Challenges of Designing a Passive Thermal Control System for the Astrobotic Peregrine Lunar Lander

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Outline

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  - Narrow temperature limits of critical components
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- Thermal Control Solutions to Challenges
  - Dictating lander orientation
  - Defining component locations
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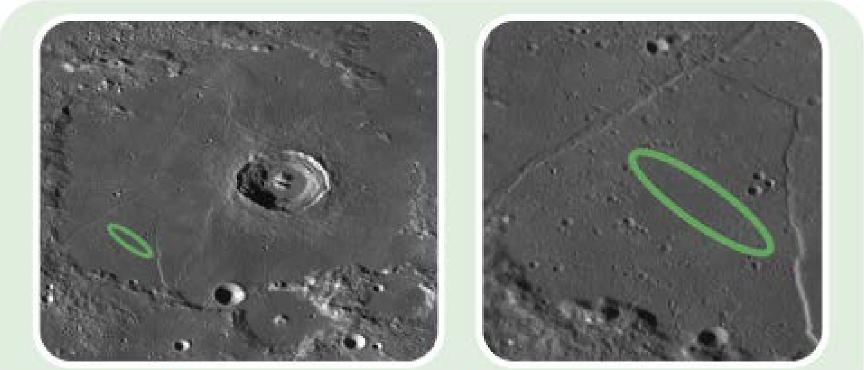
What is Astrobotic & Peregrine?

"Astrobotic Technology, Inc. is a space robotics company that seeks to make space accessible to the world. The company's lunar lander, Peregrine, delivers payloads to the Moon for companies, governments, universities, non-profits, and individuals."
(www.astrobotic.com)

- Peregrine Lander
  - Launch date: June 2021 (will land on lunar surface by July, 17th 2021)
  - Size:
    - Lander height ~1.9m (6'2.8''), width ~2.5m (8'2.4'')
    - Lander wet mass ~1283kg, including propellant and payloads
  - Payload capacity: 36 (currently 28)
  - Mission 1 Location: Lacus Mortis (43.914°N, 25.148°E)
  - Surface operation duration: at least 192 hours (8 earth days), all during the lunar day.



Graphical representation of landing ellipse for reference only.

How is NASA Involved?

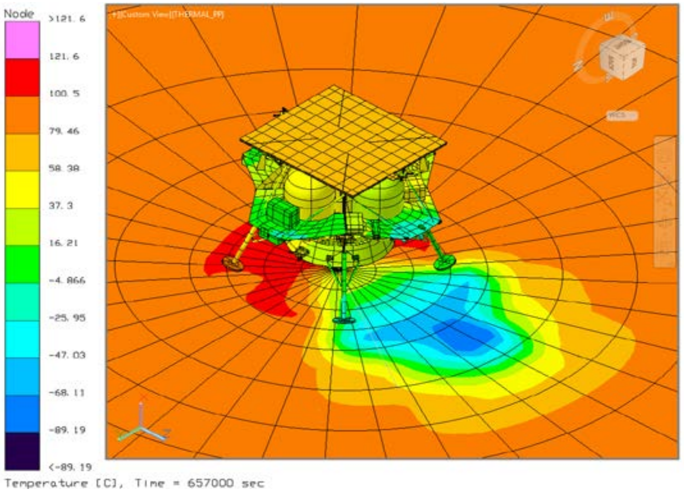
- Lunar CATALYST: Lunar Cargo Transportation and Landing by Soft Touchdown (2014-2019)
  - Astrobotic has a no-funds-exchanged Space Act Agreement (SAA) partnership with NASA.
  - NASA helps the company to develop lunar lander capabilities.
  - The majority of the thermal design and analysis of Peregrine has been done at Marshall Space Flight Center.
  - Additional companies part of Lunar CATALYST:
    - Moon Express
    - Masten Space Systems

- CLPS: Commercial Lunar Payload Services (2018-ongoing)
  - CLPS is part of the Artemis program.
  - Commercial companies will provide end-to-end transportation services to send NASA payloads to the moon.
  - Additional companies selected by CLPS:
    - ~~Orbit Beyond, Inc.~~
    - Intuitive Machines

