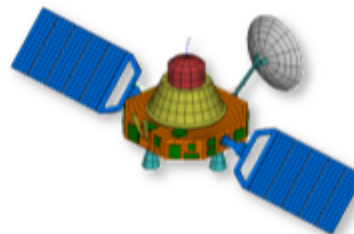


ESATAN-TMS
thermal modelling suite

Support Contact Information:

<http://www.esatan-tms.com>



Modelo térmico de un satélite con ESATAN-TMS

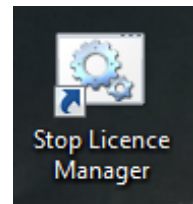
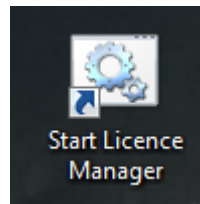
1. Introducción

- Ejercicio práctico: Modelo térmico de un satélite en fase de diseño preliminar.
- Como ejemplo de geometría y misión para este ejercicio: Sentinel-2 (ESA).

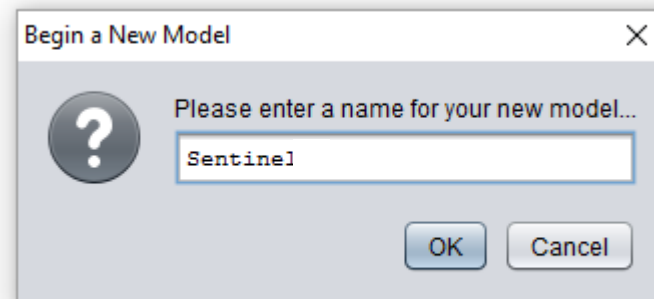
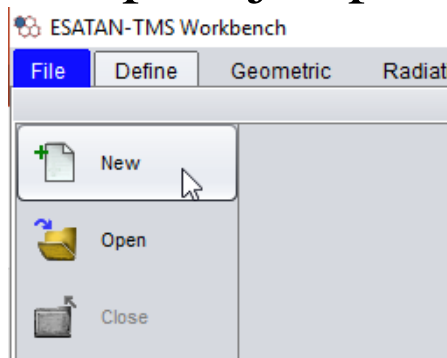


2. Creación del modelo

- Software: ESATAN-TMS. Hay que iniciar la licencia siempre que se vaya a utilizar (y cerrarla al terminar).

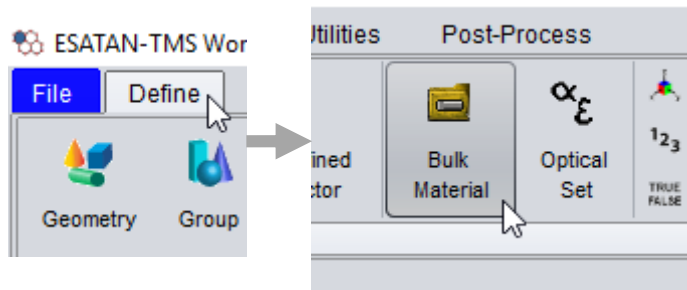


- Crear un modelo nuevo y asignarle un nombre (Sin espacios en blanco, por ejemplo Sentinel).



3. Definición de materiales y propiedades termo-ópticas

- Definir los materiales (Bulk): introduciendo nombre, densidad, calor específico y conductividad en unidades del S.I.



Bulk	Density (kg/m ³)	Specific Heat (J/kgK)	Conductivity (W/mK)
Al_6061	2700	900	160
MLI_foil	300	900	0
GaAs	5300	1000	55

3. Definición de materiales y propiedades termo-ópticas

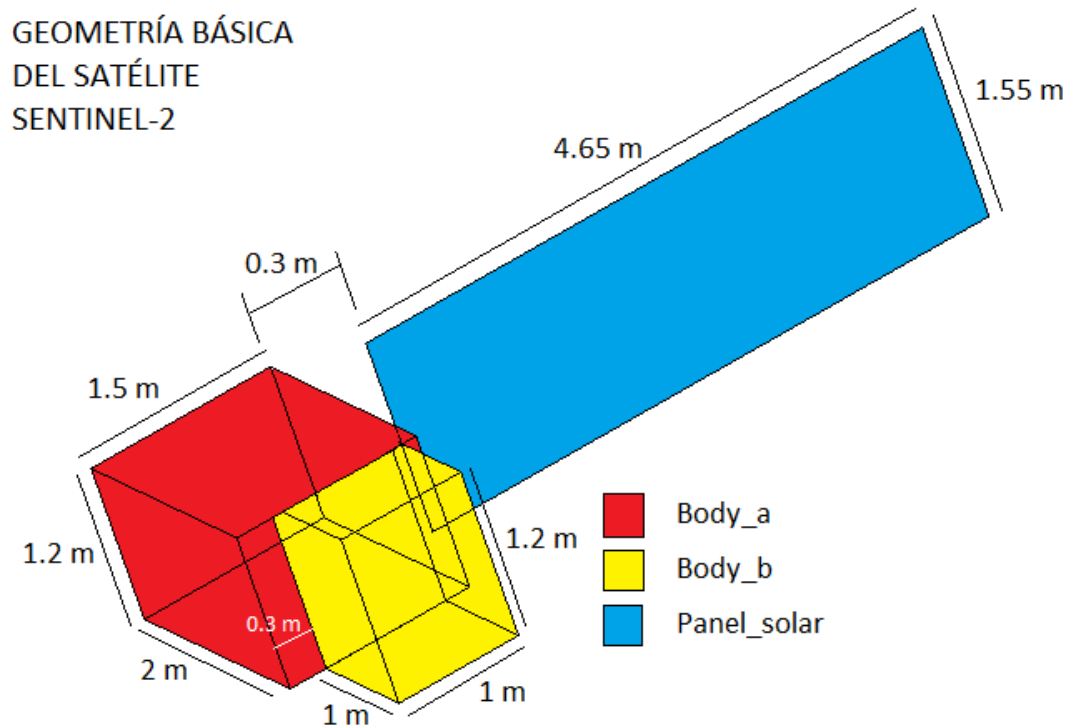
- Definir propiedades ópticas (Optical Set): α y ϵ

Optical	ϵ	α
Black	0.84	0.97
White	0.8	0.2
Low_e	0.1	0.2

Optical	ϵ	α
Solar_Cells	0.84	0.75
Kapton	0.61	0.36

4. Construcción de la geometría

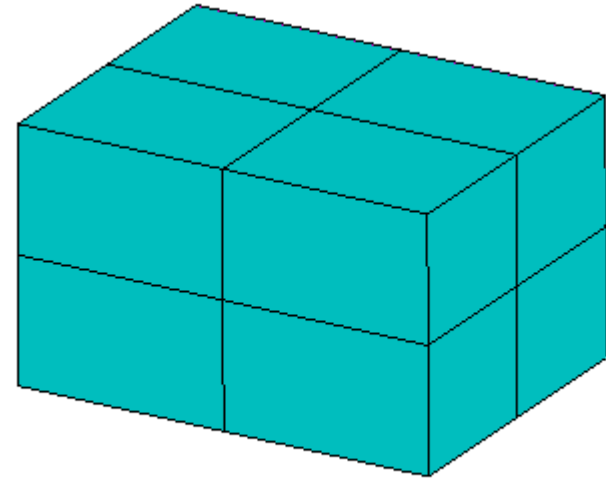
- Se construyen los tres elementos básicos de la figura con distintas estrategias



► Body_a

Definición de la geometría

Property	Value
Geometry Name	Body_a
Shape	Box
Defined By	Parameters
height (m)	1.2
xmax (m)	1.5
ymax (m)	2.0



- **Body_a** Se introduce el mallado, las propiedades de cada cara, el material y el espesor

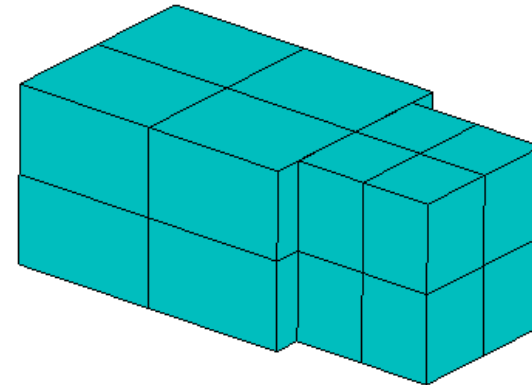
Property	Value
Nº of faces direction 1	2
Nº of faces direction 2	2
Nº of faces direction 3	2
Surface 1	
Label	Body_a_MLI
Base node number	100
Optical	Low_e
Surface 2	
Label	Body_a_int
Base node number	200
Optical	Black

Property	Value
Composition	DUAL
S1 – Material	MLI_Foil
S1 – Thickness	0.0005
S2 – Material	Al_6061
S2 – Thickness	0.002
Through Conductance	
Calculation Type	EFFECTIVE
Emittance	0.01

► Body_b

Definición de la geometría

Property	Value
Geometry Name	Body_b
Shape	Box
Defined By	Parameters
height (m)	1.2
xmax (m)	1.0
ymax (m)	1.0
Tansformation	
X Distance (m)	0.25
Y Distance (m)	2.001



- **Body_b** Se introduce el mallado, las propiedades de cada cara, el material y el espesor

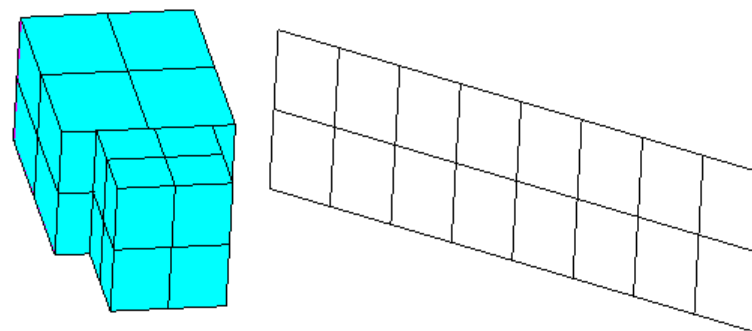
Property	Value
Nº of faces direction 1	2
Nº of faces direction 2	2
Nº of faces direction 3	2
Surface 1	
Label	Body_b_MLI
Base node number	125
Optical	Low_e
Surface 2	
Label	Body_b_int
Base node number	225
Optical	Black

