

Building Your First SINDA Model

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Disclaimer

The Systems Improved Numerical Differencing Analyzer (SINDA) computer program or its forebears has been a mainstay of thermal analysis for more than 50 years.

SINDA is offered by a number of different vendors and syntax and features may vary from product to product.

For this lesson, SINDA/FLUINT by Cullimore and Ring Technologies (C&R Technologies[®]), Inc. is used. However, similar concepts apply to other versions of SINDA. *The use of this product in this lesson should not be construed as an endorsement of one product or another.*

Introduction

Engineers rely on a wide variety of modern thermal tools to model thermal problems;

Many of these tools offer graphical “front ends” whereby users formulate their analytical models using a CAD interface;

Behind the scenes, the analysis is performed on a thermal network – this is true whether the analyst uses finite differencing or finite element methodologies;

While graphical front ends are very powerful, understanding the resulting thermal network representation used for a model gives the user the ability to check or even modify the models at a basic level.

Introduction

Additionally, there are instances where an engineer may prefer to develop network models from scratch or use heritage code that does not have a graphical front end;

Some front-end programs output thermal networks in the widely used SINDA format;

Our lesson will focus on this input format.

Course Outline

- Review of Basic Heat Transfer
- Discretizing a Physical System
- Nodes
- Conductors
- Problem Statement
- Abstraction of the Problem Geometry
- Material Thermophysical and Thermo-Optical Properties
- SINDA Syntax and the Input Deck
- Transient Results
- Setting Up a Steady State Run
- Steady State Results
- Brief Introduction to Abbreviated Input Formats
- Concluding Remarks
- Acknowledgements

Review of Basic Heat Transfer

Heat transfer is energy transfer due to a temperature difference and can only be measured at the boundary of a system.

Conduction - Heat transfer from one object to another by direct contact.

Convection - Heat transfer via movement of fluids such as water or air.

Radiation – Heat transfer via electromagnetic waves.

Review of Basic Heat Transfer

Conduction is described by Fourier's Law:

$$\dot{Q}_{1-2} = \frac{kA}{L} (T_1 - T_2)$$

where...

\dot{Q}_{1-2} is the heat transfer between objects 1 and 2

k is the thermal conductivity of the material through which heat is transported

A is the cross-sectional area of heat flow

L is the distance between objects 1 and 2, perpendicular to the heat flow direction

T_1, T_2 are the temperatures of objects 1 and 2, respectively

Review of Basic Heat Transfer

Convection is described by Newton's Law of Cooling:

$$\dot{Q}_{1-2} = hA(T_1 - T_2)$$

where...

\dot{Q}_{1-2} is the heat transfer between objects 1 and 2

h is the convective heat transfer coefficient

A is surface area on which convection is taking place

T_1, T_2 are the temperatures of objects 1 and 2, respectively

Review of Basic Heat Transfer

Radiation is described by the Stefan-Boltzmann Law:

$$\dot{Q}_{1-2} = \varepsilon_1 B_{12} A_1 \sigma (T_1^4 - T_2^4)$$

where...

- \dot{Q}_{1-2} is the heat transfer between objects 1 and 2
- $\varepsilon_1 B_{12} A_1$ is the radiation conductance, G_{rad} between objects 1 and 2
- ε_1 is the infrared emittance of object 1
- B_{12} is grey body factor between objects 1 and 2
- A_1 is the surface area of object 1
- T_1, T_2 are the absolute temperatures of objects 1 and 2, respectively

Review of Basic Heat Transfer

Note that heat transfer via conduction and convection are directly proportional to the absolute¹ temperature difference ($\Delta T = T_1 - T_2$) between the two objects of interest.

However, heat transfer via radiation is proportional to the difference of the absolute¹ temperatures raised to the fourth power ($\Delta T^4 = T_1^4 - T_2^4$).

¹Use of absolute temperatures in conduction and convection calculations is not strictly required since ΔT is the same regardless of whether or not absolute temperature of units is used. Use of absolute temperatures for radiation, however, is required.

Review of Basic Heat Transfer

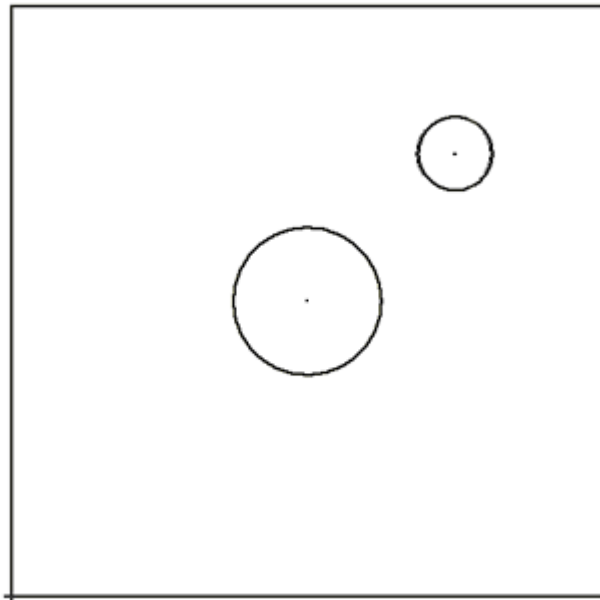
Engineers use thermal models as a tool to aid in design and understand the performance of thermal systems;

A thermal model is an abstraction of a physical system.

