Thermal Control

1 Emission

Some parts of the spacecraft can only operate in a certain temperature range. So **thermal control** is needed. Its goal is to keep the temperatures with the allowable ranges. It should achieve this by exchanging heat with space, and dividing the heat within the structure.

For internal heat exchange, conduction is an important mechanism. However, to exchange heat with space, radiation should be considered. The **radiation power** E that every square meter of a spacecraft emits can be found by

$$E_{emission} = \varepsilon \sigma T^4, \tag{1.1}$$

where ε is the **emissivity** and $\sigma = 5.67 \cdot 10^{-8} W/m^2K^4$ is the **Stephan Boltzmann's constant**.

2 Absorption

You of course don't only emit radiation. You also recieve it. Three things can happen with radiation. A part α (the **absorptivity** is being absorbed. Another part ρ (the **reflectivity**) is being reflected. The final part τ (the **transmissivity**) simply passes through the object. Naturally is must be true that

$$\alpha + \rho + \tau = 1. \tag{2.1}$$

The radiation power that is received from the sun, if you're near earth (1AU from the sun) is $\Phi = 1371 W/m^2$ (varying slightly). Radiation from other plants/stars is usually negligible, although sometimes the **albedo** (sunlight reflected by the earth) should be taken into account.

If we don't consider the albedo, then the radiation that every square meter of a spacecraft will absorb will be

$$E_{absorbtion} = \alpha \Phi. \tag{2.2}$$

Because of this radiation, the temperature in the spacecraft will change. It will finally come to a stable point when $E_{emission} = E_{absorption}$, or equivalently,

$$\alpha A_s \Phi = \varepsilon A_{ext} \sigma T^4, \tag{2.3}$$

where A_s is the radiated surface area of the spacecraft and A_{ext} is the external surface area. From this **heat balance equation** we can find the stable temperature of the spacecraft, at which **thermal equilibrium** occurs.

There is a relation between the emissivity and the absorptivity. For a particular wavelength λ the absorptivity and emissivity are equal, so $\alpha_\lambda = \epsilon_\lambda$. This then also holds for the entire spectrum, so $\alpha = \epsilon$. However, keep in mind that this is only true for the same spectrum. So for the infrared spectrum, we can indeed say that $\alpha_{ir} = \epsilon_{ir}$. However, the sun emits a totally different spectrum, with thus a different α_s.

3 Heat Exchange

What happens when we're having heat exchange between two objects? Suppose we have two opposite plates i and j. If we use radiation to exchange heat, then the **heat flow** is found using

$$Q_{ij} = R_{ij} \left(\sigma T_i^4 - T_j^4 \right) = \frac{\varepsilon}{2 - \varepsilon} A \left(\sigma T_i^4 - T_j^4 \right), \tag{3.1}$$

where R_{ij} is the **radiative coupling**. Here we have assumed that $\alpha = \varepsilon$.

We can do the same for conduction. However, now the heat flow is

$$Q_{ij} = C_{ij} \left(T_i - T_j \right), \tag{3.2}$$

where C_{ij} is the **conductive coupling**. For simple beams with length L, cross-sectional area A and conductivity k, the conductive coupling is $C_{ij} = \frac{kA}{L}$. However, for two parts with interfacing contact area a and **contact conductance** h_c, we find that $C_{ij} = h_c A$.

When multiple conductors are stacked in a series, than $1/C_{total} = 1/C_1 + 1/C_2 + \ldots$. However, when they are stacked in parallel, then $C_{total} = C_1 + C_2 + \ldots$.

If thermal equilibrium is present, than $Q_{out} = Q_{in}$. If not, then the change in temperature over time can be found, using

$$Q_{in} - Q_{out} = \Delta Q = m c_p \frac{dT}{dt}, \tag{3.3}$$

where c_p is the **specific heat capacity** of the material. If necessary, Q_{in} can be increased by bringing along heat sources on the spacecraft.

4 Thermal Control Systems

Thermal control systems can be divided into two categories. Some spacecraft have a **passive** thermal control system. It consumes no power, it's simple and usually low-weight. An **active** system, however, offers more flexibility and has greater capacities.

To keep heat inside the spacecraft, **insulation** is important. Often **multi-layer insulation** (MLI) is used. This is a package of radiating screens. Since the amount of radiation that every layer lets through is small, the amount of radiation eventually getting out the spacecraft is very small. If the layers are also highly reflective, than few heat will enter the spacecraft as well.

Sometimes a spacecraft, however, wants to get rid of its heat. For this, **radiators** can be used. These are parts that need to send out as much radiation as possible. So their emissivity should be high. They shouldn't absorb much radiation though, so in particular the coefficient ϵ/α should be as high as possible.