Lunar Surface Innovation CONSORTIUM

Extreme Environments Focus Group August Meeting

August 10, 2021

Dr. Benjamin Greenhagen
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Johns Hopkins Applied Physics Laboratory

Facilitator_ExtremeEnvironments@jhuapl.edu

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Lunar Surface Innovation CONSORTIUM

Today's Agenda

- LSIC Updates & New FG Facilitator (15 min – Greenhagen & Porter)
- LuSTR Opportunity (10 min – Somervill)
- Featured Presentations (25 min – Brian Hamill)
  - "Overview of the Lunar Thermal Analysis Guidebook - LTAG - HLS-UG-001"
- Open floor (time permitting)

LSIC Updates

LSIC Fall Meeting is confirmed for November 3-4, 2021

- Hosted at Bowie State University (Bowie, MD)
- Hybrid format with most content available virtually
- Theme: Autonomy and Robotics (EA and EE focus)
- Registration opens late August; Abstracts submissions open through 8/31/21
- http://lsic.jhuapl.edu/News-and-Events/Agenda/index.php?id=148

Upcoming LSIC Workshops (http://lsic.jhuapl.edu/News-and-Events/)

- LSIC Excavation & Construction Workshop (8/20/21)
  - 2-hour workshop focused on high-technology readiness level (TRL) excavation and construction tools and methods to support initial development of the lunar surface
  - Registration is open!
  - http://lsic.jhuapl.edu/News-and-Events/Agenda/index.php?id=139

LSIC Updates

Lunar Community Meetings

- LEAG Fall Meeting 2021 (8/31-9/2/21)
  - Theme: Lunar Science and Exploration in the Next Five Years
  - https://www.hou.usra.edu/meetings/leag2021/

- LSSW Fundamental and Applied Lunar Surface Research in Physical Sciences (8/18-8/19/21)
  - Discussing investigations on reduced gravity and lunar environmental effects in physical sciences research
  - https://www.hou.usra.edu/meetings/lunarsurface2020/

- LSSW: Lunar Science Accomplished with a Robotic Arm 1 (9/9/21 & 9/30/21)
  - Goal: generate a document that identifies and prioritizes science that may be done with robotic arms and can aid in the drafting of requirements, prioritizing robotic arm capabilities/instruments, and in outlining conops
  - Part 1 will be a two-hour webinar with invited overview talks covering overviews
  - Part 2 will feature contributed talks from the community followed by open discussion periods https://www.hou.usra.edu/meetings/lunarsurface2020/

Lunar Surface Innovation Initiative (LSII)

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NASA
Space Technology Mission Directorate
Lead, Lunar Surface Innovation Initiative
Niki Werkheiser
Carol Galica

APL Lunar Surface Innovation Initiative Team

Lead – Ben Bussey
Program Manager – Brenda Clyde
Chief Technologist – Mason Peck
Chief Scientist – Dana Hurley
Admin – Lisa Turner

Systems Integration Team

Systems Engineering Lead – Sanae Kubota
Lunar Science Lead – Brett Denevi
Senior Technical Advisor – Michael Paul

Lunar Surface Innovation Consortium (LSIC)

LSIC Director – Rachel Klima
LSIC Deputy Director – Josh Cahill
Executive Committee – Institutional Representatives
Admin – Andrea Harman

Capability Focus Areas

Dust Mitigation
Jorge Nunez
- Focus Group Coordination
- System Integration Tasks

Excavation & Construction
Athonu Chatterjee
- Focus Group Coordination
- System Integration Tasks

In-Situ Resource Utilization
Karl Hibbitts
- Focus Group Coordination
- System Integration Tasks

Extreme Access
Angela Stickle
- Focus Group Coordination
- System Integration Tasks

Extreme Environments
Ben Greenhagen
- Focus Group Coordination
- System Integration Tasks

Surface Power
Wes Fuhrman
- Focus Group Coordination
- System Integration Tasks

System Integrator Task

JHU/APL has identified System Integration Leads for each LSI Capability Area in order to integrate and communicate the key technology development themes, gaps, etc. relevant to the TRL advancement required for necessary lunar surface technologies. The products delivered will synthesize NASA's architectural needs, as well as input gathered from industry and academia.

- Review expected needs and opportunities for science, exploration and commercial operations on the lunar surface.
- Identify novel concepts for systems, design features and operations techniques for surviving the lunar environment.
- Provide a path from high-level goals to the deployment roadmap and near-term technology development. Match technical requirements and interfaces with capability needs timelines.
- Evaluate internal and external technology options at sufficient TRL for near-term surface activities.
- Review available technology testing and demonstration facilities for their applicability.
    - Identify needs and promote usage of existing facilities or identify new facilities needed.
- Maintain awareness and amplify NASA investments and solicitations
- Support the government with preparation for and/or attendance at NASA meetings and reviews, conferences, industry meetings, and site visits.

