Overview of Research Experience and Capabilities

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Outline

- Background
- Capabilities
- Facilities
- Research Projects
- Modeling Tools

Microelectronics Heat Transfer Laboratory

- established in 1984 within the Department of Mechanical Engineering at the University of Waterloo
- research and development related to heat transfer and other thermodynamic phenomena
- fully funded through industrial and governmental grants and contracts
- staff includes:
  - 1 faculty member + 1 retired faculty member
  - 2 research engineers
  - 4 graduate students
  - 1 post doctoral fellow
  - 1 technician

Modeling Capabilities

- conjugate heat transfer for microelectronics
- convection and conduction from bodies of arbitrary shape
- thermal contact resistance
- thermal spreading resistance
- fluid flow and heat transfer for heat exchangers and cold plates

Experimental Capabilities

- conjugate heat transfer for packages & boards
- air and liquid cooled heat sink performance
- thermal contact & spreading resistance
- thermal conductivity measurements
- testing of thermal interface materials
- surface characterization
- radiation heat transfer

Facilities

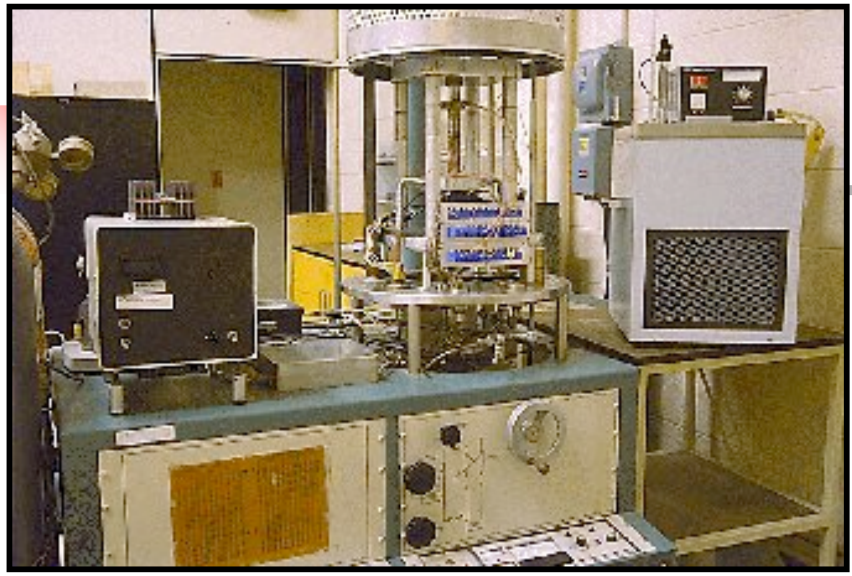
- wind tunnel
- heat exchanger test rig
- contact resistance test rig
- thermal interface material test rig
- surface analysis
- computing equipment

