ESA - European Space Thermal Engineering Workshop 2024

THERMAL MODELLING OF LARGE DEPLOYABLE REFLECTOR MESH SURFACE

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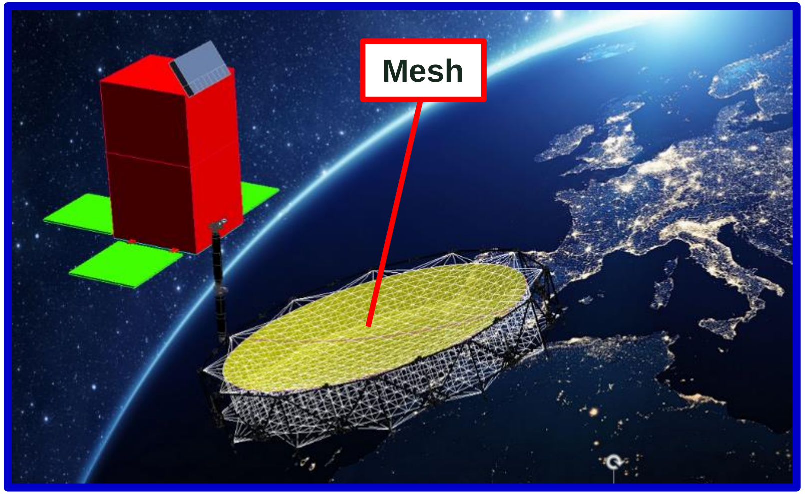
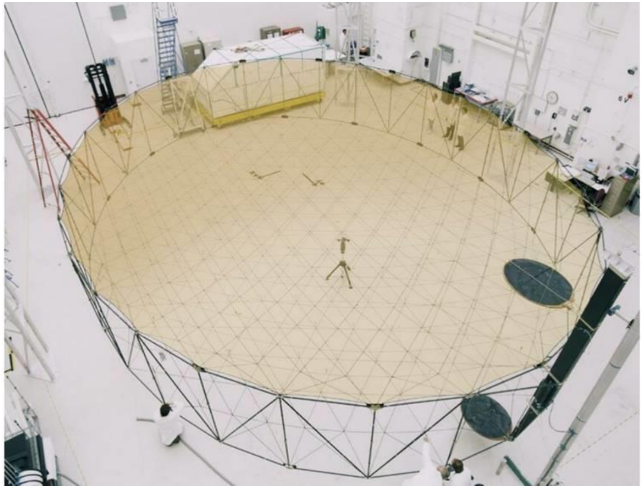
INTRODUCTION – LARGE DEPLOYABLE REFLECTOR

The demand for lightweight, deployable reflectors has greatly increased since they are useful for telecommunications, Earth observation, and interplanetary missions, covering various frequencies and reflector sizes.

The LDR is a space antenna class providing compact configurations at launch and large reflective surfaces once deployed.

Such technology significantly improves directivity-to-mass and directivity-to-stowed volume ratios w.r.t. solid reflectors; it mainly consists of a metallic mesh reflecting surface deployed and kept in shape thanks to a cable network and a supporting truss system.





INTRODUCTION – REFLECTIVE MESH

The reflective mesh is constructed by weaving metal wires to meet the RF performance requirements when tensioned, tailored to the reflector's operating frequency bands.

The mesh design must meet the following criteria:

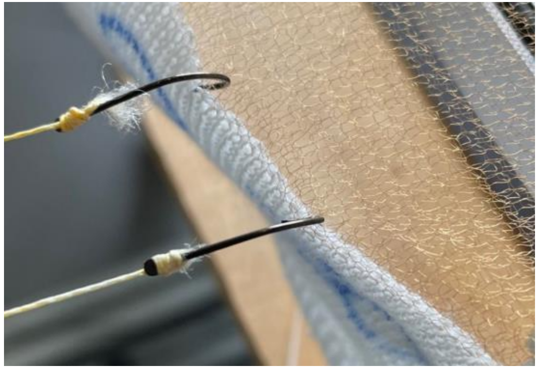
Flexibility and adjustability to support the use of the LDR (Large Deployable Reflector) across a wide range of frequency bands.