Industry and Academia related System Integration Tasks

JHU/APL will assist NASA in identifying best solutions in the balance of technical performance and programmatic needs that satisfy the requirements of NASA's lunar campaign, regardless of their origin.

- Evaluate Industry developed technology options at sufficient TRL for near-term lunar surface activities.
- Incorporate industry technologies into LSII capability roadmaps.
- Explore and help formulate public/private partnerships to develop sustainable capabilities and the potential for commercial lunar infrastructure services.
- Assess university capabilities which directly support the six LSII capability areas.
    - Assessment will be incorporated into capability area assessments and mapped to the NASA exploration objectives and timeline.
- Facilitate site visits with industry and academia

Introduction

Dr. Jamie Porter, Johns Hopkins Applied Physics Laboratory

- *What is my day job?*
  - *Radiation Effects engineer specializing in radiation transport and charging effects for planetary missions*
  - *Assistant Group Supervisor of Space Environmental Effects Engineering (SEN) which covers radiation analysis and test, charging analysis and test, materials and processes, planetary protection, and contamination control*
- *What is my backstory?*
  - *PhD in Nuclear Engineering (Radiation Concentration)*
  - *Graduate research focused on the transport modeling for the CRaTER instrument on LRO*
  - *Current missions include Europa Clipper and Dragonfly*
- *What are my interests?*
  - *Comparing radiation in situ data to our environment predictions models using multiple transport codes*
  - *Sharpening the pencil on these tool packages to allow for more confidence in radiation effects analysis for the crew and on board electronics*

Introduction

Dr. Jamie Porter, Johns Hopkins Applied Physics Laboratory

- *Why am I here?*
  - *To ensure fruitful communication between the LSIC-EE community and NASA STMD in bridging the technology gaps for successful operation in the lunar environment*
- *Where will I start?*
  - *Conduct interviews with willing members of the LSIC-EE community*
    - *How are we doing?*
    - *Are there things we are missing?*
    - *Are there specific things you would like to see?*
    - *Etc.*
  - *If you would like to me to reach out to you for an interview in the next month please contact me at* ***Facilitator_ExtremeEnvironments@jhuapl.edu***

Lunar Surface Technology Research (LuSTR) Opportunities

University-led efforts to develop and mature technologies that address high-priority lunar surface challenges

Technical Characteristics:

- Entry TRL: 2 – 4 (meaningful TRL advancement required)
- Unique, disruptive or transformational lunar surface technology development efforts that directly respond to one of 4 topics:
  1. Autonomous Systems for Excavation and Site Preparation
     - The goal of this topic is to develop and demonstrate autonomous surface construction technologies, specifically those for lunar launch and landing pads, required to enable a sustained presence on the lunar surface.
  2. Lunar Regolith Mineral Beneficiation
     - The goal of this topic is to enable greater efficiency and ultimately reduce waste during the physical separation and concentration of lunar surface minerals of importance to ISRU and manufacturing/construction processes.
  3. Cold-Temperature Analog Integrated Circuits
     - The goal of this topic is to develop analog integrated circuits and analog-to-digital electronics, fabricated using standard foundry processes, that will function under the extreme low temperature of the lunar night and shadowed regions.
  4. Novel Heat Transfer Fluids
     - The goal of this topic is to develop and/or characterize novel heat transfer fluids that may provide significant mass and performance improvements in thermal control systems for lunar surface applications.

The Appendix: https://tinyurl.com/LuSTR21 Email questions to: hq-LuSTR@mail.nasa.gov

Lunar Surface Technology Research (LuSTR) Opportunities

University-led efforts to develop and mature technologies that address high-priority lunar surface challenges

Eligibility

- Organization submitting proposal must be an accredited U.S. university
- Faculty and research staff may serve as PIs (see Appendix for full details)
- ≥ 60% of budget must go to accredited U.S. universities
- Up to 40% paid teaming with other universities, industry and non-profits encouraged
- OGAs and non-NASA FFRDCs may collaborate on an unfunded basis

Key Information

- Expected duration: **2 years**
- Anticipated awards: **4**
- Awards from **$1-2M** each
- Oversight: Annual reviews and semi-annual briefings at LSIC meetings
- Award instrument: Grants
- Release Date: **July 22, 2022**
- NOIs Due: **08/20/2021**
- Proposals Due: **09/17/2021**

The Appendix: https://tinyurl.com/LuSTR21

Email questions to: hq-LuSTR@mail.nasa.gov

Featured Presentation

- Overview of the Lunar Thermal Analysis Guidebook - LTAG - HLS-UG-001
  - Brian Hamill, NASA MSFC

National Aeronautics and Space Administration

HLS-UG-001, Lunar Thermal Analysis Guidebook

Brian Hamill

8/4/2020

ARTEMIS

Agenda

- L-TETT Charter
- Lunar Thermal Analysis Guidebook Intro
- LTAG Overview
- Detailed example (Orbital)

