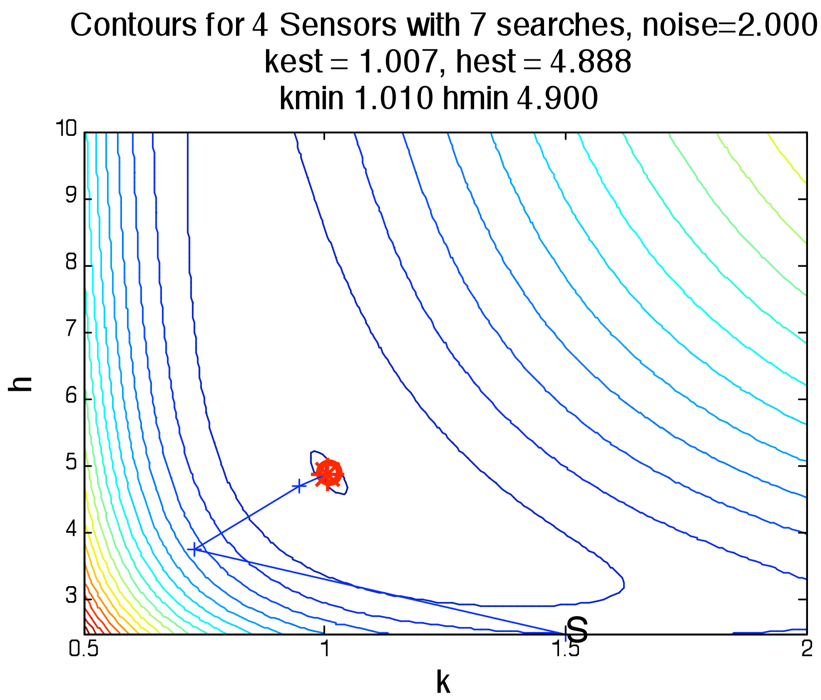
Contours for Sensor 7 with 22 searches, noise=2.000
kest = NaN, hest = NaN
kmin 0.920 hmin 5.650

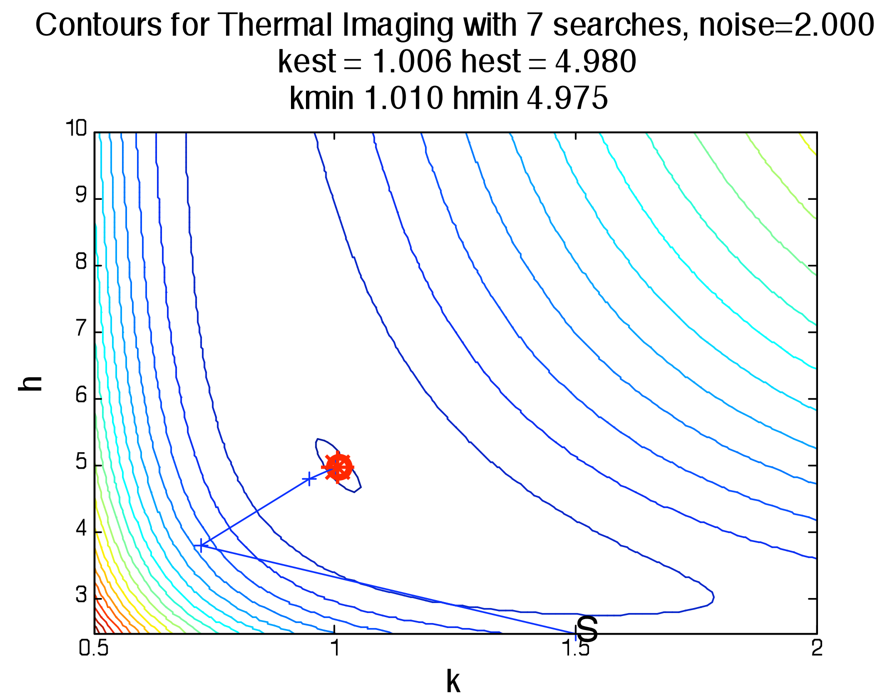


Contours for Sensor 11 with 10 searches, noise=2.000
kest = 1.018, hest = 4.879
kmin 1.025 hmin 4.900