Property	Value
Composition	DUAL
S1 – Material	MLI_Foil
S1 – Thickness	0.0005
S2 – Material	Al_6061
S2 – Thickness	0.002
Through Conductance	
Calculation Type	EFFECTIVE
Emittance	0.01

► Solar Panel

Property	Value
Geometry Name	Solar_Panel
Shape	Rectangle
xmax (m)	4.65
ymax (m)	1.55
Tansformation	
X Angle (deg)	90
Z Angle (deg)	-37.5
X Distance (m)	-4.5
Y Distance (m)	2.5
Z Distance (m)	-0.775

Definición de la geometría



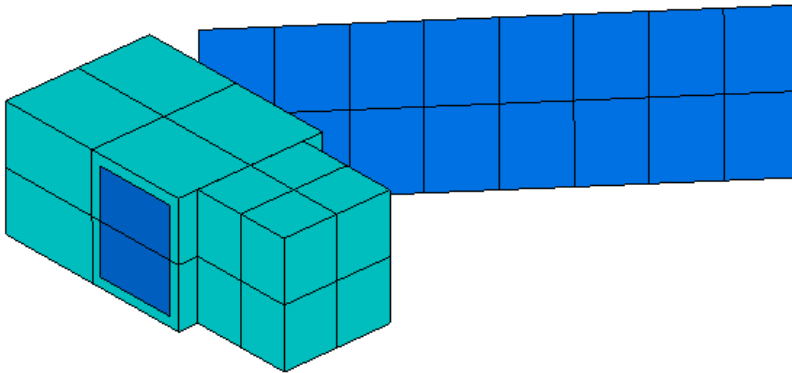
► Solar Panel

Property	Value
Nº of faces direction 1	8
Nº of faces direction 2	2
Surface 1	
Label	Solar_Panel_Cells
Base node number	150
Optical	Solar_Cells
Surface 2	
Label	Solar_Panel_Support
Base node number	250
Optical	White

Property	Value
Composition	DUAL
S1 – Material	GaAs
S1 – Thickness	0.0004
S2 – Material	Al_6061
S2 – Thickness	0.001
Through Conductance	
Calculation Type	EFFECTIVE
Conductance (W/m²K)	50.0

$$\dot{Q} = h_{eff} \cdot A \cdot \Delta T$$

► Radiador : Geometría



Property	Value
Geometry Name	Radiator
Shape	Rectangle
xmax (m)	1
ymax (m)	0.8
Tansformation	
Y Angle (deg)	-90
X Distance (m)	1.505
Y Distance (m)	1.1
Z Distance (m)	0.1

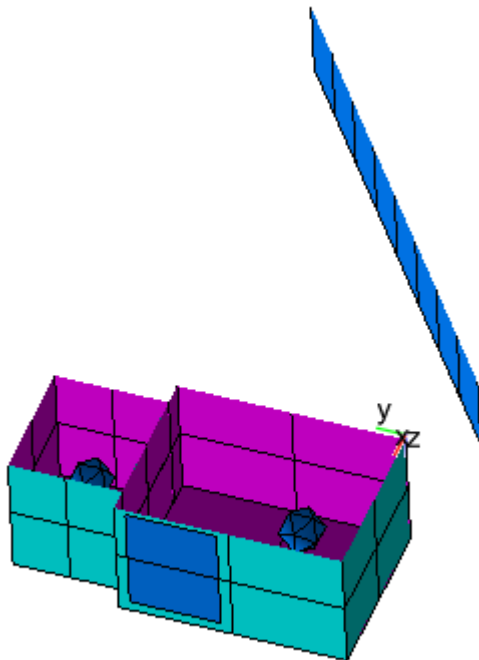
► Radiador : Propiedades

Property	Value
Nº of faces direction 1	1
Nº of faces direction 2	1
Surface 1	
Label	Radiator
Activity	Conductive
Base node number	300
Optical	White
Surface 2	
Label	Radiator
Base node number	300
Optical	White

Property	Value
Composition	SINGLE
Material	Al_6061
Thickness	0.002

Nodos no geométricos

- ▶ Simulan carga de pago en cuanto a masa y/o disipación



Payload 1

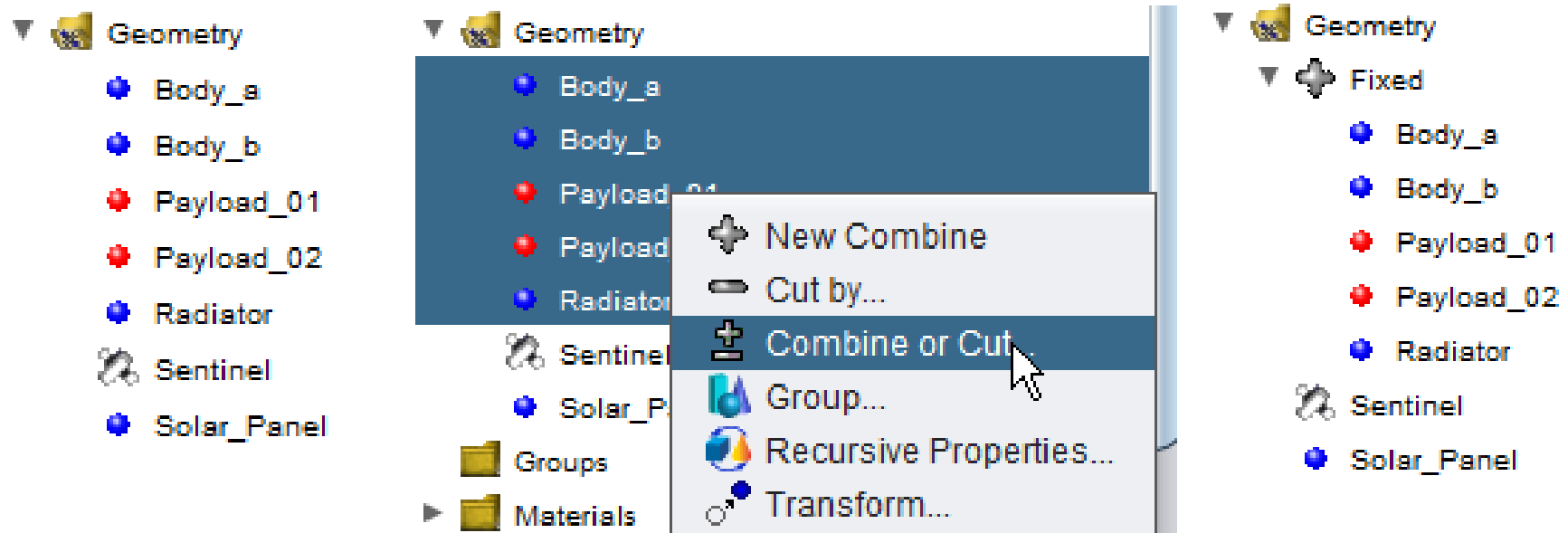
Property	Value
Origin	[0.75, 0.65, 0.6]
Radius (m)	0.2
Node number	1000
Capacitance	
Method	VALUE
Value	20000

Payload 2

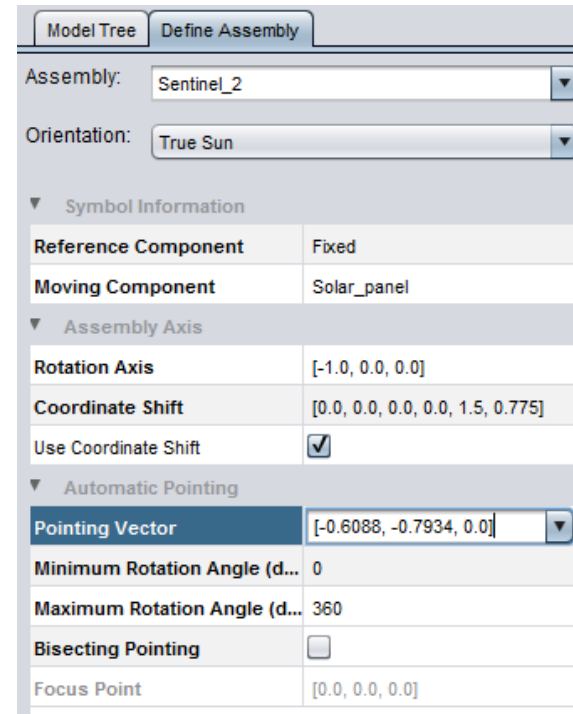
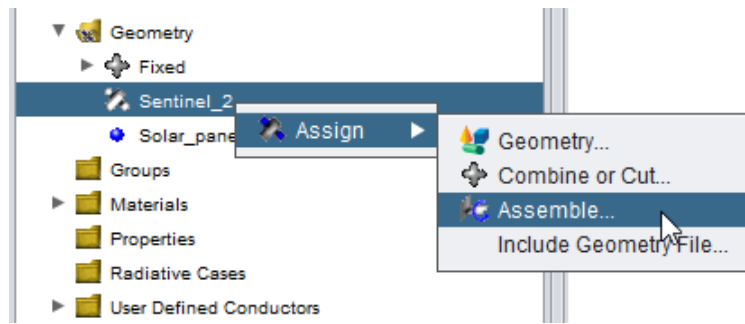
Property	Value
Origin	[0.75, 2.5, 0.6]
Radius (m)	0.2
Node number	2000
Capacitance	
Method	VALUE
Value	10000