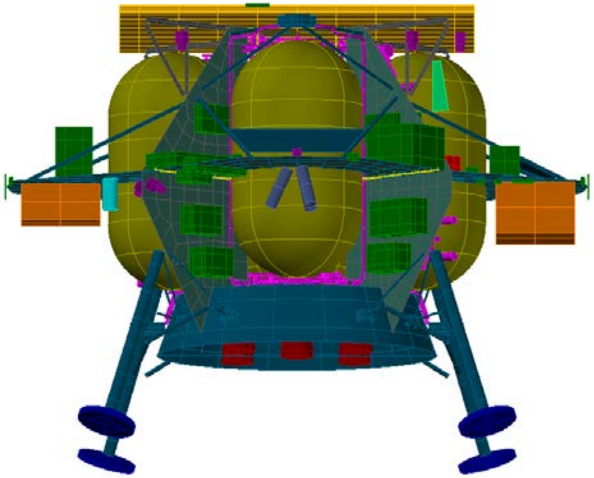
ASTROBOTIC AWARDED $79.5 MILLION NASA CONTRACT TO DELIVER PAYLOADS TO THE MOON

Thermal Challenges

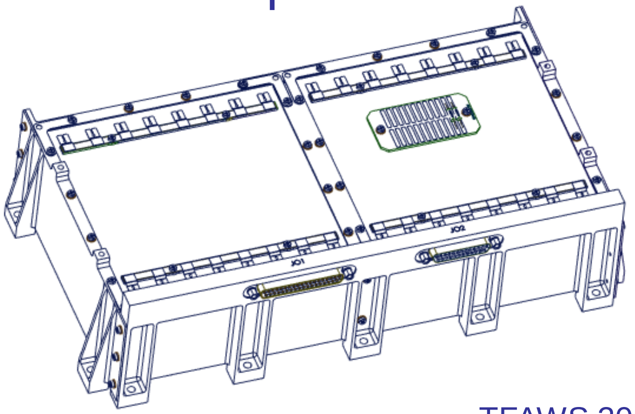
Extreme worst hot and worst cold case environments



Limited available locations for spacecraft component placement



Narrow temperature limits of critical components



Unexpected changes

Extreme Environments

- Worst case hot environment: lunar surface
  - – 129 hours (8 earth days) of operation
    - Different parts of the lander receive more sunlight at different times
    - Shadows create large temperature differences
  - – Must survive through hottest part of lunar day (noon)

Peregrine and Lunar Surface Temperature Predictions

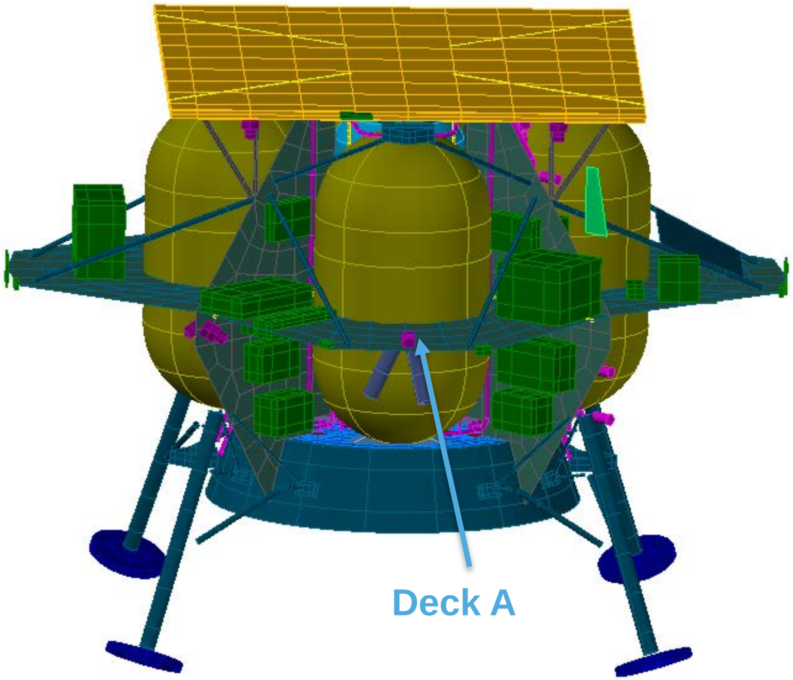
- Worst case cold environments: transit and eclipses
  - – Transit:
    - Solar panel is facing the sun
    - Bottom side is facing deep space
  - – Lunar eclipse:
    - Solar panel is facing cold lunar surface
    - Bottom side is facing deep space

Narrow Temperature Limits

- Battery
  - Allowable flight temps: 10 to 35°C (50 to 95°F)
  - Heat dissipation: ~ 0 to 40W
- Lidar
  - Allowable flight temps of electronics: 10 to 30°C (50 to 86°F)
  - Heat dissipation of electronics: ~0 to 100W
  - Allowable flight temps of optics: 10 to 30°C (50 to 86°F)
- Transponder
  - Allowable flight temps: -20 to 55°C (-4 to 131°F)
  - Heat dissipation: ~7 to 110W

