Building Your Third 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.*

Data used in this lesson are for demonstration purposes and should not be used for design purposes or to replace use of any project-directed data.

Prerequisites

Viewers watching this lesson are assumed to have some familiarity with thermal network modeling and the SINDA input format.

To fully understand the content of this lesson, watching the NESC Academy lessons entitled *Building Your First SINDA Model* and *Building Your Second SINDA Model* is recommended.

Introduction

Engineers rely on a wide variety of modern 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 using 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 a model 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.

This is the third in a series of lessons that focus on understanding SINDA input and demonstration of its flexibility.

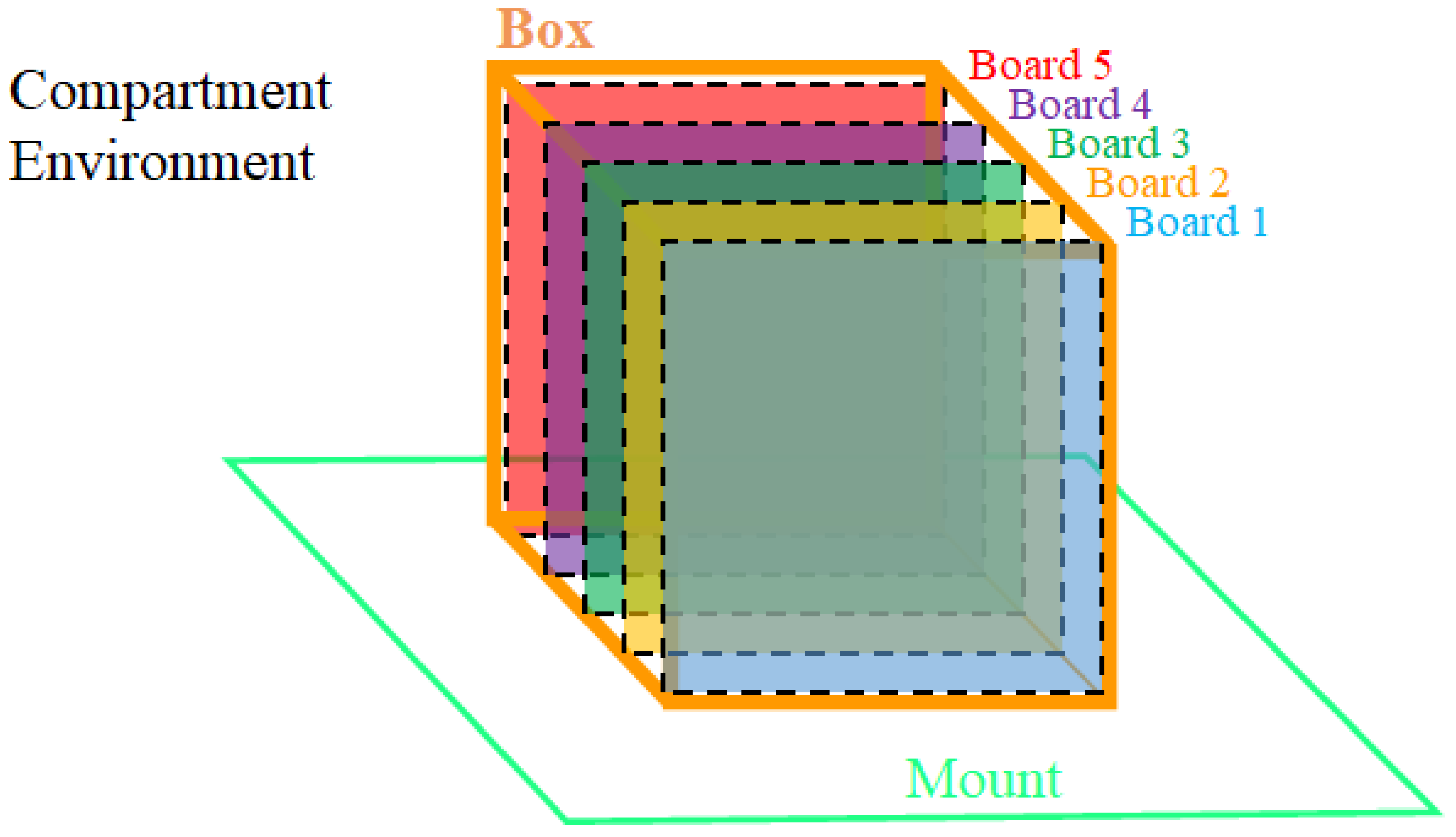
Lesson Scope

In this lesson, we will focus on:

- Use of submodels;
- Customizing input and output;
- Running multiple cases within a single SINDA run.

Problem Statement (1 of 2)

- Consider the simplified spacecraft component shown below.



Problem Statement (2 of 2)

- The component is situated inside of a spacecraft equipment bay;

- Both the bay radiation environment temperature and the component mount temperature vary;

- *For each powered component on the component circuit boards, determine the steady state temperature for the specified environment temperatures, mount temperatures, and powered component configurations.*

Box Key Dimensions and Properties

Parameter	Value
Length, Width, Height	$7.0\ inches\ (0.1778\ m)$
Wall Thickness	$0.10\ inches\ (0.00254\ m)$
Density	$2705.0\ \ kg/m^3$
Specific Heat	$c_p(T)$
Thermal Conductivity	$k(T)$
Optical Properties	
Infrared Emittance (Anodize)	0.8
Contact Parameter	
Contact Conductance* (representative)	$10000\ \ W/m^2 \cdot ℃$

*Representative value from: http://www.thermopedia.com/content/1188

Component Board Key Dimensions and Properties

Parameter	Value
Length, Width	7.0 $inches$ (0.1778 m)
Thickness	3 mm (0.003 m)
Areal Density	73.07285 kg/m^2
Effective Lateral Thermal Conductivity	45.0 $W/m \cdot °C$
Effective Specific Heat	976.0 $kJ/kg \cdot °C$
Card Lock Conductance (per 7 inch)*	1.72414 $W/°C$

*Representative value derived from: connex-electronics.com (No endorsement given). Value will be divided over five nodes per side.

Node and Conductor Values

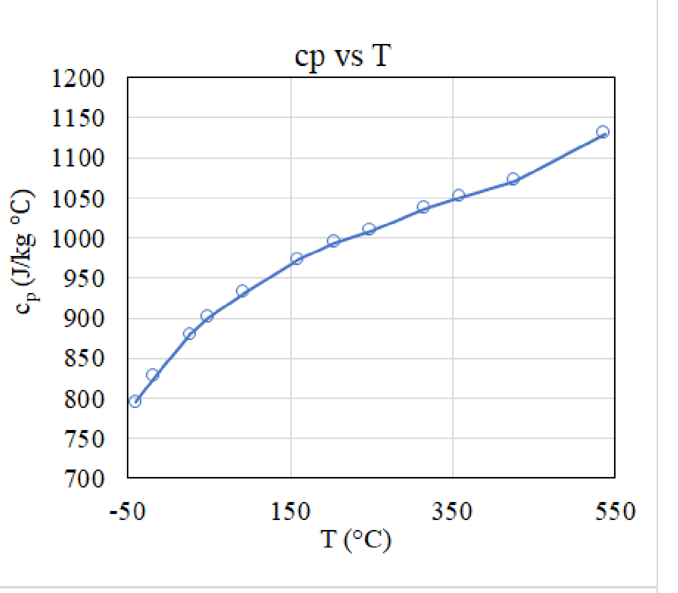
Node	$l\ (m)$	$w\ (m)$	$t\ (m)$	$\rho\ (kg/m^3)$	$c_p\ (J/kg \cdot °C)$	$C\ (J/°C)$
Box	0.03556	0.03556	0.00254	2705.0	$c_p(T)$	8.668e-3*$c_p(T)$
Board	0.03556	0.03556	0.003	2311.483	976.0	8.5583