Agrupación y cinemática

- Agrupar shells para formar estructura jerárquica del modelo



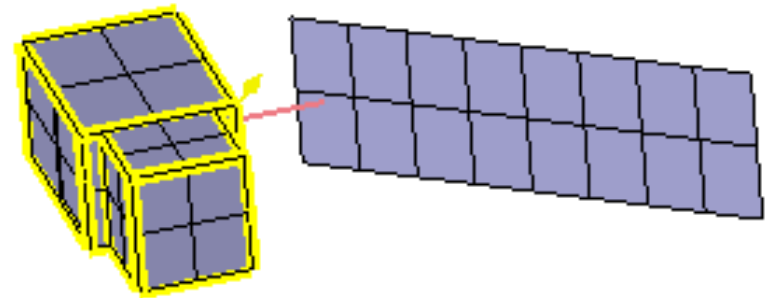
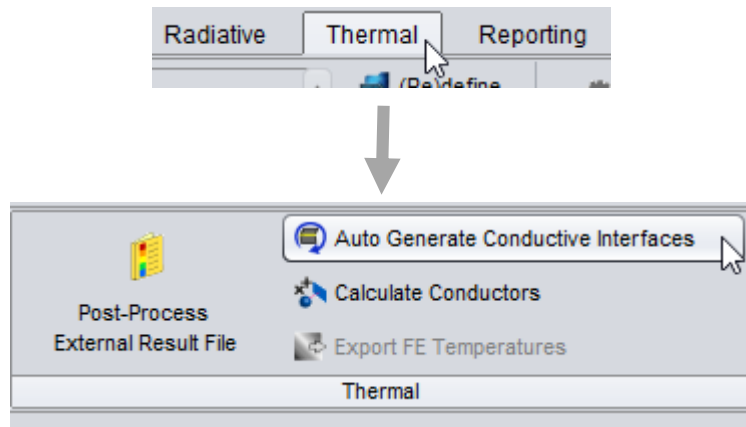
- Cinemática del panel solar: siempre perpendicular a la dirección satélite-sol.



- Como referencia se selecciona la agrupación 'fixed' y como componentes móviles el panel solar.

7. Generación de interfaces conductivas

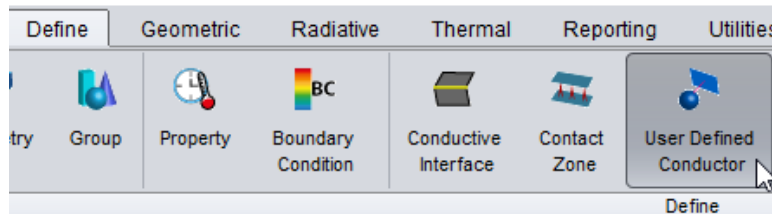
- ▶ Se generan aquellas que ESATAN detecta automáticamente.



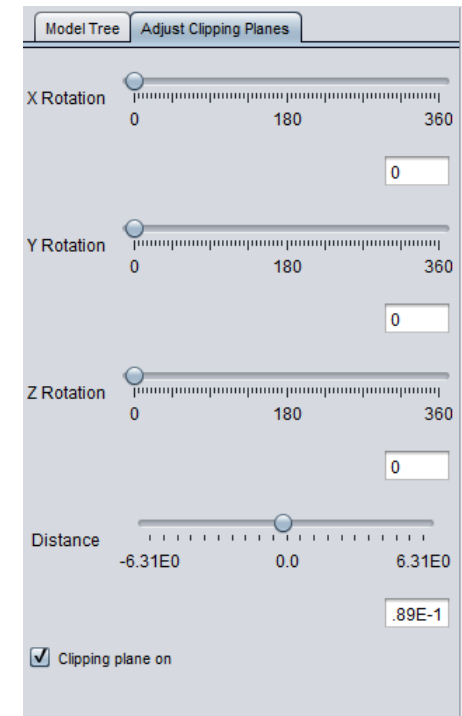
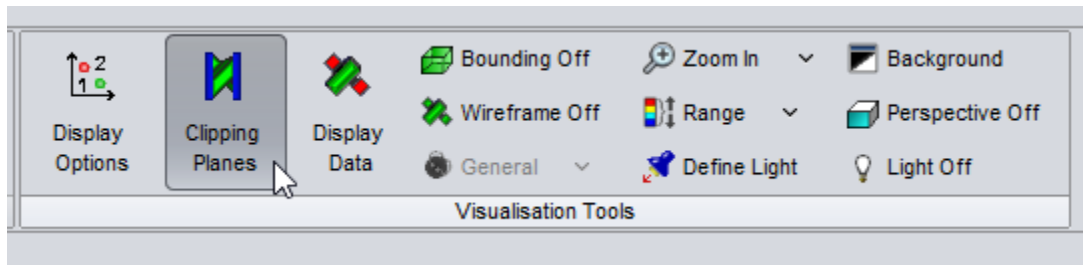
- ▶ Se cambian todas las interfaces a tipo 'Fused' (por defecto)

Conductores no geométricos

- Se crean desde la opción User Defined Conductor



- Es más sencillo visualizar los nodos de origen y destino activando el plano de corte



Nodos interiores - radiador

Define Non-Geometric Conductor

Conductor: PL_01_Rad

Type: Conductive

Connection

Source Reference	Payload_01
Destination Refer...	Radiator:surface1

Definition

Method	VALUE
Value (W/K)	50.0

Define Non-Geometric Conductor

Conductor: PL_02_Rad

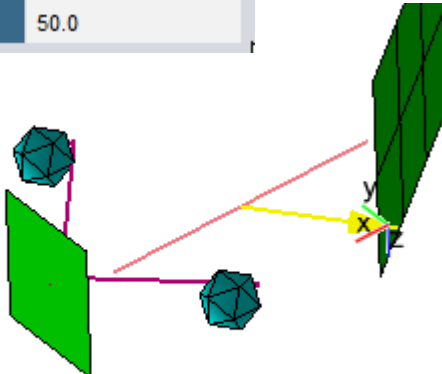
Type: Conductive

Connection

Source Reference	Payload_02
Destination Refer...	surface1

Definition

Method	VALUE
Value (W/K)	40.0

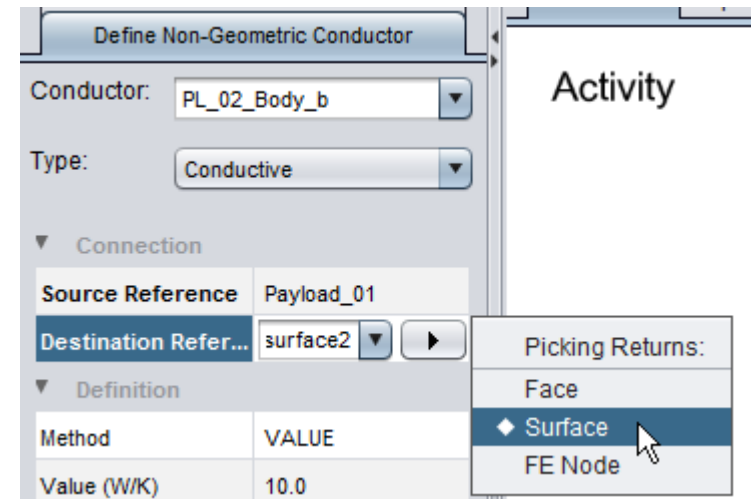
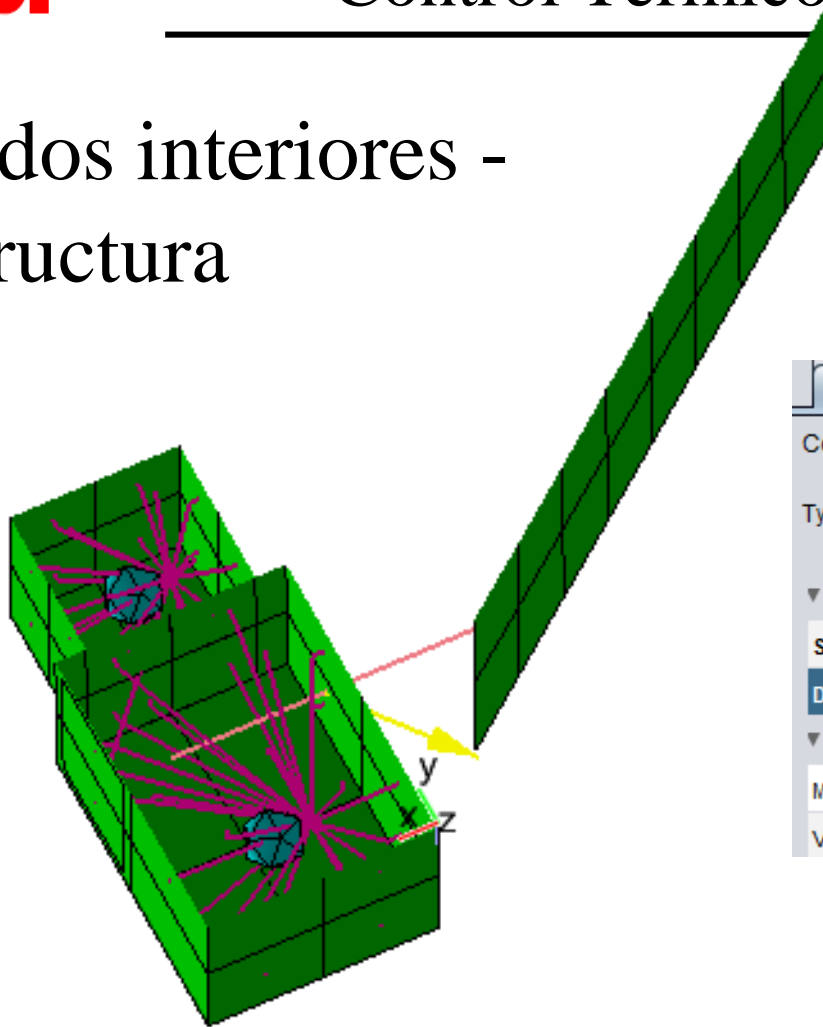