Limited Available Locations

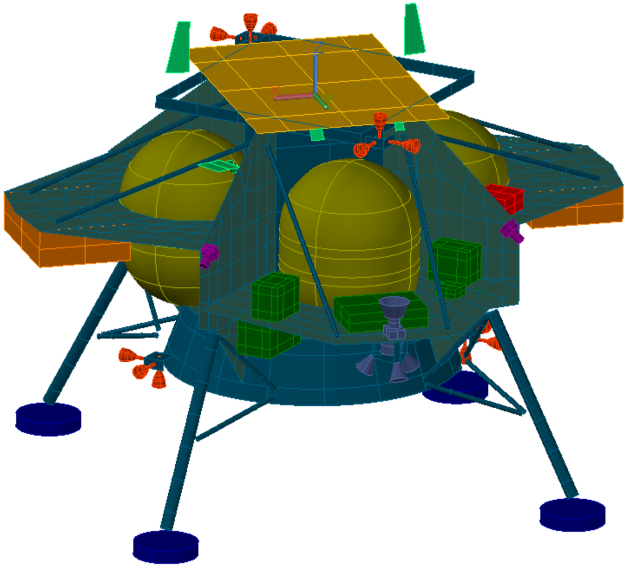
- Dedicated avionics deck
  - Almost all lander critical components (not payloads) are mounted on Deck A (shown in image to right).
  - Some components have had to move to alternate decks due to overheating concerns.
- Other decks are dedicated payload space
  - Specific payloads and locations have been unknown for most of the design process
- Vertical shear panels
  - Have low view factor to space on the lunar surface and so are no good locations for potentially hot components



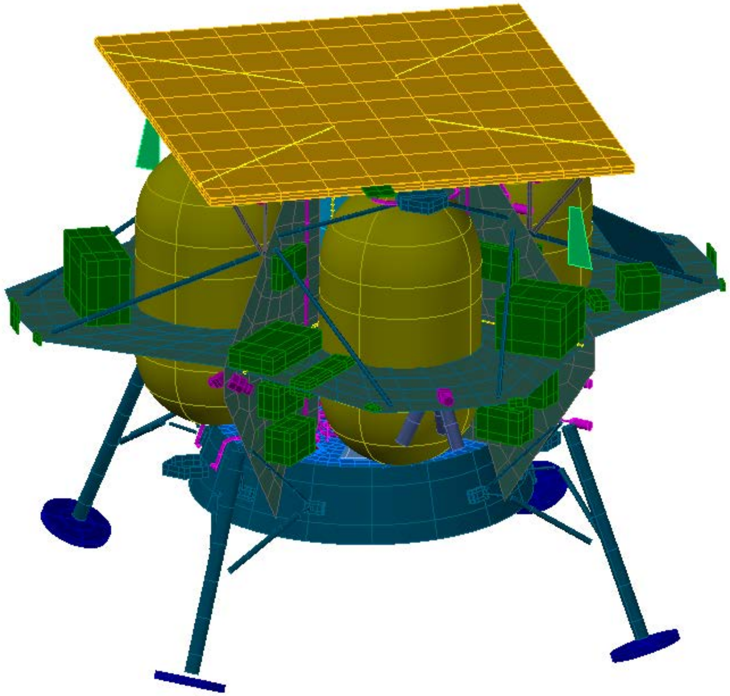
Thermal Model without Payloads

Unexpected Changes

- Always a challenge with engineering projects
- Examples of changes/updates with thermal impacts
  - Engines are currently in development and have had fluctuating design parameters and temperature limits
  - Change in transponder
  - Addition of CLPS payloads



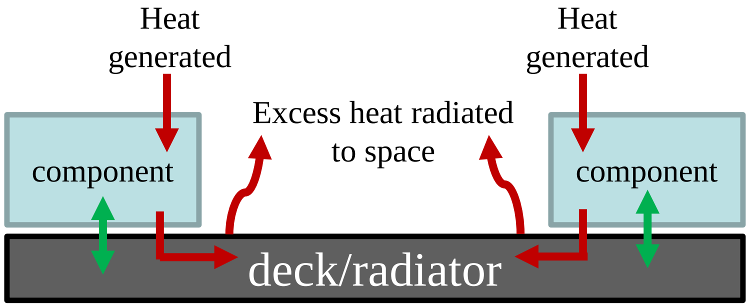
Thermal Model 2016



Thermal Model 2019

Initial Thermal Control Strategy

- Simple passive design: cold-bias the lander
  - Thermally couple all lander critical components to one mounting deck (deck A = the avionics deck)
    - Deck surface also doubles as a radiator
      - Top: Silver Teflon tape (ε=0.81, α=0.08)
      - Bottom: MLI to protect from reflected heat from lunar surface after landing
  - More radiator surfaces would be added as needed
    - Radiator would be sized based on worst-case-hot heat dissipations and environment to maintain temps below the high allowable flight temps.
  - Heaters would make up for heat lost through radiator surfaces
    - Heaters would be sized for worst-case-cold heat dissipations and environment to maintain temps above the low allowable flight temps.