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

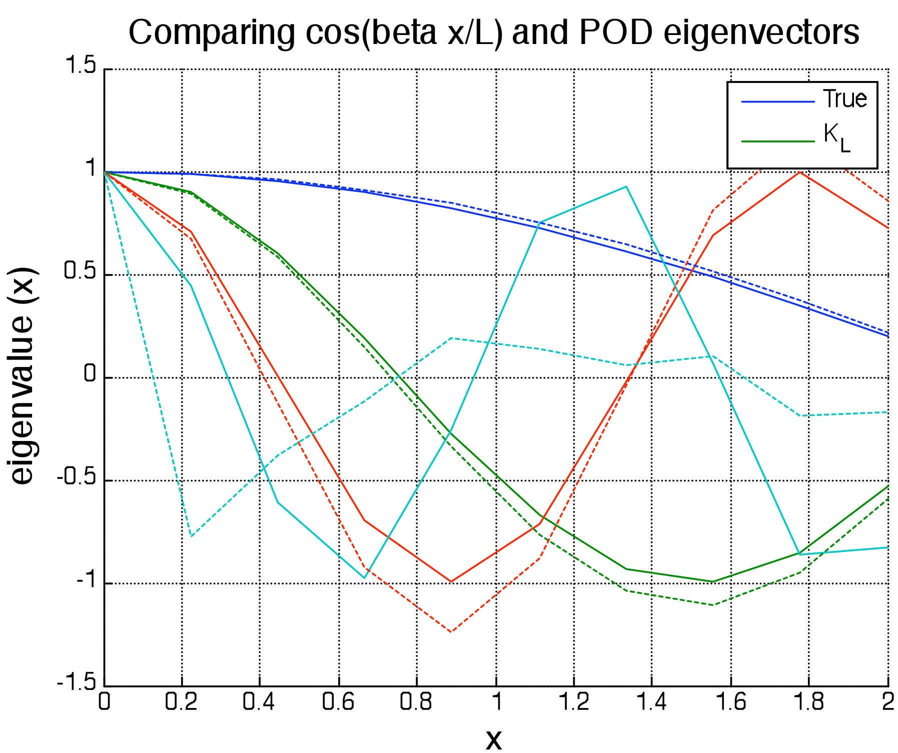
1) No proof that the solution using a reduced model approaches the true response
2) Solutions can be obtained only for parameters within the range of the sampled responses