Activity

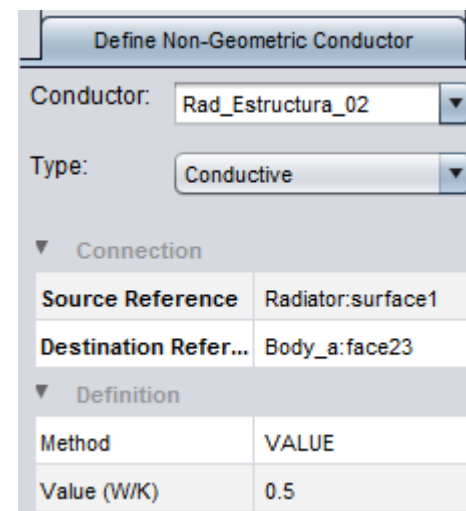
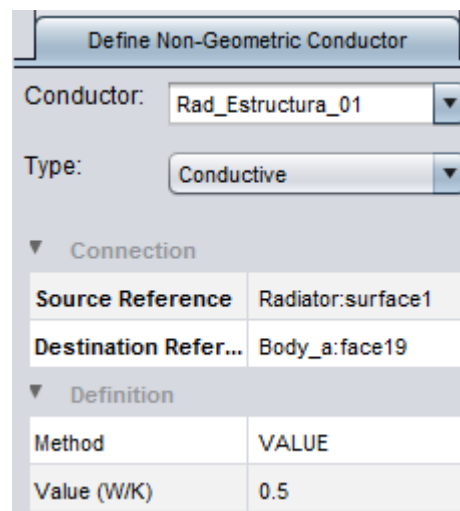
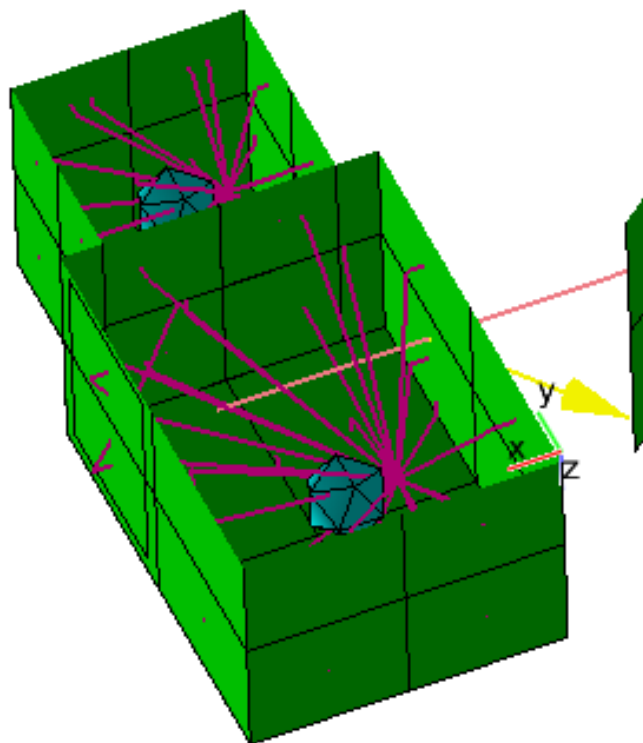
Picking Returns:

- Face
- ◆ Surface
- FE Node

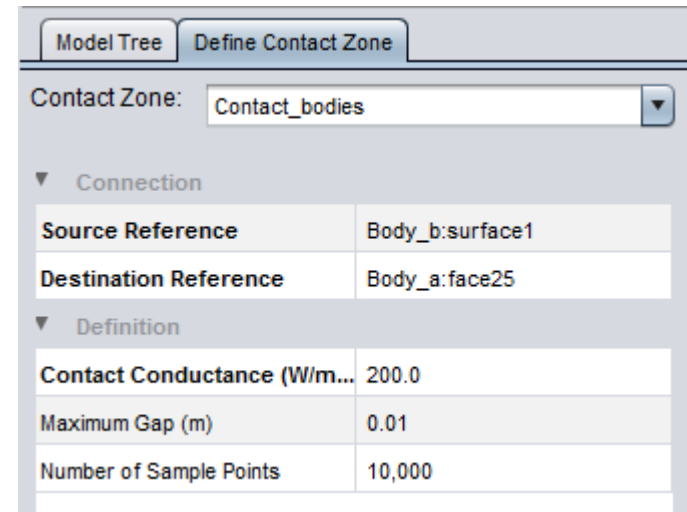
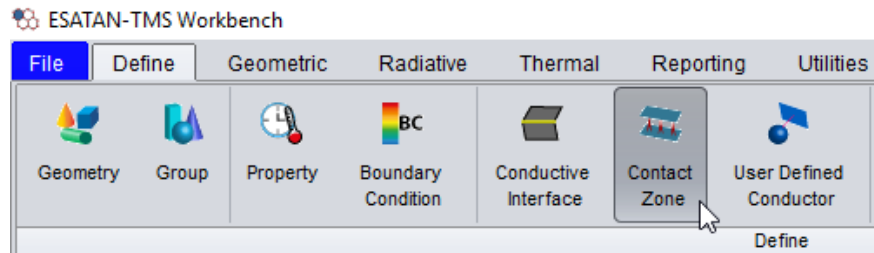
■ Nodos interiores - estructura



■ Estructura - radiador



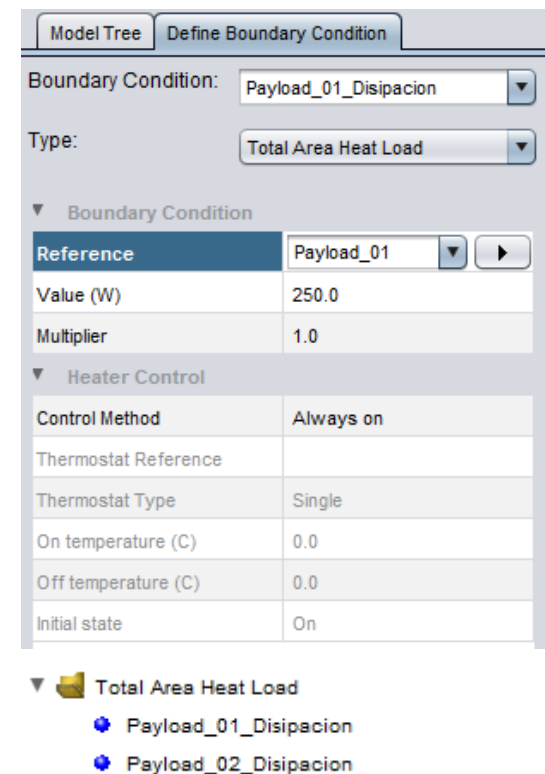
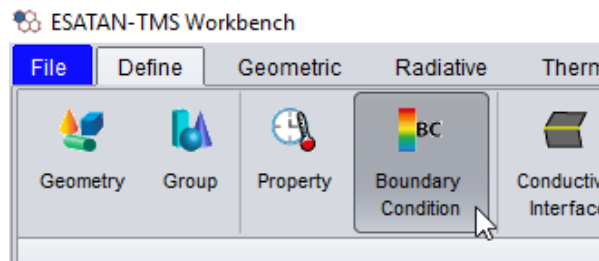
Contacto entre Body_a y Body_b



- Se define un contacto térmico entre las dos superficies con un valor de $h_c = 200 \text{ W/m}^2\text{K}$.

Condiciones de contorno

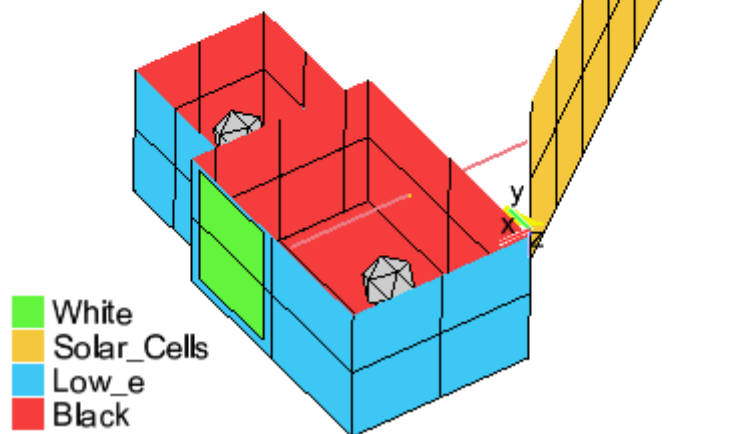
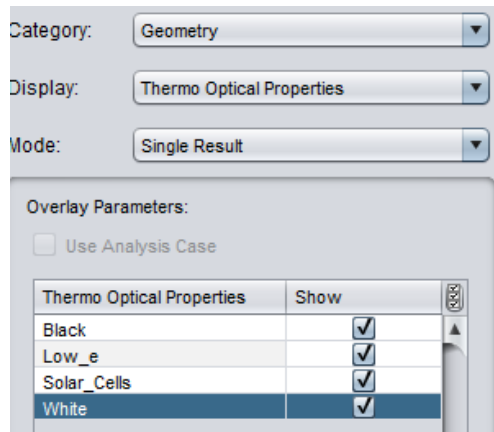
- Introducir las potencias disipadas por los equipos mediante interfaz gráfica