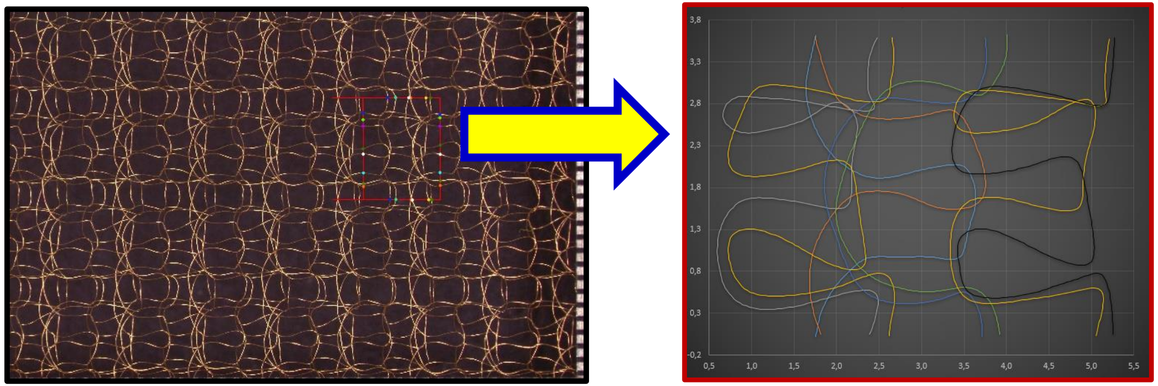
Uniformity and consistency in wire dimensions and tensile strength.

Assurance of an accurate and repeatable deployed surface shape, ensuring reliability despite the mesh's large size.

Gold-plated molybdenum and tungsten wires are the most commonly used materials for this application since they offer light weight and a highly elastic behavior as well as non-linear stiffness and thermal stability.

LDR meshes have to be designed to withstand challenging environments such as thermal fluctuations, radiation, micrometeorite impacts, UV exposure, and atomic oxygen; their typical wire diameter ranges in between 20 and 50 microns.





ISSUES – THERMAL CHARACTERIZATION

The small diameter of the mesh wires implies significant challenges from thermal predictions point of view since standard methodologies are not applicable; to overcome such issue the following strategy was implemented:

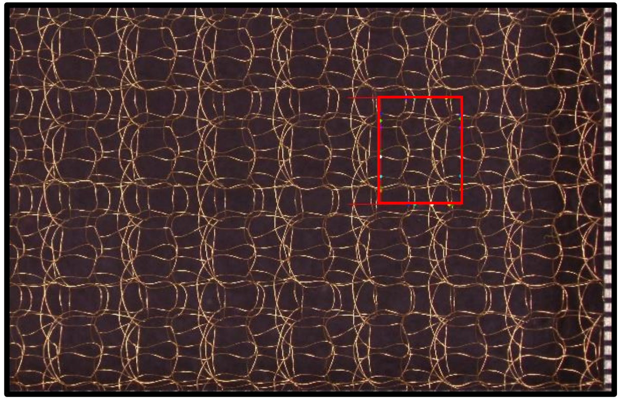
- A detailed 3D thermal mathematical model of a representative unit cell of the mesh was developed using a dedicated algorithm derived from the mesh geometry.
- On the basis of thermal analyses performed of the 3D model, the equivalent thermo-optical properties (UV-IR transmissivity and a sun angle-dependent corrective α/ε factor) to be applied on a 2D model were carried out.
- Sensitivity analyses were conducted to evaluate the impact of wire diameter and the number of nodal networks in the 3D model.
- An equivalent 2D thermal mathematical model of the mesh was then developed enabling accurate predictions and at the same time achieving time and cost savings.

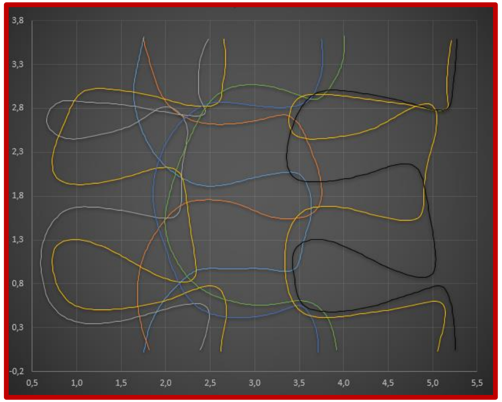
Thermal Desktop 6.3 and Visual Basic for Excel software tools were used for the study

RESULTS – MESH UNIT CELL - 3D MODEL

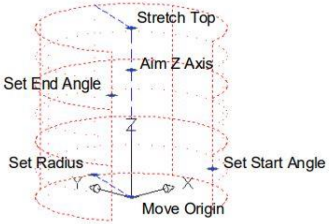
The reflective mesh is designed to guarantee an accurate and repeatable deployed surface shape.

A 5mm x 5mm mesh element (composed by 8 wires) was taken from the global pattern of the reflective mesh as representative unitary cell.