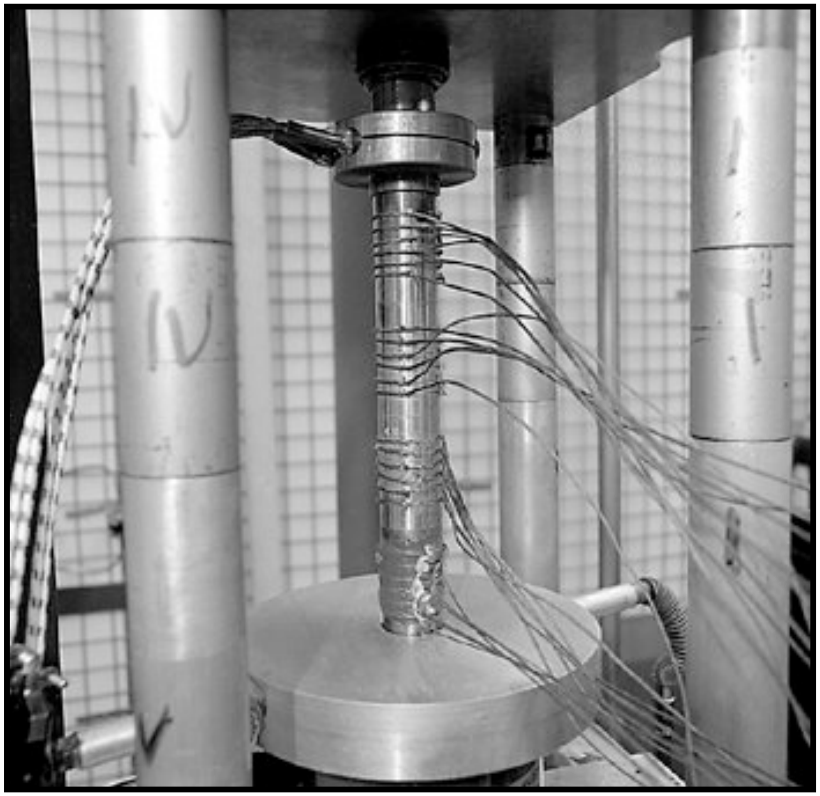
Wind Tunnel

- 18” open circuit wind tunnel
- adaptable test section
- airflow up to 15 m/s

Heat Exchanger Test Rig

- flow rates up to 3 gpm
- power input up to 3 kW
- water, glycol, other fluids



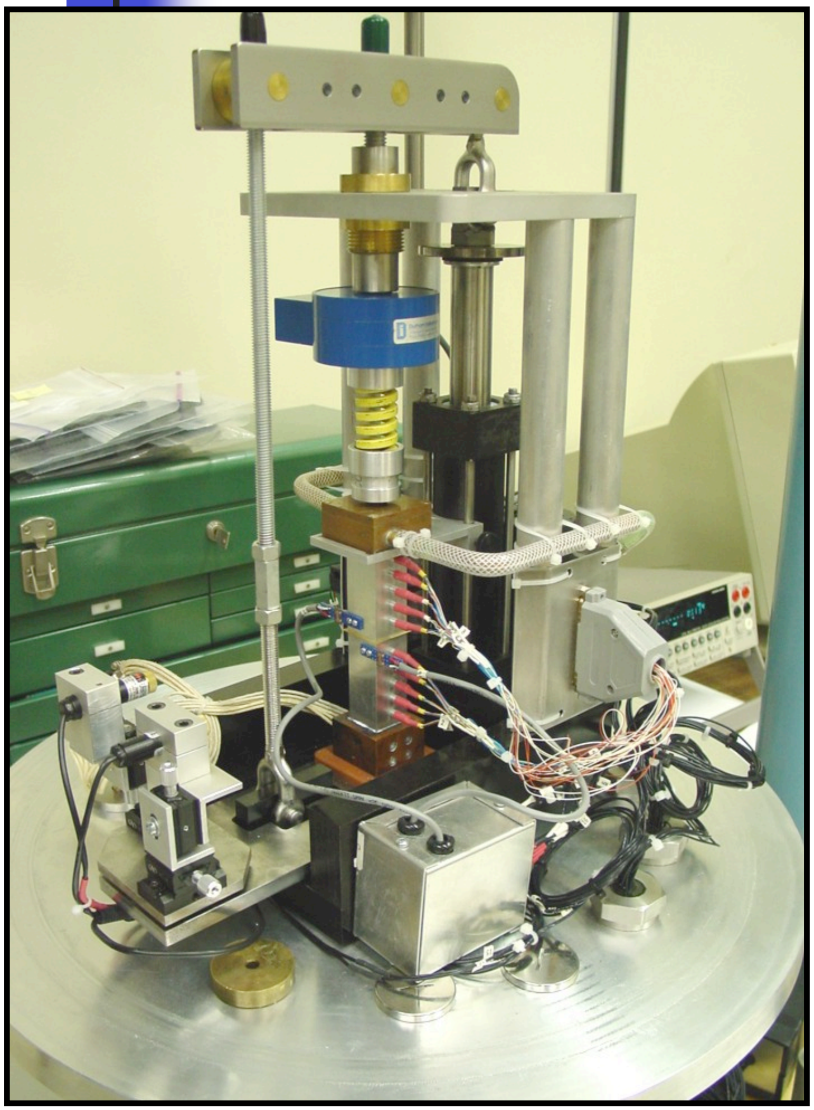


Contact Resistance Rig

Working Ranges

	Minimum	Maximum
Interface Temperature	-20 °C	400 °C
Environment Pressure	10^{-10} atm	1 atm
Load	50 N	5000 N
Interface Pressure	0.4 MPa	10 MPa
Working Fluids	Air Argon Helium Nitrogen	