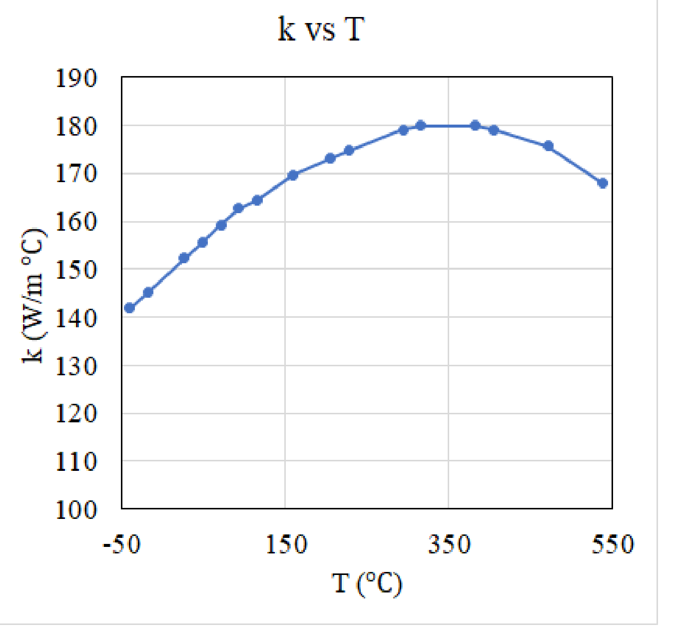
Conductor	$l\ (m)$	$w\ (m)$	$t\ (m)$	$k\ (W/m \cdot °C)$	$G\ (W/°C)$
Box to Box	0.03556	0.03556	0.00254	$k(T)$	2.54e-3*$k(T)$
Board to Board	0.03556	0.03556	0.003	45.0	0.135
Board to Board Edge	0.03556	0.01778	0.003	45.0	0.270
Board Edge to Box via Card Lock	N/A	N/A	N/A	N/A	0.34483

Radk	$l\ (m)$	$w\ (m)$	ε	$\sigma\ (W/m^2 \cdot K^4)$	$G_{Rad}\ (W/K^4)$
Box to Environment	0.03556	0.03556	0.8	$5.67e-8$	1.8144e-11

Aluminum Properties

The aluminum box is assumed to have both specific heat (c_p) and thermal conductivity (k) vary as a function of temperature.





Analysis Cases and Input Format

We wish to demonstrate how to perform multiple analysis cases using different input conditions.

For this model, we want to see the effect of varying:

1. Environment temperature
2. Mount temperature
3. Component board power levels.

Analysis Cases

			Component Power *PER COMPONENT*				
Case Number	Compartment Environment Temperature (°C)	Mount Temperature (°C)	Board 1 (W)	Board 2 (W)	Board 3 (W)	Board 4 (W)	Board 5 (W)
1	-40.0	-20.0	5.0	5.0	5.0	5.0	5.0
2	-40.0	-15.0	2.0	5.0	3.0	5.0	2.0
3	-30.0	0.0	4.0	1.0	3.0	2.0	1.0
4	-30.0	5.0	2.0	1.0	2.0	1.0	2.0
5	-30.0	10.0	1.0	1.0	1.0	1.0	1.0

Analysis Case Input Format

It is convenient to set up our model such that cases on interest can be read into the model from an input file.

The input file is a line-by-line specification of the parameters we wish to vary – each line having the form…

`RT, MT, B1Q, B2Q, B3Q, B4Q, B5Q`

where…

`RT`	is the radiation environment temperature (°C)
`MT`	is the spacecraft mount temperature (°C)
`B1Q–B5Q`	is the power dissipation per component on Boards 1-5 (W)

Analysis Cases and Input Format

We'll store our input in a file named: `RUNINPUTS.DAT`

```
-40.0, -20.0, 5.0, 5.0, 5.0, 5.0, 5.0
-40.0, -15.0, 2.0, 5.0, 3.0, 5.0, 2.0
-30.0,   0.0, 4.0, 1.0, 3.0, 2.0, 1.0
-30.0,   5.0, 2.0, 1.0, 2.0, 1.0, 2.0
-30.0,  10.0, 1.0, 1.0, 1.0, 1.0, 1.0
```

Forming the Nodal Network

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

We want to ensure the model has sufficient capability to resolve temperature differences in the box nodes – especially where the circuit boards connect to the box structure.

We also want to ensure that localized heat dissipations on the component boards can be represented.

Review of Node Types

There are three* primary node types 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. Arithmetic nodes can also offer some convenience when connecting two different materials to one another;

Boundary Nodes – represent an "infinite" thermal capacitance – they are used as heat reservoirs or heat sinks.

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

Review of Conductor Types

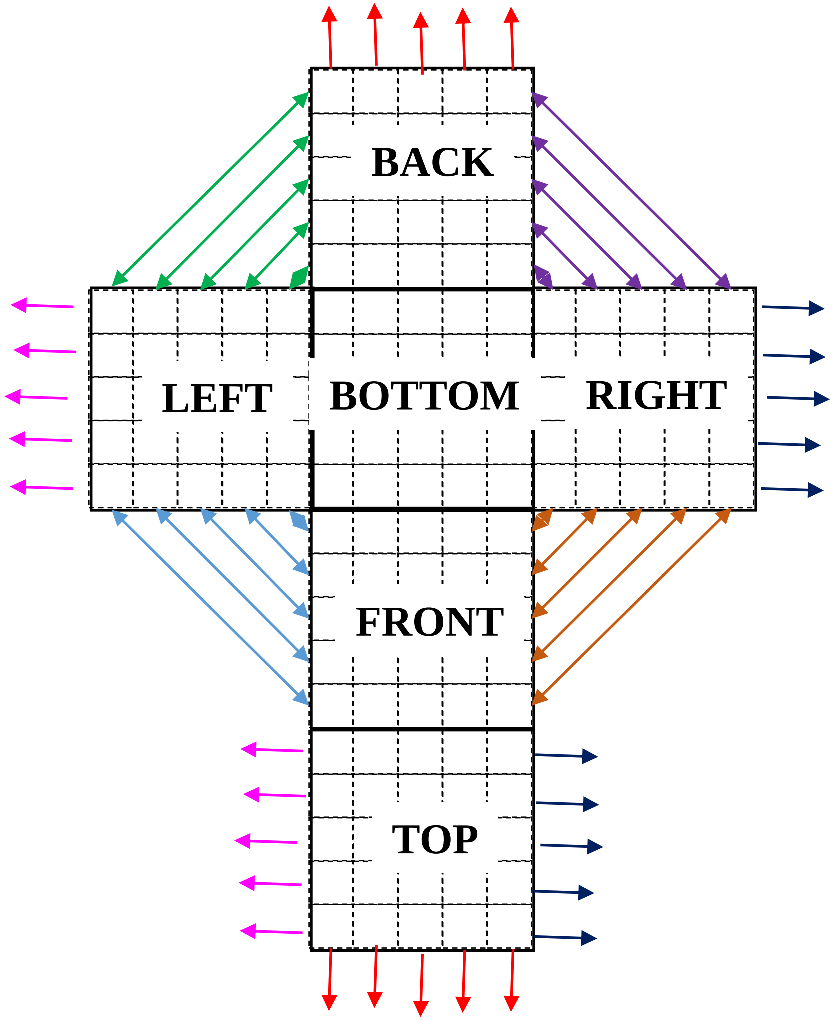
In a thermal network model, heat flows from one node to another along pathways called conductors – there are two types:

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

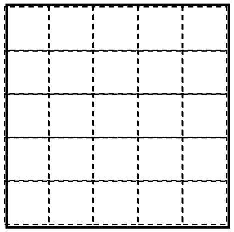
Radiation Conductors -- heat flow between two objects is highly non-linear – that is, it is a function of the $\Delta(T^4)$ between the two objects where the temperature is expressed in absolute units.