Mesh wires were modelled using Thermal Desktop shell cylindrical elements



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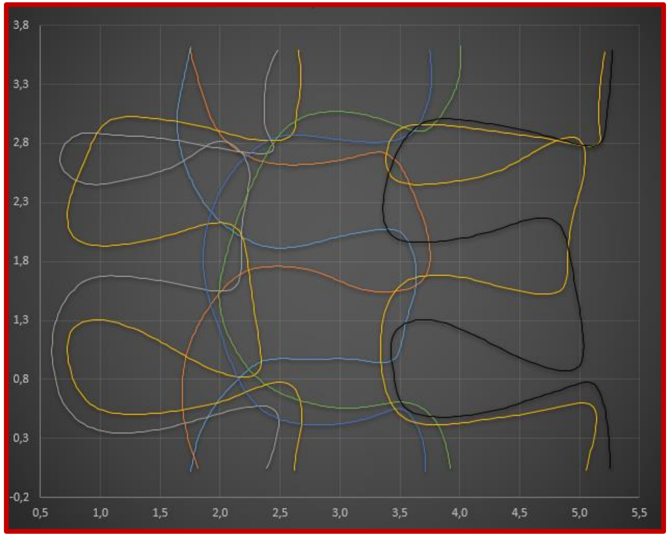
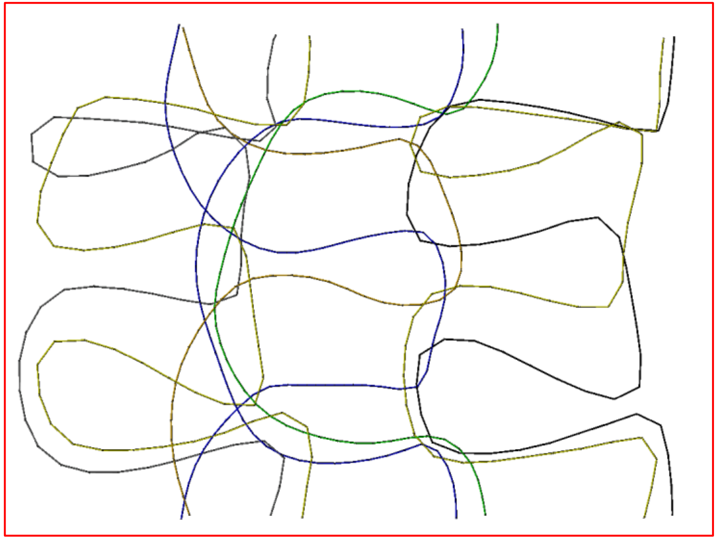
RESULTS – MESH UNIT CELL - 3D MODEL

To calculate the translation and rotation of each 3D elements of the representative unit cell of the mesh, a dedicated algorithm developed by TASI was implemented.

The algorithm allows the tuning of parameters such as the number of points for the coordinated and the number of elements of the Geometrical Mathematical Model (GMM)



3D wire GM model



The above study was based on 250 points and two configuration (50 and 250 elements)

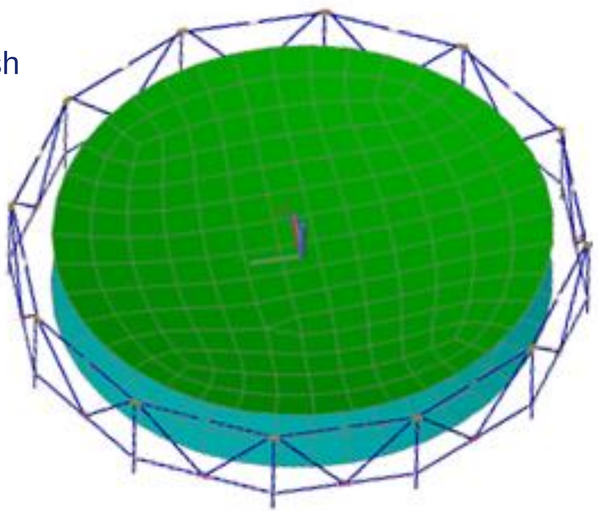
RESULTS – EQUIVALENT 2D MODEL

The development of a 2D elements model was necessary since the use of a detailed 3D model would be heavier, thus too time consuming and costly.