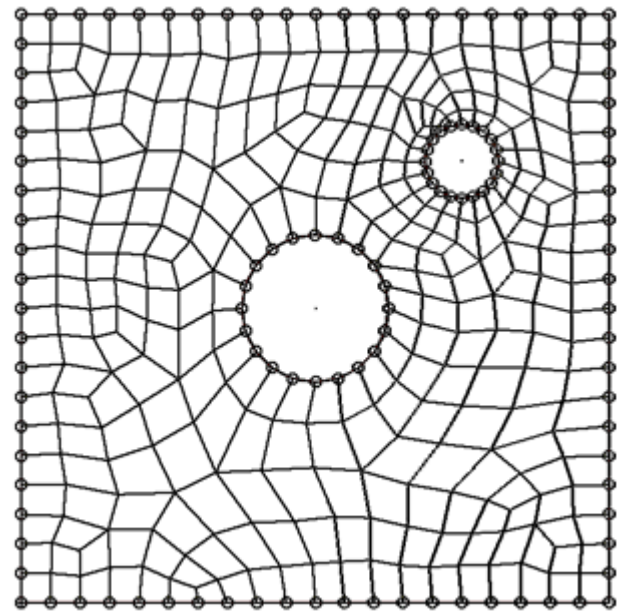
Thermal models take the form of thermal networks comprised of lumps of mass and heat transfer paths between them – analogous to electrical networks.

Review of Basic Heat Transfer

Closed-form solutions do not exist for all physical systems or geometries -- so they are discretized into smaller pieces, called elements.



Geometry



**Geometry Discretized into a
Finite Element Mesh**

Note: Geometry and mesh created using MSC Patran®

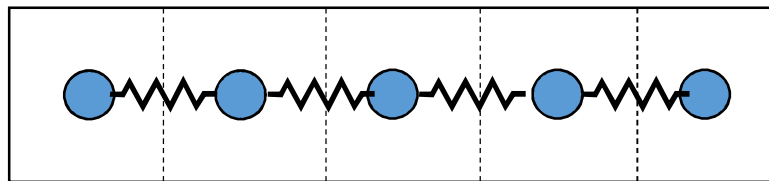
Review of Basic Heat Transfer

Finite Difference -- uses the differential formulation -- i.e., equations are formulated using the governing *differential equation* -- where we replace the partial derivatives by approximations obtained by Taylor series expansions near the point of interest;

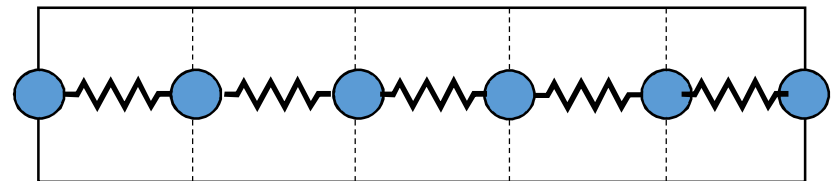
Finite Element -- uses a variational formulation -- i.e., equations are formulated from an *integral formulation* arising from the Calculus of Variations.

For our first SINDA model, we will use finite difference.

Discretizing a Physical System



Finite Difference Network



Finite Element Network

Nodes

There are three* primary types of nodes used in thermal network models:

Diffusion Nodes – represent a finite thermal capacitance – when heat flows into or out of a diffusion node, the temperature changes gradually;

Arithmetic Nodes – represent a “massless” object – when heat flows into or out of an arithmetic node, the temperature changes instantly;

Boundary Nodes – represent an “infinite” thermal capacitance – they are used as heat sources or heat sinks.

*Heater Nodes are a special case of Boundary Nodes and will not be discussed in this lesson.





Conductors

In a thermal network model, heat flows from one node to another along pathways called conductors – there are two types:

Linear Conductors -- heat flow for conduction and convection is linear – that is, it is based on the ΔT between the two objects of interest;

Radiation Conductors -- heat flow between two objects is highly non-linear – that is, it is a function of the $\Delta(T^4)$ between the two objects.

Symbols Used for the Thermal Network in this Lesson*

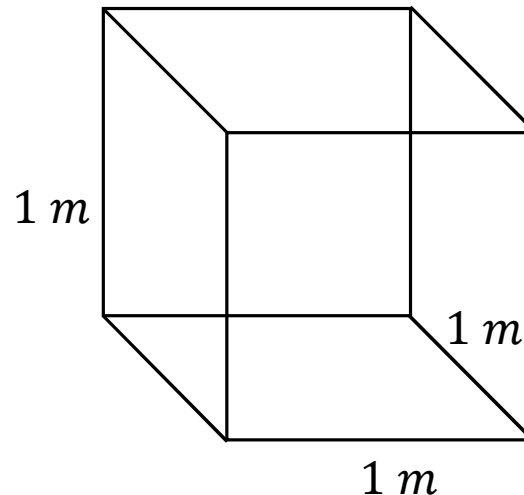
Diffusion Node	
Boundary Node	
Linear Conductor	
Radiation Conductor	