Nodalization and Connectivity

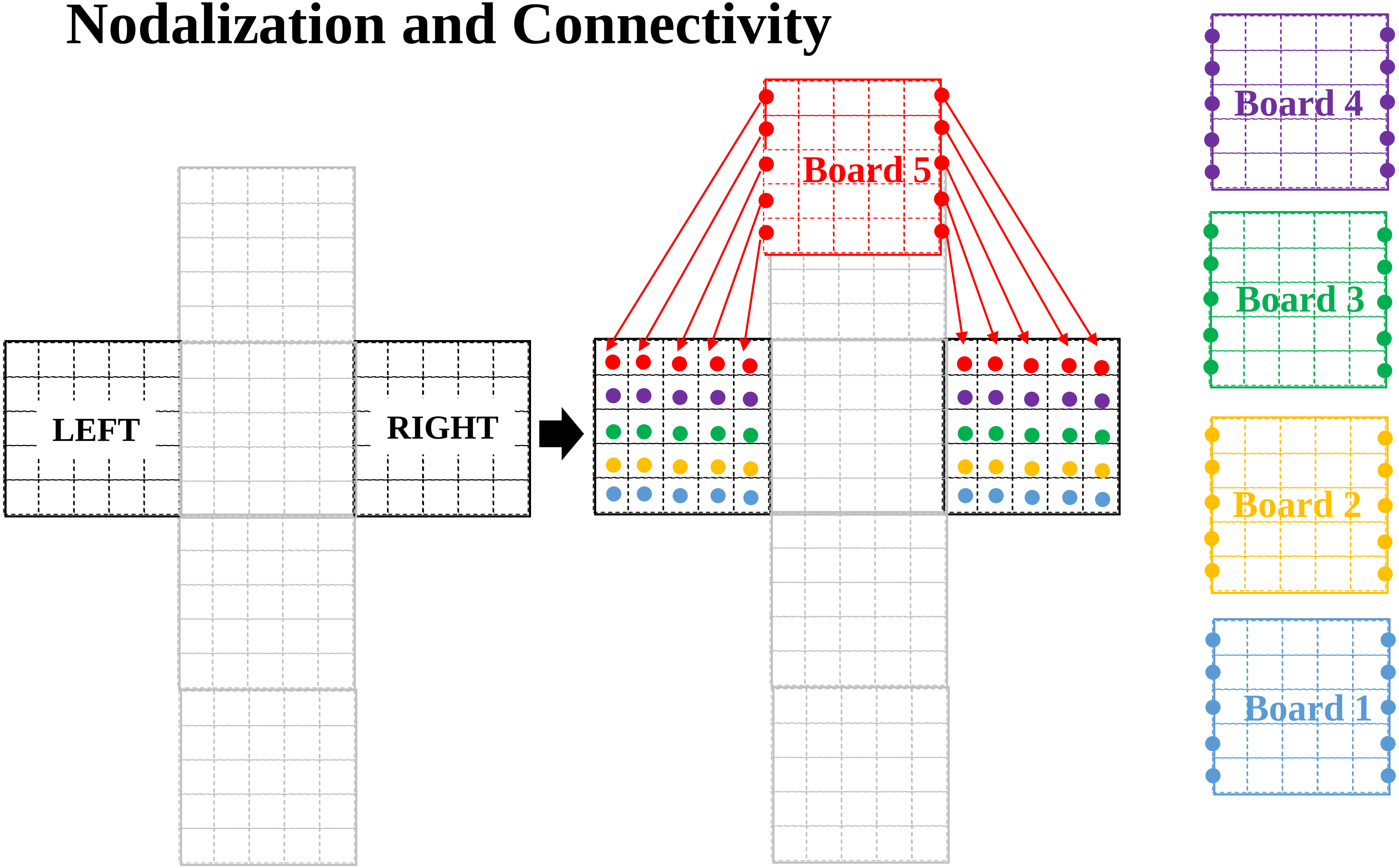
Box (Unfolded)



Component Board (Typical)



Nodalization and Connectivity



Note: Connections for Board 5 shown – color-coded connections analogous for Boards 1, 2, 3 and 4

Assumptions in Forming the Nodal Network (1 of 2)

The box sides and the component boards are represented by diffusion nodes.

Board edges, where heat transfer paths to the box are established, will be modeled using arithmetic nodes.

Compartment environment is a boundary node.

The structure to which the box is mounted to is a boundary node;

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

Contact conduction between the component board and the box is modeled with a linear conductor.

All box sides, except the side connected to the mounting structure, radiate to the compartment environment (using radiation conductors).

Assumptions in Forming the Nodal Network (2 of 2)

No internal radiation is considered.

Heating sources on the component board are applied directly to the component board at specified locations.

Assembling the SINDA Input Deck

For our third SINDA model, we will use the following blocks:

```
OPTIONS DATA
NODE DATA
CONDUCTOR DATA
ARRAY DATA
CONTROL DATA
OPERATIONS DATA
VARIABLES 1
```

The input deck ends with the last line:

```
END OF DATA
```

For this lesson, we will introduce the concept of submodels.

Using Submodels

Submodels offer a number of conveniences to SINDA users such as allowing assembly of models developed by different analysts into a single model without worrying about node and conductor number conflicts.

For the model used in this lesson…

Submodeling allows duplication of components that might otherwise require unnecessary duplication of nodal networks that would require increments to numbering schemes.

Submodeling also allows a higher-level grouping to aid analysts in logically organizing their models.

Using Submodels

Submodels include groupings including nodes, arrays, conductors, and even variables logic.

Nodes defined to be within a given submodel must appear beneath the header for that submodel…

```
HEADER NODE DATA, smn
```

where `smn` is the submodel name.

The same is true for arrays that are tied to a specific submodel…

```
HEADER ARRAY DATA, smn
```

Using Submodels

Conductors in `CONDUCTOR DATA` and logic in the `VARIABLES 1` and `VARIABLES 2` blocks specific to a submodel are also defined within their respective header statements…

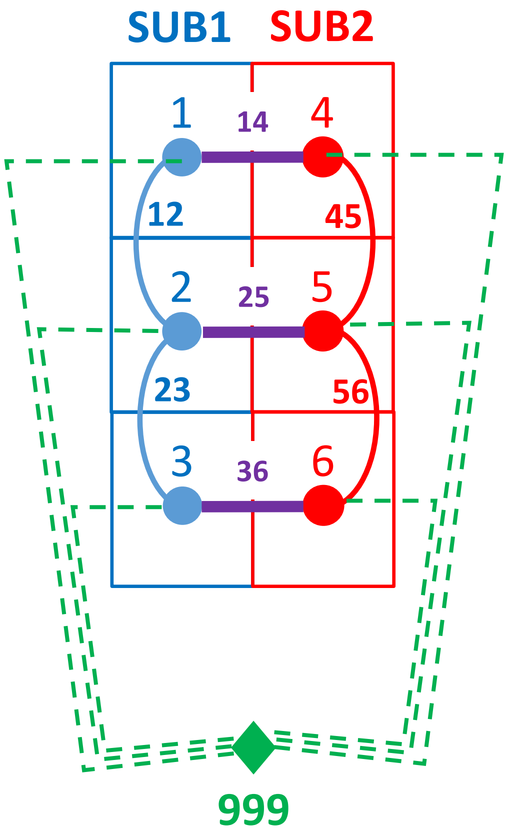
```
HEADER CONDUCTOR DATA, smn

HEADER VARIABLES 1, smn

HEADER VARIABLES 2, smn
```

Note: VARIABLES 2 is not discussed further in this lesson but is noted for completeness.

