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CHALLENGES OF DESIGNING A PASSIVE THERMAL CONTROL SYSTEM FOR THE ASTROBOTIC PEREGRINE LUNAR LANDER

Stephanie Mauro
NASA, MSFC, ES22

ABSTRACT

The Astrobotic Peregrine is a lunar lander currently undergoing design by Astrobotic Technology with help from NASA through the Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) program. This paper will discuss the challenges of designing a passive thermal control system for the lander, and how the design has evolved from the initial passive concept. These challenges include drastically varying worst hot and worst cold case thermal environments, narrow temperature limits of critical components, limited available locations for spacecraft component mounting, and unexpected changes causing significant thermal impacts. The initial thermal control strategy was to cold bias the spacecraft by thermally coupling all spacecraft components to one mounting deck, which also doubled as a radiator, and using heaters ű ƨ Ɣ ǀ ǎ ƴ ű ǀ ǎ ƴ Ŝ ǀ Ŏ Ƙ Ŏ ƨ ƔLJƨ ƴ Ŝ ƴ ű Ω ă ű Ŝ ƔLJŜ temperature limit when in the cold environments. As the design evolved, this strategy alone became inadequate. As heat dissipations increased and became more varying with the addition of components, the thermal design was changed and additional thermal control technologies added. Thermal control strategies incorporated into the design include dictating the lander orientation in demanding environments, defining locations for critical spacecraft components, limiting component operation when possible, and using technology to create variable thermal contacts. Additional design changes will occur as the design continues to evolve to optimize the most effective thermal control system. The thermal design of Peregrine is still in progress, with Critical Design Review (CDR) scheduled for December 2019.

NOMENCLATURE

h	Solar Absorptivity
ACT	Advanced Cooling Technologies
C	Celsius
CATALYST	Cargo Transportation and Landing by Soft Touchdown
CDR	Critical Design Review
CLPS	Commercial Lunar Payload Services
ʁ	Infrared Emissivity
IAU	Integrated Avionics Unit
IR	Infrared
JPL	Jet Propulsion Laboratory
LIDAR	Light Detection and Ranging

m	Meters
M1	Mission 1
MLI	Multilayer Insulation
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
RF	Radio Frequency
SAA	Space Act Agreement
TD	Thermal Desktop
VCHP	Variable Conductance Heat Pipe
W	Watts

BACKGROUND

Astrobotic

Astrobotic Technology, Inc. is a space robotics company founded in 2008 that began working with NASA in 2014 as part of the Lunar CATALYST project. Through the Lunar CATALYST initiative, NASA competitively selected three partners to galvanize commercial cargo transportation means to the surface of the Moon. Each of the companies has a no-funds-exchanged Space Act Agreement (SAA) partnership through which NASA works with the company to help develop their lunar lander capabilities with the goal of developing robotic lunar landers for integration with the United States commercial launch capabilities to deliver payloads to the lunar surface.[1] As part of the CATALYST project, engineers at NASA Marshall Space Flight Center conduct the majority of the thermal engineering work for Astrobotic Peregrine. The end of CATALYST is September 30, 2019.

In May 2019, NASA selected Astrobotic as one of the first three commercial Moon landing service providers that will deliver science and technology payloads under Commercial Lunar Payload Services (CLPS) as part of the Artemis program. Through CLPS, NASA awarded Astrobotic with $79.5 million to fly as many as 14 CLPS payloads to the Moon.[2]

Peregrine

Peregrine is the lunar lander being developed by Astrobotic throughout Lunar CATALYST, and the same lander that will deliver CLPS payloads to the moon. Mission 1 (M1) will launch in late June 2021, and land on the lunar surface by July 17, 2021. The lander is relatively small at about 1.9m high, 2.5m wide. Error! Reference source not found. shows the Thermal Desktop (TD) representation of Peregrine. The landing location is Lacus Mortis, at 43.9142°N, 25.1479°E, between 55 and 110 hours after lunar sunrise. The surface operation goal is to operate for 192 hours total (eight earth days), throughout the lunar day. The lander is not attempting to survive the lunar night for M1.