Lunar Thermal Environments Task Team

- The Lunar Thermal Environments Task Team (L-TETT) chartered by HLS to support MSFC/EV44 in formulating Sections 3.3.9.1 and 3.4.6 of the Cross-Program Design Specification of Natural Environments (DSNE) as stated. It will also develop and document thermal analysis methodologies for orbital and surface missions.
- Responsibility for defining Lunar Thermal Environments for DSNE belongs to MSFC/EV44.
- The L-TETT will generate a **companion document** to DSNE to aid thermal analysts in appropriate application of Lunar Thermal Environments.
- L-TETT will be led by MSFC/EV34 (including assigning a “L-TETT Coordinator”) with support from the Core Membership list to develop the guidebook document.
- The Support Membership will provided review to the product and feedback to the Core Membership.
    - Core Members represent their organization/project in the L-TETT.
    - Supporting Members are stakeholders in the products and will be provided draft versions of the documentation products to be reviewers.

Lunar Thermal Analysis Guidebook

- The guidebook describes methodologies for performing lunar thermal analyses in support of the Human Landing System (HLS) Program.

- Developed by the HLS Lunar Thermal Environments Task Team (L-TETT) composed of members from Marshall Space Flight Center (MSFC) Natural Environments team and members of the thermal discipline from across NASA,
  - Including Marshall Space Flight Center (MSFC), Johnson Space Center (JSC), Glenn Research Center (GRC), and Jet Propulsion Laboratory (JPL).

- Core Team Membership:
  - MSFC Nat Env: Robert Suggs, Leo Paez, Anthony DeStefano, Caleb Fasset, Michael Zanetti
  - MSFC Thermal: Callie Mckelvey, Greg Schunk, Brian Hamill, Brian O’Conner
  - JSC: Lisa Erickson, Angel Alvarez-Hernandez, Clark Craig
  - GRC: Ryan Edwards
  - JPL: Eric Sunada