Using Submodels

However, conductors in the `CONDUCTOR DATA` block may refer to nodes within other submodels.

```
HEADER CONDUCTOR DATA, SUB1
       12,  1,                 2,     2.5
       23,  2,                 3,     2.5
       14,  1,            SUB2.4,     2.5
       25,  2,            SUB2.5,     2.5
       36,  3,            SUB2.6,     2.5
GEN -9991,  3, 1, 999, 0,      1, 1, 4.56E-08
GEN -9994,  3, 1, 999, 0, SUB2.4, 1, 4.56E-08
HEADER CONDUCTOR DATA, SUB2
       45,          4,         5,     2.5
       56,          5,         6,     2.5
```



Using Submodels

Nodes and conductors may even refer to *arrays* in different submodels.

```
HEADER NODE DATA, SUB1
       SIV 10, 20.0, SUB2.A1, 5.0
       SIV 20, 20.0, SUB2.A1, 5.0
HEADER CONDUCTOR DATA, SUB1
       SIV 1000, 10, 20, SUB2.A2, 3.0
```

And *combinations of conductors and arrays* from across submodels is also permitted.

```
HEADER CONDUCTOR DATA, SUB1
       SIV 10000, SUB3.100, SUB2.200, SUB2.A2, 3.0
```

Using Submodels

Logic in `VARIABLES 1` and `VARIABLES 2` may also refer to entities outside of a given submodel.

```
HEADER VARIABLES 1, SUB1
        CALL D1DEG1(SUB2.T4, SUB2.A1, STEST)
        G12 = STEST
        SUB2.G45 = 2.0*STEST
        WRITE(NUSER1, *) T1
        WRITE(NUSER1, *) T2
        WRITE(NUSER1, *) T3
        WRITE(NUSER1, *) SUB2.T4
        WRITE(NUSER1, *) SUB2.T5
        WRITE(NUSER1, *) SUB2.T6
```

VARIABLES 1 for submodel SUB1

The interpolation call refers to the temperature of node 4 in SUB2 and interpolates from Array #1 in SUB2

Assign a value of the conductor SUB2.45

Outputting temperatures for SUB2 nodes 4, 5, and 6

Submodel Breakdown

One possible logical arrangement of the problem is to consider the box as one submodel and each component board as a separate submodel. The spacecraft mount and environment can reside in yet another submodel.

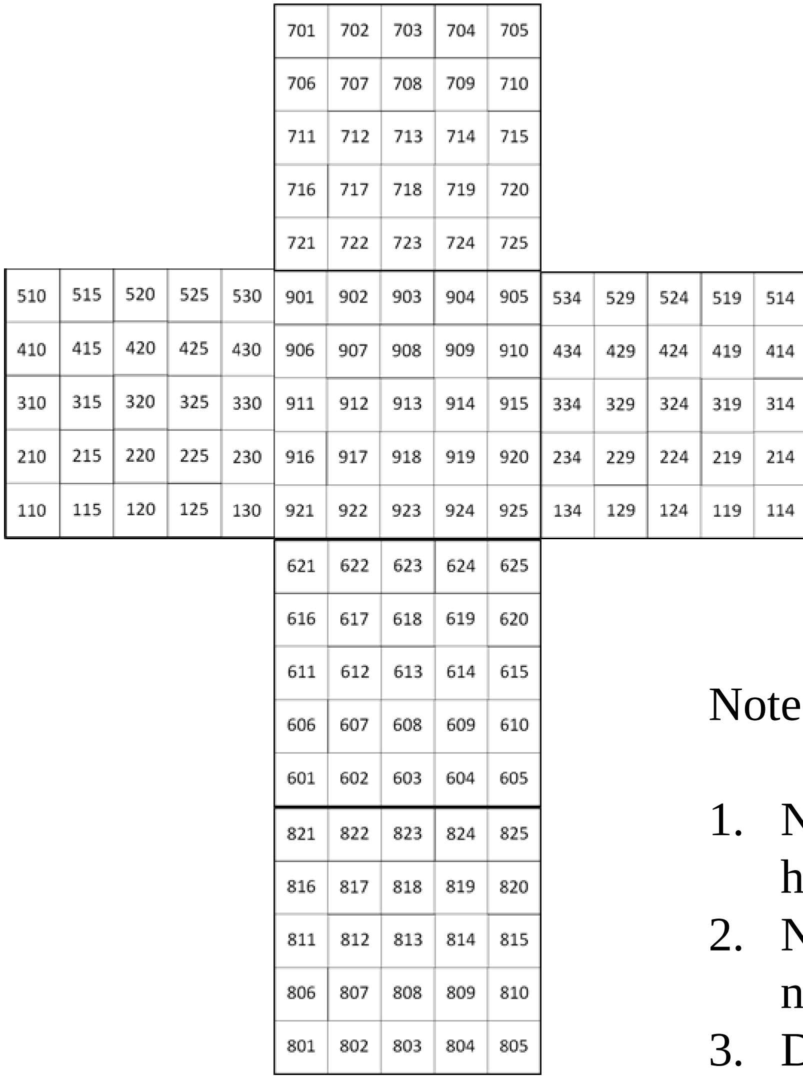
The submodel designations for our model will be:

Component	**Submodel Name**
Spacecraft Mount and Compartment Environment	SCENV
Box	BOX
Component Board 1	BOARD1
Component Board 2	BOARD2
Component Board 3	BOARD3
Component Board 4	BOARD4
Component Board 5	BOARD5

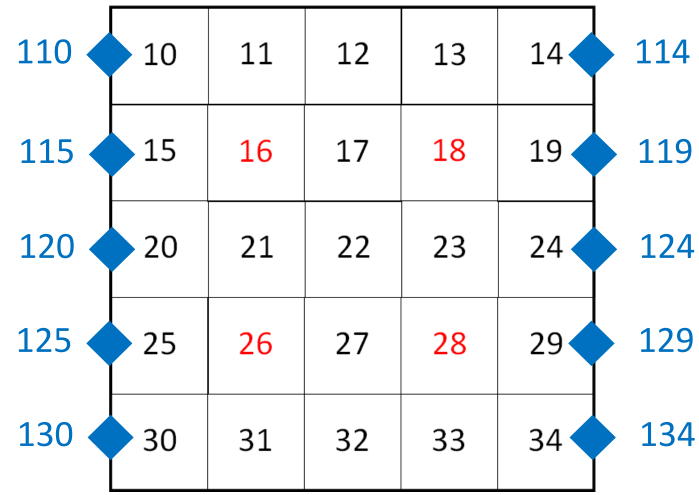
SINDA Deck Structure with Submodels and INCLUDE Statements

```
HEADER OPTIONS DATA
        .   .   .
HEADER NODE DATA, BOX
INCLUDE BOXNODES.TXT
C
HEADER NODE DATA, BOARD1
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD2
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD3
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD4
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD5
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, SCENV
        .   .   .
HEADER CONDUCTOR DATA, BOX
INCLUDE BOXCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD1
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD2
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD3
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD4
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD5
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER ARRAY DATA, BOX
        .   .   .
HEADER CONTROL DATA, GLOBAL
        .   .   .
HEADER OPERATIONS DATA
        .   .   .
HEADER VARIABLES 1, BOX
        .   .   .
END OF DATA
```

Node Numbering and Submodel Designation



BOX



BOARD1 (Identical for BOARD2-BOARD5)

Notes:

1. Nodes numbers in red denote application of heat due to components.
2. Node numbers in blue denote arithmetic nodes.
3. Diagram of BOARD is enlarged relative to scale of BOX diagram.

OPTIONS DATA

```
HEADER OPTIONS DATA
TITLE   MY THIRD SINDA MODEL
        MODEL   = CONFIG
        OUTPUT = RESULTS.DAT
        USER1   = RUNINPUTS.DAT
        USER2   = RUNOUTPUTS.DAT
```

Model specification begins with OPTIONS DATA.