*No arithmetic nodes are used in the sample problem

Problem Statement

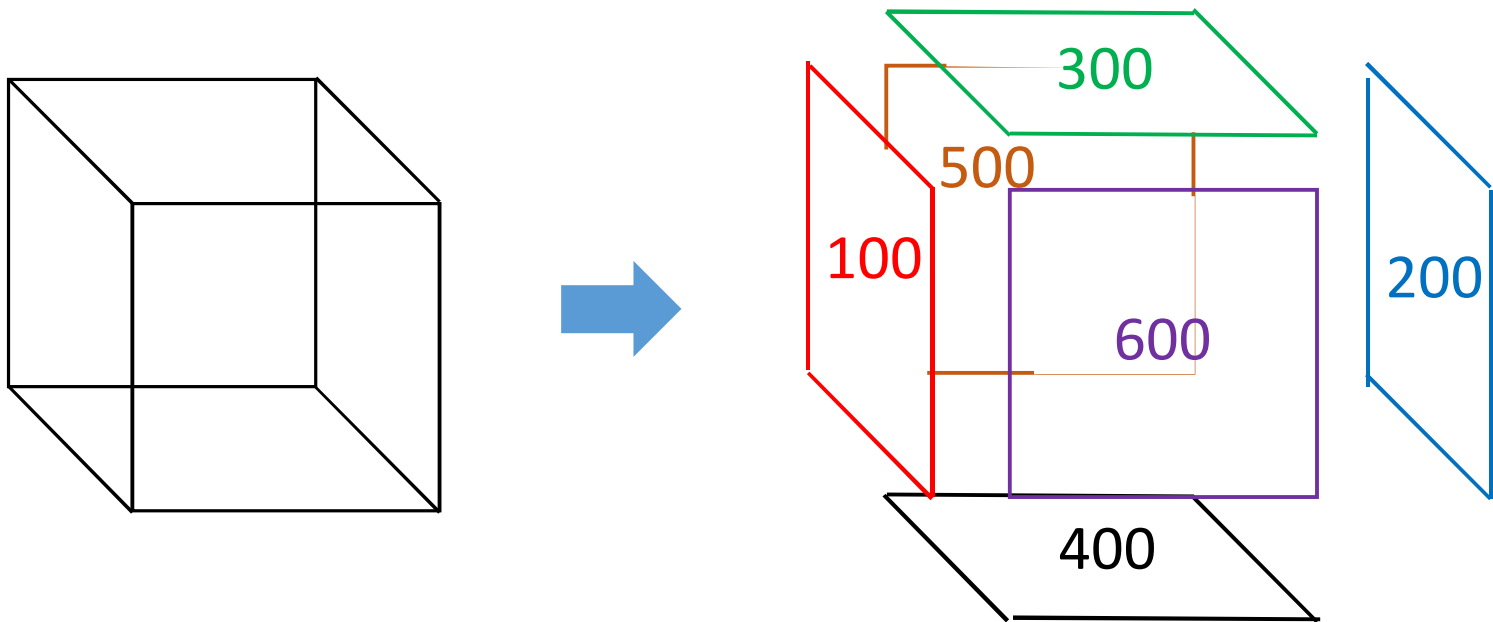
A white-painted hollow aluminum box measuring $1\text{ m} \times 1\text{ m} \times 1\text{ m}$ with sides 2.54 mm thick is floating in deep space far from any planet with an incident solar flux of 1371 W/m^2 incident on one side. Assuming an initial temperature of 20°C , what is the steady state temperature of each side of the box? How long does it take the box to reach this temperature?

$$\dot{q}_{sol} = 1371\text{ W/m}^2$$



Abstraction of the Problem Geometry

For a finite difference discretization, let's model the box as six separate sides for which individual temperatures will be calculated.



Abstraction of the Problem Geometry

The six box sides meet at twelve edges:

100 and 300

100 and 400

100 and 500

100 and 600

200 and 300

200 and 400

200 and 500

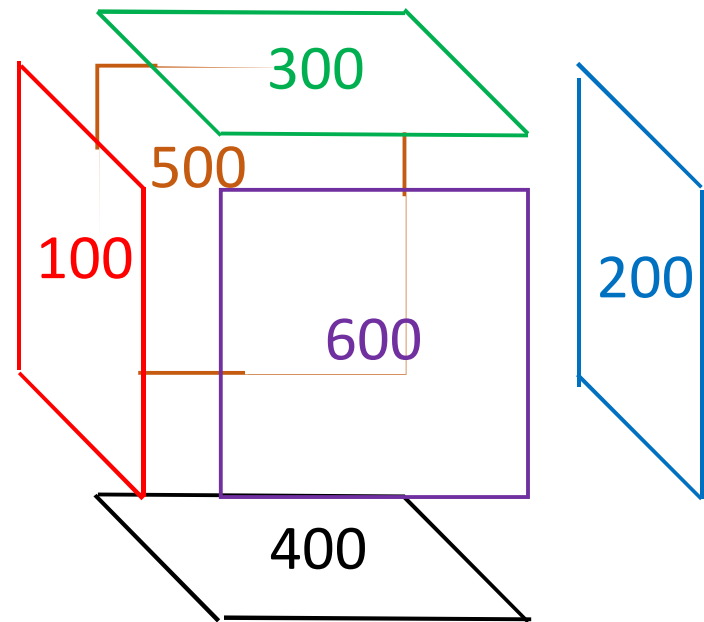
200 and 600

300 and 500

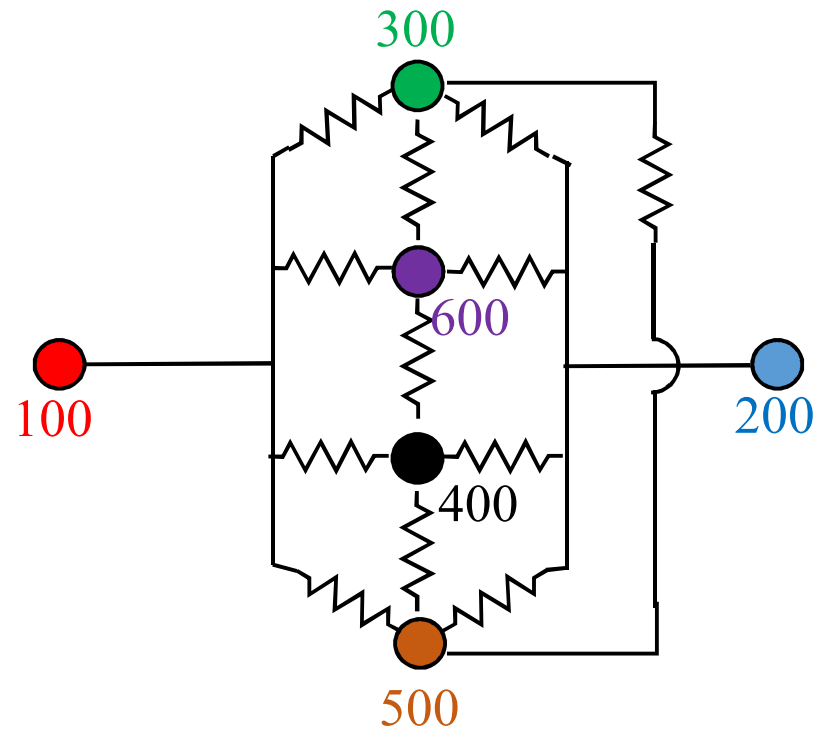
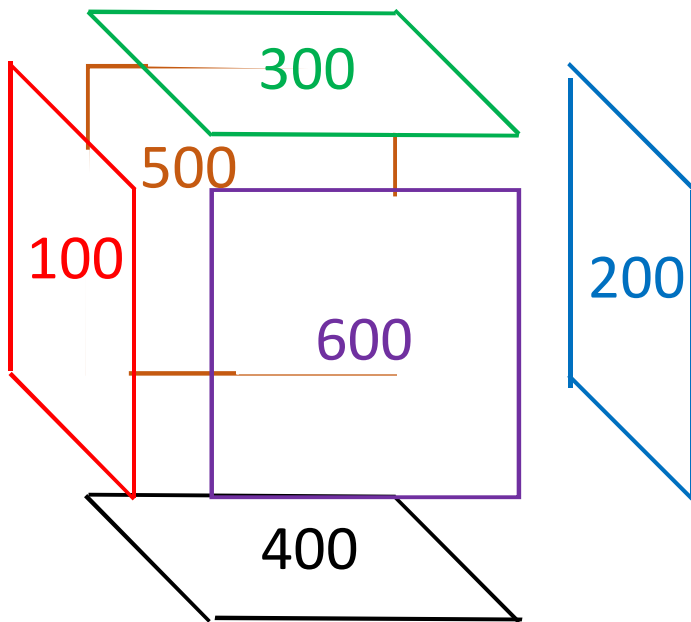
300 and 600