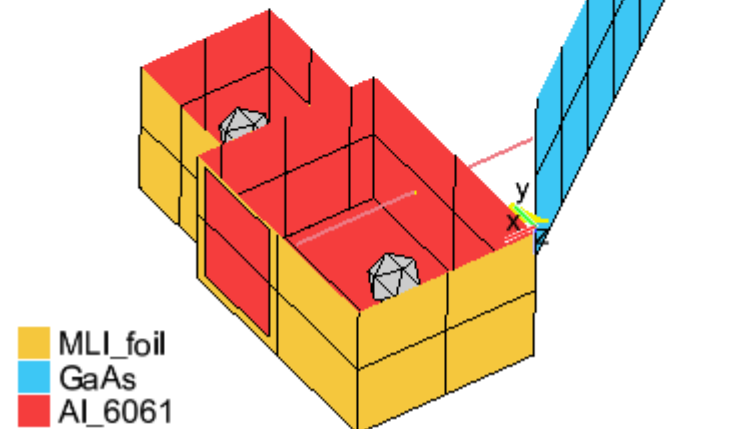
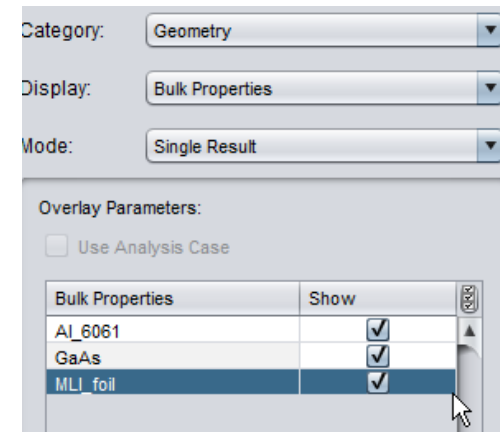
- Se reparten 400W entre los dos nodos interiores: 250W en el Payload_1 y 150W en Payload_2.

Comprobación del modelo

Propiedades termo-ópticas

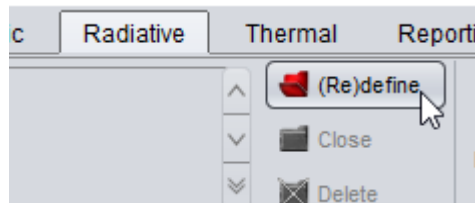


Materiales



Caso radiativo

- Se define una órbita circular heliosíncrona (SSO).



Model Tree Radiative Case Dialog

Overview Environment Orbit Pointing

Radiative Case: SSO

Definition Method: Orbit Parameters

Position Method: Angles

▼ Ellipse

Eccentricity	0
Semi-Major Axis (m)	7,139,000
Altitude of Apogee (m)	768,000
Altitude of Perigee (m)	768,000
Inclination (deg)	98.54
Right Ascension (deg)	37.5
Argument of Periapsis (deg)	0

▼ Arc

Initial True Anomaly (deg)	0
Final True Anomaly (deg)	360

▼ Positions

Angle Gap (deg)	30
Number of Positions	12
True Anomalies Vector (deg)	
Eclipse Entry Exit Points	<input checked="" type="checkbox"/>
Eclipse Offset (deg)	0.5

Model Tree Radiative Case Dialog

Overview Environment Orbit Pointing

Radiative Case: SSO

Pointing Method: Vectors & Directions

▼ Primary Pointing

Pointing Vector	[0.0, 1.0, 0.0]
Pointing Direction	VELOCITY
General Direction	[1.0, 0.0, 0.0]

▼ Secondary Pointing

Pointing Vector	[0.0, 0.0, -1.0]
Pointing Direction	NADIR
General Direction	[0.0, -1.0, 0.0]

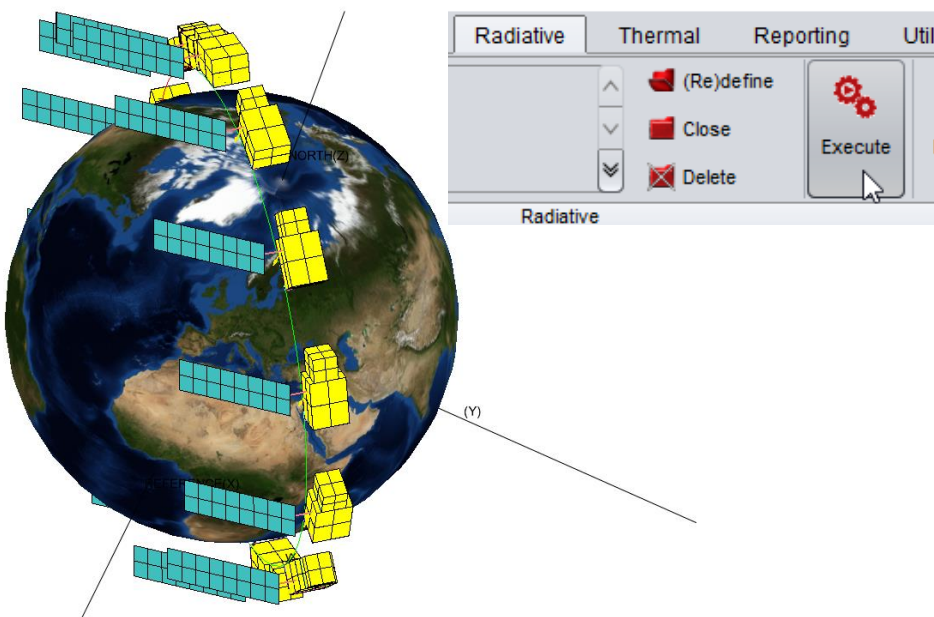
▼ LOCS Orientation

Orientation	PLANET_ORIENTED
-------------	-----------------

▼ User Defined Move...

Phi (deg)	0.0
Psi (deg)	0.0
Omega (deg)	0.0
Phi Rotation Rate (deg/s)	0
Psi Rotation Rate (deg/s)	0
Omega Rotation Rate (deg/s)	0
Application Order	phi, psi, omega

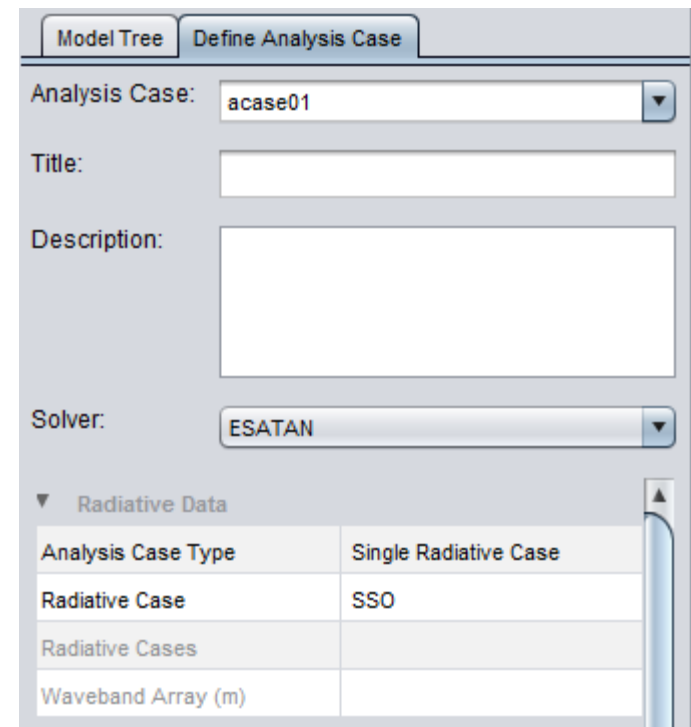
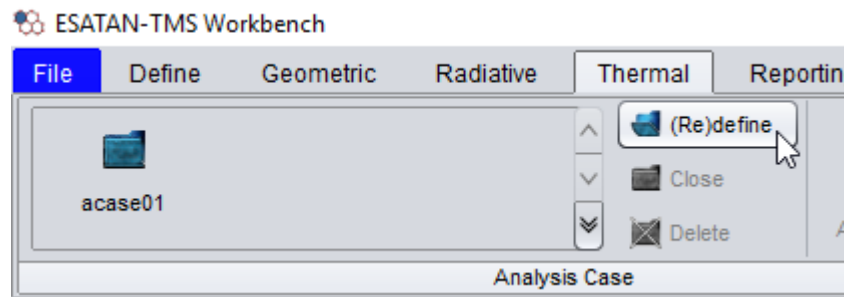
- Se ejecuta para obtener los factores de vista, GRs y las cargas del Sol (QS), Albedo (QA) e infrarrojo terrestre (QE).



Model Tree		Execute Dialog
▼ Accuracy Parameters		
Control Method	FIXED_RAYS	
Ray (VF/REF) Total Cutoff	0.005	
Ray (VF/REF) Non-Critical	1,000	
Ray (VF/REF) Normal	10,000	
Ray (VF/REF) Critical	100,000	
Ray Density Non-Critical	10,000	
Ray Density Normal	100,000	
Ray Density Critical	1,000,000	
Line Accuracy Non-Critical	0.1	
Line Accuracy Normal	0.03	
Line Accuracy Critical	0.001	
Line Confidence Non-Critical	0.95	
Line Confidence Normal	0.95	
Line Confidence Critical	0.95	
Ray (HF) Non-Critical	1,000	
Ray (HF) Normal	10,000	
Ray (HF) Critical	100,000	
▼ Raytracing Parameters		
Seed	1,000	
Extinct Threshold	0.001	
▼ Calculations		
VF Geometric	<input checked="" type="checkbox"/>	
REF MCRT	<input checked="" type="checkbox"/>	
Solar Direct Flux	<input checked="" type="checkbox"/>	
Solar Absorbed MCRT	<input checked="" type="checkbox"/>	
Planet & Albedo Direct Flux	<input checked="" type="checkbox"/>	
Planet & Albedo Abs MCRT	<input checked="" type="checkbox"/>	
UV Emission Direct Flux	<input type="checkbox"/>	
UV Emission Absorbed Flux	<input type="checkbox"/>	

Caso de análisis

- ▶ Se selecciona el radiative case deseado: SS0



- Se define el esquema de solución (transitorio en este caso) y se añade al bloque de ejecución.