Descriptive title.

The model is named CONFIG.

Model results (and output assigned to logical unit NOUT) will be sent to RESULTS.DAT

Inputs will come from the USER1 file (logical unit NUSER1) RUNINPUTS.DAT

User specified outputs will go to the USER2 file (logical unit NUSER2) RUNOUTPUTS.DAT

ARRAY DATA

```
HEADER ARRAY DATA, BOX
 1 = -40.0, 795.3, -17.8, 826.7,  26.7, 879.2
      48.9, 900.2,  93.3, 931.6, 160.0, 973.4
     204.4, 994.4, 248.9,1009.0, 315.6,1036.2
     360.0,1050.9, 426.7,1071.8, 537.8,1130.4
 2 = -40.0, 141.9, -17.8, 145.3,  26.7, 152.3
      48.9, 155.8,  71.1, 159.2,  93.3, 162.7
     115.6, 164.4, 160.0, 169.6, 204.4, 173.1
     226.7, 174.8, 293.3, 179.1, 315.6, 180.0
     382.2, 180.0, 404.4, 179.1, 471.1, 175.7
     537.8, 167.9
```

Array Data block header. This will be referenced from the BOX submodel.

Array 1 is a T, c_p doublet array where temperatures are in deg C and specific heat is in units of J/kg/°C

Array 2 is a T, k doublet array where temperatures are in deg °C and thermal conductivity is in units of W/m °C

NODE DATA

```
HEADER NODE DATA, BOX
INCLUDE BOXNODES.TXT
C
HEADER NODE DATA, BOARD1
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD2
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD3
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD4
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, BOARD5
INCLUDE BOARDNODES.TXT
C
HEADER NODE DATA, SCENV
C
        -998, 20.0, 1.0    $ SPACECRAFT STRUCTURAL MOUNT
        -999, 20.0, 1.0    $ RADIATION BOUNDARY
C
```

Define the Node Data block for the BOX submodel. Nodes for this submodel are added using the INCLUDE statement.

Five component board submodels (BOARD1 – BOARD5) are created. Since each board is identical, we can define it once in BOARDNODES.TXT and INCLUDE it for each submodel.

The spacecraft connection and the environment boundary nodes are defined in the submodel SCENV.

The spacecraft structure is a boundary node.

A space boundary node is defined.

NODE DATA

In the BOXNODES.TXT file…

```
C
C  LEFT SIDE NODES...
C
      SIM 110, 5, 100, 20.0, A1, 8.668e-3
      SIM 115, 5, 100, 20.0, A1, 8.668e-3
      SIM 120, 5, 100, 20.0, A1, 8.668e-3
      SIM 125, 5, 100, 20.0, A1, 8.668e-3
      SIM 130, 5, 100, 20.0, A1, 8.668e-3
C
C  RIGHT SIDE NODES...
C
      SIM 114, 5, 100, 20.0, A1, 8.668e-3
      SIM 119, 5, 100, 20.0, A1, 8.668e-3
      SIM 124, 5, 100, 20.0, A1, 8.668e-3
      SIM 129, 5, 100, 20.0, A1, 8.668e-3
      SIM 134, 5, 100, 20.0, A1, 8.668e-3
```

510	515	520	525	530
410	415	420	425	430
310	315	320	325	330
210	215	220	225	230
110	115	120	125	130

534	529	524	519	514
434	429	424	419	414
334	329	324	319	314
234	229	224	219	214
134	129	124	119	114

NODE DATA

Continuing…

```
C
C  FRONT SIDE NODES...
C
        SIM 601, 25, 1, 20.0, A1, 8.668e-3
C
C  BACK SIDE NODES...
C
        SIM 701, 25, 1, 20.0, A1, 8.668e-3
C
C  TOP SIDE NODES...
C
        SIM 801, 25, 1, 20.0, A1, 8.668e-3
C
C  BOTTOM SIDE NODES...
C
        SIM 901, 25, 1, 20.0, A1, 8.668e-3
C
```

621	622	623	624	625
616	617	618	619	620
611	612	613	614	615
606	607	608	609	610
601	602	603	604	605

701	702	703	704	705
706	707	708	709	710
711	712	713	714	715
716	717	718	719	720
721	722	723	724	725

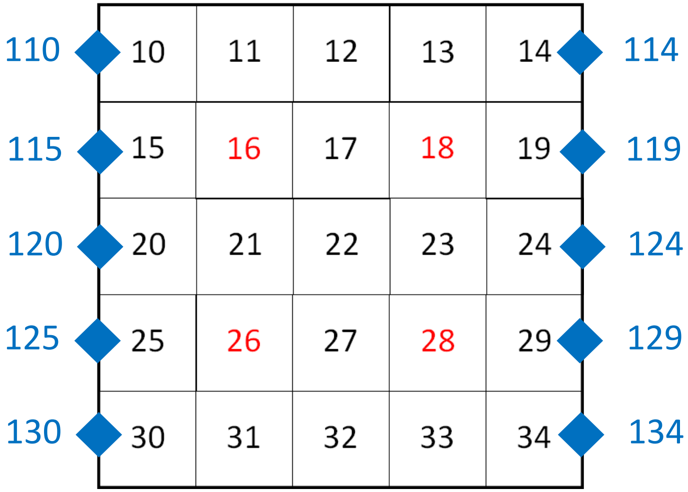
821	822	823	824	825
816	817	818	819	820
811	812	813	814	815
806	807	808	809	810
801	802	803	804	805

901	902	903	904	905
906	907	908	909	910
911	912	913	914	915
916	917	918	919	920
921	922	923	924	925

NODE DATA

Node data for each component board is simply stated using a GEN statement in the BOARDNODES.TXT file…

```
C
       GEN 10, 25,    1, 20.0,  8.558
C
C  ARITHMETIC NODES ON BOARD LEFT AND RIGHT EDGES
C
       GEN 110, 5,    5, 20.0, -1.0
       GEN 114, 5,    5, 20.0, -1.0
```



Note: Node numbers in red denote regions where heat will be applied.

CONDUCTOR DATA

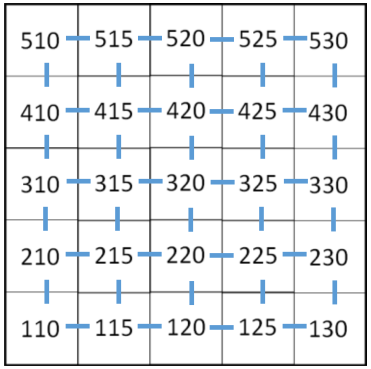
```
HEADER CONDUCTOR DATA, BOX
INCLUDE BOXCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD1
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD2
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD3
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD4
INCLUDE BOARDCONDUCTORS.TXT
C
HEADER CONDUCTOR DATA, BOARD5
INCLUDE BOARDCONDUCTORS.TXT
C
```

Conductor Data for the BOX submodel – conductors are in separate INCLUDE file.

A separate submodel is used for each board's conductors but since they are identical, we use the same INCLUDE file.