400 and 500

400 and 600



Abstraction of the Problem Geometry



Diffusion Node	●
Boundary Node	◆
Linear Conductor	—⚡—
Radiation Conductor	—⚡↗—

Abstraction of the Problem Geometry

The box sides are represented by nodes.

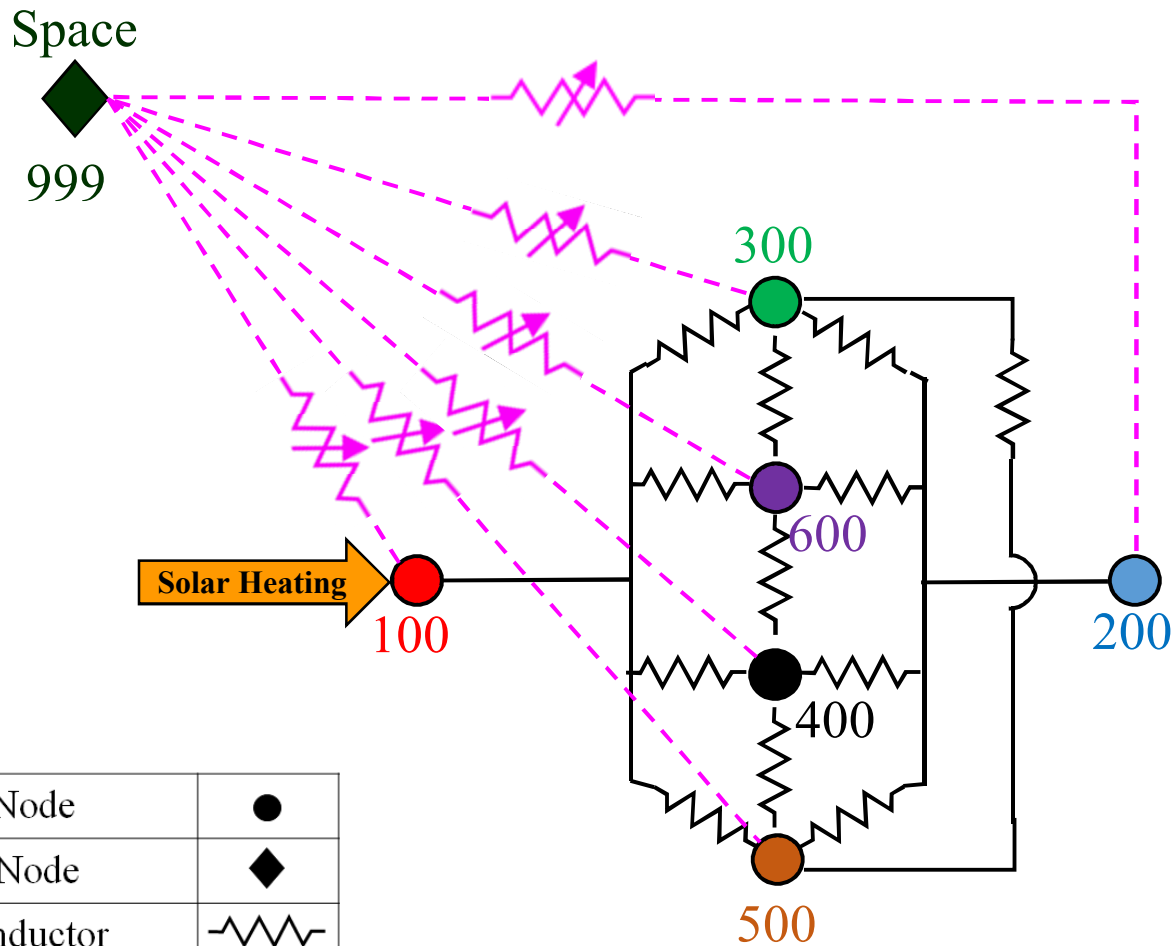
The edges that are common to any two sides will indicate a heat transfer path (conductor) between those two sides is necessary.

Each exterior box side radiates to deep space – but we will not consider internal radiation within the box for this example).

Solar heating is applied to one box side.

We will establish a thermal network to represent our geometry.