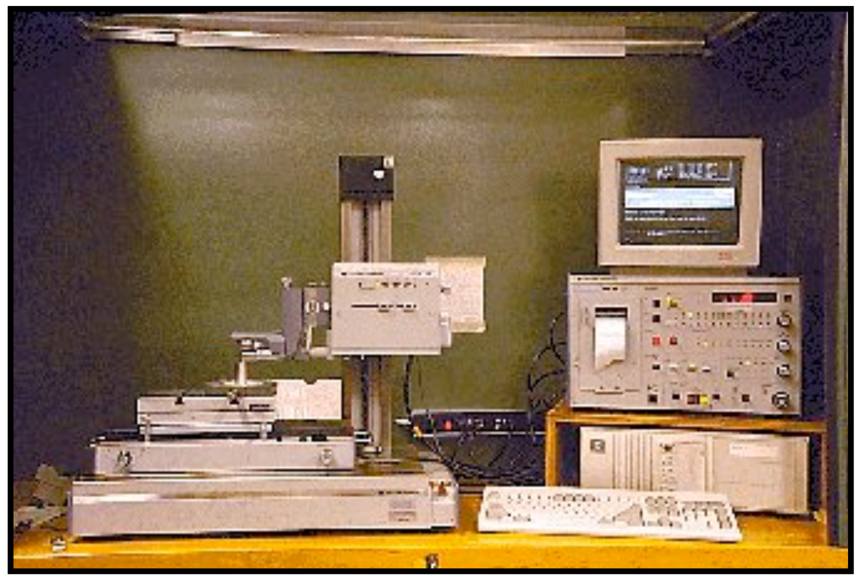
Thermal Interface Materials



- load cell
  - 100 or 1000 lbs
- linear actuator
  - digitally controlled stepper motor
  - 400 steps / rev
    0.1 inch per revolution
- laser-based thickness measurement:
  - 1 micron precsion

Surface Characterization

- ➢ Leitz Durimet Microhardness Tester
  - indenter loads: 15 - 2000 g
  - sample temperatures: up to 200 ^{o}C



- ➢ Talysurf 5 surface profilometer
  - surface roughness, wavines and profile for flat or circular surfaces
  - calculates RMS roughness & RMS surface slope
- ➢ Taylor Hobson Surtronic 3+
  - portable surface profilometer
  - resolution $0.01\ \mu m \rightarrow 300\ \mu m$

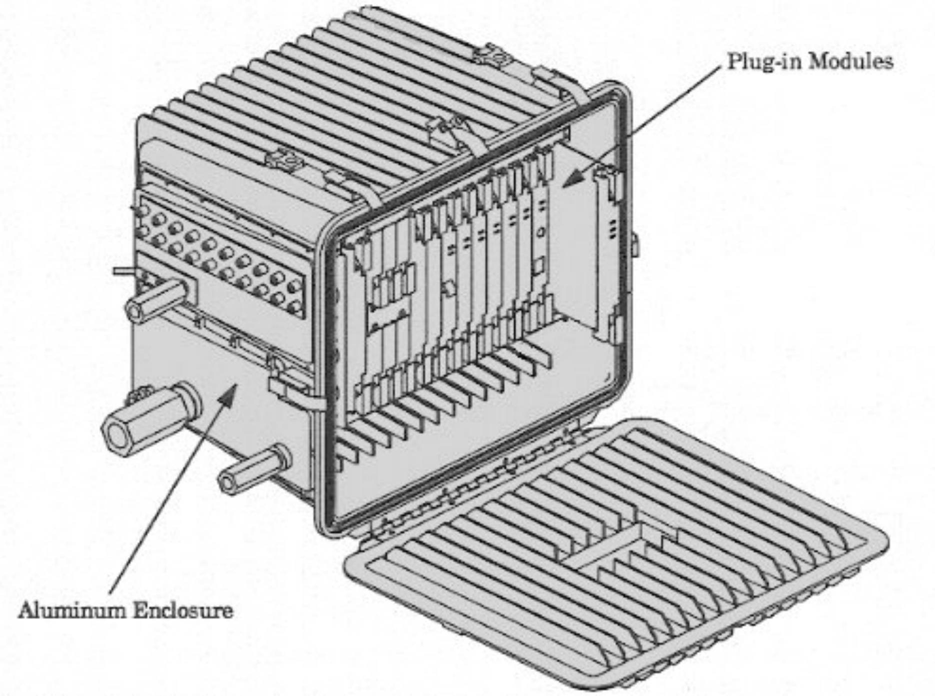
Computing Facilities

- ***Hardware:***
  - SUN SunBlade 1000 dual processor UltraSparc
  - SUN SunBlade 2000 dual processor UltraSparc III (2003)
  - SGI Octane dual processor R10000 workstation
  - 14 networked PC's
- ***Software:***
  - Numerical CFD Simulation: Flotherm, Ideas, Icepack
  - Symbolic Mathematics: Mathematica, Maple, Matlab
  - Code Development: Visual Basic, C++, CGI, Java, Javascript

Research Projects

- natural convection in microelectronic enclosures
- analytical modeling of heat sinks
  - ➢ flow by-pass
  - ➢ design optimization
- modeling of liquid cooled cold plates
- contact & spreading resistance models
  - ➢ non-conforming, rough surfaces
  - ➢ sources on compound disks and flux channels
- characterization of thermal interface materials
- virtual reality modeling of heating/ventilation in car seats

Natural Convection in Enclosures



Overview

- combine conduction and laminar natural convection limiting cases using composite solution technique
- simple model formulation can include radiation and conduction effects