Heat generated

Heat generated

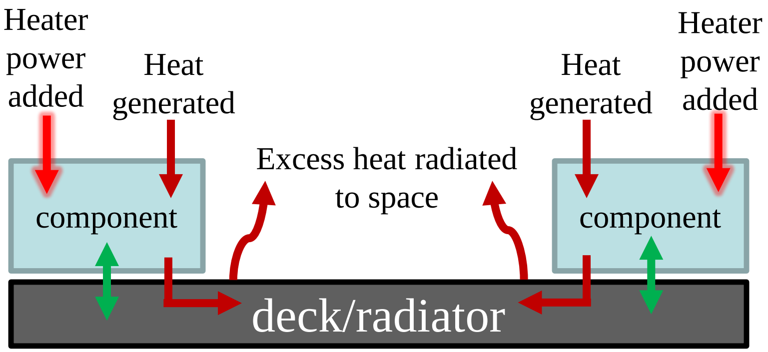
Excess heat radiated to space

component

component

deck/radiator

Worst-Case-Hot Environment



Heater power added

Heat generated

Excess heat radiated to space

Heat generated

Heater power added

component

component

deck/radiator

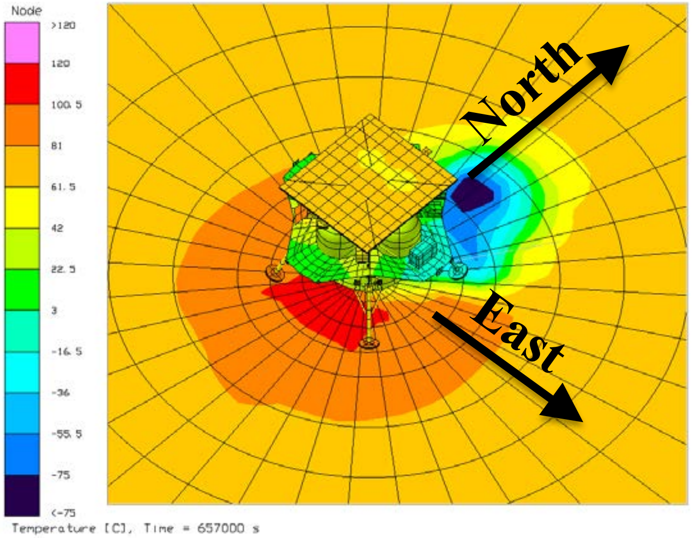
Worst-Case-Cold Environment

Why This Didn't Work

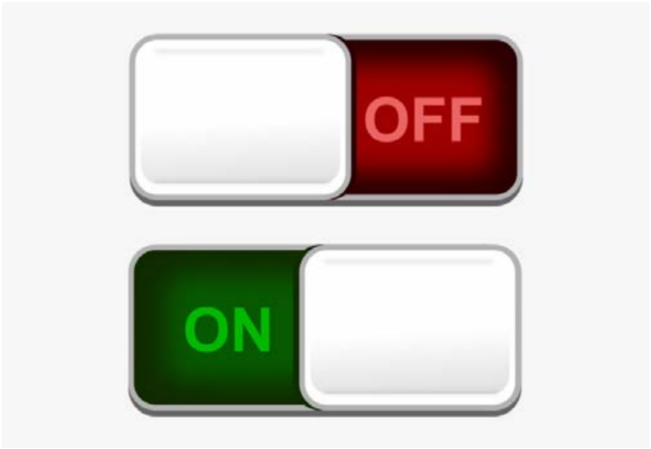
- Increase in components and heat dissipated on avionics deck
  - Requires more radiator surface than just the deck surface (mass increase).
  - Because all of the components are attached to the same deck, components with wider temp limits need to be controlled to a narrower range so as not to negatively effect components with narrower temp limits (inefficient).
  - Additional heater power is required to compensate for heat loss through radiator in worst-case-cold conditions (power increase).
- Bottom line: Too much power and mass would be required. More efficient (yet more complex) designs are possible