Abstraction of the Problem Geometry

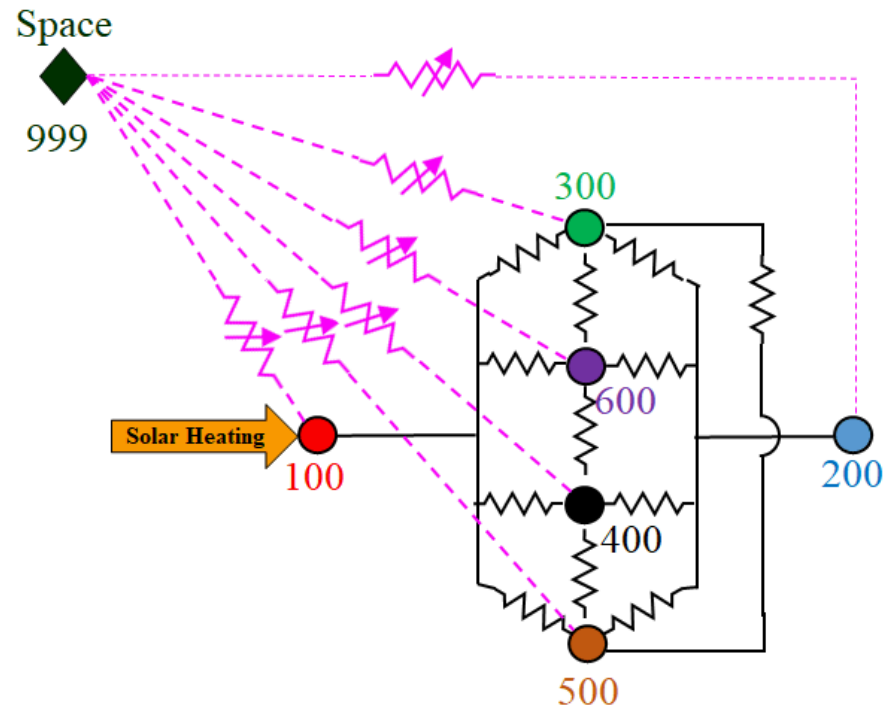


Diffusion Node	●
Boundary Node	◆
Linear Conductor	—⚡—
Radiation Conductor	—⚡↗—

Abstraction of the Problem Geometry

Our model is consists of:

- 6 box nodes (diffusion)
- 1 space node (boundary)
- 12 conductors (linear)
- 6 conductors (radiation)
- 1 heat source



Diffusion Node	●
Boundary Node	◆
Linear Conductor	—⚡—
Radiation Conductor	—⚡↗—

Material Thermophysical and Thermo-Optical Properties

For our first model, we will assume constant properties;

For aluminum (typical values shown):

$$\rho = 2710 \text{ kg/m}^3$$

$$c_p = 910 \text{ J/kg} \cdot ^\circ\text{C}$$

$$k = 204 \text{ W/m} \cdot ^\circ\text{C}$$

For radiative heat transfer, assume the exterior white paint thermo-optical properties:

$$\alpha = 0.27$$

$$\varepsilon = 0.88$$

SINDA Syntax and the Input Deck

SINDA relies on the user to maintain consistency in units used throughout the model;

It is critical for users to ensure that the value set of absolute zero (SINDA variable: ABSZRO) is in the units desired for the model;

For our model, we will use SI units so the following assignment must be made in the model (more on this shortly):

$$\text{ABSZRO} = -273.15$$

SINDA Syntax and the Input Deck

SINDA allows submodeling wherein a number of different model components may be brought together and run as a single thermal model;

Submodels help the analyst organize their model for, both, the thermal design and post-processing of the results;

For our first model, we will need only one submodel and it will be named: SUB1

SINDA Syntax and the Input Deck

A SINDA input deck is composed of numerous blocks;

There are numerous ways to specify a model – for our first model, however, we will limit our discussion to the following input blocks:

OPTIONS DATA

NODE DATA

CONDUCTOR DATA

SOURCE DATA

CONTROL DATA

OPERATIONS DATA

OUTPUT CALLS

The input deck ends with the last line:

END OF DATA

SINDA Syntax and the Input Deck

```
HEADER OPTIONS DATA
TITLE  MY FIRST SINDA MODEL
      MODEL    = BOX
      OUTPUT   = RESULTS.DAT
      USER1    = TEMPERATURES.DAT
```

SINDA Syntax and the Input Deck

The box will react in a finite amount of time (as opposed to instantly) and we will represent it as a *diffusion* node;

And if we assume, for the time being, that the thermophysical properties are constant, our description of the node takes on the format:

```
Node#, Tinitial, Thermal Capacitance
```

For our deep space node, we must specify a constant temperature boundary node – we signify this with a “-” sign next to the node number:

```
- Node#, Tboundary, Any Positive Number
```

SINDA Syntax and the Input Deck

For each node, we calculate the Thermal Capacitance as follows:

$$C = \rho \cdot c_p \cdot l \cdot w \cdot t$$

Where...

l is the box side length

w is the box side width

t is the box side thickness

ρ is the aluminum density

c_p is the aluminum specific heat

SINDA Syntax and the Input Deck

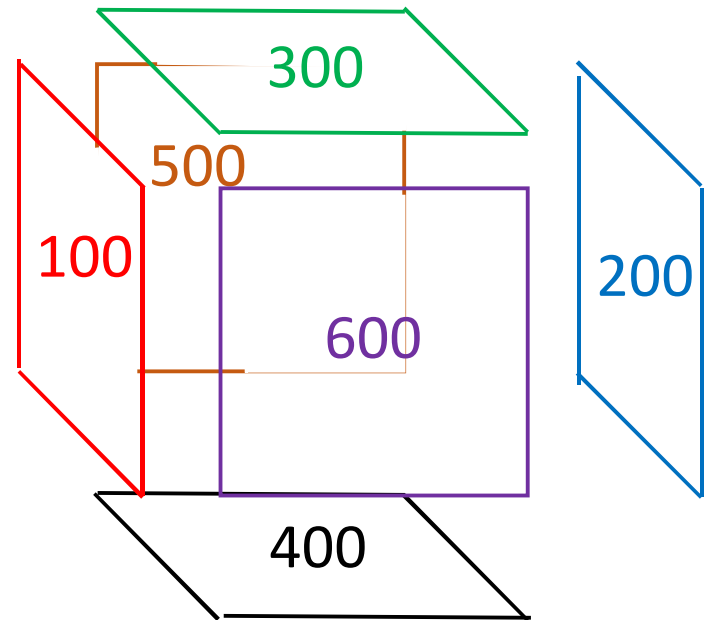
For our model, all box sides are the same size so the capacitance becomes:

$$C = \rho \cdot c_p \cdot l \cdot w \cdot t$$
$$C = (2710 \text{ kg/m}^3) \cdot (910 \text{ J/kg} \cdot ^\circ\text{C}) \cdot (1 \text{ m}) \cdot (1 \text{ m}) \cdot (0.00254 \text{ m})$$

$$C = 6263.9 \text{ J/}^\circ\text{C}$$

SINDA Syntax and the Input Deck

```
HEADER NODE DATA, SUB1
    100,    20.0, 6263.9
    200,    20.0, 6263.9
    300,    20.0, 6263.9
    400,    20.0, 6263.9
    500,    20.0, 6263.9
    600,    20.0, 6263.9
-999, -273.15,    1.0
```



SINDA Syntax and the Input Deck

Conduction from one box side to another is linear and, assuming constant thermal conductivity, is expressed in the follow format:

Conductor Number, 1st Node, 2nd Node, Ther. Conductance

Radiation is non-linear so we must indicate to SINDA which heat transfer paths are radiative – this is done by placing a “-” in front of the Conductor Number:

-Conductor Number, 1st Node, 2nd Node, Rad. Conductance

SINDA Syntax and the Input Deck

For each node, we calculate the Thermal Conductance as follows:

$$G = k \cdot w \cdot t / l$$

Where...

l is the box side length

w is the box side width

t is the box side thickness

k is the aluminum thermal conductivity

SINDA Syntax and the Input Deck

For our model, the thermal conductance between all adjacent box nodes is the same, namely:

$$G = k \cdot w \cdot t / l$$
$$G = (204 \text{ W}/\cancel{m} \cdot ^\circ\text{C}) \cdot (1 \cancel{m}) \cdot (0.00254 \cancel{m}) / (1 \cancel{m})$$

$$G = 0.51816 \text{ W}/^\circ\text{C}$$

SINDA Syntax and the Input Deck

We must also calculate the Rad. Conductance to account for the radiative heat loss from each box side to deep space:

$$G_{rad} = \varepsilon \cdot \sigma \cdot l \cdot w$$

Where...

ε is the surface infrared emissivity

σ is the Stefan-Boltzmann constant ($5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$)

l is the box side length

w is the box side width

SINDA Syntax and the Input Deck

Each box side has the same radiation conductance to space, namely:

$$G_{rad} = \varepsilon \cdot \sigma \cdot l \cdot w$$
$$G_{rad} = (0.88) \cdot (5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4) \cdot (1 \text{ m}) \cdot (1 \text{ m})$$

$$G_{rad} = 4.9896 \times 10^{-8} \text{ W/K}^4$$

SINDA Syntax and the Input Deck

Heating is applied in the SOURCE DATA block using the following command:

```
Node Number, Heating
```

SINDA Syntax and the Input Deck

We must also calculate the solar heating input to one box side:

$$\dot{Q} = \alpha \cdot \dot{q}_{sol} \cdot l \cdot w$$

Where...

α is the white paint solar absorptivity

\dot{q}_{sol} is the magnitude of the incoming solar flux

l is the box side length

w is the box side width

SINDA Syntax and the Input Deck

This heating will be applied to only one box side (i.e., node 100):

$$\dot{Q} = \alpha \cdot \dot{q}_{sol} \cdot l \cdot w$$
$$\dot{Q} = (0.27) \cdot (1371 \text{ W/m}^2) \cdot (1 \text{ m}) \cdot (1 \text{ m})$$

$$\dot{Q} = 370.17 \text{ W}$$

SINDA Syntax and the Input Deck

```
HEADER SOURCE DATA, SUB1  
100, 370.17
```

SINDA Syntax and the Input Deck

```
HEADER CONTROL DATA, GLOBAL  
    TIMEND = 50000.0  
    OUTPUT = 100.0  
    ABSZRO = -273.15
```

SINDA Syntax and the Input Deck

For a transient analysis...

```
HEADER OPERATIONS DATA  
BUILD BOX, SUB1  
CALL TRANSIENT
```

And for a steady state analysis...

```
HEADER OPERATIONS DATA  
BUILD BOX, SUB1  
CALL STEADY
```

Our first analysis will be transient.

SINDA Syntax and the Input Deck

```
HEADER OUTPUT CALLS, SUB1  
      CALL TPRINT('SUB1')
```

Or, for a formatted output...

```
HEADER OUTPUT CALLS, SUB1  
      WRITE(NUSER1,100) TIMEN, T100, T200, T300,  
      +                T400, T500, T600  
100    FORMAT(F8.1,3X,6(F8.1,3X))
```

