Intro to. Spacecraft Thermal Analysis

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AA420 Space Design

Outline

- Goals
  - Maintain temperature range within payload and system component qualification limits.
  - Minimize or manage temperature gradients
- Strategies
  - Employ passive (aka low cost) techniques to reach a target temperature.
  - Use heaters or radiators to heat or cool as required by spacecraft operations.
  - Selection of external α/ε ratio determines average spacecraft temperature.
  - Payload heat rejection is most often the largest internal heat source. Heaters are often needed when systems are shut down.
  - High ε surfaces to radiatively couple internal surfaces and conductance pathways are important parts of passive design

Spacecraft Thermal Control Hardware

Passive	Semi-Passive	Active
Thermal Coatings • Paints • Metallized Tapes • Anodize, Sputter or other coating technique	Heat Pipes	Heaters • Resistance • Isotope
MLI Blankets	Capillary Pumped Loops	Thermostats & Temp. Controllers
Radiating Surfaces	Louvered Radiators	Pumped Coolant Loops with Cold Plates and Radiators
Phase Change Devices	Evaporative Cryogenic Dewars	Cryocoolers

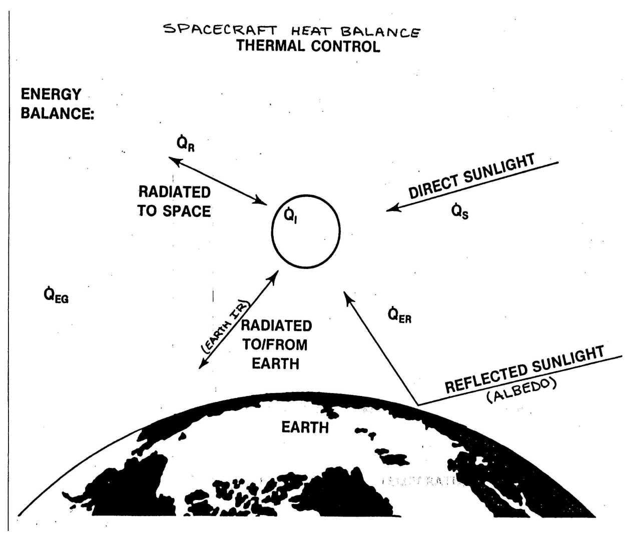
Thermal Analysis Flow Plan

1. Identify thermal environments and interfaces with other systems
2. Determine component/subsystem temperature requirements
3. Perform preliminary analysis
   – Simple finite difference models, hand calculations
   – Work with design and structural on key thermal interfaces
4. Component/subsystem development tests if needed
5. Perform detailed thermal modeling and analysis
6. Present design and analysis results to the customer
7. Perform qualification tests to demonstrate requirement compliance (and margin)
   – thermal-vacuum
   – thermal cycling
   – temperature withstand
8. Update detailed thermal model
9. Document analysis and test results

Spacecraft Thermal Analysis

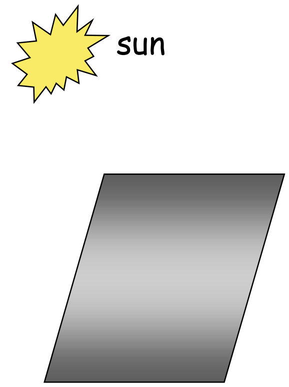
- Spacecraft Heat Balance
  - Heat Gains
    - Direct Solar, Earth IR, Earth Albedo, Internal Heat Dissipation
  - Heat Rejection
    - Radiation is the only heat transfer modality
    - Absence of convection greatly changes performance relative to our earthbound experience
- Orbital Environment has a large influence on results
  - Low orbit: Periodic boundary conditions, large earth effect
  - High orbit: Nearly constant boundary conditions smaller earth effect
  - Knowledge of β angle needed for full thermal analysis
- Spacecraft Operational Modes influence thermal performance
  - Payload heat loads continuous or duty-cycle dependent
  - "Sun-safe" and other ACS modes

Spacecraft Thermal Analysis



A Simple Example

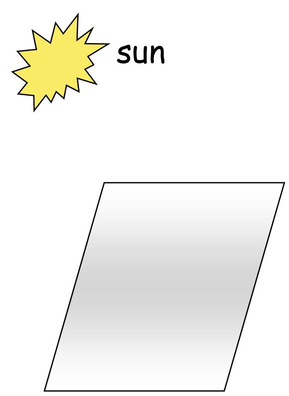
- An aluminum plate in free space perpendicular to a vector to the center of the sun, at 1 AU
- 10 cm x 10 cm, thin
- 3 K space in all other directions
- α = 0.379, ε = 0.0346
- Q_s = 1400 W/m^2
- Calculate T_{Al}



Now Paint it White

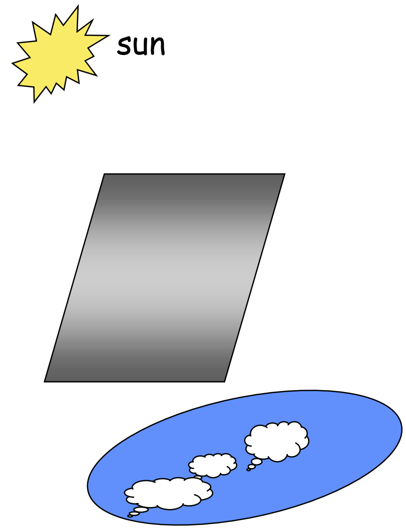
- A white painted aluminum plate in free space perpendicular to a vector to the center of the sun, at 1 AU
- 10 cm x 10 cm, thin
- 3 K space in all other directions
- α = 0.225, ε = 0.825
- Q_s = 1400 W/m^2
- Calculate T_{Al}

- Black: α = 0.95, ε = 0.90
- Gold: α = 0.299, ε = 0.023



Now Add the Earth

- An aluminum plate in space perpendicular to a vector to the center of the sun, at 1 AU. The other side is nadir pointing to a full visual field earth.
- 10 cm x 10 cm, thin
- 3 K space in the sun direction
- $\alpha = 0.379$, $\varepsilon = 0.0346$
- $Q_s = 1400\ W/m^2$
- $Q_e = 240\ W/m^2 + 420\ W/m^2$ solar reflection (albedo 0.3)
- $T_e = 300\ K$
- Calculate T_{Al}



Homework

- An thin aluminum plate is bonded to 1 cm thick Teflon and orbits the earth with the white side down. 10 cm x 10 cm,
- Teflon $\alpha = 0.100$, $\varepsilon = 0.60$, **k** = 0.2 W/m-K
- Calculate T_{Al}, T_{Tef} for:

1. Full sun case shown before
2. Eclipse case on opposite side of the Earth
3. Sun angle of 45º

extra credit: flip the plate over