Lunar Thermal Analysis Guidebook

- Earth’s Moon

FIGURE 3.1-1: NEAR AND FAR SIDES OF THE MOON

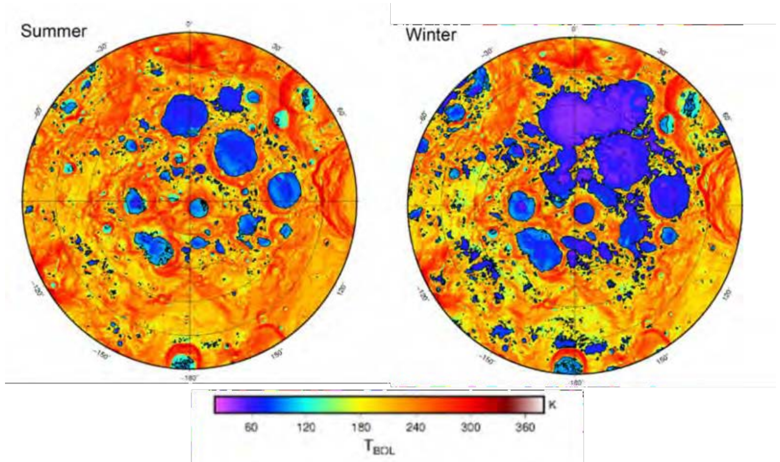


FIGURE 3.2-4: DIVINER MAXIMUM BOLOMETRIC TEMPERATURES OF THE SOUTH POLE (85°-90°S) SPLIT INTO SEASONS

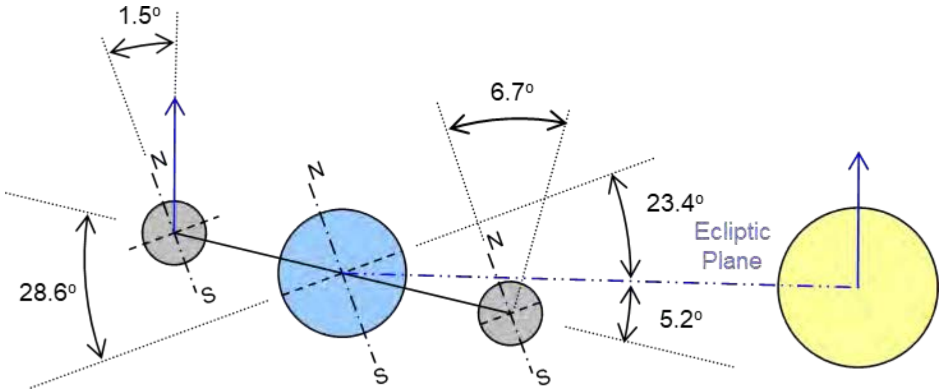


FIGURE 3.2-1: LUNAR ORBIT

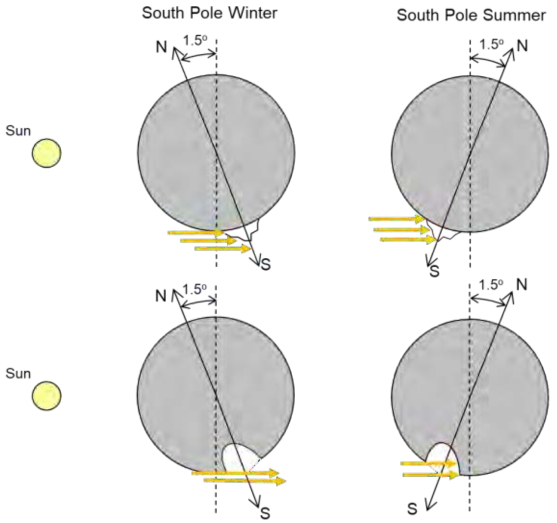
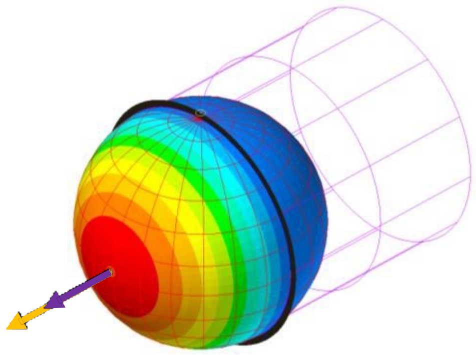
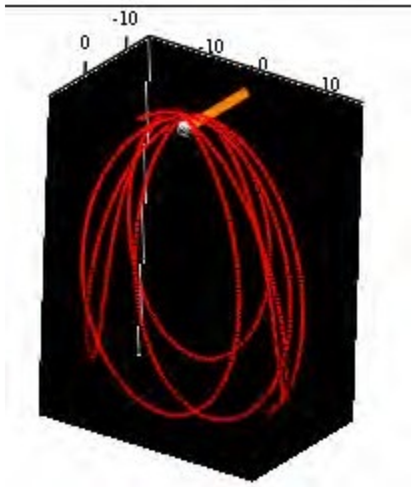


FIGURE 3.2-3: SEASONAL VARIATION ON THE MOON

Lunar Thermal Analysis Guidebook

- Orbital Environments
  - NRHO
  - LLO
  - Decent/Ascent





- Orbital Modeling Techniques

TABLE 8.1.2.2-1: KEPLERIAN APPROXIMATION ORBITAL PARAMETERS

Orbital Parameter	Hot (Beta 0°)	Cold (Beta 0°)	Cold (Beta 90°)
Orbit Inclination	90	90	90
Right Ascension of Ascending Node (RAAN)	270	270	90
Argument of Periapsis	88	88	90
Right Ascension of the Sun (RAS)	90	270	0
Right Ascension of the Prime Meridian	0	0	0

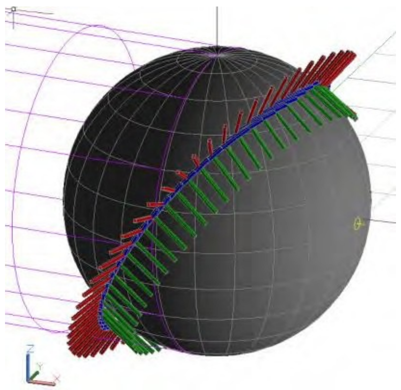


FIGURE 8.3.2-2: IMAGES OF LANDER ORIENTATION DURING DESCENT.

Lunar Thermal Environments

- Given the properties of Lunar regolith:
  A vehicle may receive almost as much energy from the Lunar surface (Albedo and Planetshine) as Direct Solar.
  - 1250W/m^2 OLR + 170W/m^2 Albedo vs 1426 W/m^2 Solar
- Unlike Earth, Surface cannot be set to a fixed boundary and interacts with vehicle.