A characterization of a equivalent 2D surface models of the mesh was performed considering:

- Calculation of equivalent UV-IR transmissivity of 2D model
- Calculation of a sun angle dependent α/ε corrective factor

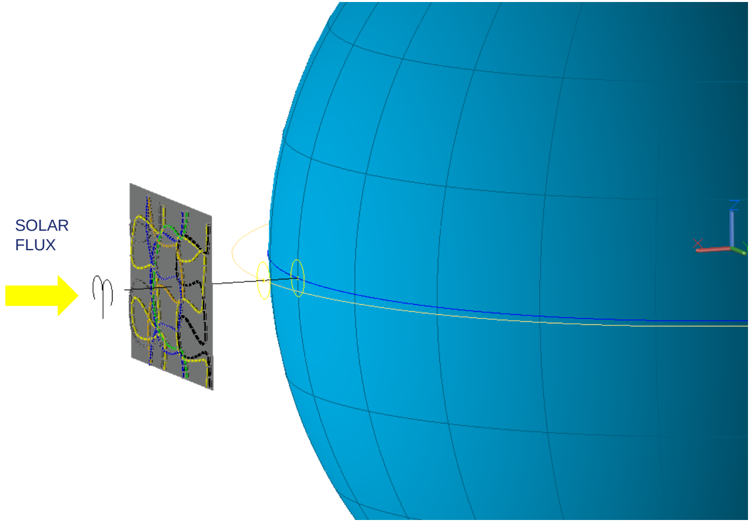
Typical 2D model
of the reflective mesh

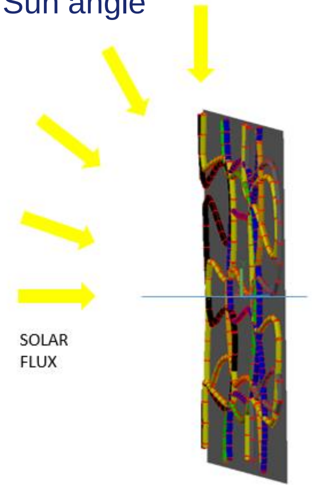


RESULTS – EQUIVALENT 2D MODEL - TRANSMISSIVITY

Equivalent properties of the 2D model were calculated as follows:

- 3D Model of the unit cell was positioned in front of a black body surface to evaluate the amount of solar energy passing through the model which is absorbed by the black surface.
- Equivalent "transmissivity" of 2D model of the unit cell has been evaluated in IR and UV and considering the different sun angle.





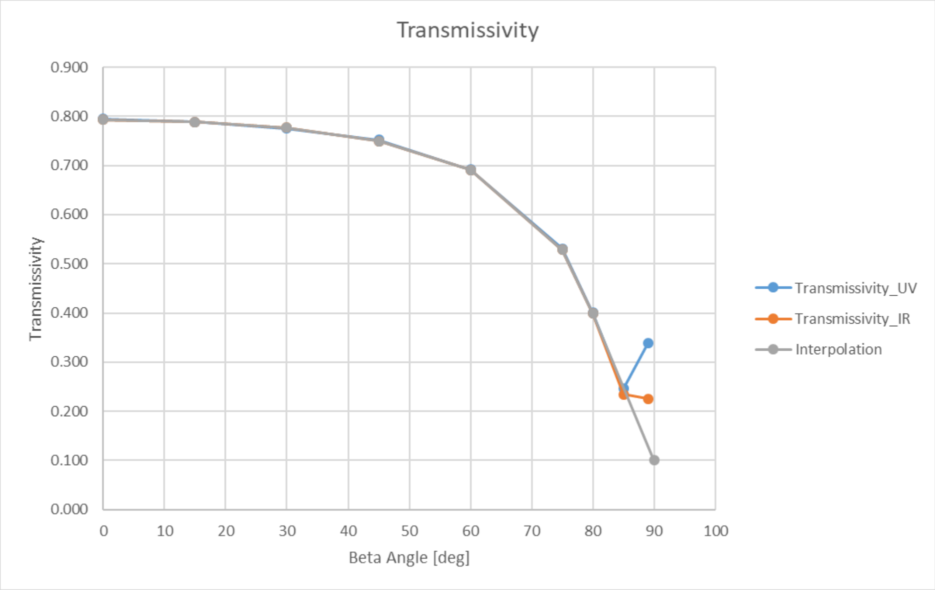
* 3D model is enhanced to improve the visibility

RESULTS – EQUIVALENT 2D MODEL - TRANSMISSIVITY

The discrepancy between IR and UV values is negligible except for beta angles close to 90° since solar rays are parallel to 2D surface.

Beta angle [deg]	Absorbed flux with 3D Mesh [W]	Absorbed flux w/o Mesh [W]	Transmissivity UV
0	0.01866	0.0235	**0.795**
15	0.01788	0.0227	**0.789**
30	0.01577	0.0203	**0.775**
45	0.01248	0.0166	**0.752**
60	0.00812	0.0117	**0.692**
75	0.00322	0.0061	**0.531**
80	0.00163	0.0041	**0.401**
85	0.00050	0.0020	**0.246**
89	0.00014	0.0004	**0.338**

