Cubesats: A passive thermal analysis approach

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Introduction

A brief reminder
Introduction

Cubesats launched since 2000
Introduction

Idea about what Cubesats look like...
Introduction

Cubesats weight
The purpose of satellite thermal control?

- Adapting exchanges with the environment to ensure a suitable average temperature
- Playing on internal exchanges to facilitate the evacuation of internally dissipated powers
There are two types of thermal control:

- Passive thermal control which attempts, by means of passive devices (paintings, multi-layer insulation, reflectors, etc.) to control heat transfers that are carried out by conduction and thermal radiation. It is a less expensive, lightweight, reliable solution with little impact on mass and power estimation.

- Active thermal control which is often justified by the uncertainties of the model, the variable environment and the aging of the microsatellite.
The temperature of a body in space depends heavily on the thermo-optical characteristics of its coatings: Solar Absorptivity $\alpha$ and IR emissivity $\varepsilon$.

If we consider the ratio $\alpha / \varepsilon$ as a criterion, these coatings can be classified into four categories:

- Cold coatings with low $\alpha / \varepsilon < 1$: White paint.
- Average coatings at $\alpha / \varepsilon \sim 1$: Black paint.
- Hot coatings at $\alpha / \varepsilon > 1$: Polished golden aluminum.
- Super hot coatings at $\alpha / \varepsilon > 4$: Black chrome.
Thermal analysis process

The main heat source when the Cubesat is in orbit is the Photosphere, the thermal transfer is governed by:

\[ \sigma A_{\text{Sat}} \epsilon T^4 = Q_i + \alpha J_s A_{\text{Sun}} + \alpha J_a A_{\text{albedo}} + \epsilon J_p A_{\text{Earth}} \]

- Internal flow
- Solar radiation
- Reflected Solar radiation
- Infrared Terrestrial radiation

Heat Transfer Formula:

- Average value of solar flux: 1371 ± 5 W/m²
- Solar Albedo: 30 ± 5% (S)
- Emission of radiation to space
- Infrared radiation: 337 ± 21 W/m²
- Low Earth Orbit Satellite
- Planet Earth
Assumptions and boundary conditions

The expression of the calculation of the temperature is:

\[ T^4 = \frac{A_{Earth} J_p}{A_{Sat} \sigma} + \frac{Q_i}{A_{Sat} \sigma \varepsilon} + \left[ \frac{A_{Sun} J_s}{A_{Sat} \sigma} + \frac{A_{albedo} J_{albedo}}{A_{Sat} \sigma} \right] \times \frac{\alpha}{\varepsilon} \]

With,

- Circular dawn-dusk Orbit is a near-polar orbit at low altitude, which does not suffer from eclipses.
- Js, Ja, Jp and Qi are constant.
- The sidereal temperature is 2.7K.
- The solar flux, the albedo and the infrared terrestrial flux reach the nanosatellite perpendicularly.
- The nanosatellite is considered to be a real body.

Orbit at 240Km
- Js = 1371 W/m²
- Ja = 67,8645 W/m²
- Jp = 220 W/m²
- Qi = 0 W/m²
Results

System validation

The results are:

$$\alpha/\varepsilon = 0.25$$

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Results

System validation

The results are:

![Diagram showing solar absorptance vs. emittance for various materials with temperature labeling]

- For Sphere:
  - Temperature: [Indicated values with units of Kelvin]
  - Data: [Date: 10/08/2020, Time: 20:34]
  - Values: 292.72 Max, 292.72 Min

- $\alpha/\varepsilon = 1$
System validation

The results are:

- At Sphere
  - Température
  - Type: Température
  - Unité: K
  - Temps: 1
  - 10/08/2020 20:32
- $\alpha/\varepsilon = 2$

- $\alpha/\varepsilon = 10$
- $\alpha/\varepsilon = 2$
- $\alpha/\varepsilon = 1.5$
- $\alpha/\varepsilon = 1$
- $\alpha/\varepsilon = 0.75$
- $\alpha/\varepsilon = 0.5$
- $\alpha/\varepsilon = 0.25$
- $\alpha/\varepsilon = 0$

- 500 K
- 337 K
- 314 K
- 284 K
- 264 K
- 238 K
- 200 K
Results

Cubesat analysis “Steady state”

- $\alpha/\varepsilon = 0.25$ ; $T = -69.483 \degree C \sim -70.001 \degree C$
Cubesat analysis “Steady state”

- $\alpha/\varepsilon = 1 ; T = -7.07^\circ \text{C} \sim -8.45^\circ \text{C}$
Results

Cubesat analysis “Steady state”

- \( \alpha/\varepsilon = 2 \); \( T = 37.41^\circ \text{C} \approx 34.63^\circ \text{C} \)
Cubesat analysis “Transient state”

- For transient analysis, some parameters should be defined:  
- Beta Angle is still positive while revolving (Counter clock revolution).
- $R_{\text{Earth}} = 6378$ Km
- $H = 240$ Km
- Orbit’s semi major axis $a = H + R_{\text{Earth}} = 6618$ Km
- Gravitational parameter $\mu = 3.986 \times 10^5$ Km$^3$/s$^2$
- Period revolution $P = 2\pi \times (a^3/\mu)^{0.5} = 5358$ s
- Number of periods per day $n = (3600 \times 24)/P = 16$ Rev/day
- Velocity $v = (\mu/a)^{0.5} = 7.76$ Km/s
Results

Cubesat analysis “Transient state”

- $\alpha/\varepsilon = 0.25$ ; $[T = -69.48^\circ \text{C} \sim -70.00^\circ \text{C}]$ Steady state Temperature
- $[T_{\text{moy}} = -69.74^\circ \text{C}]$ Initial Temperature injected in Transient analysis

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Results

Cubesat analysis “Transient state”

- $\alpha/\varepsilon = 1$ ; \[ T = -7.07^\circ \text{C} \sim -8.45^\circ \text{C} \] Steady state Temperature

\[ T_{\text{moy}} = -7.76^\circ \text{C} \] Initial Temperature injected in Transient analysis

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Results

Cubesat analysis “Transient state”

- $\alpha/\varepsilon = 2$ ; $[T = 37.46^\circ \text{C} \sim 34.68^\circ \text{C}]$ Steady state Temperature
- $[T_{\text{moy}} = 36.02^\circ \text{C}]$ Initial Temperature injected in Transient analysis

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CONCLUSION
Thanks for attending the presentation
Please feel free to ask questions

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