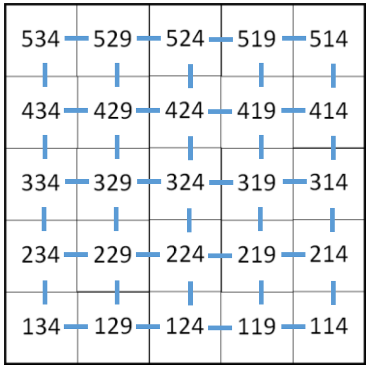
CONDUCTOR DATA (for the Box)

```
C
C  LEFT SIDE CONNECTIONS...
C
       SIM 110210, 4, 100100, 110, 100, 210, 100, A2, 0.00254
       SIM 115215, 4, 100100, 115, 100, 215, 100, A2, 0.00254
       SIM 120220, 4, 100100, 120, 100, 220, 100, A2, 0.00254
       SIM 125225, 4, 100100, 125, 100, 225, 100, A2, 0.00254
       SIM 130230, 4, 100100, 130, 100, 230, 100, A2, 0.00254
C
       SIM 110115, 4,   5005, 110,   5, 115,   5, A2, 0.00254
       SIM 210215, 4,   5005, 210,   5, 215,   5, A2, 0.00254
       SIM 310315, 4,   5005, 310,   5, 315,   5, A2, 0.00254
       SIM 410415, 4,   5005, 410,   5, 415,   5, A2, 0.00254
       SIM 510515, 4,   5005, 510,   5, 515,   5, A2, 0.00254
```



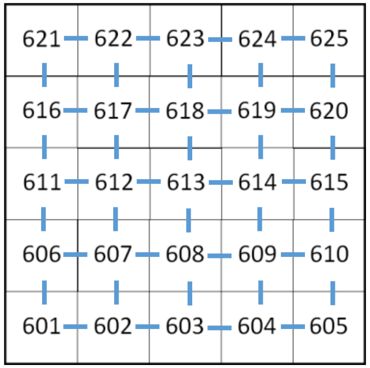
CONDUCTOR DATA (for the Box)

```
C
C  RIGHT SIDE CONNECTIONS...
C
       SIM 114214, 4, 100100, 114, 100, 214, 100, A2, 0.00254
       SIM 119219, 4, 100100, 119, 100, 219, 100, A2, 0.00254
       SIM 124224, 4, 100100, 124, 100, 224, 100, A2, 0.00254
       SIM 129229, 4, 100100, 129, 100, 229, 100, A2, 0.00254
       SIM 134234, 4, 100100, 134, 100, 234, 100, A2, 0.00254
C
       SIM 114119, 4,   5005, 114,   5, 119,   5, A2, 0.00254
       SIM 214219, 4,   5005, 214,   5, 219,   5, A2, 0.00254
       SIM 314319, 4,   5005, 314,   5, 319,   5, A2, 0.00254
       SIM 414419, 4,   5005, 414,   5, 419,   5, A2, 0.00254
       SIM 514519, 4,   5005, 514,   5, 519,   5, A2, 0.00254
```



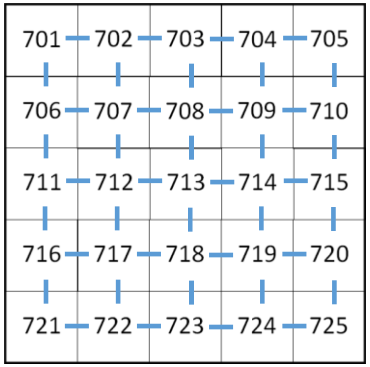
CONDUCTOR DATA (for the Box)

```
C
C  FRONT SIDE CONNECTIONS...
C
        SIM 601602, 4, 1001, 601, 1, 602, 1, A2, 0.00254
        SIM 606607, 4, 1001, 606, 1, 607, 1, A2, 0.00254
        SIM 611612, 4, 1001, 611, 1, 612, 1, A2, 0.00254
        SIM 616617, 4, 1001, 616, 1, 617, 1, A2, 0.00254
        SIM 621622, 4, 1001, 621, 1, 622, 1, A2, 0.00254
C
        SIM 601606, 4, 5005, 601, 5, 606, 5, A2, 0.00254
        SIM 602607, 4, 5005, 602, 5, 607, 5, A2, 0.00254
        SIM 603608, 4, 5005, 603, 5, 608, 5, A2, 0.00254
        SIM 604609, 4, 5005, 604, 5, 609, 5, A2, 0.00254
        SIM 605610, 4, 5005, 605, 5, 610, 5, A2, 0.00254
```



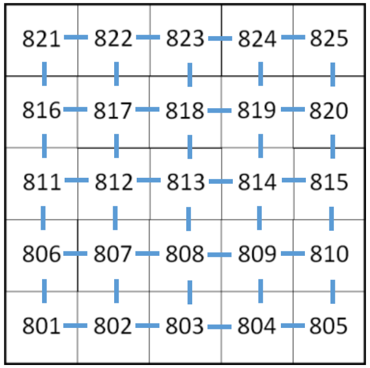
CONDUCTOR DATA (for the Box)

```
C
C  BACK SIDE CONNECTIONS...
C
       SIM 701702, 4, 1001, 701, 1, 702, 1, A2, 0.00254
       SIM 706707, 4, 1001, 706, 1, 707, 1, A2, 0.00254
       SIM 711712, 4, 1001, 711, 1, 712, 1, A2, 0.00254
       SIM 716717, 4, 1001, 716, 1, 717, 1, A2, 0.00254
       SIM 721722, 4, 1001, 721, 1, 722, 1, A2, 0.00254
C
       SIM 701706, 4, 5005, 701, 5, 706, 5, A2, 0.00254
       SIM 702707, 4, 5005, 702, 5, 707, 5, A2, 0.00254
       SIM 703708, 4, 5005, 703, 5, 708, 5, A2, 0.00254
       SIM 704709, 4, 5005, 704, 5, 709, 5, A2, 0.00254
       SIM 705710, 4, 5005, 705, 5, 710, 5, A2, 0.00254
```



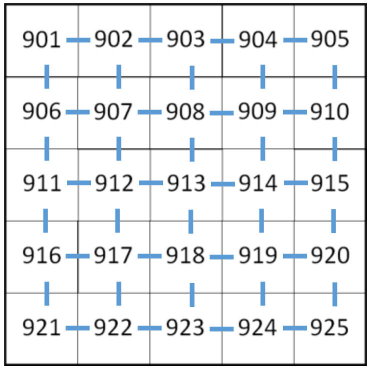
CONDUCTOR DATA (for the Box)

```
C
C  TOP SIDE CONNECTIONS...
C
        SIM 801802, 4, 1001, 801, 1, 802, 1, A2, 0.00254
        SIM 806807, 4, 1001, 806, 1, 807, 1, A2, 0.00254
        SIM 811812, 4, 1001, 811, 1, 812, 1, A2, 0.00254
        SIM 816817, 4, 1001, 816, 1, 817, 1, A2, 0.00254
        SIM 821822, 4, 1001, 821, 1, 822, 1, A2, 0.00254
C
        SIM 801806, 4, 5005, 801, 5, 806, 5, A2, 0.00254
        SIM 802807, 4, 5005, 802, 5, 807, 5, A2, 0.00254
        SIM 803808, 4, 5005, 803, 5, 808, 5, A2, 0.00254
        SIM 804809, 4, 5005, 804, 5, 809, 5, A2, 0.00254
        SIM 805810, 4, 5005, 805, 5, 810, 5, A2, 0.00254
```



