Cornell University

Spacecraft Thermal Management
MAE 4950/6950
Spring 2022

Instructor: Sadaf Sobhani
Office location: Upson 371
E-mail: sobhani@cornell.edu

Office hours: Tues 11am-noon
Credits: Letter grade
Undergraduate fluid mechanics and heat transfer recommended

Course Description: Thermal management in spacecraft refers to the strategies and technologies implemented to control and protect against extreme heating or cooling. This course will overview the physical principles governing existing spacecraft thermal management technologies, including conductive and radiative heat transfer, passive and active fluid transport, and ablation. In the first part of the class, we will focus on thermal protection, which consists of materials and systems designed to protect spacecraft from extreme high temperatures and heating, particularly during atmospheric entry. Next, we will shift our focus to thermal control systems, which maintain all vehicle surfaces and components within an appropriate temperature range throughout the many mission phases despite changing heat loads and thermal environments. Students will apply these principles, along with software that will be introduced in the class, to numerically estimate thermal transport and predict heat shielding performance. Integral to the class is the reading and discussion of scientific research articles on the topics of spacecraft thermal control and protection. Please note that this class was developed in close collaboration with NASA Goddard and Ames research centers and will include several guest lectures from NASA scientists working in spacecraft thermal management.

Student Learning Outcomes: As a result of participating in this course, you will be able to:

- identify flight paths and operating conditions most suitable for insulative versus ablative heat shields in thermal protection systems
- calculate numerically (using NASA software PuMA) porous material properties
- calculate numerically (using NASA software PATO) the ablation process of porous materials used as heat shields in spacecraft

- identify the thermofluidic mechanisms (e.g., radiation, capillary forces, etc.) governing existing thermal control technologies
- compare and apply different models for predicting conductive and radiative heat transport
- calculate heat dissipation rates in solar arrays and thermal control loops
- distinguish passive versus active thermal control technologies and the ideal conditions for their respective application
- scientific writing in LaTeX
- reading and discussing scientific research articles

Academic integrity: Each student in this course is expected to abide by the Cornell University Code of Academic Integrity.

Collaboration policy: Exclusively for the homework, discussion of the concepts related to the problems with your classmates is encouraged but submitted solutions should represent your own individual efforts. No collaboration is permitted for quizzes and exams.

Life happens policy: In case of a legitimate situation or emergency that arises during the semester that is going to hinder your ability to complete work on time, consult with me as soon as possible and we will work out a solution.

Students with Disabilities: Your access in this course is important to me. Please request your accommodation letter early in the semester, or as soon as you become registered with SDS. If you are approved for exam accommodations, please consult with me at least two weeks before the scheduled exam date to confirm the testing arrangements. If you experience any access barriers in this course or any communication barriers; reach out to me and your SDS counselor right away. sds_cu@cornell.edu, 607-254-4545, sds.cornell.edu.

Assessment

Readings and Discussion (35%): We will read and discuss 1–2 papers each week. Typically, these are formative works in an area of spacecraft thermal management. Students should come prepared to actively discuss assigned papers and to make substantive intellectual contributions. This means that you need to thoroughly read each paper ahead of time. Before each section, students will submit a short summary and reaction for each paper, as well as a proposal of one discussion question for class. Students should **submit the reading assignments through Gradescope the day before class**. Grading will be based 25% on these written responses and 10% on in-class participation. Do not underestimate the amount of time required to properly read and process a research paper. Expect to spend several hours preparing for each section.

Topic presentation (15%): While reading a few formative papers helps demonstrate how a subfield started, it oftentimes leaves us wondering how the area has evolved. To fill this gap, each student will read 3-

4 more recent papers and provide a 10-minute presentation about the current state of a research area at the start of one class. Sign up here.

Problem sets (15%): We will have 3 problem sets this semester, each aimed at helping you develop skills that can benefit your final project and overall technical understanding of the material.

Final project (35%): For the final project, you will work in groups to design, model and analyze a heat shield. Groups will present their work during the last two classes as well as submit a 6–10 page report, similar to the papers we read in the course, to be submitted in this format.