Control Logic

Solution Control	Default	...
Output Calls	Default	
Generate Min-Max Data	<input type="checkbox"/>	

Solution Control Dialog

Analysis: Thermal ☒ Thermo-hydraulic ☐

Solution: Transient

Method: Crank-Nicolson

Routine Name

Routine Name	SLCRNC
--------------	--------

Transient Definition

Solution start time (s)	0
Solution end time (s)	6,009.794454904987
Output interval (s)	600.9794454904987

Iteration Control

Max number of iterations	500
Convergence criterion (K)	0.01
Damping factor	1

Timestep Control

Initial time step (s)	10
Max change in temp per time step (...)	10,000,000,000
Minimum time step (s)	0
Maximum time step (s)	10,000,000,000
Temperature rate of change conv ...	10,000,000,000
Arith. node cut-off	0

Steady Cyclic Solution

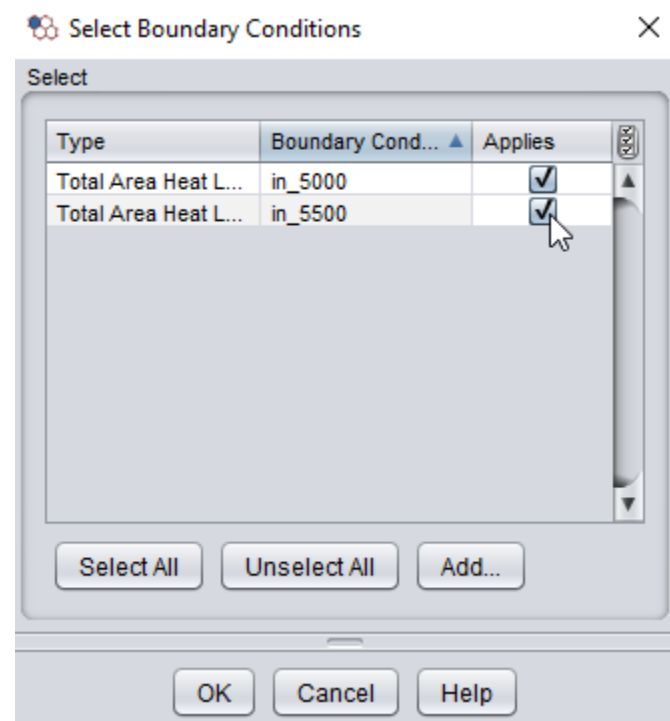
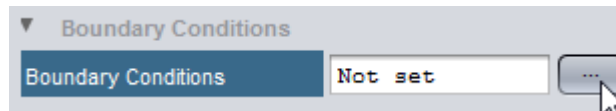
Cyclic solution	<input checked="" type="checkbox"/>
Temp convergence criterion (K)	0.1
RoC convergence criterion	0.01
Max number of cycles	500
Period of cycles (s)	6,009.794454904987
Nodes for conv criteria	
Output type required	NONE

Add at Cursor

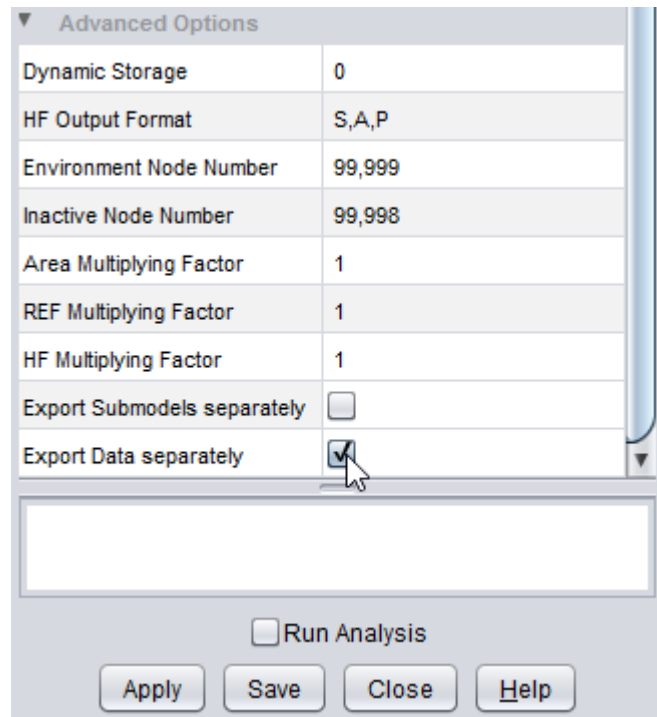
```

C
  TIMEND=6009.794454904987
  OUTINT=600.9794454904987
  NLOOP=500
  RELXCA=0.01
  DTIMEI=10.0
  CALL SOLCYC('SLCRNC',0.1D0,0.01D0,6009.794454904987,
C
  CALL SLCRNC
C
  
```

- ▶ Se seleccionan las condiciones de contorno, que en este caso son las potencias disipadas.



- Se pide que incluya los los flujos solar, albedo e infrarrojo y se pone número a los nodos de contorno (ambiente e inactivo).

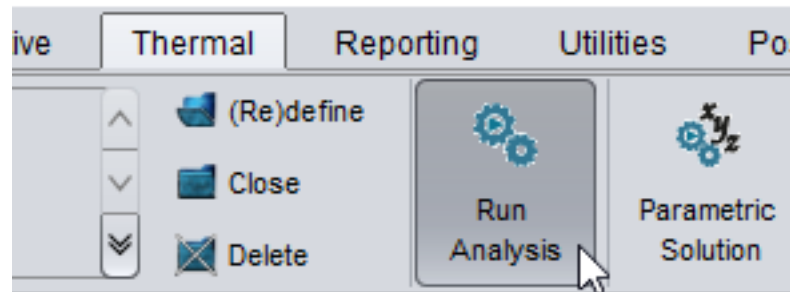


The image shows a software dialog box titled "Advanced Options". It contains a table of settings and several checkboxes. A mouse cursor is pointing at the "Export Data separately" checkbox, which is checked.

Advanced Options	
Dynamic Storage	0
HF Output Format	S,A,P
Environment Node Number	99,999
Inactive Node Number	99,998
Area Multiplying Factor	1
REF Multiplying Factor	1
HF Multiplying Factor	1
Export Submodels separately	<input type="checkbox"/>
Export Data separately	<input checked="" type="checkbox"/>

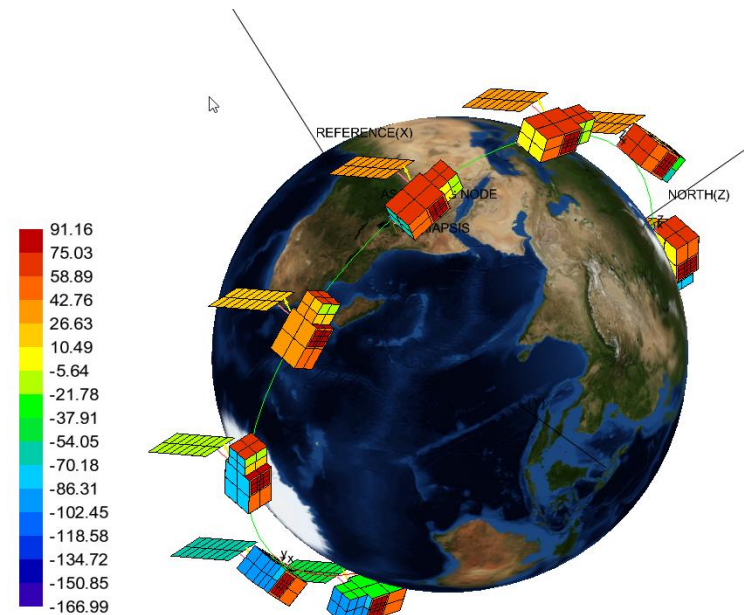
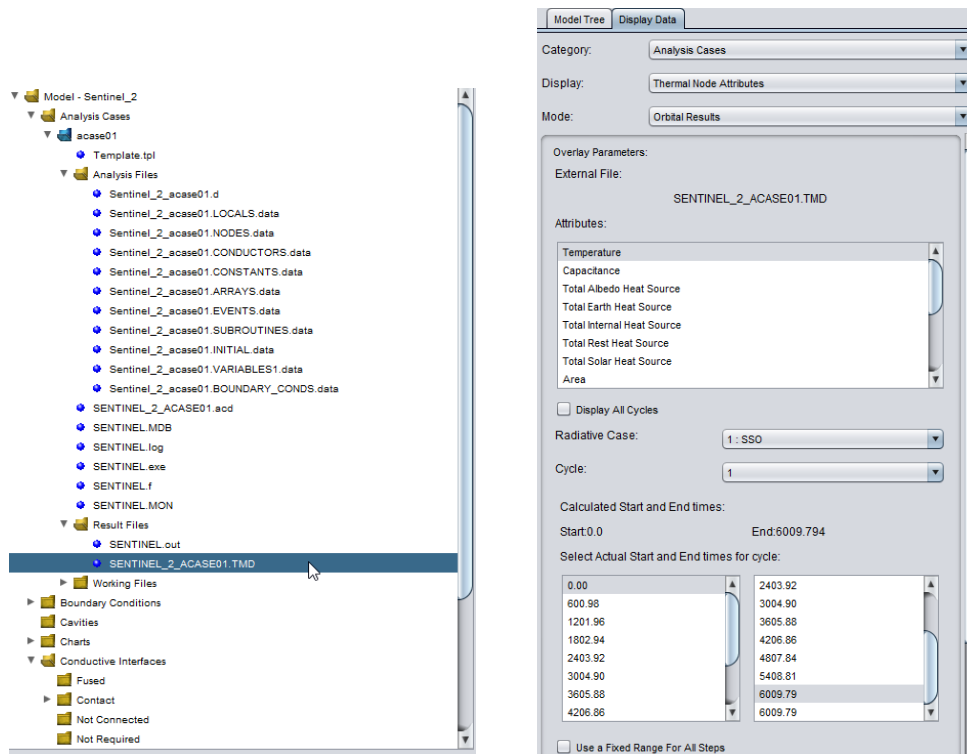
Below the table is a large empty text area. At the bottom of the dialog, there is a checkbox labeled "Run Analysis" which is unchecked. Below this are four buttons: "Apply", "Save", "Close", and "Help".