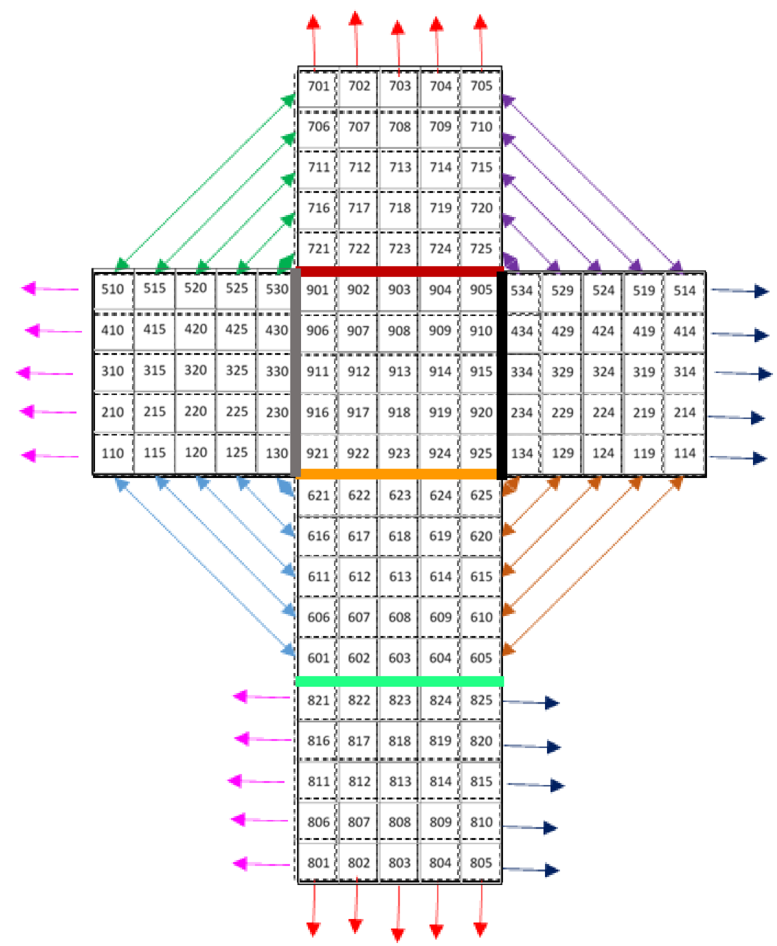
CONDUCTOR DATA (for the Box)

```
C
C  BOTTOM SIDE CONNECTIONS...
C
       SIM 901802, 4, 1001, 901, 1, 902, 1, A2, 0.00254
       SIM 906807, 4, 1001, 906, 1, 907, 1, A2, 0.00254
       SIM 911812, 4, 1001, 911, 1, 912, 1, A2, 0.00254
       SIM 916817, 4, 1001, 916, 1, 917, 1, A2, 0.00254
       SIM 921822, 4, 1001, 921, 1, 922, 1, A2, 0.00254
C
       SIM 901906, 4, 5005, 901, 5, 906, 5, A2, 0.00254
       SIM 902907, 4, 5005, 902, 5, 907, 5, A2, 0.00254
       SIM 903908, 4, 5005, 903, 5, 908, 5, A2, 0.00254
       SIM 904909, 4, 5005, 904, 5, 909, 5, A2, 0.00254
       SIM 905910, 4, 5005, 905, 5, 910, 5, A2, 0.00254
```



CONDUCTOR DATA (for the Box)

```
C
C   CONNECT BOX SIDES TO ONE ANOTHER...
C
     SIM 1 , 5, 1, 110, 100, 821, -5, A2, 0.00254
     SIM 6 , 5, 1, 114, 100, 825, -5, A2, 0.00254
     SIM 11, 5, 1, 130, 100, 921, -5, A2, 0.00254
     SIM 16, 5, 1, 134, 100, 925, -5, A2, 0.00254
     SIM 21, 5, 1, 601,   1, 821,  1, A2, 0.00254
     SIM 26, 5, 1, 621,   1, 921,  1, A2, 0.00254
     SIM 31, 5, 1, 701,   1, 801,  1, A2, 0.00254
     SIM 36, 5, 1, 721,   1, 901,  1, A2, 0.00254
     SIM 41, 5, 1, 110,   5, 601,  5, A2, 0.00254
     SIM 46, 5, 1, 510,   5, 701,  5, A2, 0.00254
     SIM 51, 5, 1, 114,   5, 605,  5, A2, 0.00254
     SIM 56, 5, 1, 514,   5, 705,  5, A2, 0.00254
```



CONDUCTOR DATA (for Boards to the Box)

```
C
C   CONNECT BOARDS TO BOX SIDES...
C
C   LEFT SIDE...
C
      GEN 11010, 5, 505, 110, 5, BOARD1.110, 5, 0.34483
      GEN 21010, 5, 505, 210, 5, BOARD2.110, 5, 0.34483
      GEN 31010, 5, 505, 310, 5, BOARD3.110, 5, 0.34483
      GEN 41010, 5, 505, 410, 5, BOARD4.110, 5, 0.34483
      GEN 51010, 5, 505, 510, 5, BOARD5.110, 5, 0.34483
C
C   RIGHT SIDE...
C
      GEN 11414, 5, 505, 114, 5, BOARD1.114, 5, 0.34483
      GEN 21414, 5, 505, 214, 5, BOARD2.114, 5, 0.34483
      GEN 31414, 5, 505, 314, 5, BOARD3.114, 5, 0.34483
      GEN 41414, 5, 505, 414, 5, BOARD4.114, 5, 0.34483
      GEN 51414, 5, 505, 514, 5, BOARD5.114, 5, 0.34483
```

CONDUCTOR DATA (to the environment boundaries)

```
C
C  CONNECT BOX BOTTOM TO MOUNT...
C
       GEN 998901, 25, 1, SCENV.998, 0, 901, 1, 12.6452
C
C
C  RADIATION CONDUCTORS FROM BOX EXTERNAL SURFACES TO ENVIRONMENT
C  EXCLUDES BOTTOM WHICH IS CONNECTED TO MOUNTING PLATE...
C
C  LEFT SIDE NODES...
C
      GEN -999110, 5, 100, SCENV.999, 0, 110, 100, 1.8144e-11
      GEN -999115, 5, 100, SCENV.999, 0, 115, 100, 1.8144e-11
      GEN -999120, 5, 100, SCENV.999, 0, 120, 100, 1.8144e-11
      GEN -999125, 5, 100, SCENV.999, 0, 125, 100, 1.8144e-11
      GEN -999130, 5, 100, SCENV.999, 0, 130, 100, 1.8144e-11
C
C  RIGHT SIDE NODES...
C
      GEN -999114, 5, 100, SCENV.999, 0, 114, 100, 1.8144e-11
      GEN -999119, 5, 100, SCENV.999, 0, 119, 100, 1.8144e-11
      GEN -999124, 5, 100, SCENV.999, 0, 124, 100, 1.8144e-11
      GEN -999129, 5, 100, SCENV.999, 0, 129, 100, 1.8144e-11
      GEN -999134, 5, 100, SCENV.999, 0, 134, 100, 1.8144e-11
```

CONDUCTOR DATA (to the environment boundaries)

```
C
C  FROM SIDE NODES...
C
      GEN -999601, 25, 1, SCENV.999, 0, 601, 1, 1.8144e-11
C
C  BACK SIDE NODES...
C
      GEN -999701, 25, 1, SCENV.999, 0, 701, 1, 1.8144e-11
C
C  TOP SIDE NODES...
C
      GEN -999801, 25, 1, SCENV.999, 0, 801, 1, 1.8144e-11
C
```

CONDUCTOR DATA (for the boards)

```
C
        GEN  1011, 4, 101,  10, 1, 11, 1, 0.135
        GEN  1516, 4, 101,  15, 1, 16, 1, 0.135
        GEN  2021, 4, 101,  20, 1, 21, 1, 0.135
        GEN  2526, 4, 101,  25, 1, 26, 1, 0.135
        GEN  3031, 4, 101,  30, 1, 31, 1, 0.135
C
        GEN  1015, 4, 505,  10, 5, 15, 5, 0.135
        GEN  1116, 4, 505,  11, 5, 16, 5, 0.135
        GEN  1217, 4, 505,  12, 5, 17, 5, 0.135
        GEN  1318, 4, 505,  13, 5, 18, 5, 0.135
        GEN  1419, 4, 505,  14, 5, 19, 5, 0.135
C
        GEN  1110, 5,  5,   10, 5,110, 5, 0.270
        GEN  1114, 5,  5,   14, 5,114, 5, 0.270
```

The contents of BOARDCONDUCTORS.TXT describe the connectivity between each board node.