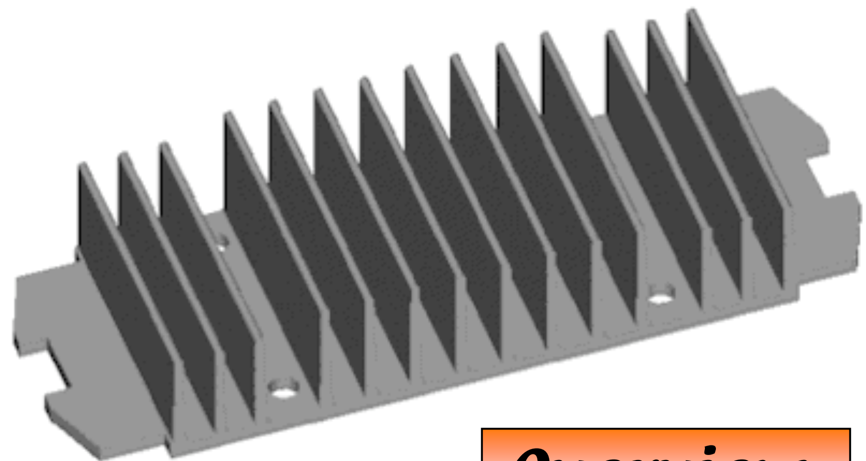
Objectives

- develop analytical models for steady-state natural convection from a heated body to its surrounding, cooled enclosure

Heat Sinks: Optimization Routines

Objectives

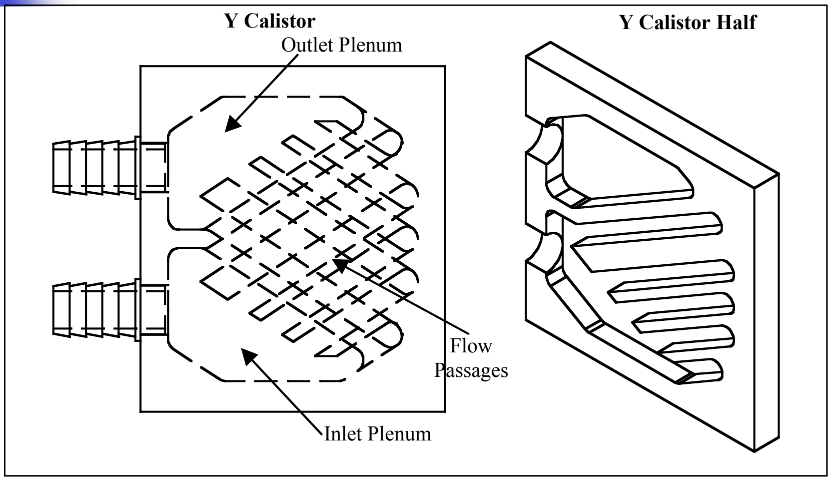
- develop thermal simulation tools that optimize heat sink design variables based on the minimization of entropy generation
- establish a thermodynamic balance between heat transfer, viscous dissipation and mass transport



Overview

- entropy production $\propto$ amount of energy degraded to a form unavailable for work
- lost work is an additional amount of heat that could have been extracted
- minimizing the production of entropy provides a concurrent optimization of all design variables

Modelling of Heat Exchangers & Cold Plates

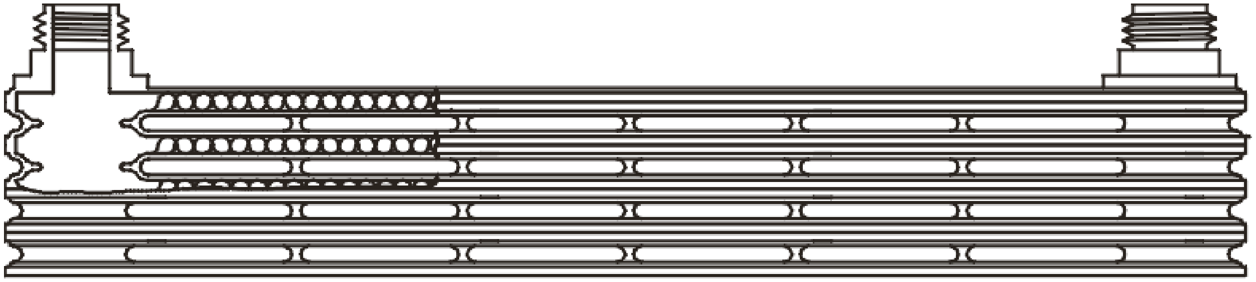


Objectives

- develop analytical models for predicting the heat transfer and fluid friction characteristics of heat exchangers and cold plates