Thermal Control Solutions to Challenges

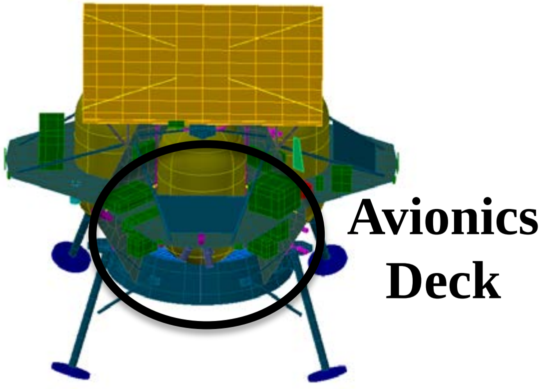
Dictate Lander Orientation



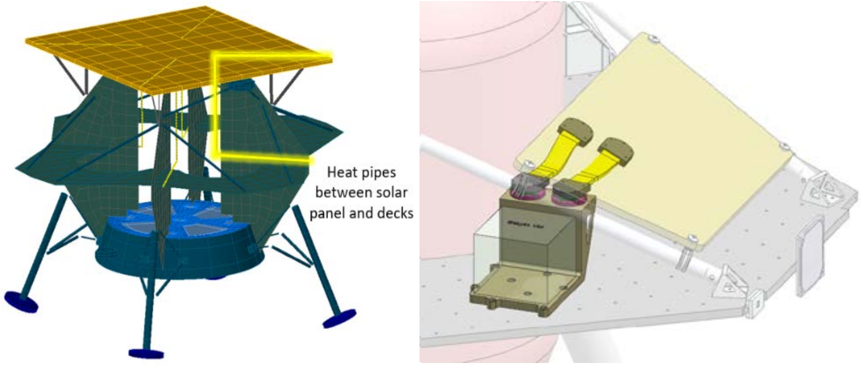
Limit Component Operation



Define Component Location

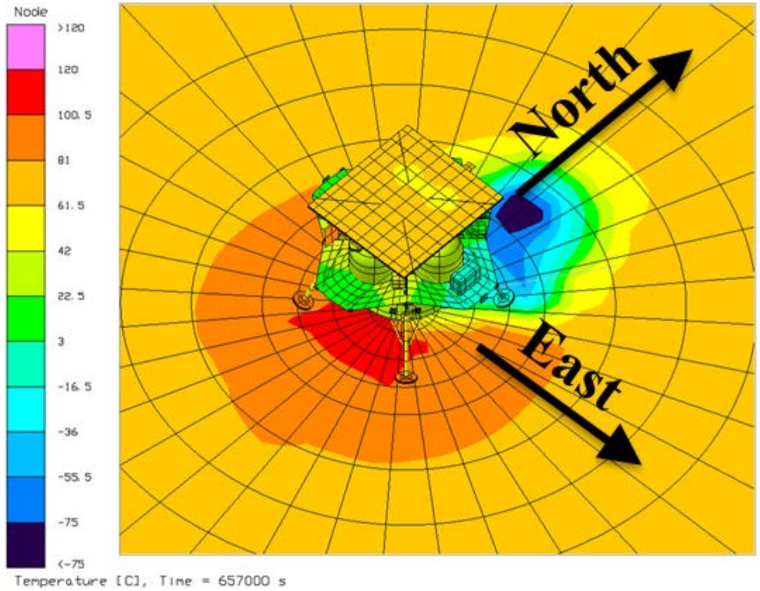


Thermal Control Technology with Variable Thermal Contact



Dictate Lander Orientation

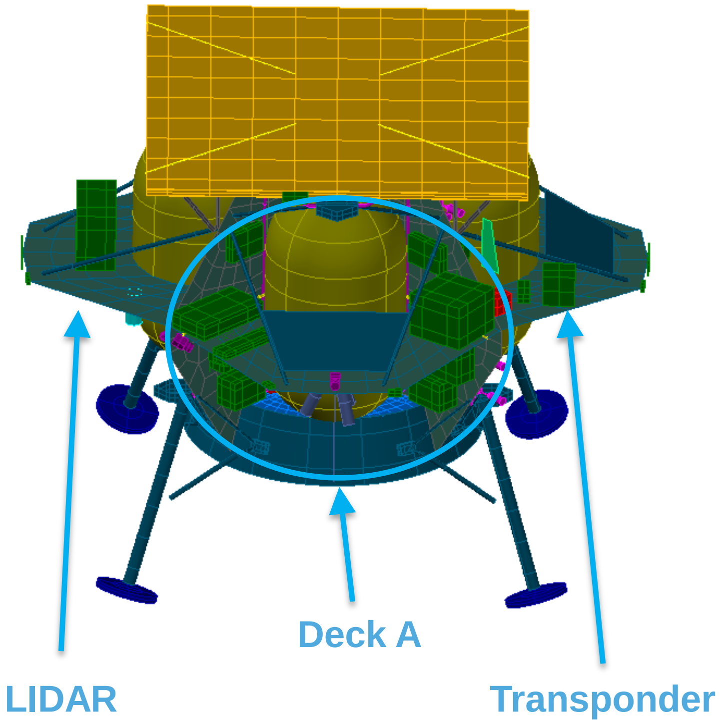
- Transit and Lunar Orbit:
  - Solar inertial: solar panel always facing towards the sun
- Lunar Surface Operations:
  - Nominal landing orientation: avionics deck facing north
  - Lander will survive +/- 45° rotation off nominal orientation
  - Each lander deck experiences a different thermal environment at different times on the Lunar Surface