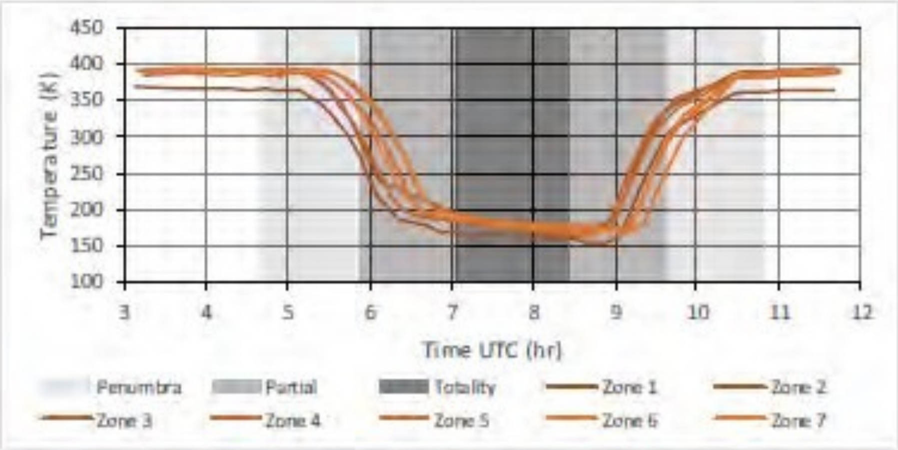


FIGURE 4.4.1.1-1: LUNAR ECLIPSE SURFACE TEMPERATURES, FEBRUARY 1971

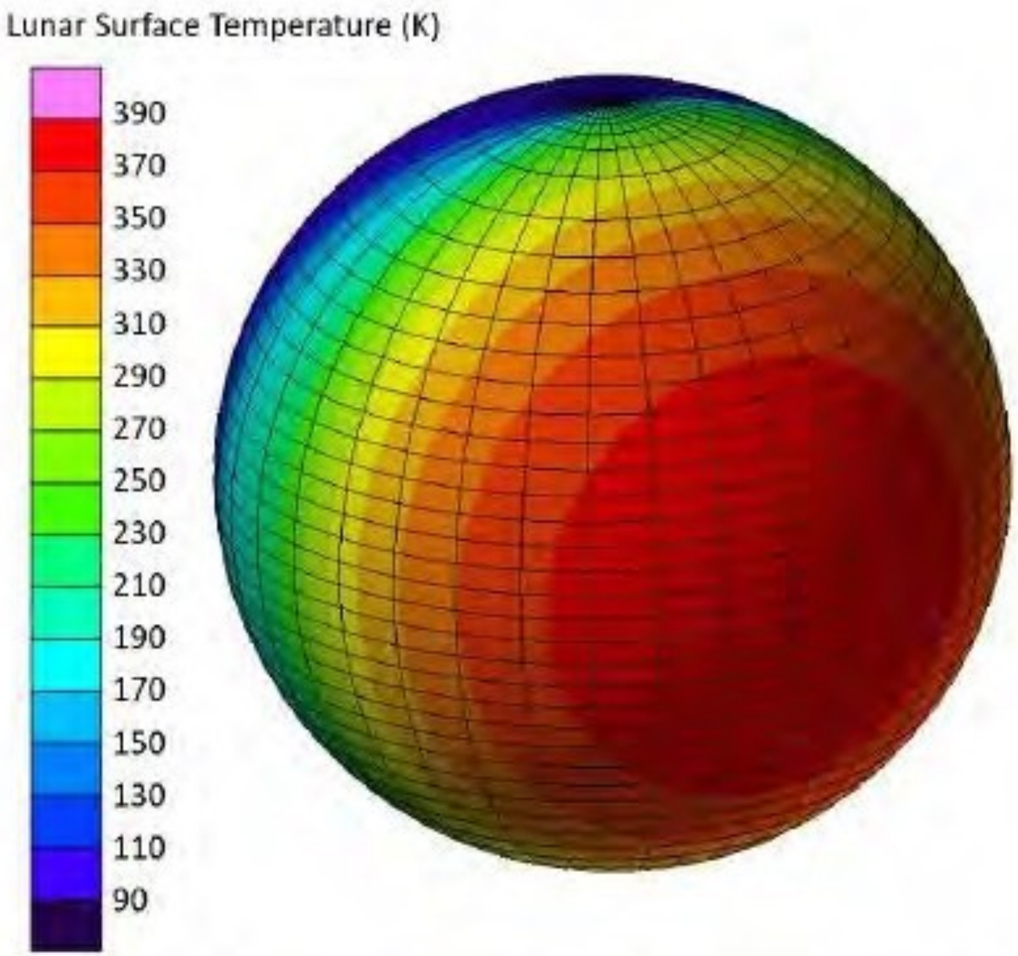
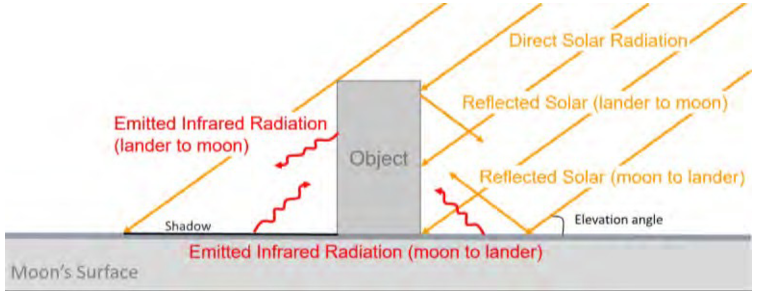
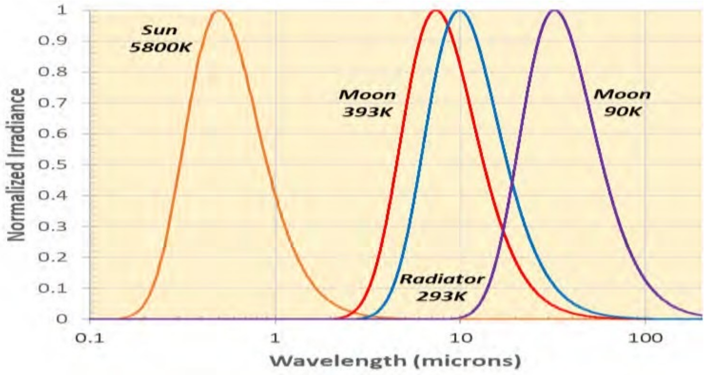


