Created in COMSOL Multiphysics 6.2

Orbit Calculation

Introduction

This model is a first introduction to defining and verifying a satellite orbit, and computing the solar, albedo, and Earth infrared thermal loads.

A 1U CubeSat is in a circular orbit at 400 km altitude, inclination of 50°, and longitude of ascending node of 0°. The satellite is rotating slowly about its nadir-pointing axis.

This type of analysis is usually performed prior to computing the temperature evolution within the structure of the satellite. The model Spacecraft Thermal Analysis shows the workflow for computing the satellite temperature on multiple orbit periods.

Model Definition

For the purposes of a quick preliminary computation of the orbital heat loads, it is sufficient to use a geometry that describes the outside envelope of a 1U CubeSat satellite with a protruding sensor. A cube of 10 cm side length is used with a 2 cm radius cylinder protruding 2 cm from the center of one side.

The two-band solar and ambient radiation model is used, with the separation point of 2.5 µm between the spectral bands. The sides of the satellite have solar cells mounted on them, which have high absorptivity in all bands. All other surfaces have the same emissivity of 0.2 in the solar band and 0.85 in the ambient band. For surfaces of a temperature less than 573.15 K (300°C), 99% of all emitted radiation will be in the ambient band, while 97% of the solar and albedo irradiation will be in the solar band.

The solar loads are evaluated at the point where Earth is at perihelion, the winter solstice. The Sun is treated as an infinitely faraway ideal blackbody emitter with fixed intensity of 1414 W/m^2 over the entire orbit, as long as the satellite is not in eclipse. The proportion of solar radiation incident onto Earth reflected diffusely back toward the satellite, or albedo, is set to 0.3 everywhere on the planet. Earth is relatively warm compared to background deep space and is modeled as a distributed emitter having a uniform flux of 225 W/m^2.

The orientation of the satellite is such that the $+Z$ direction, in the geometry coordinate system, points toward Earth. The satellite is slowly rotating about this primary axis, so the secondary axis can be any vector that is not parallel to nadir, in this case the vector parallel to the velocity direction is used.

Results and Discussion

Figure 1 shows the satellite in orbit around Earth. The yellow arrow represents the Sun vector. The orbit line is colored black or yellow depending on whether the satellite is in eclipse or not. Use this plot to verify that the sensor is facing Earth at all times.

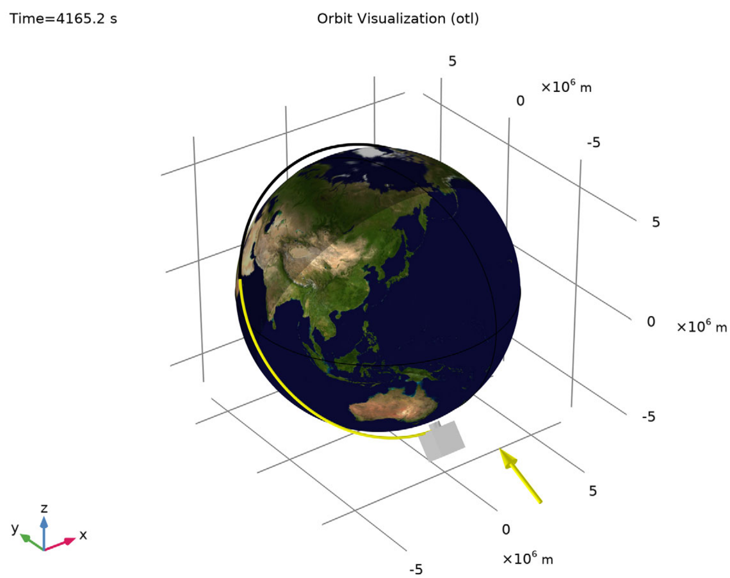

Figure 1: Satellite orbit around Earth after 4165 s[1].

Figure 2 shows the external irradiation and the Sun and nadir vector, respectively, in yellow and blue. Again, the path of the Sun vector around the satellite is colored black or yellow depending on whether the satellite is in eclipse or not. Observe the partial shading around the sensor.

1. NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights).

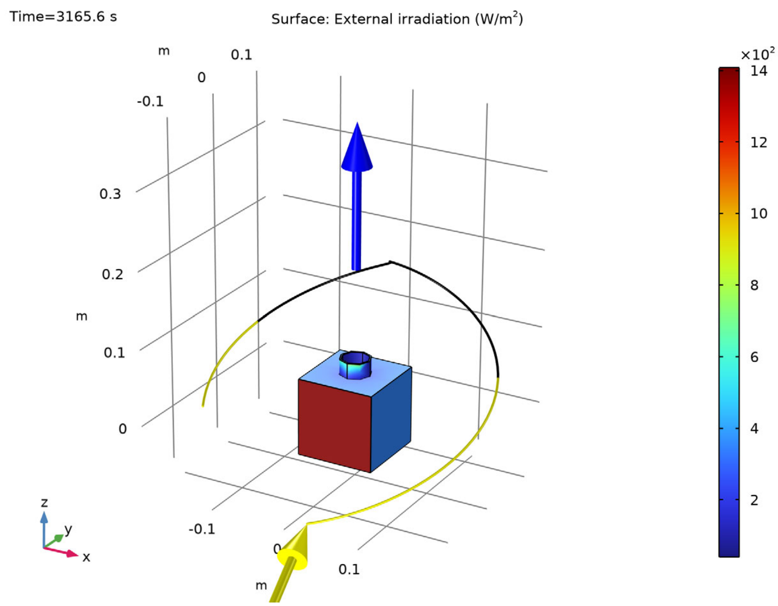

Figure 2: External irradiation after 3165 s.

Figure 3 shows the external irradiation over time. When the satellite is in eclipse, the irradiation is only due to Earth's infrared flux.

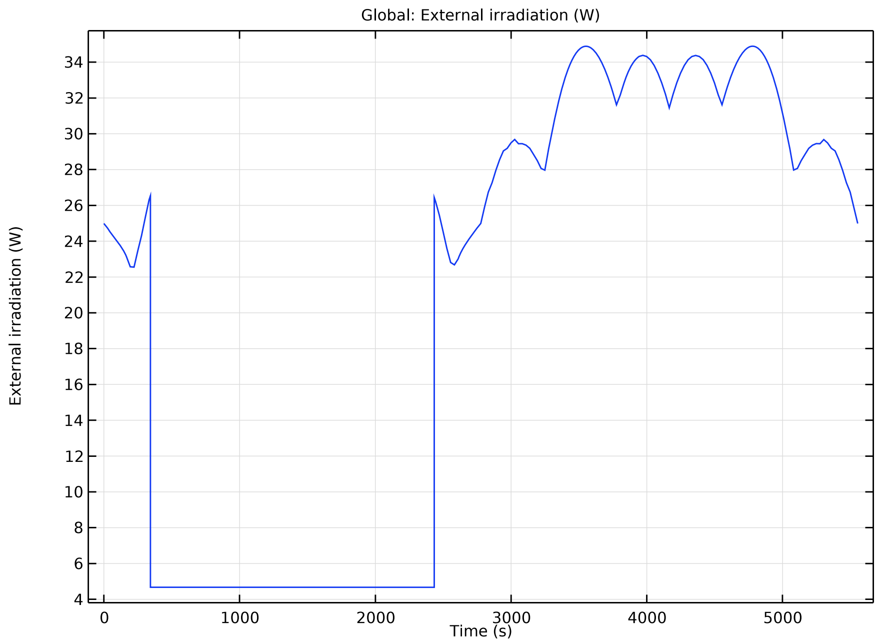

Figure 3: External irradiation over time.

The average of the total environmental irradiation over the entire orbit is 20.5 W. This satellite has very few exterior surfaces that shadow and face each other. That is, its exterior is very nearly convex, so the total environmental loads are reasonably well estimated from the irradiation.

Application Library path: `Heat_Transfer_Module/Orbital_Thermal_Loads/orbit_calculation`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.
2 In the **Select Physics** tree, select **Heat Transfer>Radiation>Orbital Thermal Loads (otl)**.
3 Click **Add**.
4 Click **Study**.
5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Orbit Calculation**.
6 Click **Done**.

GEOMETRY 1

Block 1 (blk1)

1 In the **Geometry** toolbar, click **Block**.
2 In the **Settings** window for **Block**, locate the **Size and Shape** section.
3 In the **Width** text field, type `10[cm]`.
4 In the **Depth** text field, type `10[cm]`.
5 In the **Height** text field, type `10[cm]`.
6 Locate the **Position** section. From the **Base** list, choose **Center**.

Cylinder 1 (cyl1)

1 In the **Geometry** toolbar, click **Cylinder**.
2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.
3 In the **Radius** text field, type `2[cm]`.
4 In the **Height** text field, type `2[cm]`.
5 Locate the **Position** section. In the **z** text field, type `5[cm]`.