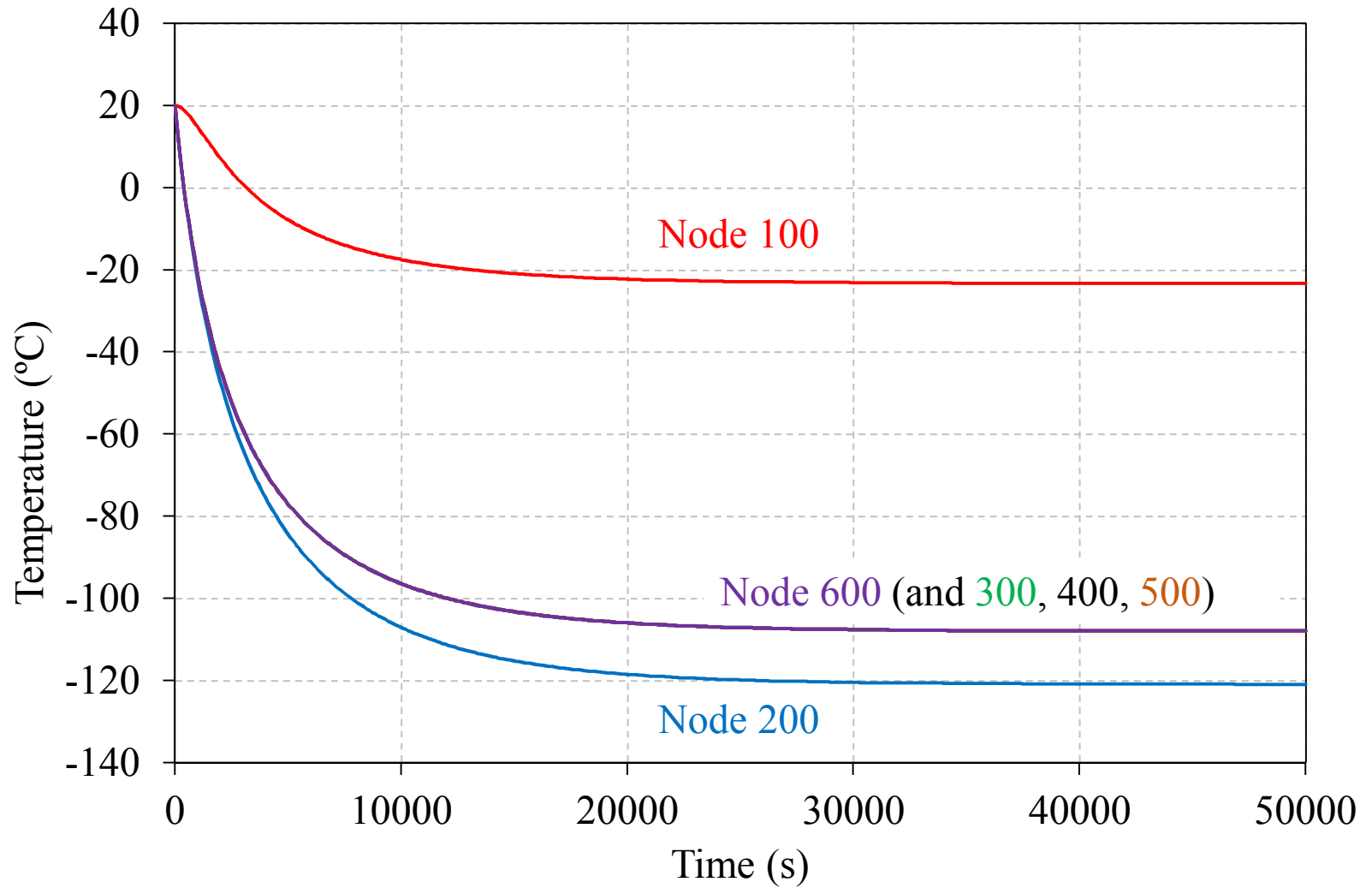
The output above specifies each number to be floating point, with eight digits including one decimal space. Each number is to be separated by three spaces.

SINDA Syntax and the Input Deck

```
HEADER OPTIONS DATA
TITLE MY FIRST SINDA MODEL
      MODEL = BOX
      OUTPUT = RESULTS.DAT
      USER1 = TEMPERATURES.DAT
HEADER NODE DATA, SUB1
      100,    20.0, 6263.9
      200,    20.0, 6263.9
      300,    20.0, 6263.9
      400,    20.0, 6263.9
      500,    20.0, 6263.9
      600,    20.0, 6263.9
      -999, -273.15,    1.0
HEADER CONDUCTOR DATA, SUB1
      100300, 100, 300, 0.51816
      100400, 100, 400, 0.51816
      100500, 100, 500, 0.51816
      100600, 100, 600, 0.51816
      200300, 200, 300, 0.51816
      200400, 200, 400, 0.51816
      200500, 200, 500, 0.51816
      200600, 200, 600, 0.51816
      300500, 300, 500, 0.51816
      300600, 300, 600, 0.51816
      400500, 400, 500, 0.51816
      400600, 400, 600, 0.51816
      -999100, 999, 100, 4.9896E-8
      -999200, 999, 200, 4.9896E-8
      -999300, 999, 300, 4.9896E-8
      -999400, 999, 400, 4.9896E-8
      -999500, 999, 500, 4.9896E-8
      -999600, 999, 600, 4.9896E-8
```

```
HEADER SOURCE DATA, SUB1
      100, 370.17
HEADER CONTROL DATA, GLOBAL
      TIMEND = 50000.0
      OUTPUT = 100.0
      ABSZRO = -273.15
HEADER OPERATIONS DATA
BUILD BOX, SUB1
      CALL TRANSIENT
HEADER OUTPUT CALLS, SUB1
      WRITE (NUSER1,100) TIMEN, T100, T200, T300,
      + T400, T500, T600
      100 FORMAT (F8.1,3X,6 (F8.1,3X))
END OF DATA
```

Transient Results



Setting Up a Steady State Run

Instead of running the transient analysis all the way to steady state, we can also specify a steady state analysis by calling the steady state routine within the OPERATIONS DATA block...

```
HEADER OPERATIONS DATA  
BUILD BOX, SUB1  
CALL STEADY
```