Beta angle [deg]	Absorbed flux with 3D Mesh [W]	Absorbed flux w/o Mesh [W]	Transmissivity IR
0	0.00067	0.00084	**0.793**
15	0.00064	0.00082	**0.788**
30	0.00057	0.00073	**0.777**
45	0.00045	0.00060	**0.749**
60	0.00029	0.00042	**0.691**
75	0.00012	0.00022	**0.529**
80	0.00006	0.00015	**0.399**
85	0.00002	0.00007	**0.234**
89	0.00000	0.00002	**0.226**



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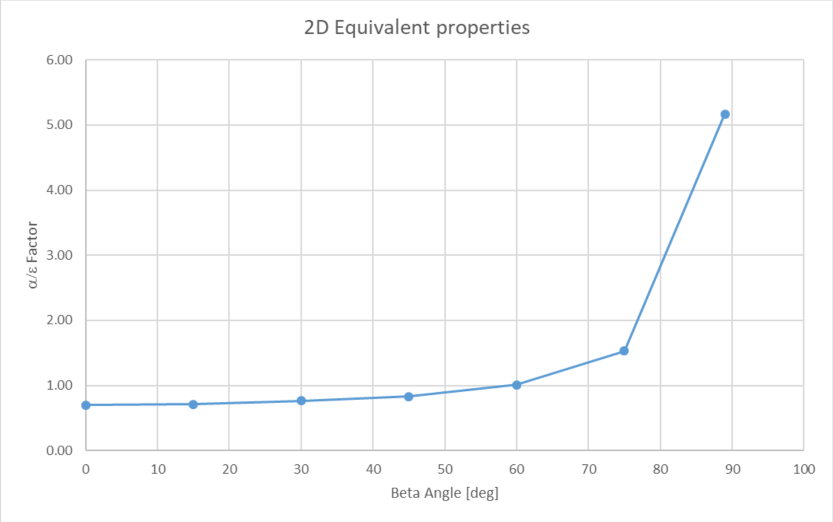
RESULTS – EQUIVALENT 2D MODEL – CORRECTIVE FACTOR

Sun angle-dependent α/ε corrective factor was derived from the correlation of the Temperature of 3D and 2D equivalent mesh wire model.

The analysis was based on the following assumptions:

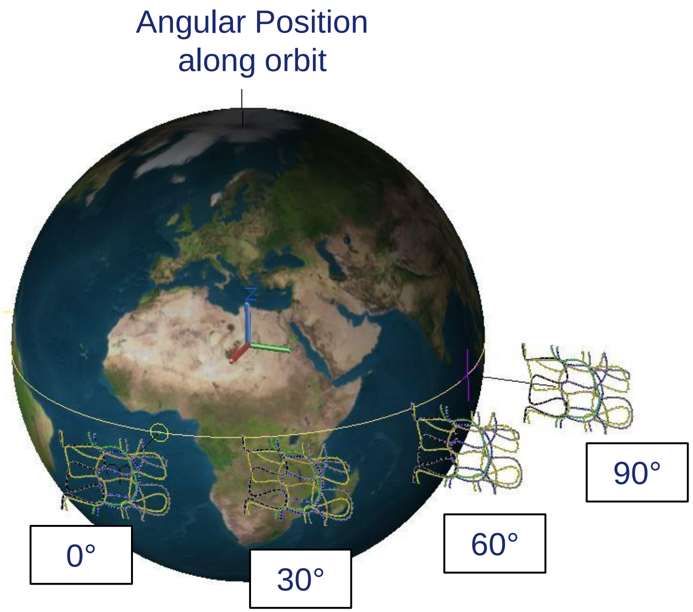
- Wires having the gold typical optical properties
- Just Solar flux was considered (no Albedo and IR Planet)

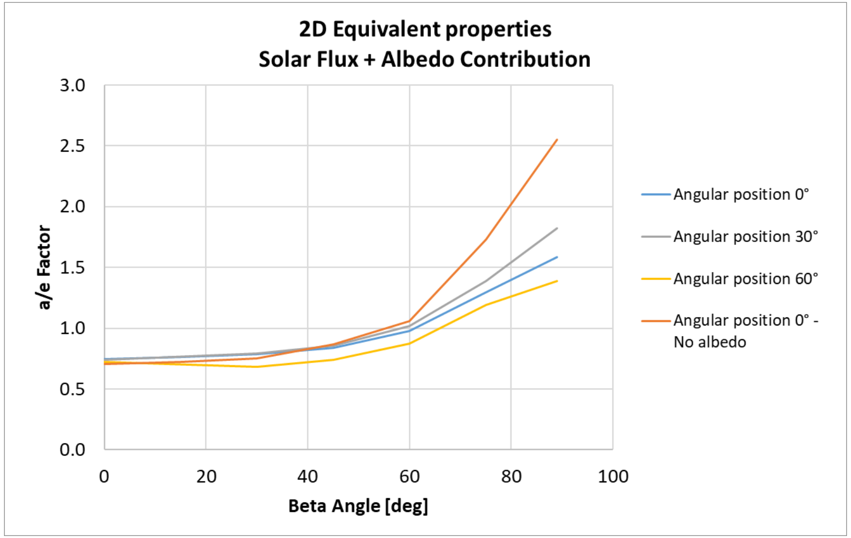
Beta angle [deg]	**Theoretical Temperature [°C]**	**2D Model Temperature [°C]**	**3D Model Average Temp. [°C]**	**α/ε Factor**
0	171.2	170.9	134.3	**0.707**
15	167.4	167.0	133.2	**0.724**
30	155.5	154.8	128.2	**0.768**
45	134.4	134.2	119.9	**0.865**
60	100.5	99.7	109.4	**1.098**
75	43.8	43.6	94.11	**1.802**
89	-111.5	-111.5	14.6	**10.067**