FIGURE 3-1: LUNAR SURFACE TEMPERATURES

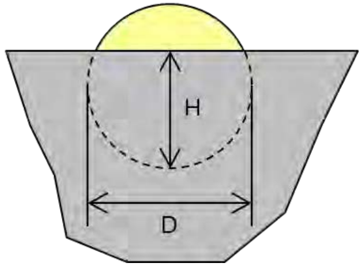
Lunar Thermal Analysis Guidebook

- Surface Environments



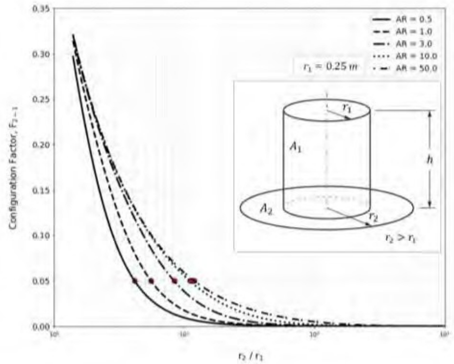


$$\%Visible = \frac{acos\left(\frac{2H}{D}-1\right)-\left(\frac{2H}{D}-1\right)\sqrt{1-\left(\frac{2H}{D}-1\right)^2}}{\pi}$$

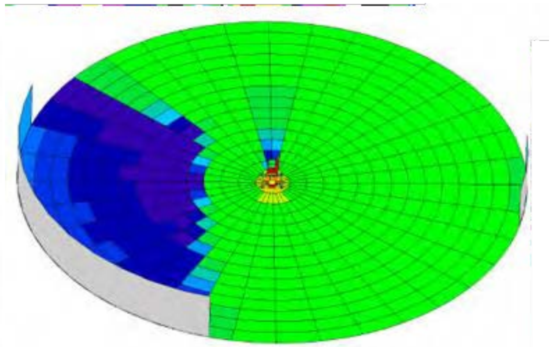


SOLAR OCCULTATION BASED ON HEIGHT AND DIAMETER

- Surface Modeling Techniques
  - Ground Plane
  - Subsurface
  - Terrain
  - Dust
  - Special Considerations for Permanently Shadowed Regions (PSRs)



GROUND PLANE SIZING



LUNA 27 FAR-FIELD BOUNDARY

TERRAIN MODELING

LTAG Environments Definition example

- Creating inputs for planetshine – orbital cases
  - Can use planetary coordinate system, requiring care to calculate the subsolar point with respect to the lunar coordinate system including lunar declination.

$$Q_{IR} = \left(\cos\left(Long_{planetary} - Long_{subsolar}\right) \cdot \left(Lat_{planetary} - Lat_{subsolar}\right)\right) \cdot \left((1-a) \cdot S_0 - \sigma \cdot \varepsilon \cdot T_{Dark}^4\right) + \sigma \cdot \varepsilon \cdot T_{Dark}^4$$

  - Or use option in Thermal Desktop (or other software) to utilize a subsolar coordinate system

$$Q_{IR} = \sin(Lat_{SS}) \cdot \left((1-a) \cdot S_0 - \sigma \cdot \varepsilon \cdot T_{Dark}^4\right) + \sigma \cdot \varepsilon \cdot T_{Dark}^4$$

LTAG Environments Definition example

- Subsolar definition results in a simpler input table
  - Could have been defined as 2 columns, but 0 Longitude included for clarity.