Overview

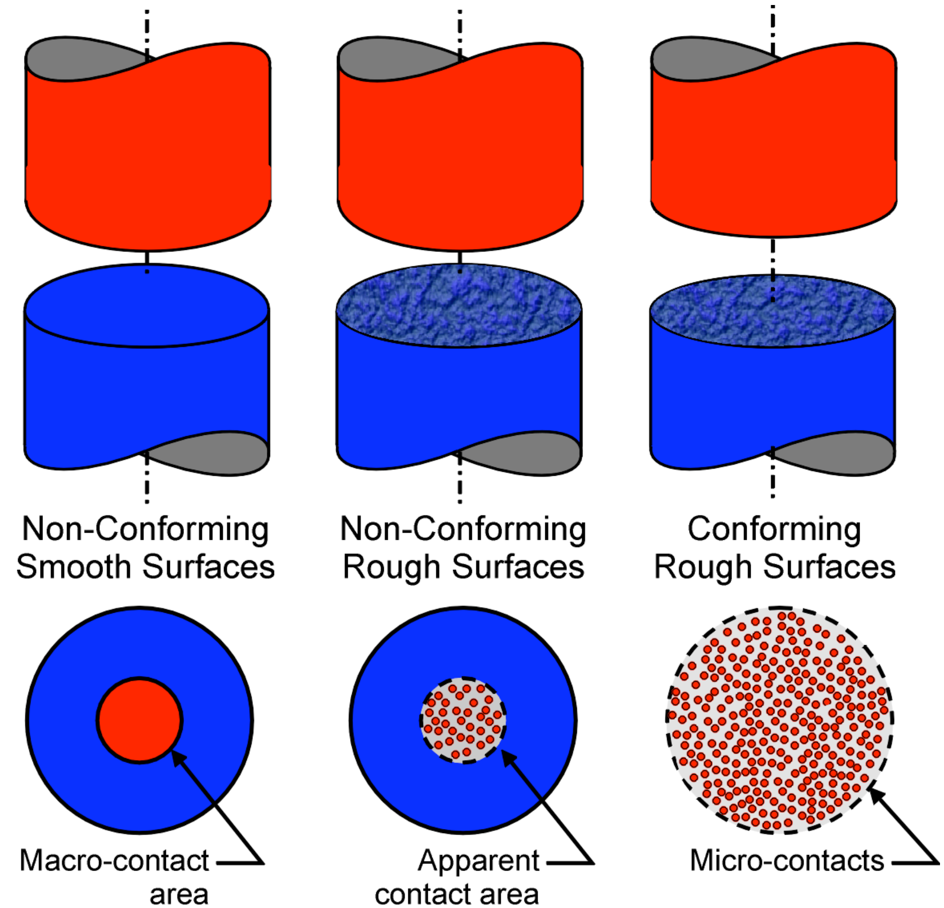
- general models for predicting friction factors and Nusselt numbers for fully developed, thermally developing, and simultaneously developing flow in non-circular ducts.
- models are developed by combining the asymptotic behavior for various flow regions.



Thermal Contact Resistance: Non-Conforming, Rough Surfaces

Objectives

- develop thermo-mechanical models for predicting contact resistance in real surfaces with microscopic roughness and waviness



Overview

- mechanical models combine the effects of plastic deformation at the microscopic level with elastic deformation at the macroscopic level

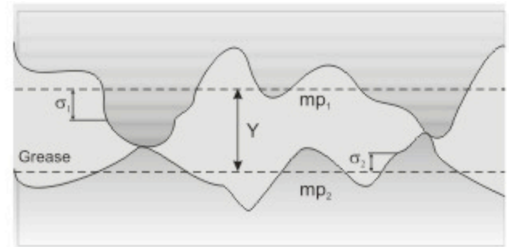
Thermal Interface Materials: Grease

Objectives

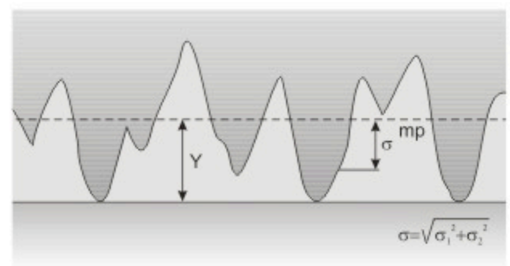
- develop a simple model for determining thermal joint resistance with grease filled interstitial gaps

Overview

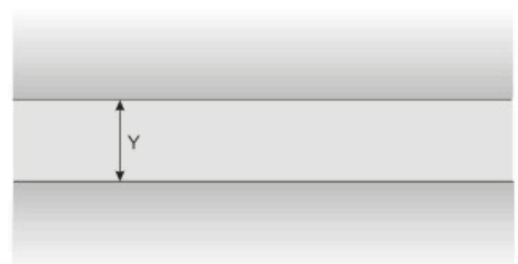
- combine joint conductance models with a bulk resistance model for grease, based on an equivalent layer thickness



a) Two Nominally Flat Rough Surfaces



b) Equivalent Rough Surface, Smooth Plane Contact



c) Equivalent Uniform Gap Model

Heating and Ventilation in Car Seats

Objectives

- develop thermofluid models for simulating heating and cooling of car seats
- develop a human interaction model to assess the ergonomic response between the human and the seat

Overview

- a 21 segment model of a human is developed to determine the response to rapid chances in temperature
- models must be fast and accurate in order to provide near real time simulation as part of a virtual reality model