Temperature Contour Plot during Lunar Noon Environment

Define Component Locations

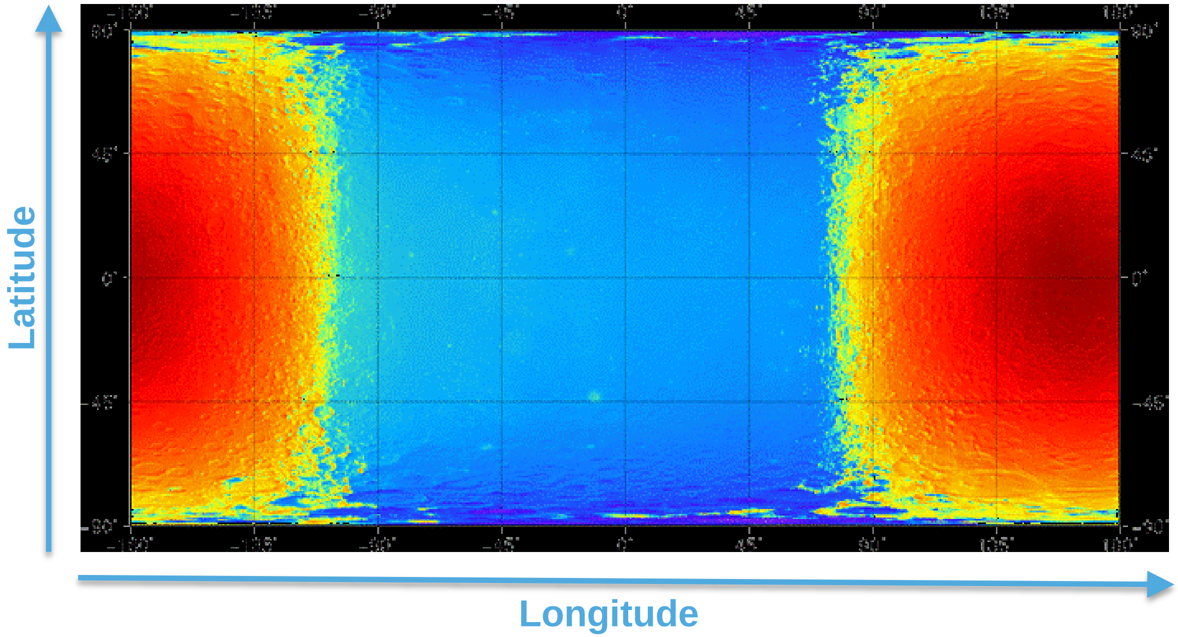
- Most lander critical avionics components are mounted to the avionics deck
  - Puts these components in the coolest thermal environment during lunar surface operations
  - Components with narrower temperature limits are on top of deck, instead of on the bottom
- Lander critical components excepted from the avionics deck
  - Some lander critical components could not be mounted to the avionics deck because they negatively impacted the other components
    - Transponder: dissipates high amount of heat during lunar descent and lunar surface operation
    - Doppler LIDAR: dissipates high amount of heat during lunar descent and is not required after short period on lunar surface



Placement of Avionics

Limit Component Operation

- Reduce capability of components to reduce heat generation
  - The transponder can operate at different levels of RF output, which dissipate different amounts of heat
- Turn off or put components into ‘stand-by’ for a short period of time.
  - Putting components into ‘stand-by’ mode protects components from overheating during the hottest environments, like during lunar noon.

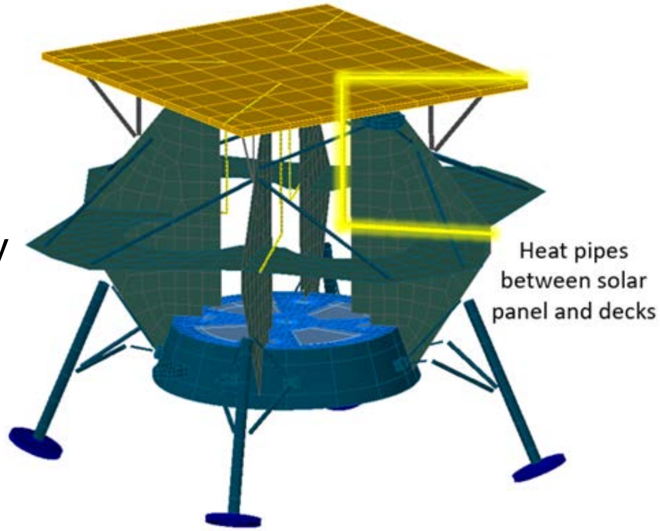


Diviner-measured Lunar Surface Temperatures

https://www.diviner.ucla.edu/science

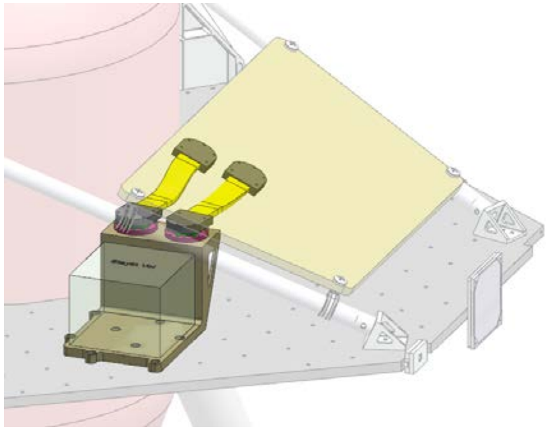
Variable Thermal Contact Technology

- Diode Heat Pipes
  - Creates a thermal path between the solar panel and the lander decks
    - Diode heat pipe = only transfers heat one way from the solar panel to the decks
    - Reduces temperature of solar panel
    - Increases temperature of decks during transit and orbits to reduce heater power required
  - Does not operate on lunar surface due to lunar gravity