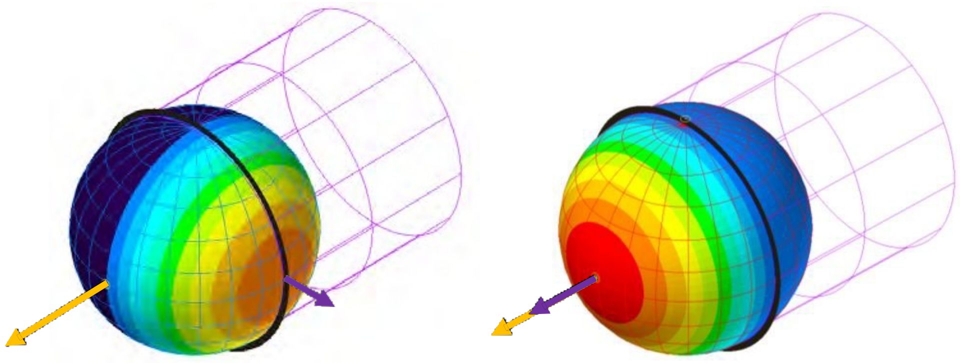
		Planetary Longitude																				
		-180	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	180
Planetary Latitude	-90	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	-80	12	12	49	85	119	150	177	199	214	224	227	224	214	199	177	150	119	85	49	12	12
	-70	12	12	85	157	224	285	337	380	411	430	437	430	411	380	337	285	224	157	85	12	12
	-60	12	12	119	224	322	411	488	550	596	624	633	624	596	550	488	411	322	224	119	12	12
	-50	12	12	150	285	411	525	624	704	763	799	811	799	763	704	624	525	411	285	150	12	12
	-40	12	12	177	337	488	624	741	836	907	950	964	950	907	836	741	624	488	337	177	12	12
	-30	12	12	199	380	550	704	836	944	1023	1072	1088	1072	1023	944	836	704	550	380	199	12	12
	-20	12	12	214	411	596	763	907	1023	1109	1162	1180	1162	1109	1023	907	763	596	411	214	12	12
	-10	12	12	224	430	624	799	950	1072	1162	1217	1236	1217	1162	1072	950	799	624	430	224	12	12
	0	12	12	227	437	633	811	964	1088	1180	1236	**1255**	1236	1180	1088	964	811	633	437	227	12	12
	10	12	12	224	430	624	799	950	1072	1162	1217	1236	1217	1162	1072	950	799	624	430	224	12	12
	20	12	12	214	411	596	763	907	1023	1109	1162	1180	1162	1109	1023	907	763	596	411	214	12	12
	30	12	12	199	380	550	704	836	944	1023	1072	1088	1072	1023	944	836	704	550	380	199	12	12
	40	12	12	177	337	488	624	741	836	907	950	964	950	907	836	741	624	488	337	177	12	12
	50	12	12	150	285	411	525	624	704	763	799	811	799	763	704	624	525	411	285	150	12	12
	60	12	12	119	224	322	411	488	550	596	624	633	624	596	550	488	411	322	224	119	12	12
	70	12	12	85	157	224	285	337	380	411	430	437	430	411	380	337	285	224	157	85	12	12
	80	12	12	49	85	119	150	177	199	214	224	227	224	214	199	177	150	119	85	49	12	12
	90	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

		Subsolar Longitude		
		-180	0	180
Subsolar Latitude	-90	12	12	12
	0	12	12	12
	5	120	120	120
	10	227	227	227
	15	333	333	333
	20	437	437	437
	25	537	537	537
	30	633	633	633
	35	725	725	725
	40	811	811	811
	45	891	891	891
	50	964	964	964
	55	1030	1030	1030
	60	1088	1088	1088
	65	1138	1138	1138
	70	1180	1180	1180
	75	1213	1213	1213
	80	1236	1236	1236
	85	1250	1250	1250
	90	**1255**	**1255**	**1255**

- Using the subsolar coordinate system also avoids another issue…

LTAG Environments Definition example

- Aligning Subsolar and Planetshine maximums
  - Solar and Planetshine environments are input separately in many analysis softwares. (Thermal Desktop used here for example)



  - If care is not taken when using planetary coordinate system for planetshine, the solar and OLR environments may not be aligned.
    - At time of publication, there was no way to align coordinate systems when using Sun/Planet Vector orbit definition, so subsolar coordinate system MUST be used.

LTAG Modeling example – NRHO Orbits

- For NRHO orbits, Sun/Planet Vector lists describing an as flown NRHO can be used. L-TAG users are directed to the Gateway Program Documentation.
  - Difficult to visualize in post processing, or when using complex orientations.
  - Hard to create bounding orbital thermal environments from “as flown” trajectories.
  - Does not utilize Thermal Desktop features like inserting orbit positions at terminator.
  - If inputs aren’t curated carefully model may incur unnecessary calculation durations.
- Keplerian Orbits can of er a close approximation.
  - Keplerian orbit may be “tuned” to provide close approximation of NRHO trajectory while providing for worst case thermal analysis.

Orbit Parameter	NRHO Trajectory	Keplerian Approx.	Keplerian Approx.
Apolune	71283 km (avg)	71283 km	65122 km (adj)
Perilune	3354 km (avg)	3354 km	3354
Period	6.58 days (avg)	7.47 days	6.58 days