- ▶ Ejecutando el caso de análisis (Run Analysis) el programa calcula las temperaturas y flujos en cada posición orbital.

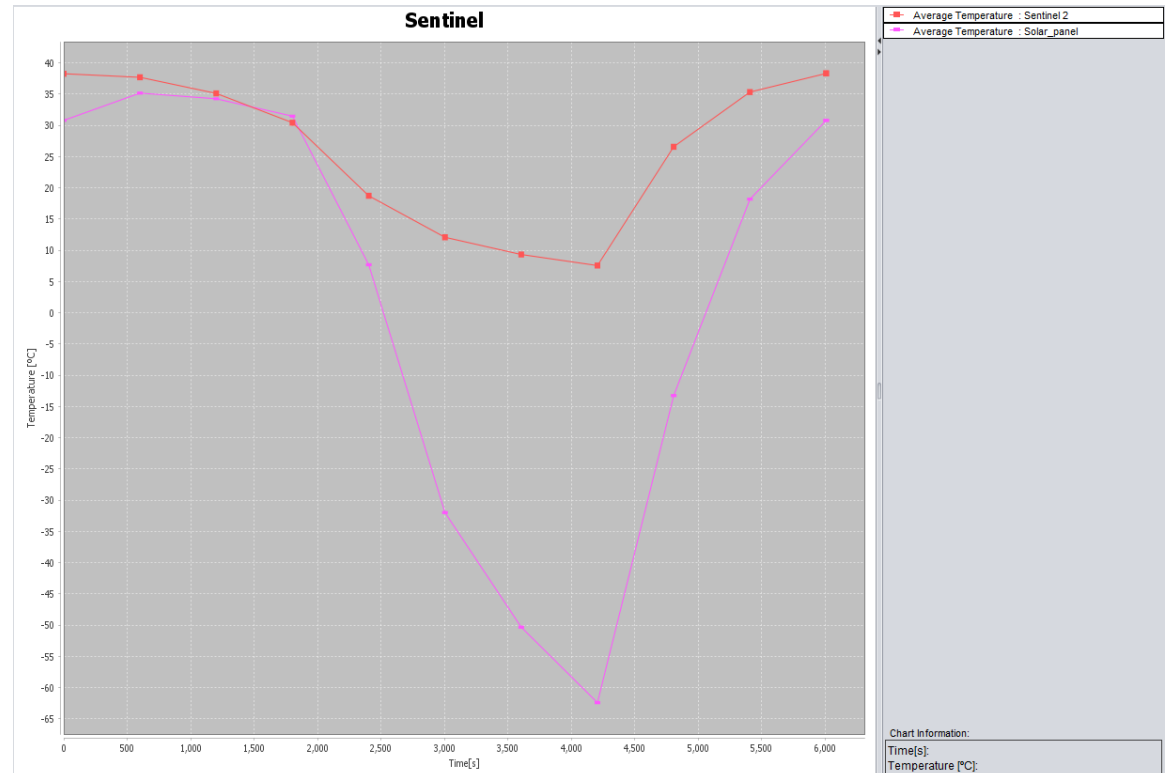
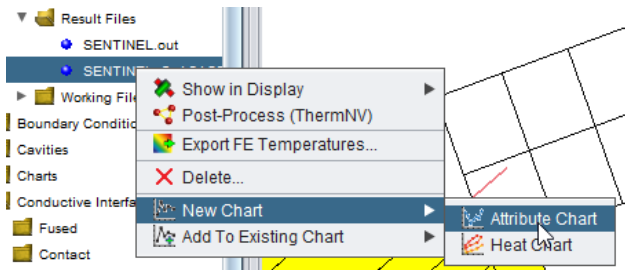


Visualización de resultados

- Los resultados se guardan en un archivo TMD y se configura su visualización haciendo doble click en el archivo.



Visualización de resultados



AI. Cálculo de GLs

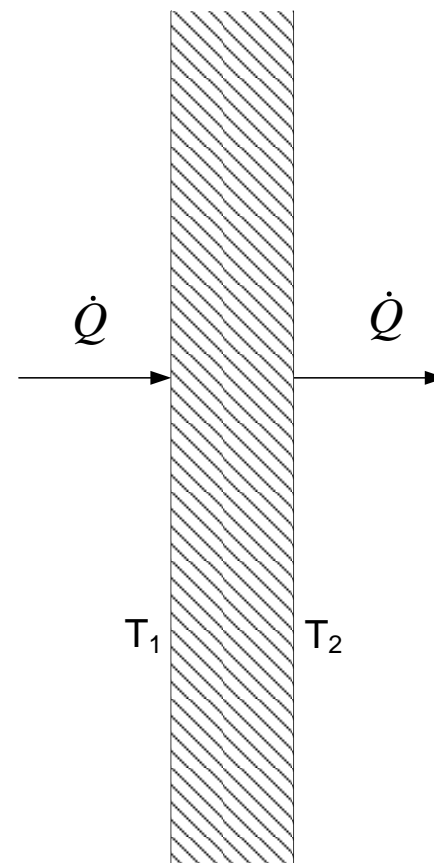
- Las conductancias térmicas lineales (GLs) se definen como:

$$\dot{Q} = k \frac{A (T_1 - T_2)}{l}$$



$$GL = k \frac{A}{l}$$

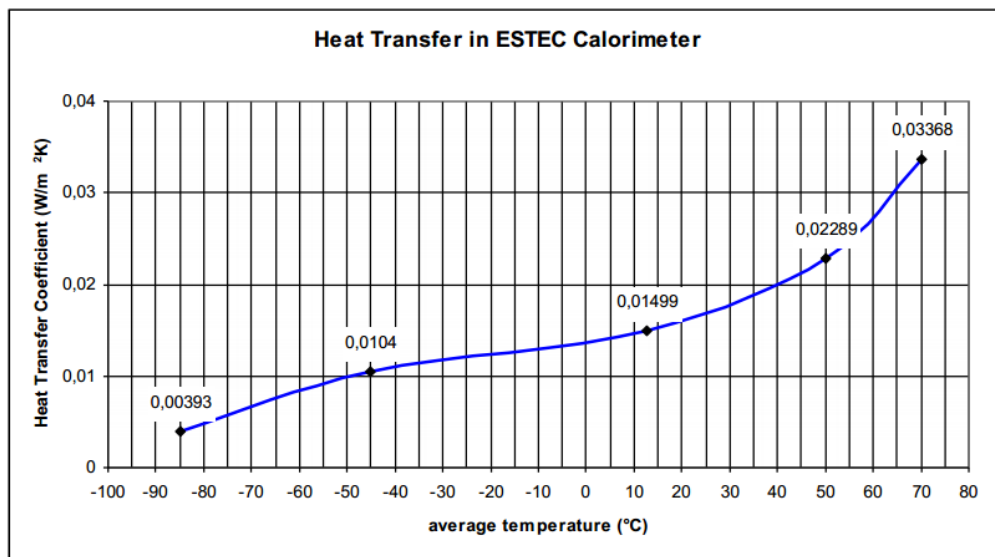
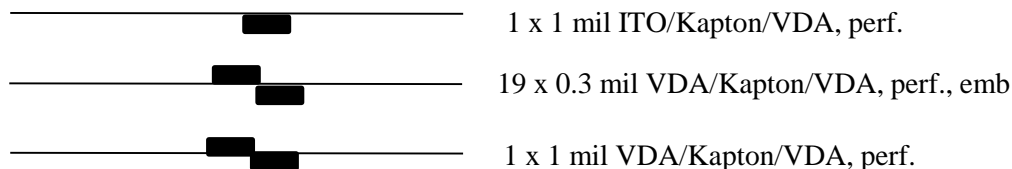
$$\dot{Q} = GL(T_1 - T_2)$$



- Siendo k la conductividad térmica del material, A el área transversal y l la distancia entre los dos nodos.

