ASEN 3113: Design Lab

ASEN 3113: Thermodynamics and Heat Transfer
University of Colorado at Boulder

Please refer to Canvas and the class schedule for lab groups, due dates, and supporting documents.

Objectives

- Understand spacecraft thermal control requirements
- Integrate heat knowledge transfer into practical design analysis
- Learn research skills using various mediums
- Further develop teamwork and presentation skills

Background and Introduction

GOES-16

The Geostationary Operational Environmental Satellite (GOES) constellation provides continuous monitoring of meteorological conditions in the western hemisphere. Operated by the National Oceanic and Atmospheric Administration (NOAA), the two active GOES spacecraft also monitor the space environment, receive and transmit search-and-rescue data, and relay ground-based environmental platform data.

A major upgrade to this system, known as GOES-16 (formerly known as GOES-R), was launched on November 19th, 2016. GOES-16 is a major step forward in the fields of weather, atmosphere, climate, solar observation, and ocean monitoring. Its launch marked the first technological advance in GOES instrumentation since 1994. The combined instrument downlink data rate increased by a factor of 60, and the number of environmental product types increased by a factor of four. The amount of environmental data being rebroadcast to users throughout the hemisphere increased by an order of magnitude. The GOES-16 satellite is currently active in the GOES-East position, while the GOES-17 satellite occupies the GOES-West position.

Fig. 1 GOES-16 Satellite

Monitoring the Solar EUV Irradiance from GOES-16

The sun's Extreme Ultraviolet (EUV) radiation consists of emissions from the solar chromosphere, transition region, and corona at wavelengths less than 127 nanometers ($\lambda < 127$ nm). EUV radiation accounts for <0.01% of the Total Solar Irradiance (TSI), from which >99% originates in the photosphere. The Sun's EUV spectra can have variations from a factor of 2 up to a factor of 100 (wavelength dependent), whereas TSI variations are typically only 0.1%. EUV is completely absorbed in Earth's atmosphere, and EUV photons are energetic enough to ionize the atmosphere (creating the ionosphere). The highly variable solar irradiance in the 0.1 nm to 200 nm range is absorbed in the Earth's mesosphere and thermosphere causing ionization, dissociation, and heating. These lead to photochemistry and dynamics. Variability in the solar irradiance leads to variability in the Earth's atmosphere, which impacts communications, satellite drag, navigation, etc. An EUV instrument has been designed to be on board GOES-16 to monitor the solar EUV variation.

Lab Assignment

Design Objective

The EUV instrument must maintain a high level of data accuracy over the 10 year mission lifetime (i.e. it must be able to measure the solar EUV at all times as along as the sun is within its field of view). As such, the stability of the instrument's optical bench is imperative to maintaining this accuracy. The optical bench is sensitive to thermal distortions, so strict operational temperature requirements must be met during science data acquisition. The instrument will be passively cooled using a radiator and actively heated using a heater to maintain the thermal requirements as the space environment varies.

As a group, your assignment is to perform a design analysis of an instrument radiator and heater. Specifically, you will be optimizing a spacecraft's mass and power budgets by minimizing the size of the radiator and by minimizing the heater power required, all while meeting the design requirements outlined below. You will also need to conduct research to find an improved radiator coating with flight heritage, with which you will evaluate performance improvements over the radiator's initial coating. You will then report your findings in a group presentation, upon which your group grade will be based. The following design requirements will serve as the basis of your design analysis.