LTAG Modeling example – NRHO Orbits

Orbital Parameter	Hot (Beta 0°)	Cold (Beta 0°)	Cold (Beta 90°)
Orbit Inclination	90	90	90
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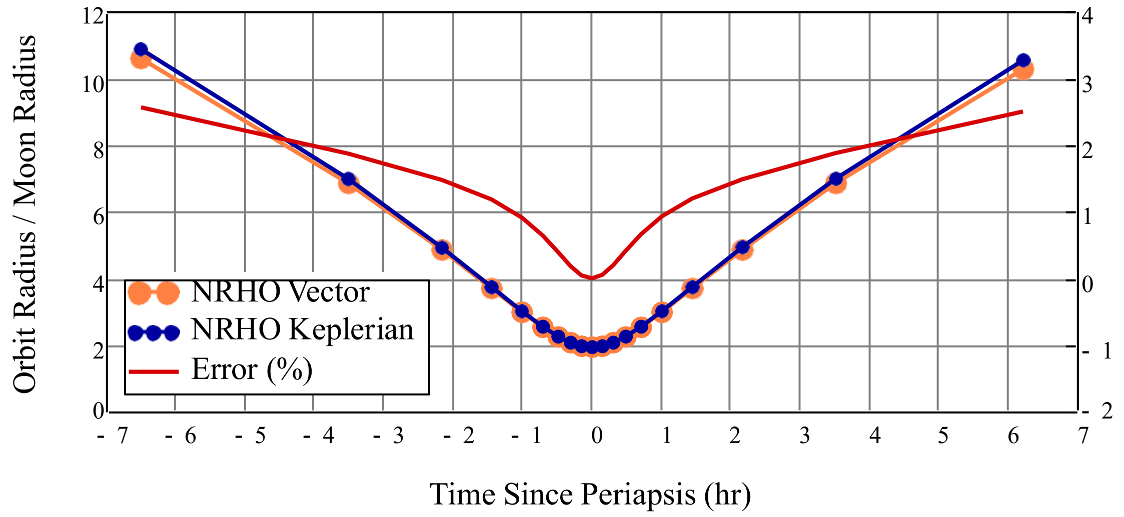

FIGURE 8.1.2.2-2: COMPARISON OF NRHO AND KEPLERIAN ORBITAL RADII NEAR MOON

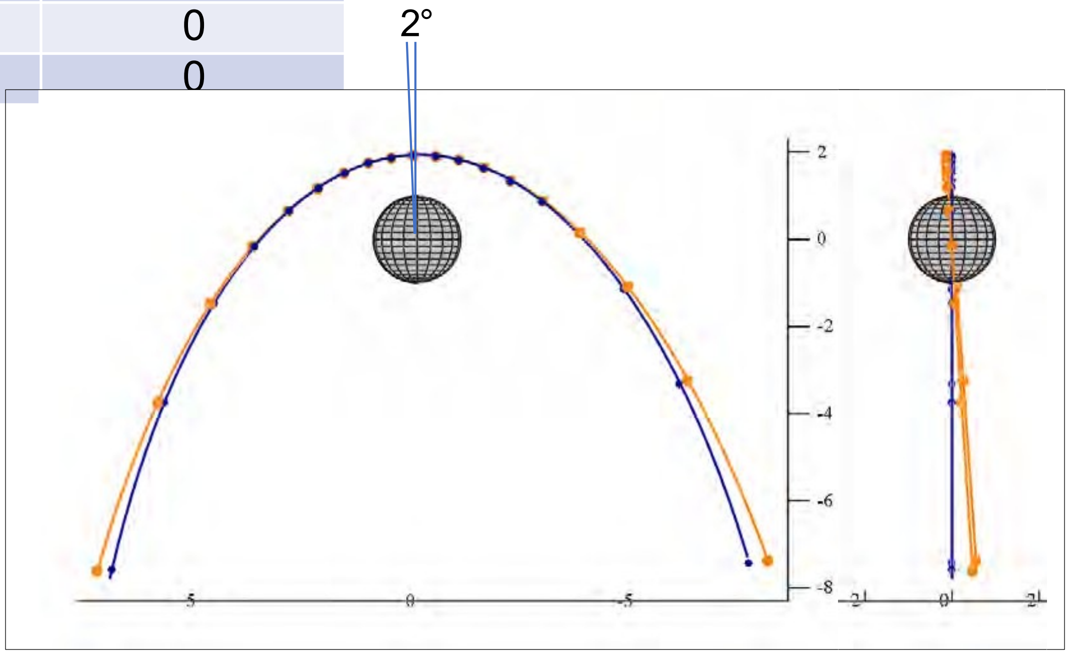

FIGURE 8.1.2.2-1: COMPARISON OF NRHO AND KEPLERIAN PERILUNE TRUE ANOMALY

-Thanks to Jonah Smith for collaborating on these sections

Questions?

- LTAG: Human Landing System Lunar Thermal Analysis Guidebook - NASA Technical Reports Server (NTRS)
- DSNE: Cross-Program Design Specification for Natural Environments (DSNE) Revision H - NASA Technical Reports Server (NTRS)
- Lunar Thermal Environments Task Team (LTETT): msfc-ltett@mail.nasa.gov


NASA
ARTEMIS

Lunar Surface Innovation CONSORTIUM

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- LuSTR Opportunity (10 min – Somervill)
- Featured Presentations (25 min – Brian Hamill)
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