Heat Pipes Between Solar Panel and Deck Highlighted

- Thermal Switch System
  - Creates a thermal path from the transponder mount to a radiator
    - When the transponder reaches a defined high temp, the switch enables ~0.9 W/°C contact
    - When the transponder reaches a defined low temp, the switch contact reduces to 0.002 W/°C



Thermal Switch System

Conclusions

- Astrobotic Peregrine Lunar Lander will deliver payloads to the lunar surface by July 2021.
- Thermal control challenges presented by a lunar lander:
  - Extreme worst-hot-case and worst-cold-cold environments
  - Narrow temperature limits of critical components
  - Limited available locations for spacecraft component placement
  - Unexpected changes
- Useful thermal control strategies
  - Dictating lander orientation
  - Defining component location
  - Limiting component operation
  - Using thermal control technology with variable thermal contact

Acknowledgements

- NASA CATALYST Team
- Brian O'Connor
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- Dave Bugby
- Astrobotic Team
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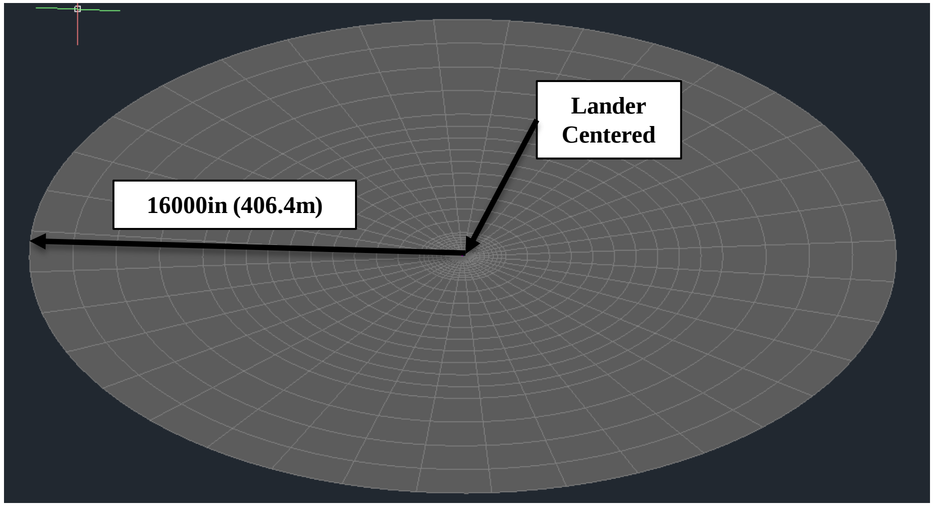
- Ander Solorzano

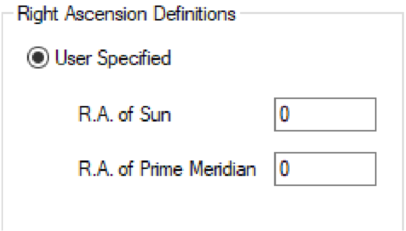
Questions

Back-up: Lunar Surface Environment



- Lunar Surface modeled as a TD disk
  - e=0.92; a=0.8; 10% specular
  - Low k thermophysical properties surface (~7 W/K)
  - 0.1in thickness; arithmetic nodes (no mass)
  - Simulates low in-plane conductivity with minimal overhead (lunar regolith depth modeling not necessary)
  - 5.2 W/m^2 uniform surface load to simulate re-radiation of lunar regolith

- Rover location modeled via Latitude/Longitude input in Heating Rate Case:

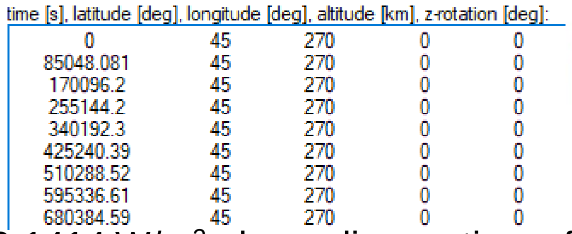


Right Ascension Definitions

● User Specified

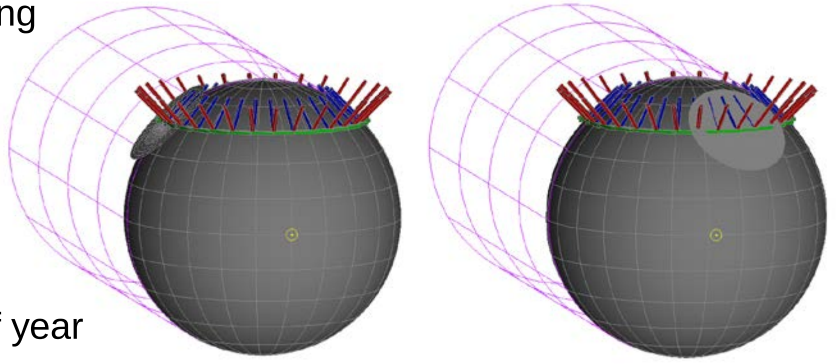
R.A. of Sun: 0

R.A. of Prime Meridian: 0



time [s]	latitude [deg]	longitude [deg]	altitude [km]	z-rotation [deg]
0	45	270	0	0
85048.081	45	270	0	0
170096.2	45	270	0	0
255144.2	45	270	0	0
340192.3	45	270	0	0
425240.39	45	270	0	0
510288.52	45	270	0	0
595336.61	45	270	0	0
680384.59	45	270	0	0

  - Solar constant = 1322-1414 W/m^2, depending on time of year
  - Albedo = 0.1
- Mean Solar Day: 708.733hrs
- Sun position at model time=0 is “sunrise”
- Landing time & Mission duration variables used to denote start/stop times and MET times.