Projects have four graded components:

- **Project Proposal (5%).** Project groups will meet with Prof. Sobhani to discuss their project during the sixth week of class and submit a one-page project proposal. Written proposals are due on 03/08.

- **Progress Report (5%).** Submit a short (1–2 pages) progress report part way through the semester. The report should indicate what has been accomplished, what work is remaining, obstacles the team has encountered, and any preliminary data or insights. Due 03/31.

- **Class Presentation (10%).** Each group will give a class presentation during the last two sessions of the class.

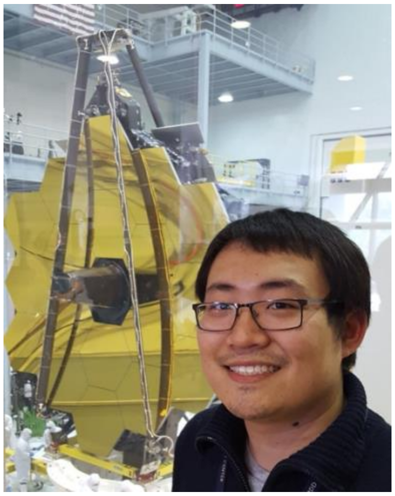
- **Final Paper (15%).** Groups will submit a final project report like the papers we read in the course. Papers should be 6–10 pages and use this format. Due 05/13.

Guest Lecturers:

Joseph Ferguson is a NASA Fellow and PhD candidate at Stanford University. Since 2013, he has worked in the Entry Systems Modeling project at the NASA Ames Research Center. His research focuses on microscale modeling of thermal protection materials. He is the creator and lead developer of the Porous Microstructure Analysis (PuMA) software, an open-source NASA software for material response modeling.

Jeremie Meurisse studied electromechanics at the Louvain Polytechnic School and aerospace at the National Higher French Institute of Aeronautics and Space. He is a research scientist with Analytical Mechanics Associates Inc., an on-site contractor at NASA Ames Research Center working in the Entry Systems & Technology Division. He works on material response modeling and high-enthalpy arc heater simulations. His research focuses on the simulations of the atmospheric entry of the Mars Science Laboratory and Mars 2020 heatshields.

Veronica Otero is Branch Head for the Thermal Engineering Branch at Goddard Space Flight Center since October 2021. She is also supporting as Thermal Systems Lead for the upcoming Mars Sample Return (MSR) / CCRS Mission until a replacement is selected. Ms. Otero completed a bachelor's in mechanical engineering and a master's in aerospace engineering from the University of Maryland. She has over eighteen years of experience supporting lead roles in the thermal engineering discipline, supporting programs such as NASA's Shuttle Small Payloads Project Office, Space Environment Testbeds (SET) program, Geostationary Operational Environmental Satellites (GOES-R) program, ICESat-2 program, and Landsat program. Her experience ranges from early development and design of instrument payloads, integration, and testing of space hardware, and launch and early mission operations support. Ms. Veronica Otero was also an Associate Branch Head for the Goddard Space Flight Center Thermal Engineering Branch for nearly eight years prior to accepting a position as Branch Head.



Kan Yang is a Technical Manager at NASA's Goddard Space Flight Center. He received a BSE in Aerospace Engineering from the University of Michigan in 2008 and an MS in Aerospace Engineering from the University of Maryland in 2010. Since joining NASA Goddard in 2010, he has held many different roles including Thermal Systems Lead for the Large Ultraviolet/Infrared/Optical Surveyor (LUVOIR) mission concept and Lead Thermal Analyst for the James Webb Space Telescope OTIS Cryo-Vacuum Test, for which he won a NASA Exceptional Achievement Medal. Kan is currently the Acting Team Lead for the Instrument Design Laboratory, part of Goddard's Integrated Design Center.

Wes Ousley has worked as a thermal engineer at NASA's Goddard Space Flight Center for 45 years, including 9 years as Head of the Thermal Engineering Branch. He led thermal systems efforts on 10 free flying satellites including the JWST Spacecraft element, Lunar Reconnaissance Observatory, and Gamma Ray Observatory. He was also lead thermal engineer on the JWST Cryogenic Optical Test program and Hubble Space Telescope Servicing Missions.