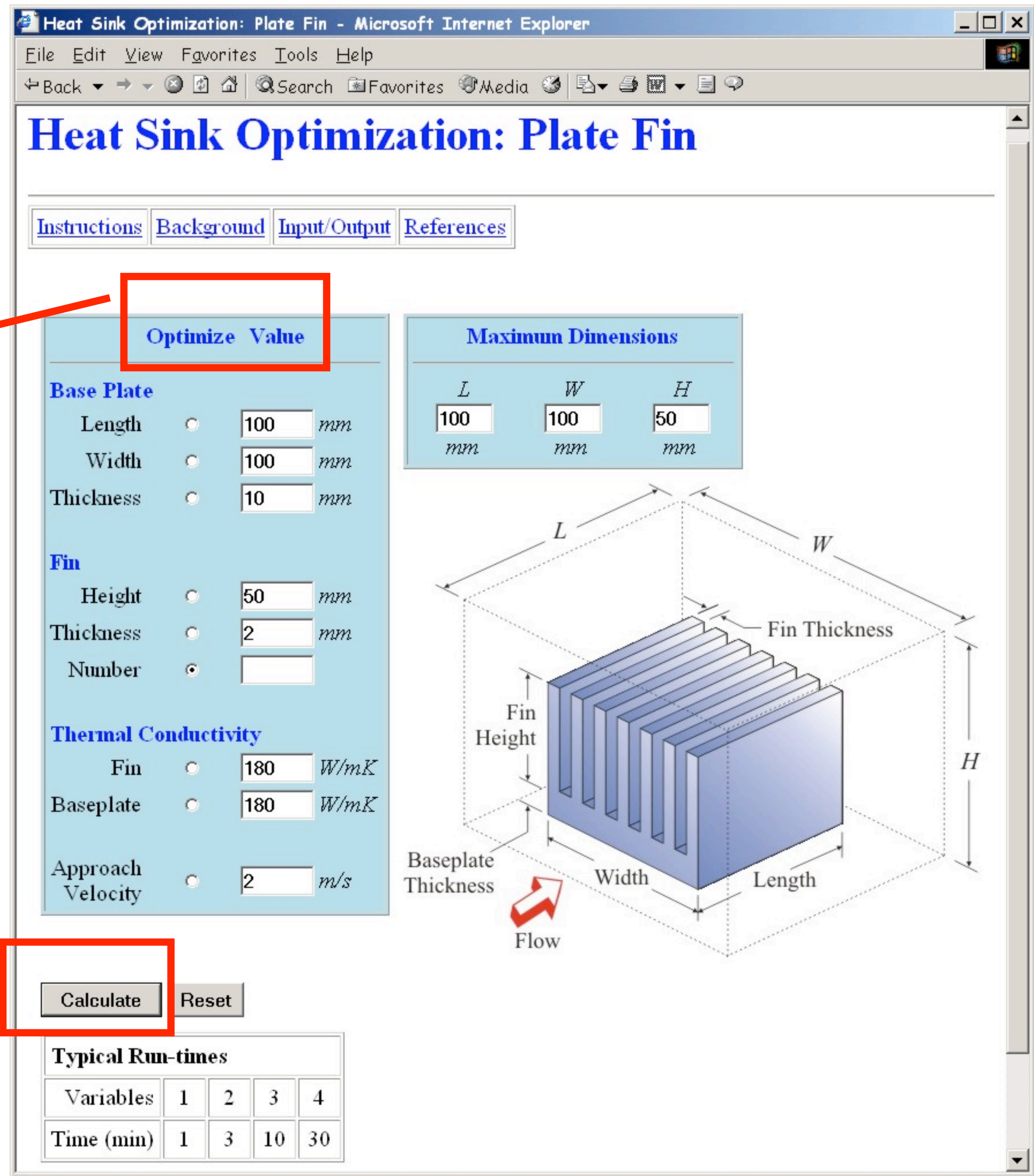
Design Tools

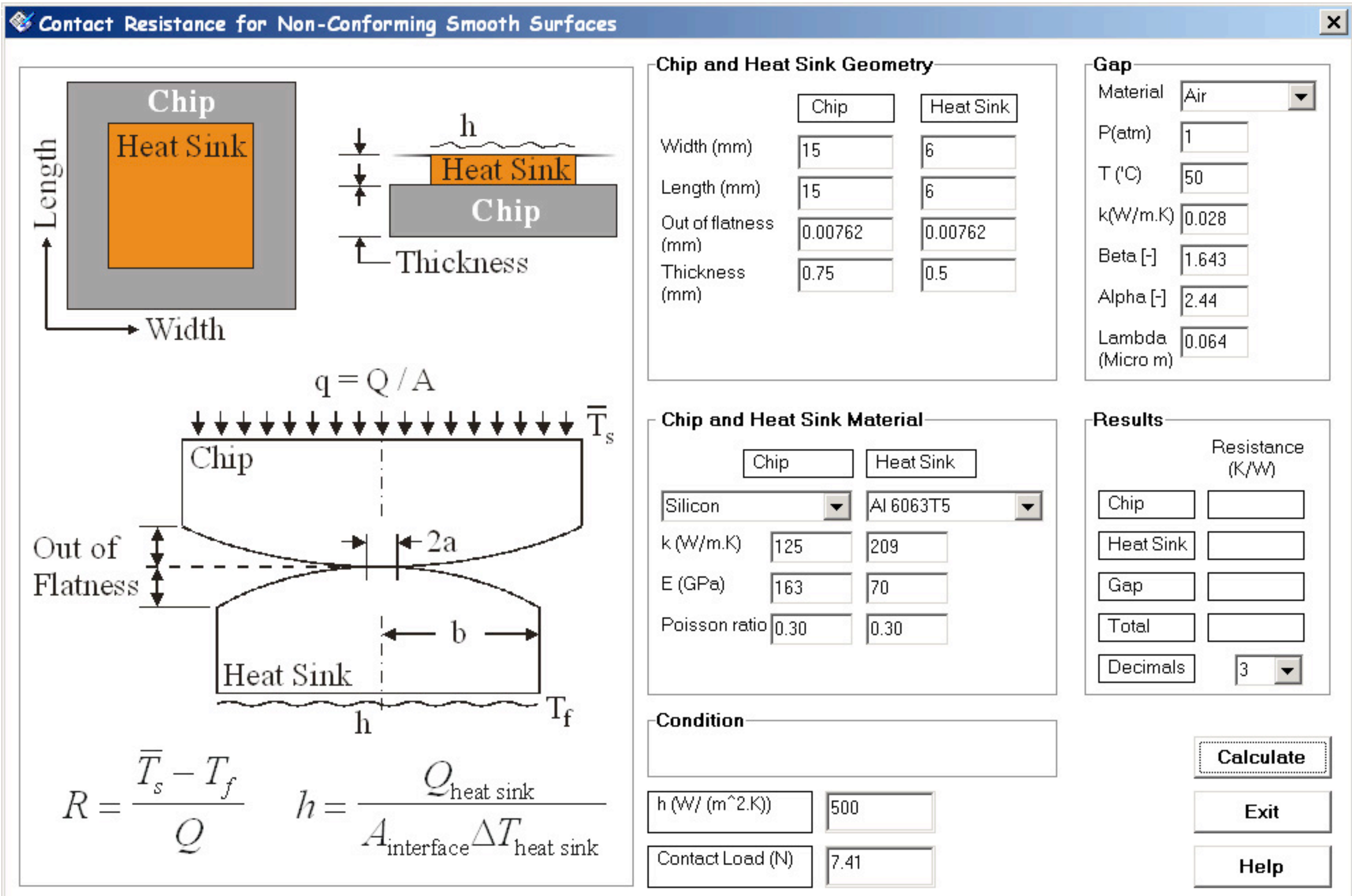
- URL for the MHTL Web page
  http://www.mhtlab.uwaterloo.ca
- tool set includes:
  - ➢ natural convection in heat sinks: radial fins, plate fins
  - ➢ spreading resistance:
    - circular source on a compound disk, flux tube or half space
    - rectangular source on a rectangular disk, flux tube or half space
  - ➢ PCB thermal simulation
  - ➢ thermophysical property calculator
  - ➢ special function calculator