RESULTS – EQUIVALENT 2D MODEL – CORRECTIVE FACTOR

Introducing the albedo contribution and the variation of orbital angular position, α/ε corrective factor discrepancy is quite significant for higher beta angle since solar rays became parallel to body.





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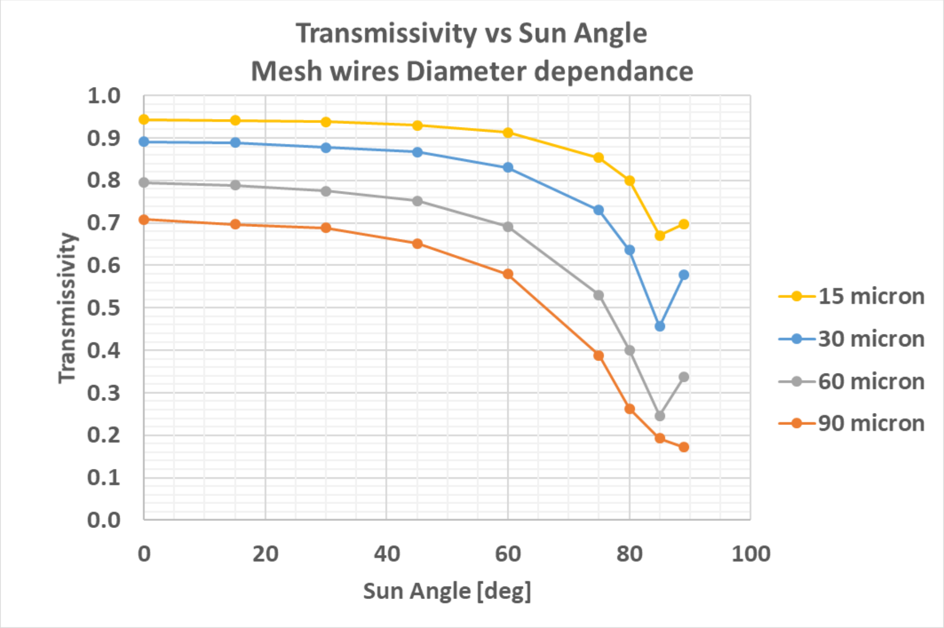
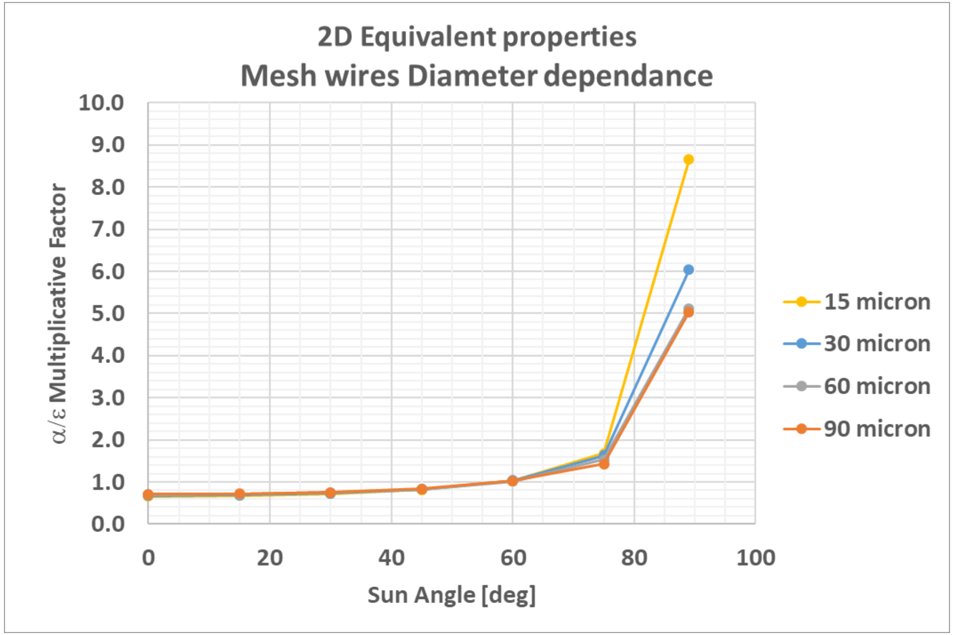
RESULTS – EQUIVALENT 2D MODEL - SENSITIVITY