Since this is the same for each component board, we can use the same INCLUDE file to describe each board.

CONTROL DATA

```
HEADER CONTROL DATA, GLOBAL
C
          NLOOPS = 5000
          ABSZRO = -273.15
```

Control block header. Note the word GLOBAL is added.

NLOOPS is a control parameter for the STEADY solution routine and specifies the upper limit on the number of iterations to perform for steady state calculations.

The value of absolute zero, in degrees Celsius, is set.

OPERATIONS DATA

Operations Data block header. Note that no submodel is specified.

The analysis model is CONFIG and is composed of submodels BOX, SCENV, and submodels BOARD1 through BOARD5.

```
HEADER OPERATIONS DATA
BUILD  CONFIG, BOX, SCENV, BOARD1, BOARD2, BOARD3, BOARD4, BOARD5
              DO ITEST = 1, 99
C
C
C
          READ(NUSER1,*, END=400) RTEST, TTEST, ATEST, BTEST, CTEST, DTEST, ETEST
C
          SCENV.T998 = TTEST
          SCENV.T999 = RTEST
C
          CALL STEADY
C
          WRITE(NUSER2,200)ITEST, RTEST, TTEST,
     +                     1, ATEST, BOARD1.T16, BOARD1.T18, BOARD1.T26, BOARD1.T28
          WRITE(NUSER2,300)2, BTEST, BOARD2.T16, BOARD2.T18, BOARD2.T26, BOARD2.T28
          WRITE(NUSER2,300)3, CTEST, BOARD3.T16, BOARD3.T18, BOARD3.T26, BOARD3.T28
          WRITE(NUSER2,300)4, DTEST, BOARD4.T16, BOARD4.T18, BOARD4.T26, BOARD4.T28
          WRITE(NUSER2,300)5, ETEST, BOARD5.T16, BOARD5.T18, BOARD5.T26, BOARD5.T28
C
200       FORMAT(i2, 2x, f5.1, 2x, f5.1, 2x, i2, 2x, 5(f5.1, 2x))
300       FORMAT(18x,i2,2x, f5.1, 2x, 4(f5.1, 2x))
400       CONTINUE
C
              END DO
```

A DO loop is used to cycle through many analysis cases.

Read in data to describe each analysis case from the USER1 file and set the mount and radiation environment boundary node temperatures.

Call the steady state solution routine.

Formatted output of the results using WRITE and FORMAT statements.

Using VARIABLES 1 Logic

As a solution progresses, we may wish to turn on a heater or apply orbital heating;

In a broader sense, there may be things we want to do, either, before or after a time step.

In this lesson, we’re going to introduce a means of affecting model parameters before each time step;

The user interacts with the model using logic that is Fortran-like;

This logic is placed in the VARIABLES 1 block.

VARIABLES 1

VARIABLES 1 block header for the BOX submodel.

```
HEADER VARIABLES 1, BOX
C
      BOARD1.Q16 = ATEST
      BOARD1.Q18 = ATEST
      BOARD1.Q26 = ATEST
      BOARD1.Q28 = ATEST
C
      BOARD2.Q16 = BTEST
      BOARD2.Q18 = BTEST
      BOARD2.Q26 = BTEST
      BOARD2.Q28 = BTEST
C
      BOARD3.Q16 = CTEST
      BOARD3.Q18 = CTEST
      BOARD3.Q26 = CTEST
      BOARD3.Q28 = CTEST
C
      BOARD4.Q16 = DTEST
      BOARD4.Q18 = DTEST
      BOARD4.Q26 = DTEST
      BOARD4.Q28 = DTEST
C
      BOARD5.Q16 = ETEST
      BOARD5.Q18 = ETEST
      BOARD5.Q26 = ETEST
      BOARD5.Q28 = ETEST
```

Heat is applied to four nodes in submodel BOARD1 based on the value read in for ATEST

Heat is applied to four nodes in submodel BOARD2 based on the value read in for BTEST

Heat is applied to four nodes in submodel BOARD3 based on the value read in for CTEST

Heat is applied to four nodes in submodel BOARD4 based on the value read in for DTEST

Heat is applied to four nodes in submodel BOARD5 based on the value read in for ETEST

Results

1	-40.0	-20.0	1	5.0	42.8	42.8	38.4	38.4
			2	5.0	44.9	44.9	40.6	40.6
			3	5.0	45.6	45.6	41.3	41.3
			4	5.0	44.9	44.9	40.6	40.6
			5	5.0	42.8	42.8	38.4	38.4
2	-40.0	-15.0	1	2.0	17.5	17.5	14.7	14.7
			2	5.0	40.0	40.0	37.1	37.1
			3	3.0	27.0	27.0	24.1	24.1
			4	5.0	40.0	40.0	37.1	37.1
			5	2.0	17.5	17.5	14.7	14.7
3	-30.0	0.0	1	4.0	39.7	39.7	37.9	37.9
			2	1.0	19.6	19.6	17.8	17.8
			3	3.0	33.0	33.0	31.3	31.3
			4	2.0	25.3	25.3	23.7	23.7
			5	1.0	17.1	17.1	15.5	15.5
4	-30.0	5.0	1	2.0	26.2	26.2	25.1	25.1
			2	1.0	19.9	19.9	18.8	18.8
			3	2.0	27.0	27.0	25.9	25.9
			4	1.0	19.9	19.9	18.8	18.8
			5	2.0	26.2	26.2	25.1	25.1
5	-30.0	10.0	1	1.0	20.6	20.6	20.1	20.1
			2	1.0	21.0	21.0	20.5	20.5
			3	1.0	21.2	21.2	20.6	20.6
			4	1.0	21.0	21.0	20.5	20.5
			5	1.0	20.6	20.6	20.1	20.1

Results

Case Number	Compartment Environment Temperature (deg C)	Mount Temperature (deg C)	Board Number	Total Power Dissipation Per Board (W)	Component Board Node Temperature (deg C) Node 16	Node 18	Node 26	Node 28
1	-40.0	-20.0	1	5.0	42.8	42.8	38.4	38.4
			2	5.0	44.9	44.9	40.6	40.6
			3	5.0	45.6	45.6	41.3	41.3
			4	5.0	44.9	44.9	40.6	40.6
			5	5.0	42.8	42.8	38.4	38.4
2	-40.0	-15.0	1	2.0	17.5	17.5	14.7	14.7
			2	5.0	40.0	40.0	37.1	37.1
			3	3.0	27.0	27.0	24.1	24.1
			4	5.0	40.0	40.0	37.1	37.1
			5	2.0	17.5	17.5	14.7	14.7
3	-30.0	0.0	1	4.0	39.7	39.7	37.9	37.9
			2	1.0	19.6	19.6	17.8	17.8
			3	3.0	33.0	33.0	31.3	31.3
			4	2.0	25.3	25.3	23.7	23.7
			5	1.0	17.1	17.1	15.5	15.5
4	-30.0	5.0	1	2.0	26.2	26.2	25.1	25.1
			2	1.0	19.9	19.9	18.8	18.8
			3	2.0	27.0	27.0	25.9	25.9
			4	1.0	19.9	19.9	18.8	18.8
			5	2.0	26.2	26.2	25.1	25.1
5	-30.0	10.0	1	1.0	20.6	20.6	20.1	20.1
			2	1.0	21.0	21.0	20.5	20.5
			3	1.0	21.2	21.2	20.6	20.6
			4	1.0	21.0	21.0	20.5	20.5
			5	1.0	20.6	20.6	20.1	20.1

10	11	12	13	14
15	16	17	18	19
20	21	22	23	24
25	26	27	28	29
30	31	32	33	34

Concluding Remarks

In this lesson, we learned how to…

Use submodels;

Run multiple cases;

Customize model input and output.

Acknowledgements

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