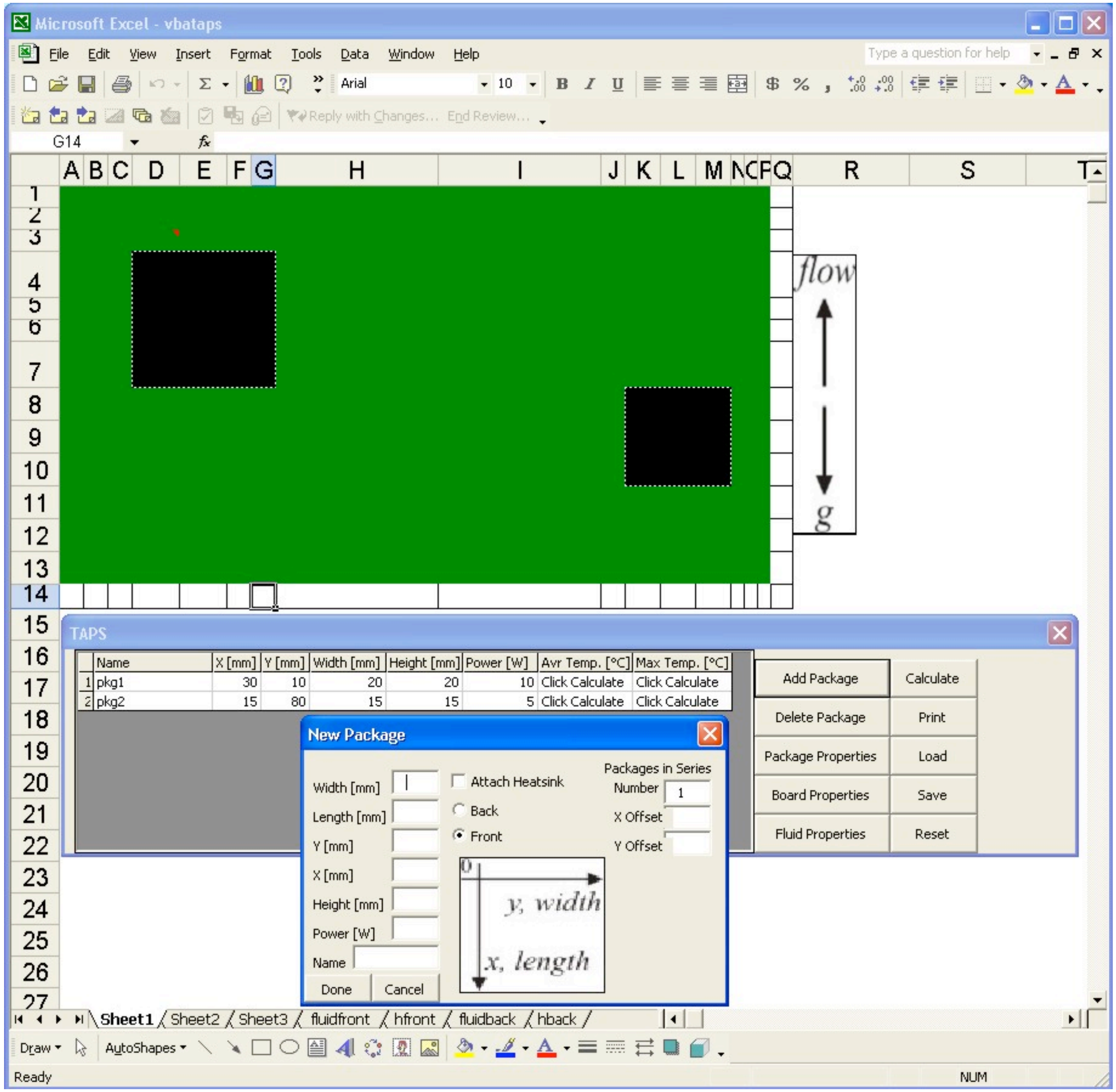
Value: provide specific values for constrained parameters

Optimize: indicate parameters to be optimized

Calculate: run optimization code to calculate design parameters for maximum thermal-fluid performance




Contact Resistance for Non-Conforming Smooth Surfaces
Chip
Heat Sink
Length
Width
h
Heat Sink
Chip
Thickness
q = Q / A
$\bar{T}_s$
Chip
Out of Flatness
2a
b
Heat Sink
h
T_f
$R = \frac{\bar{T}_s - T_f}{Q}$
$h = \frac{Q_{\text{heat sink}}}{A_{\text{interface}} \Delta T_{\text{heat sink}}}$
Chip and Heat Sink Geometry
Chip
Heat Sink
Width (mm)
15
6
Length (mm)
15
6
Out of flatness (mm)
0.00762
0.00762
Thickness (mm)
0.75
0.5
Gap
Material
Air
P(atm)
1
T ('C)
50
k(W/m.K)
0.028
Beta [-]
1.643
Alpha [-]
2.44
Lambda (Micro m)
0.064
Chip and Heat Sink Material
Chip
Heat Sink
Silicon
Al 6063T5
k (W/m.K)
125
209
E (GPa)
163
70
Poisson ratio
0.30
0.30
Results
Resistance (K/W)
Chip
Heat Sink
Gap
Total
Decimals
3
Condition
h (W/ (m^2.K))
500
Contact Load (N)
7.41
Calculate
Exit
Help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File Edit View Insert Format Tools Data Window Help
Type a question for help
Arial
10
Reply with Changes... End Review...
G14
flow
g
TAPS
Name
X [mm]
Y [mm]
Width [mm]
Height [mm]
Power [W]
Avr Temp. [°C]
Max Temp. [°C]
1 pkg1 30 10 20 20 10 Click Calculate Click Calculate
2 pkg2 15 80 15 15 5 Click Calculate Click Calculate
Add Package
Calculate
Delete Package
Print
Package Properties
Load
Board Properties
Save
Fluid Properties
Reset
New Package
Width [mm]
Length [mm]
Y [mm]
X [mm]
Height [mm]
Power [W]
Name
Done
Cancel
Attach Heatsink
Back
Front
Packages in Series
Number
1
X Offset
Y Offset
0
y, width
x, length
Sheet1 Sheet2 Sheet3 fluidfront hfront fluidback hback
Draw
AutoShapes
Ready
NUM

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