A2. MLIs

► 23 Layer VDA MLI

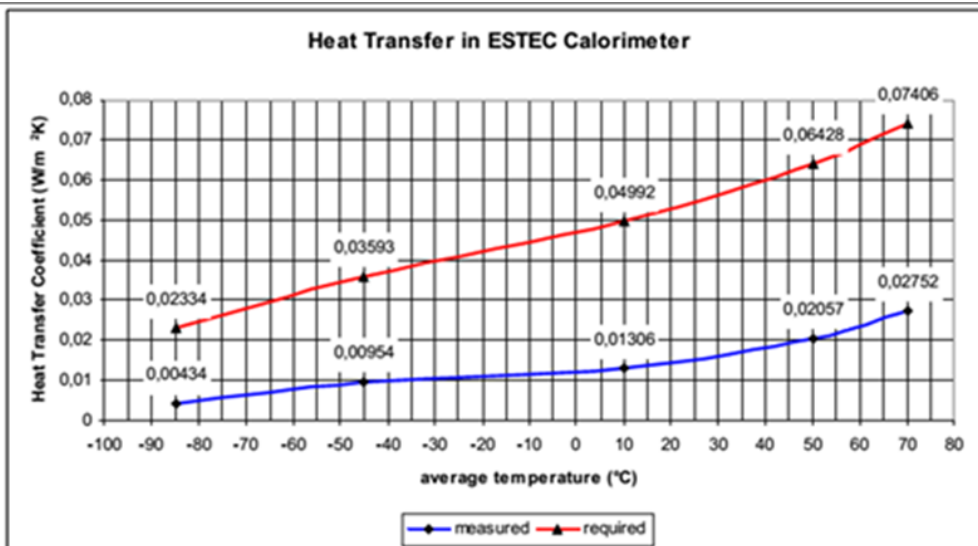
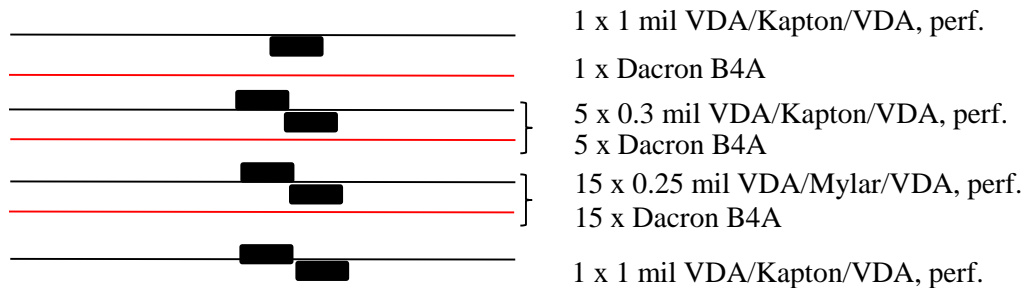


T (°C)	MLIE1 Cond. ideal
-75	0.00393
-45	0.0104
14	0.01499
50	0.02289
70	0.03368

$$GL \text{ (ext-int)} = \text{Factor} * A * \text{INTRP}(\text{Tav}(\text{Text}, \text{Tint}), \text{MLIE1})$$

A2. MLIs

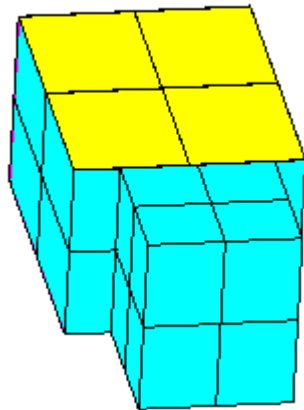
► 22 Layer VDA MLI



T (°C)	MLIE3
	Cond. ideal
-85	0.00434
-45	0.00954
10	0.01306
50	0.02057
70	0.02752

$$GL \text{ (ext-int)} = \text{Factor} * A * \text{INTRP}(\text{Tav}(\text{Text}, \text{Tint}), \text{MLIE1})$$

- MLI : Varias shells recubriendo las caras exteriores de ambos cuerpos (a 2 mm de distancia)



Para evitar huecos las MLIs tienen que medir 2 mm más por cada lado que el cuerpo del satélite

Geometric Properties Diagrams...	
Geometry Name:	MLI_body_a_Z_plus
Shape:	Rectangle
Geometry Type:	<input checked="" type="radio"/> Shell <input type="radio"/> Solid
Defined By:	Parameters
▼ Params	
xmax (m)	1.504
ymax (m)	2.004
height (m)	
xmin (m)	
ymin (m)	
▼ Transform	
Method	X Y Z
X Angle (deg)	0
Y Angle (deg)	0
Z Angle (deg)	0
X Distance (m)	-0.002
Y Distance (m)	-0.002
Z Distance (m)	1.202
Application Order	XR, YR, ZR, XT, YT, ZT
▼ Cutting	
Cutting Sense	Keep Outside

- MLI : Propiedades. Comunes a todas las shells (cambiando siempre el número de nodo).

Geometry Name:

▼ Mesh

Faces along Direction 1	2
Faces along Direction 2	2
Ratio in Direction 1	1
Ratio in Direction 2	1
Mesh Positions in Directio...	
Mesh Positions in Directio...	
Analysis Type	Lumped Parameter

▼ Surface 1

Label	MLI_ext
Activity	Active
Radiative Criticality	NORMAL
Submodel name	
Base Node Number	600
Node Increment	1
Optical Coating	Kapton
Colour	YELLOW

▼ Surface 2

Label	MLI_int
Activity	Active
Radiative Criticality	NORMAL
Submodel name	
Base Node Number	650
Node Increment	1
Optical Coating	Low_e
Colour	VERY_LIGHT_GREY

▼ Bulk Material

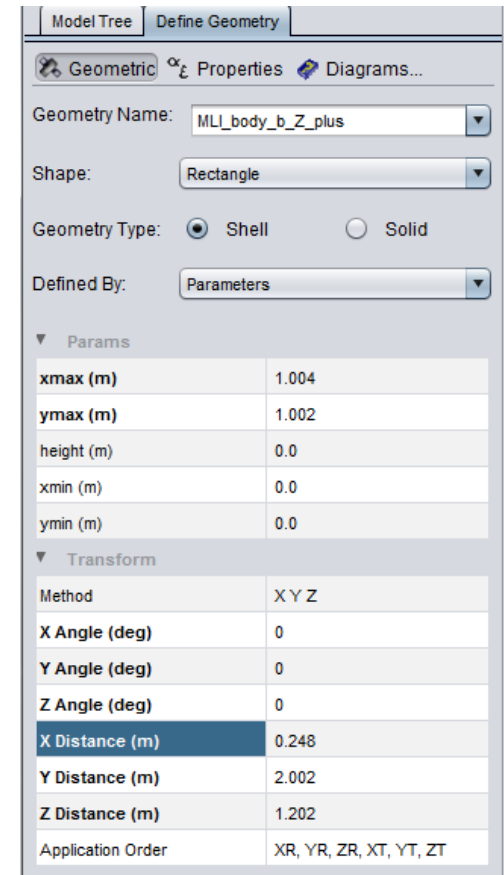
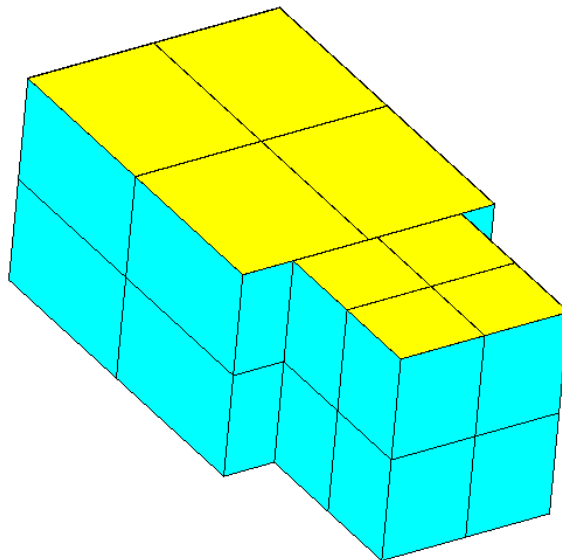
Composition	SINGLE
Material	MLI_foil
Thickness (m)	5.0E-4
Surface 1 - Material	
Surface 1 - Thickness (m)	
Surface 2 - Material	
Surface 2 - Thickness (m)	

▼ Through Conducta...

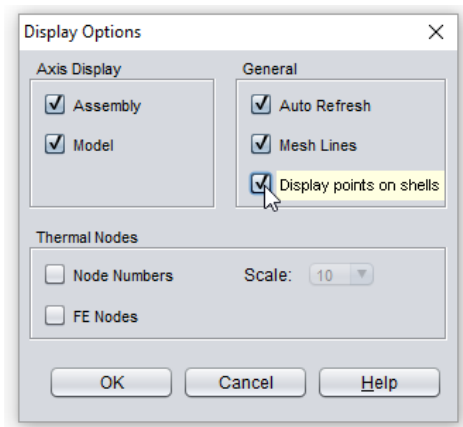
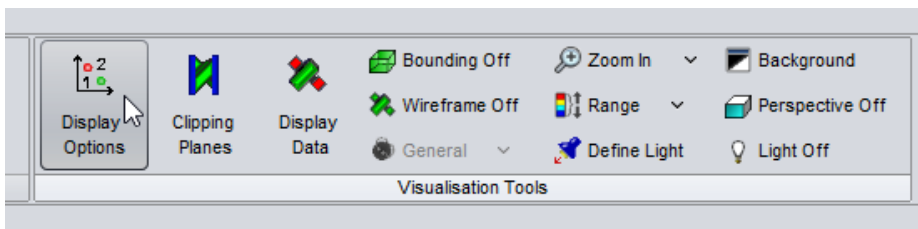
Calculation Type	EFFECTIVE
Conductance (W/m2.K)	
Emittance	0.01

$$\dot{Q} = \sigma \cdot A \cdot \epsilon_{eff} \cdot (T_e^4 - T_i^4)$$

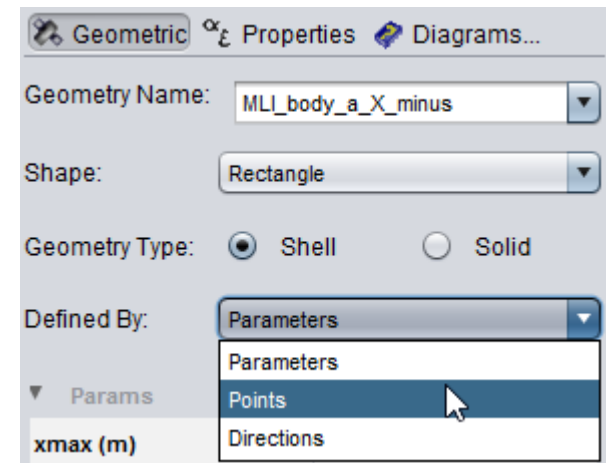
- MLI : Las MLIs superiores e inferiores se definen del mismo modo, cambiando el número de nodo



MLIs laterales a



Primero hay que mostrar los puntos en el modelo



Después seleccionar definición por puntos y pinchar en ellos