CE 133 / ME 180, Lab project #1

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Week #1 (1/25/16 - 1/31/16)

The **Death Star** (Figures 1 and 2) is a moon-sized space battle-station which is to be constructed by the Galactic Empire after the defeat of the Separatists in the Clone Wars.

Figure 1: Prototype of the Death Star.

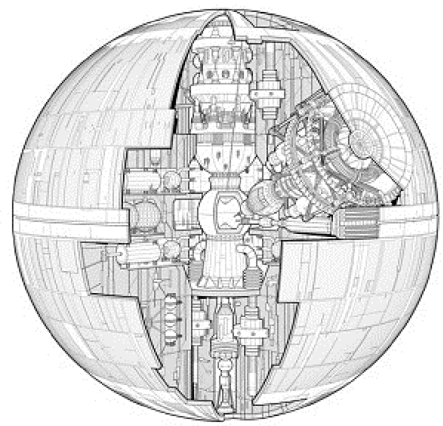

Figure 2: Design of the Ultimate Weapon.

The Death Star boasts a primary weapon (the Ultimate Weapon) with sufficient firepower to destroy an entire planet with a single shot. This weapon works with a nuclear reactor located at the center of the station that overheats the core to very high temperatures.

You have been contacted by Darth Sidious, the Emperor, to design the battle station, because it requires calculations using the Finite Element Method. His specifications are detailed in Section 1.

Follow Section 2 to analyze the station, and submit your results.

1 Geometry and material properties

The Death Star is considered as a perfect sphere of exterior radius $R_2 = 60$ km. Moreover, it contains a spheric core of radius $R_1 = 35$ km, where the thermal power of the Ultimate Weapon is generated. The Ultimate Weapon concentrates the energy in a spherical concave dish of radius $R_h = 17$ km on its northern hemisphere.

The thermal conductivity of the Death Star is $k_e = 100$ W/mK, and the heat source can be modelled, within the core, homogeneously with $Q = 0.85$ W/m^3.

As its main design problem, the Death Star is only able to dissipate heat by radiation towards the outer space. The emissivity of the outer surface of the station is $\varepsilon = 0.08$, and one can consider that the temperature of the outer space (consequence of the Big Bang explosion) is $T = 2.7$ K.

2 Analysis procedure

The following steps describe the analysis procedure of the Death Star.

Step 1. Generate the geometry

In order to start with your analysis of the Death Star, you should generate the geometry. According to Section 1, generate two concentric spheres for the core and exterior part of the station. It is convenient at this point to choose the center of these spheres as the origin.

Then, generate a third sphere (centered at $(-35, -35, 35)$ km) and subtract it from the former ones.

Step 2. Set the material properties and boundary conditions

Because the properties are provided, there is no need to go through the material library. Introduce the properties in the next section, paying attention to the equation governing the physics. Note that there is no need for density or heat capacity (can you guess why?).

Add the appropriate boundary condition. Note that this is a surface-to-ambient radiation condition. Also, add the heat source at this point.

Step 3. Generate the mesh

Once the geometry and properties have been defined, generate the mesh to analyze the station. Use a *physics-controlled mesh*, with element size *fine*.

Provide the number of tetrahedral elements of your mesh and a plot showing a general view of the mesh containing the concave dish.

Step 4. Compute the solution and analyze the results

Compute the solution and answer the following questions:

How many degrees of freedom does your model have? It is very important to note that this is the number of unknowns, i.e. the number of equations of the algebraic system that Comsol solves.

Note that this is a nonlinear problem, hence Comsol solves it iteratively (by using a variation of the Newton-Raphson method, which you have probably studied in other courses). *How many iterations does Comsol need? What is the tolerance used?*

Comsol provides some outputs by default. *Include the temperature distribution in slices of the Death Star as Comsol generates it automatically. What is the lowest temperature in Fahrenheit of the surface of the Death Star? What is the highest temperature in Fahrenheit of the core?*

It is important for the Emperor that the Ultimate Weapon works well. *Generate an arrow plot of the total heat flux. Provide a general view of the Death Star where the heat flux coming out of the core can be observed, and also a particular view of the concave dish heat flux concentrating towards its center*[1]. Also, *provide a line plot of the temperature of the Death Star from its center to the center of the concave dish.*

Finally, it is worth knowing how much energy of the reactor core is dissipated to the outer space (hence lost). *Integrate the radiative heat flux to know the dissipated energy and provide your result.*

[1] Note that these plots only have to include the arrows on the surfaces