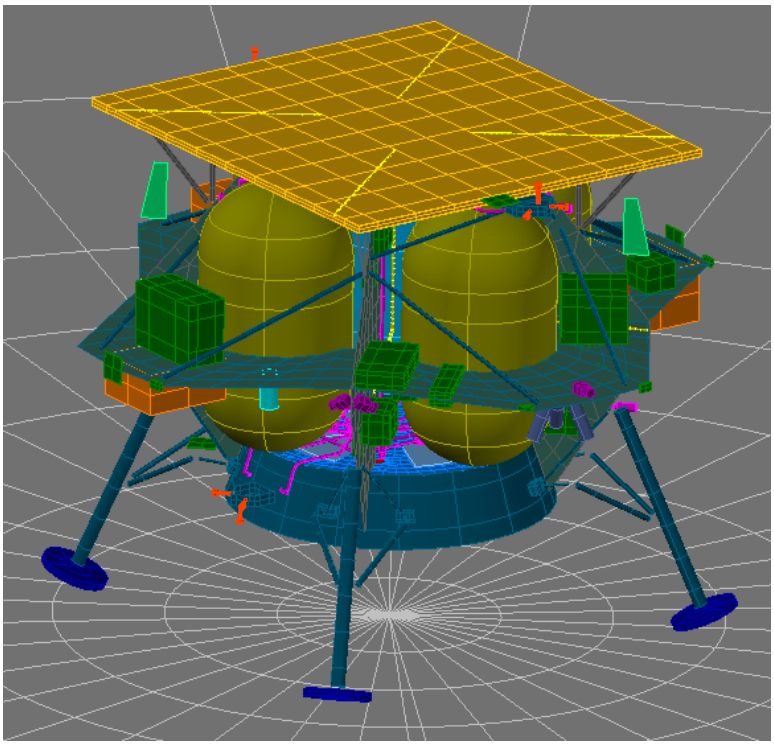

Figure 1: Peregrine Lunar Lander TD Model

THERMAL CHALLENGES

The thermal design and analysis of a lunar lander presents many interesting challenges and Peregrine is no exception. Some of the most apparent thermal challenges include drastically varying worst hot and worst cold case thermal environments, narrow temperature limits of critical components, limited available locations for spacecraft component mounting due to payload accommodations, and unexpected changes to lander subsystem designs.

Extreme Worst Hot and Worst Cold Case Environments

After landing on the moon, Peregrine will need to survive operation through eight earth days during the lunar day environment. The lander will touch down on the lunar surface between 55 and 110 hours after lunar sunrise, which means that the lander will experience the hottest part of the lunar day. The lunar day and lunar night thermal environments are dramatically different due to the negligible thermal conductivity of the regolith and the inability of the lunar surface to conduct or radiate sufficient heat to remain thermally stable throughout the lunar day. The moon also has very little atmosphere, which does not protect the surface from solar flux during the day or retain heat during the night. At roughly 45° latitude, the lunar day can be as hot as 76°C and the lunar night as cold as -190°C.[3] Even shadows on the moon have a large temperature drop from the adjacent area in the sunlight. Peregrine M1 is not planned to survive the lunar night because it is not designed to generate enough power to maintain minimum temperature limits of components through 14 earth days of a -190°C environment.

[illegible] environment is during the transit from earth to the moon, during which the solar panels maintain a solar inertial pointing, and so the bottom of the lander will always be facing away from the sun.

Narrow Temperature Limits of Critical Components

Narrow temperature limits of critical components are another thermal design challenge. One component in particular is the battery, which has allowable flight temperatures of 10°C to 35°C. Its high allowable cold temperature could mean that constant heaters are required, but its low allowable hot temperature could mean that it would need extra radiator surface area, depending on its heat dissipation. An added challenge with the battery is that it has a varying heat dissipation, depending on whether it is charging or discharging, and how much power it is supplying. As the design of the lander matures, the power needs mature, and the heat dissipation of the battery is constantly updating.

Limited Available Locations for Spacecraft Component Placement

Additionally, there is limited space on the lander to mount spacecraft critical components. One reason for this is simply because you cannot fly an unlimited amount of mass to the moon, but another reason is that [illegible] unknown [illegible] payloads. As a commercial company, Astrobotic generates revenue from selling rides to payloads, but many of the payload details were unknown during the design of the lander. This resulted in developing the thermal design while making assumptions about payloads, then providing thermal environment ranges and heat flow to the lander restrictions to the payloads. With the CLPS award, additional NASA payloads will take up space on the lander. This is not only a concern from a volume perspective, but also because placing many hot components next to each other could cause overheating.

Unexpected Changes

Unexpected changes always serve as an additional challenge on engineering projects. A few unexpected changes that have required updates to the thermal design include upgrading to a transponder that dissipates more than four times the heat of the previous transponder, and uncertain propellant temperature limits, as the engines are still in development.

INITIAL THERMAL CONTROL STRATEGY

The early thermal control design of Peregrine started as a simple passive design. The basic idea was to cold bias the spacecraft by thermally coupling all spacecraft components to one mounting deck, [illegible] which also doubles as a radiator. The deck has Silver Teflon Tape on the top ([illegible] 0.81 [illegible] =0.08) to facilitate dissipation of heat away from the lander, and multilayer insulation (MLI) on the bottom, to protect from reflected heat from the lunar surface during lunar surface operation. There is the option to add radiator surfaces if more heat needs

technology to create variable thermal contacts. As the lander design continues to evolve, the thermal control system design will likely continue to change, as well.

ACKNOWLEDGEMENTS

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[illegible] modeling greatly contributed to the Peregrine thermal design and analysis efforts. To learn more about his work, you can read his paper: TFAWS-19-PT-[illegible]

CONTACT

Stephanie Mauro works as a thermal engineer at NASA Marshall Space Flight Center in the [illegible] ES22). She received her undergraduate degree in mechanical engineering from Rochester Institute of Technology in 2013 and her masters in engineering focusing in thermal systems from The University of Arkansas in 2018. For inquiries, her email and telephone number are stephanie.l.mauro@nasa.gov and 256-544-3662.

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