Equivalent transmissivity and α/ε factor of 2D equivalent mesh were evaluated for different values of wires diameters:

- **Transmissivity** curve are shifting in function of the volume occupied by the mesh wires (field of view blockage)
- **α/ε factor** changes only at sun angle greater than 80° as the volume occupied by the mesh wires becomes significant

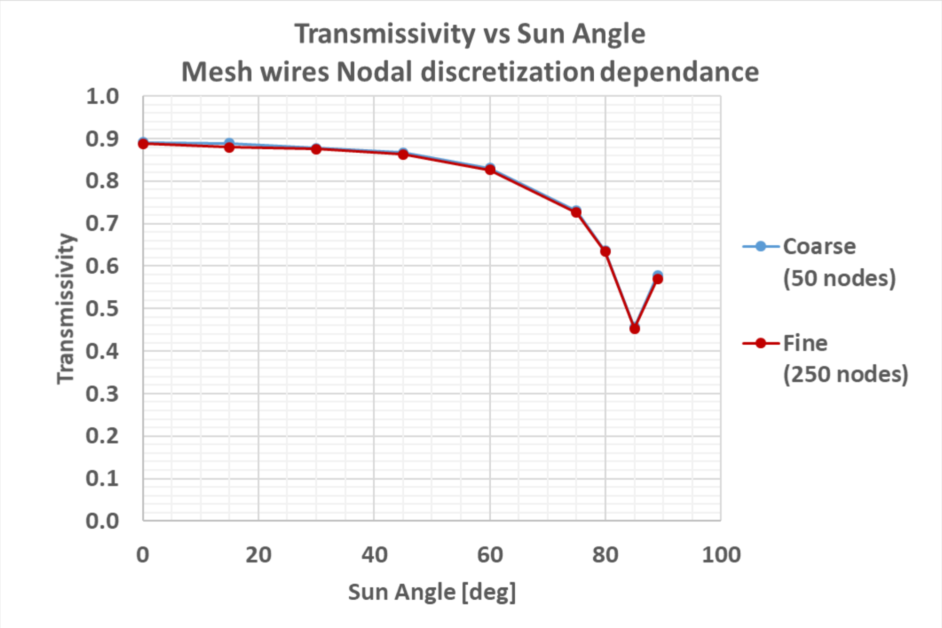


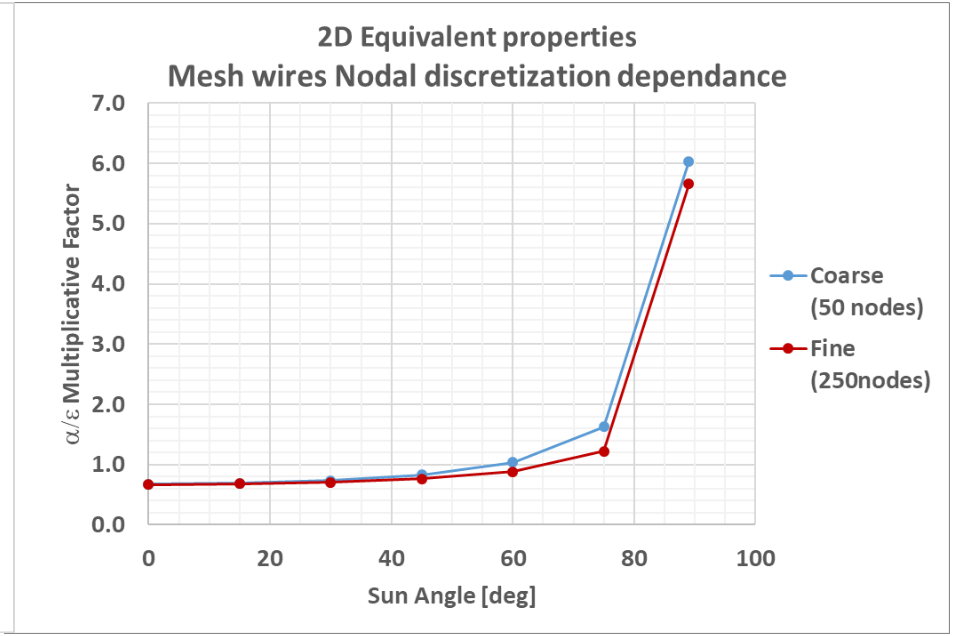


RESULTS – EQUIVALENT 2D MODEL - SENSITIVITY

Equivalent transmissivity and α/ε factor of 2D equivalent mesh has been evaluated for a ***coarse*** and ***fine*** discretization of the mesh wires:

- **Transmissivity** discrepancy is negligible (mean discrepancy value <1%)
- **α/ε factor** changes only at sun angle greater than 60° since solar rays became parallel to 2D surface



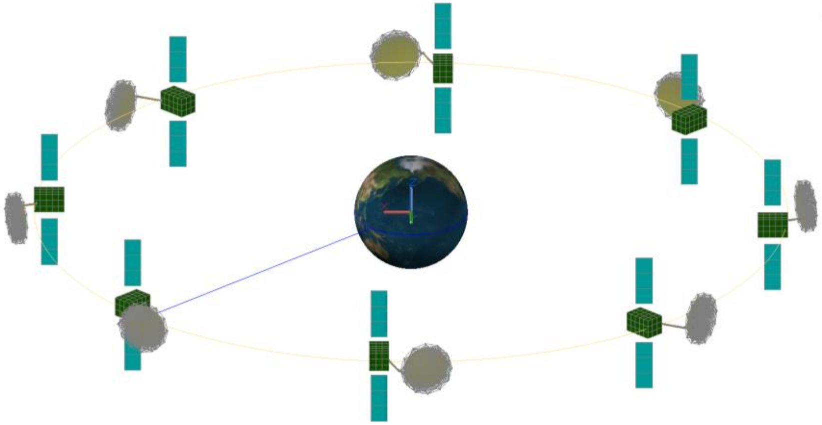


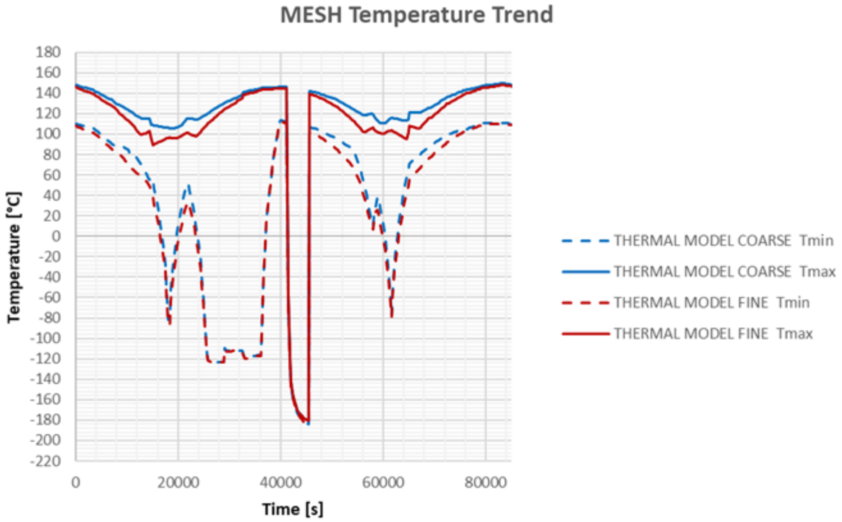
RESULTS – EQUIVALENT 2D MODEL - SENSITIVITY

A transient thermal analysis was performed implementing the parameters derived from coarse and fine 3D mesh model to 2D equivalent mesh TMM by the simulation of a GEO orbit at Equinox

The plots of the Mesh 2D Temperature highlights:

- Max and Min Temp→ negligible discrepancy
- Intermediate Temp→ discrepancy caused by sun angle close to 90°





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CONCLUSIONS

- This presentation illustrated a method for condensing the properties of a complex 3D Deployable Reflector mesh model into a more simple 2D elements thermal model
- Equivalent properties such as Equivalent UV-IR transmissivity and corrective α/ε factor were assessed at different sun angles, considering the contributions from solar flux alone, solar flux combined with albedo, and various angular positions along an orbit.
  The results indicate that the effect of albedo and angular position becomes quite significant at sun angles greater than 60°, when the solar rays become parallel to the 2D surface.
- Sensitivity analyses were conducted to evaluate the impact of wire diameter and the number of nodal networks in the 3D model, the results revealed a negligible discrepancy between the coarse and fine models.
- The described approach enables to accurate predictions, leading to time and cost savings.
  A test campaign is planned to support and validate the results of these analyses.

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THANK YOU!

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