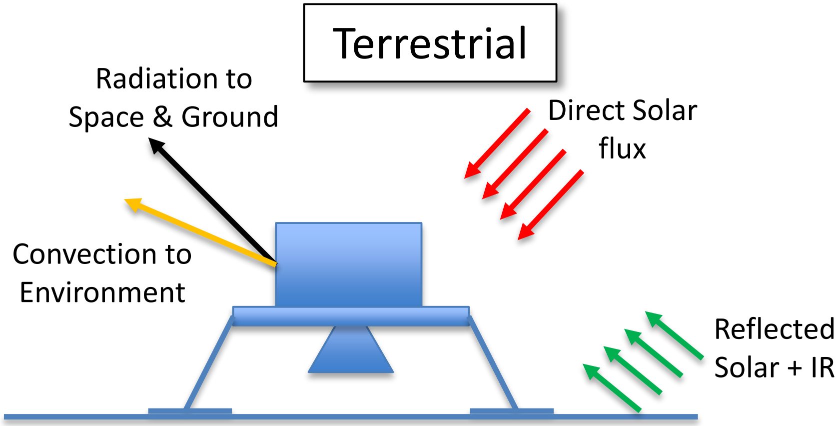


Lunar Sunrise

~Lunar Noon

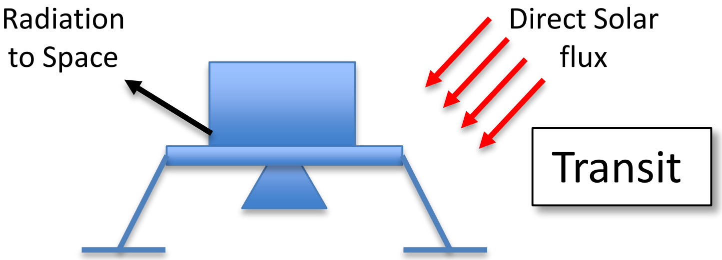
This slide provided by Shawn Breeding (MSFC ES22)

Terrestrial, Transit, & Lunar Environments



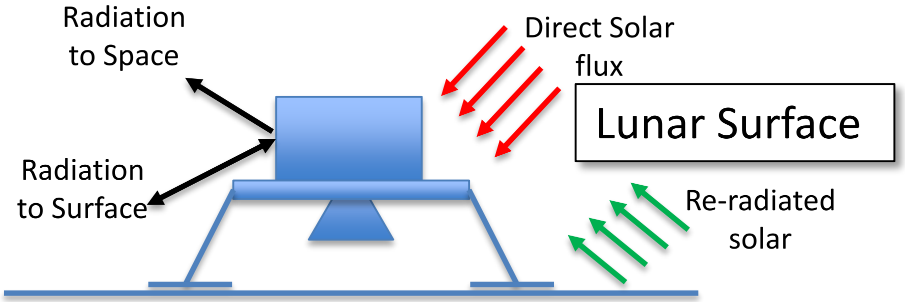
Terrestrial Environment

- Typically dominated by Convective Environment
- High Absorptivity Surfaces are subject to solar and can overheat. But, Natural Convection can moderate.
- **Electronics can dissipate heat loads via fans and natural convection (buoyancy)**. PC Boards and processors can convect heat directly off their surfaces; Heat sinks are effective also.



Transit Environment

- Typically dominated by optical properties of surfaces and orientation to the sun/space.
- Spinning can distribute flux loads but will complicate power system layout (solar arrays).
- **Electronics can't use convective methods** (no fans or finned systems). PC boards and processors must be mounted properly to provide **conductive cooling**. PC boards may require additional grounding planes or copper content. Board layout is critical to component temperatures. Heaters will be required to protect any hardware that cannot withstand low temperatures (electronics, batteries, propellants, etc.)



Lunar Surface Environment

- Typically dominated by optical properties of surfaces and orientation to the sun (flux) and space/lunar surfaces (view factors).
- **Electronics can't use convective methods** (no fans or finned systems). PC boards and processors must be mounted properly to provide **conductive cooling**. PC boards may require additional grounding planes or copper content. Board layout is critical to component temperatures. Heaters will be required to protect any hardware that cannot withstand low temperatures (electronics, batteries, propellants, etc.)
- Lunar Latitude is a large factor in environments; lunar regolith is effected by vehicle's shadow.