Design Requirements

1. **Power:** You can assume that any needed power is available from the spacecraft.
   (a) *Operational:* The instrument is active and draws 20 W of power, all of which is dissipated as heat.
   (b) *Survival:* The instrument is powered off and does not draw any power.
2. **Orbit:** The spacecraft shall be located in a geostationary orbit. Due to the orbit altitude, Earth Infrared (IR) and albedo loading can be ignored.
3. **Orientation:** The spacecraft shall have one surface continually nadir pointing. The radiator shall be rigidly mounted on the trailing surface, opposite to the ram direction or velocity vector of the spacecraft.
4. **Thermal Requirements:** You can assume that the instrument sensor is connected to the radiator and is therefore in thermal equilibrium with the radiator.
   (a) *Operational:* The instrument shall be maintained at a temperature between 20 °C and 30 °C in order to acquire science data accurately (safety margin is already included here, no need to add any extra margin).
   (b) *Survival:* The instrument shall be maintained above −40 °C to prevent any damage from occurring (safety margin is already included here, no need to add any extra margin).
5. **Spacecraft IR Backload:** The IR heat load from the rest of spacecraft to the radiator, at its given location, shall vary with the orbital environment. Use the following IR backload values (during the equinoxes, the IR backload is just the average of the values at the winter and summer solstices, except during an eclipse):
   (a) *Winter Solstice:* 88 W/m^2
   (b) *Summer Solstice:* 63 W/m^2
   (c) *During Eclipse:* 11 W/m^2
6. **Radiator Coating:** The radiator shall be coated with a space-tested radiator paint. You can assume that the coating's emissivity and absorptivity properties are taken on by the radiator as well. You can also assume that the coating's IR absorptivity value is the same as its IR emissivity value.
   (a) *Initial Coating:* The initial coating of the radiator shall have a solar absorptivity $\alpha_{sol} = 0.2$ and an IR emissivity $\epsilon_{IR} = 0.85$.
   (b) *Improved Coating:* The improved coating of your choice shall have flight heritage and improve on the initial coating's thermal emissivity/absorptivity properties.

Lab Deliverables

Your group will prepare a **8- to 10-minute presentation** reporting the results of design investigation. This presentation must demonstrate how each requirement is met by your design in a **quantitative manner** supported by **analysis and research**. It must also provide some rationale for your choices. Every group member must speak to earn full credit. You will also lose points if your presentation duration is outside the above allotted range. The presentation result and content is worth **80 points**, while the presentation delivery and quality is worth **20 points**. You must upload both your **presentation video** and your **presentation slides** to Canvas by the assignment due date.

1. **Introduction:**
    (a) *Background:* Brief description of the design objectives, fundamental principles and governing equation(s).
    (b) *Requirements:* Brief recap of the design requirements for the instrument, spacecraft, radiator, and heater.
2. **Instrument Thermal Control Analysis:**
    (a) *Radiator Sizing:* The optimized radiator area achievable with the initial radiator coating and how this was determined.
    (b) *Total Solar Radiation Flux:* The total solar radiation flux absorbed by the radiator as a function of time for a one-day orbit at the (i) summer solstice, (ii) winter solstice, and (iii) equinox, for a total of **3 curves**.
    (c) *Unheated Temperature and Heater Power:* The unheated temperature of the instrument/radiator and heater power required for both modes (operational and survival) as a function of time for a one-day orbit at the (i) summer solstice, (ii) winter solstice, and (iii) equinox, for a total of **6 curves**.
3. **Improved Radiator Coating Research:**
    (a) *Research:* Description of the research conducted, including evidence of flight heritage, emissivity/absorptivity values, and sources.
    (b) *Total Solar Radiation Flux:* The total solar radiation flux absorbed by the radiator (with this new coating) throughout an entire day at the equinox.
    (c) *Performance Improvements:* Brief analysis on the improvements obtained from this new radiator coating for the optimizing factors (i.e. radiator size and heater power).
4. **Conclusion/Acknowledgements/References**

Suggested Activities

You are free to plan your schedule as you wish. However, we offer the following set of weekly objectives to help guide your development. Every group may adapt their own variation of these suggestions. you are expected to attend each laboratory session. Your group will be expected to present briefings (status updates) to Prof. Chu or the lead LA on the weeks of 4/4, 4/11, and 4/18.

- **Week 1:** Organize your groups. Brainstorm ideas. Draw pictures of the problem to make sure you understand the geometric configuration and the parameters of the assignment. Try to distill the problem into a few equations, particularly the energy balance equation.
- **Week 2:** Research needed information while others write the code and develop the mathematical models. At first, you can use assumed values for the parameters that you need to research. Then, as your research progresses, insert those values into your code. The final values for some parameters will be given near the end. Compute and plot the heater power (needed) and the radiator temperature as a function of time during a one-day orbit for different seasons (solstices and equinox).
- **Week 3:** Begin to draft your presentation. Identify missing pieces that require further work.
- **Week 4:** Finish your presentations. Revise and revise; practice and practice; upload your presentation slides (and then presentation videos)!

Acronyms

EUV Extreme Ultraviolet.

GOES Geostationary Operational Environmental Satellite.

IR Infrared.

NOAA National Oceanic and Atmospheric Administration.

TSI Total Solar Irradiance.