SINDA Syntax and the Input Deck

```
HEADER OPTIONS DATA
TITLE MY FIRST SINDA MODEL
MODEL = BOX
OUTPUT = RESULTS.DAT
USER1 = TEMPERATURES.DAT
HEADER NODE DATA, SUB1
  100, 20.0, 6263.9
  200, 20.0, 6263.9
  300, 20.0, 6263.9
  400, 20.0, 6263.9
  500, 20.0, 6263.9
  600, 20.0, 6263.9
  -999, -273.15, 1.0
HEADER CONDUCTOR DATA, SUB1
  100300, 100, 300, 0.51816
  100400, 100, 400, 0.51816
  100500, 100, 500, 0.51816
  100600, 100, 600, 0.51816
  200300, 200, 300, 0.51816
  200400, 200, 400, 0.51816
  200500, 200, 500, 0.51816
  200600, 200, 600, 0.51816
  300500, 300, 500, 0.51816
  300600, 300, 600, 0.51816
  400500, 400, 500, 0.51816
  400600, 400, 600, 0.51816
  -999100, 999, 100, 4.9896E-8
  -999200, 999, 200, 4.9896E-8
  -999300, 999, 300, 4.9896E-8
  -999400, 999, 400, 4.9896E-8
  -999500, 999, 500, 4.9896E-8
  -999600, 999, 600, 4.9896E-8
```

```
HEADER SOURCE DATA, SUB1
  100, 370.17
HEADER CONTROL DATA, GLOBAL
ABSZRO = -273.15
HEADER OPERATIONS DATA
BUILD BOX, SUB1
CALL STEADY
HEADER OUTPUT CALLS, SUB1
  WRITE (NUSER1,100) TIMEN, T100, T200, T300,
    + T400, T500, T600
  100 FORMAT (F8.1, 3X, 6 (F8.1, 3X))
END OF DATA
```

Steady State Results

Comparing the results of the transient and steady state analysis runs...

Node Number	Predicted Temperature After 50000 second Transient Analysis (°C)	Predicted Temperature Steady State Analysis (°C)
100	-23.2	-23.2
200	-120.9	-120.9
300	-107.9	-107.9
400	-107.9	-107.9
500	-107.9	-107.9
600	-107.9	-107.9

Brief Introduction to Abbreviated Input Formats

Our NODE DATA was specified as...

```
HEADER NODE DATA, SUB1
    100,    20.0, 6263.9
    200,    20.0, 6263.9
    300,    20.0, 6263.9
    400,    20.0, 6263.9
    500,    20.0, 6263.9
    600,    20.0, 6263.9
-999, -273.15,    1.0
```

But we observe that nodes 100 – 600 have identical initialization temperature and thermal capacitance;

SINDA allows some shortcuts when such situations arise – we can use the following format for multiple node inputs:

```
GEN Node#, #Nodes, Increment, Tinitial, C
```

Brief Introduction to Abbreviated Input Format

Using the abbreviated input, our NODE DATA becomes...

```
HEADER NODE DATA, SUB1  
      GEN 100, 6, 100, 20.0, 6263.9  
      -999,      -273.15, 1.0
```

Using this GEN command, six diffusion nodes will be generated, beginning with node 100 with node numbers incrementing by 100;

Each node will have an initial temperature of 20 °C and a capacitance of 6263.9 J/°C;

The space boundary node (999) is defined as before.

Brief Introduction to Abbreviated Input Formats

Similarly, we can use abbreviated input format in the CONDUCTOR DATA;

Previously, we had:

```
HEADER CONDUCTOR DATA, SUB1
  100300,  100,  300, 0.51816
  100400,  100,  400, 0.51816
  100500,  100,  500, 0.51816
  100600,  100,  600, 0.51816
  200300,  200,  300, 0.51816
  200400,  200,  400, 0.51816
  200500,  200,  500, 0.51816
  200600,  200,  600, 0.51816
  300500,  300,  500, 0.51816
  300600,  300,  600, 0.51816
  400500,  400,  500, 0.51816
  400600,  400,  600, 0.51816
-999100,  999,  100, 4.9896E-8
-999200,  999,  200, 4.9896E-8
-999300,  999,  300, 4.9896E-8
-999400,  999,  400, 4.9896E-8
-999500,  999,  500, 4.9896E-8
-999600,  999,  600, 4.9896E-8
```

Brief Introduction to Abbreviated Input Formats

For abbreviated input of conductors, the GEN statement takes the form:

```
GEN Con#, #Con, Inc, Nod#1, IncNod#1, Nod#2, IncNod#2, G
```

We see that our conductor input can be shortened to:

```
HEADER CONDUCTOR DATA, SUB1
GEN 100300, 4, 100, 100, 0, 300, 100, 0.51816
GEN 200300, 4, 100, 200, 0, 300, 100, 0.51816
GEN 300500, 2, 100, 300, 0, 500, 100, 0.51816
GEN 400500, 2, 100, 400, 0, 500, 100, 0.51816
GEN -999100, 6, 100, 999, 0, 100, 100, 4.989E-8
```

Brief Introduction to Abbreviated Input Formats

```
HEADER OPTIONS DATA
TITLE MY FIRST SINDA MODEL
      MODEL = BOX
      OUTPUT = RESULTS.DAT
      USER1 = TEMPERATURES.DAT
HEADER NODE DATA, SUB1
      GEN 100, 6, 100, 20.0, 6263.9
          -999, -273.15, 1.0
HEADER CONDUCTOR DATA, SUB1
      GEN 100300, 4, 100, 100, 0, 300, 100, 0.51816
      GEN 200300, 4, 100, 200, 0, 300, 100, 0.51816
      GEN 300500, 2, 100, 300, 0, 500, 100, 0.51816
      GEN 400500, 2, 100, 400, 0, 500, 100, 0.51816
      GEN -999100, 6, 100, 999, 0, 100, 100, 4.989E-8
HEADER SOURCE DATA, SUB1
      100, 370.17
HEADER CONTROL DATA, GLOBAL
      TIMEND = 50000.0
      OUTPUT = 100.0
      ABSZRO = -273.15
HEADER OPERATIONS DATA
BUILD BOX, SUB1
      CALL TRANSIENT
HEADER OUTPUT CALLS, SUB1
      WRITE(NUSE1,100) TIMEN, T100, T200, T300,
+
          T400, T500, T600
100 FORMAT(F8.1,3X,6(F8.1,3X))
END OF DATA
```

Concluding Remarks

In this lesson, we learned how to discretize a physical system into a finite difference network;

From this abstraction, we formulated a basic SINDA input deck to represent the thermal network;

Only basic functionality was demonstrated – there is a lot more to learn;

The more you learn about how to use the tool and its capabilities and limitations, the more power you will have as an analyst.

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