Cylinder 2 (cyl2)

1 In the **Geometry** toolbar, click **Cylinder**.
2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.
3 In the **Radius** text field, type `1.8[cm]`.
4 In the **Height** text field, type `3[cm]`.
5 Locate the **Position** section. In the **z** text field, type `4.5[cm]`.

Partition Domains 1 (pard1)

1. In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Partition Domains**.
2. On the object **cyl2**, select Domain 1 only.
3. In the **Settings** window for **Partition Domains**, locate the **Partition Domains** section.
4. From the **Partition with** list, choose **Faces**.
5. On the object **blk1**, select Boundary 4 only.

Difference 1 (dif1)

1. In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Difference**.
2. Select the objects **blk1** and **cyl1** only.
3. In the **Settings** window for **Difference**, locate the **Difference** section.
4. Click to select the **Activate Selection** toggle button for **Objects to subtract**.
5. Select the object **pard1** only.
6. Clear the **Keep interior boundaries** check box.
7. Click **Build All Objects**.

ORBITAL THERMAL LOADS (OTL)

Sun Properties 1

By default, the Sun vector and solar flux are set to correspond to the winter solstice.

Planet Properties 1

The Earth properties are used to define the planet.

1. In the **Model Builder** window, click **Planet Properties 1**.
2. In the **Settings** window for **Planet Properties**, locate the **Radiative Properties** section.
3. From the **Albedo** list, choose **User-defined distribution**.

   The proportion of solar radiation incident onto Earth reflected diffusely back toward the satellite, or albedo, is set to 0.3 everywhere on the planet.
4. In the $\alpha_{0,\lambda}$ text field, type `0.3`.

   Earth is relatively warm compared to background deep space and is modeled as a distributed emitter having a uniform flux of 225 W/m^2.
5. From the **Planet radiative flux** list, choose **User-defined for each band**.

6 In the table, enter the following settings:

Spectral band	Planet radiative flux (W/m^2)
Ambient: [2.5[um], +infinity[	`225[W/m^2]`

Orbital Parameters 1

A circular orbit is defined at 400 km altitude, inclination of 50°, and longitude of ascending node of 0°.

1 In the **Model Builder** window, click **Orbital Parameters 1**.

2 In the **Settings** window for **Orbital Parameters**, locate the **Orbital Parameters** section.

3 From the **Orbit type** list, choose **Circular**.

4 In the R text field, type `otl.R_planet+400[km]`.

5 In the i text field, type `50[deg]`.

Spacecraft Axes 1

By default, the axes of the satellite are defined such that the +Z direction, in the geometry coordinate system, is the primary axis and the +X direction is the secondary axis.

Spacecraft Orientation 1

The orientation of the satellite is such that the primary direction points toward Earth. The satellite is slowly rotating about its primary axis, so the secondary axis can be any vector that is not parallel to nadir. In this case the default setting, of the +X direction corresponding to the direction of travel, is used.

1 In the **Model Builder** window, click **Spacecraft Orientation 1**.

2 In the **Settings** window for **Spacecraft Orientation**, locate the **Spacecraft Orientation** section.

3 Find the **Rotations** subsection. From the **Rotation about primary axis** list, choose **Angular rate**.

4 In the ω text field, type `2*360[deg]/otl.T_orbit`.

Diffuse Surface 1

Now, define the radiative properties of the different boundaries.

1 In the **Model Builder** window, click **Diffuse Surface 1**.

2 In the **Settings** window for **Diffuse Surface**, locate the **Surface Emissivity** section.

3 From the ε list, choose **User-defined for each band**.

4 In the table, enter the following settings:

Spectral band	Emissivity (1)
Solar: [0, 2.5[um][	`0.2`
Ambient: [2.5[um], +infinity[	`0.85`

Diffuse Surface 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Diffuse Surface**.

2 In the **Settings** window for **Diffuse Surface**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `1 2 5 20` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Diffuse Surface**, locate the **Surface Emissivity** section.

7 From the ε list, choose **User-defined for each band**.

8 In the table, enter the following settings:

Spectral band	Emissivity (1)
Solar: [0, 2.5[um][	`0.99`
Ambient: [2.5[um], +infinity[	`0.95`

STUDY 1

In the **Home** toolbar, click **Compute**.