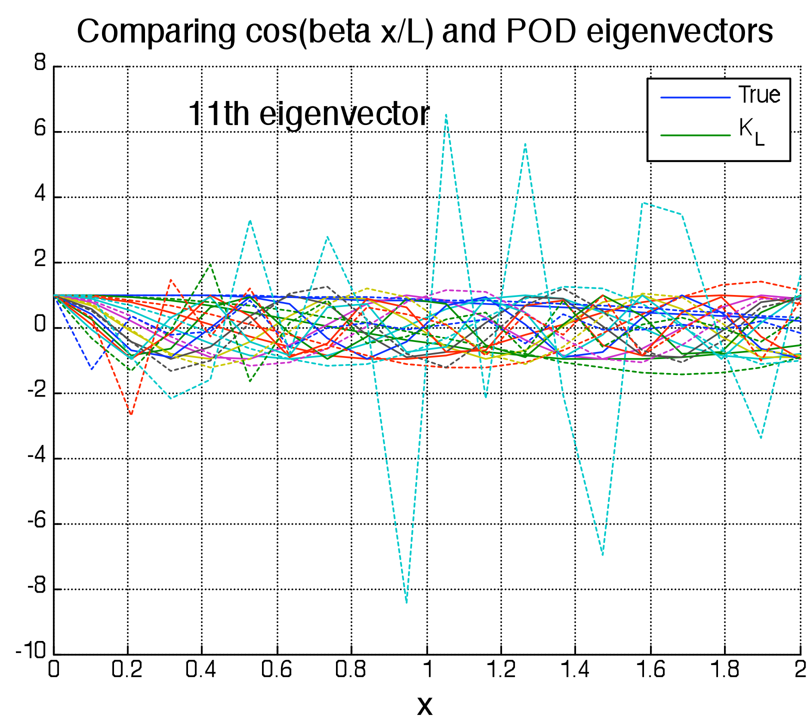
Advantage

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

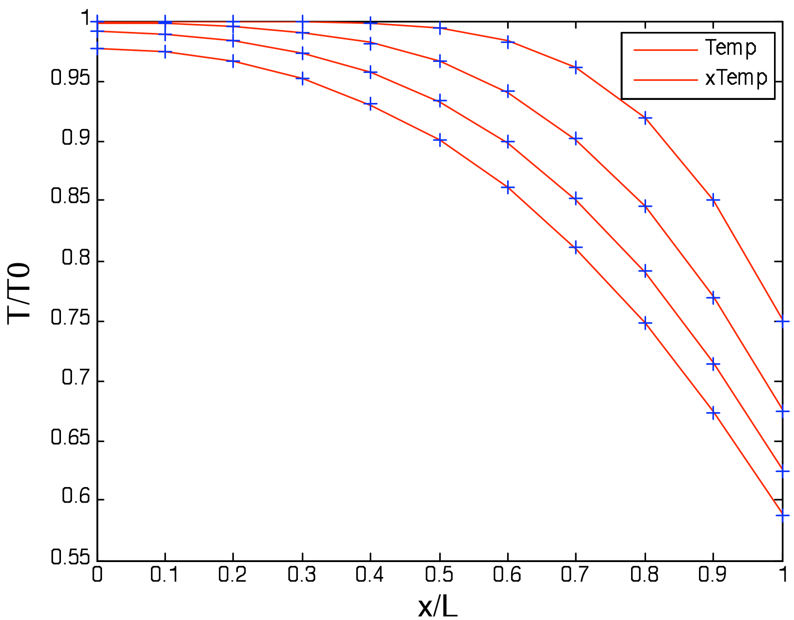
Fourier Series Solution

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

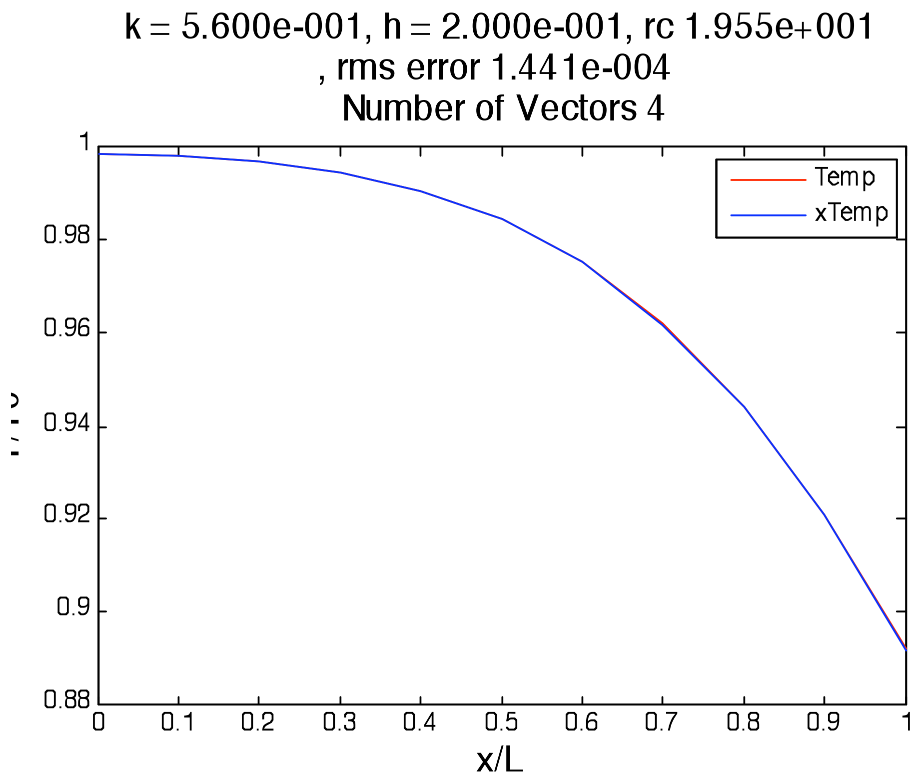




Reproducing the Exact Solution with POD



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