RESULTS

Orbit Visualization (otl)

This default plot is used to check that the orbit parameters, orientation, and events are correctly defined. Since neither the study nor the plot is computationally expensive, it is possible to adjust the model parameters and rerun the study to see the results very quickly.

Add an evaluation group to verify that the configuration is correct by extracting some orbit data.

Orbit Variables

1 In the **Results** toolbar, click **Evaluation Group**.

2 In the **Settings** window for **Evaluation Group**, type `Orbit Variables` in the **Label** text field.

3 Locate the **Data** section. From the **Time selection** list, choose **First**.

4 Locate the **Transformation** section. Select the **Transpose** check box.

5 Click to expand the **Format** section. From the **Include parameters** list, choose **Off**.

Global Evaluation 1

1 Right-click **Orbit Variables** and choose **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, locate the **Expressions** section.

3 In the table, enter the following settings:

Expression	Unit	Description
otl.t_inEclipse	s	Beginning of eclipse
otl.t_outEclipse	s	End of eclipse
otl.T_orbit	s	Orbit period

4 In the **Orbit Variables** toolbar, click **Evaluate**.

Once the orbit configuration is correct, an Orbit Thermal Loads study can be added to estimate the external irradiation on the satellite boundaries.

DEFINITIONS

An integration operator is added to integrate the external irradiation over the spacecraft boundaries.

Integration 1 (intop1)

1 In the **Definitions** toolbar, click **Nonlocal Couplings** and choose **Integration**.

2 In the **Settings** window for **Integration**, locate the **Source Selection** section.

3 From the **Geometric entity level** list, choose **Boundary**.

4 From the **Selection** list, choose **All boundaries**.

MESH 1

Since this model is only used to evaluate irradiation, a quite coarse mesh is sufficient.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Extremely coarse**.

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Orbit Thermal Loads**.

4 Right-click and choose **Add Study**.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 2

Step 1: Orbit Thermal Loads

1 In the **Settings** window for **Orbit Thermal Loads**, locate the **Study Settings** section.

2 In the **Output orbit times** text field, type `range(0,0.005,1)`.

3 In the **Home** toolbar, click **Compute**.

RESULTS

External Irradiation (otl)

This plot is used to show the external irradiation over time. The blue arrow shows the nadir direction and the yellow arrow shows the Sun direction.

Set the Line type to Tube to show the path of the Sun around the spacecraft.

Sun Vector

1 In the **Model Builder** window, expand the **External Irradiation (otl)** node, then click **Sun Vector**.

2 In the **Settings** window for **Point Trajectories**, locate the **Coloring and Style** section.

3 Find the **Line style** subsection. From the **Type** list, choose **Tube**.

Add velocity following plot to visualize the position of the satellite above Earth and the Sun vector.

ADD PREDEFINED PLOT

1 In the **Home** toolbar, click **Windows** and choose **Add Predefined Plot**.

2 Go to the **Add Predefined Plot** window.

3 In the tree, select **Study 2/Solution 2 (sol2)>Orbital Thermal Loads>Trajectory Following Visualization (otl)**.

4 Click **Add Plot** in the window toolbar.

RESULTS

Trajectory Following Visualization (otl)

1 In the **Settings** window for **3D Plot Group**, locate the **Data** section.

2 From the **Time (s)** list, choose **166.61**.

3 In the **Trajectory Following Visualization (otl)** toolbar, click **Plot**.

Plot the evolution of the external irradiation on the satellite boundaries over time (Figure 3).

External Irradiation Over Time

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 2/Solution 2 (sol2)**.

4 In the **Label** text field, type `External Irradiation Over Time`.

Global 1

1 Right-click **External Irradiation Over Time** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
intop1(otl.Gext1+otl.Gext2)	W	External irradiation

4 Click to expand the **Legends** section. Clear the **Show legends** check box.

5 In the **External Irradiation Over Time** toolbar, click **Plot**.

Finally, add an evaluation to get the average of the total environmental irradiation over the entire orbit.

Surface Average 1

1 In the **Model Builder** window, right-click **Orbit Variables** and choose **Average>Surface Average**.

2 In the **Settings** window for **Surface Average**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 2/Solution 2 (sol2)**.

4 From the **Time selection** list, choose **Last**.

5 Locate the **Selection** section. From the **Selection** list, choose **All boundaries**.

6 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
timeavg(0,otl.T_orbit, intop1(otl.Gext1+otl.Gext2), 'nointerp')	W	Orbit-averaged irradiation

7 In the **Orbit Variables** toolbar, click = **Evaluate**.