Designing a Lunar Terrain Vehicle: Thermal Challenges

Zaida Y. Hernandez[1]
NASA Johnson Space Center, Houston, Texas, 77058

Samuel Wilcox[2]
Airbus U.S. Space & Defense., Arlington, VA 22209

Thomas Slusser[3]
Jacobs Technology Inc., Houston, Texas, 77058

The Lunar Terrain Vehicle (LTV) is an unpressurized rover that will be used to transport astronauts on the South Pole of the moon under the Artemis Program. The National Aeronautics and Space Administration (NASA) will be partnering with an American industry partner to develop the LTV. This paper discusses the thermal challenges faced when designing a crewed lunar vehicle concept and shares a concept that addresses these constraints. One of the most difficult aspects of the design is surviving the cold lunar night on the South Pole which includes permanently shadowed regions (PSR) that can have an extended lunar night duration of 125 hours. Other challenges are critical component temperature limits and programmatic constraints.

Nomenclature

AES	=	Advanced Exploration Systems
CLPS	=	Commercial Lunar Payload System
EVA	=	Extravehicular Activity
JSC	=	Johnson Space Center
LRV	=	Lunar Roving Vehicle
LTV	=	Lunar Terrain Vehicle
LRO	=	Lunar Reconnaissance Orbiter
NASA	=	National Aeronautics and Space Administration
PSR	=	Permanently Shadowed Region
RFI	=	Request for Information

I. Introduction

The Lunar Roving Vehicle (LRV) (better known as the Apollo 'buggy') was a rover used by astronauts during the Apollo missions to support lunar surface exploration activities. Three LRVs were used from Apollo 15 through Apollo 17 in the early 1970s and were critical for the discoveries made in the final Apollo missions. On foot, the astronauts were only able to cover under a kilometer total travel distance and by the end of the Apollo missions, on Apollo 17, they were able to cover almost 36 kilometers. The three vehicles were unpressurized and suitable for two astronauts. The different versions of the LRVs were almost identical in design except for a few minor additions for each new iteration of the vehicle. The LRV was roughly 210 kg and had an operational life of 78 hours during the lunar day. All three LRVs were battery powered and non-rechargeable. They were built under a NASA contract to Boeing and Delco as their subcontractor[1].

---

[1] Thermal Engineer, NASA Johnson Space Center.
[2] Thermal Engineer, Airbus U.S. Space & Defense.
[3] Thermal Engineer, Jacobs Technology Inc.

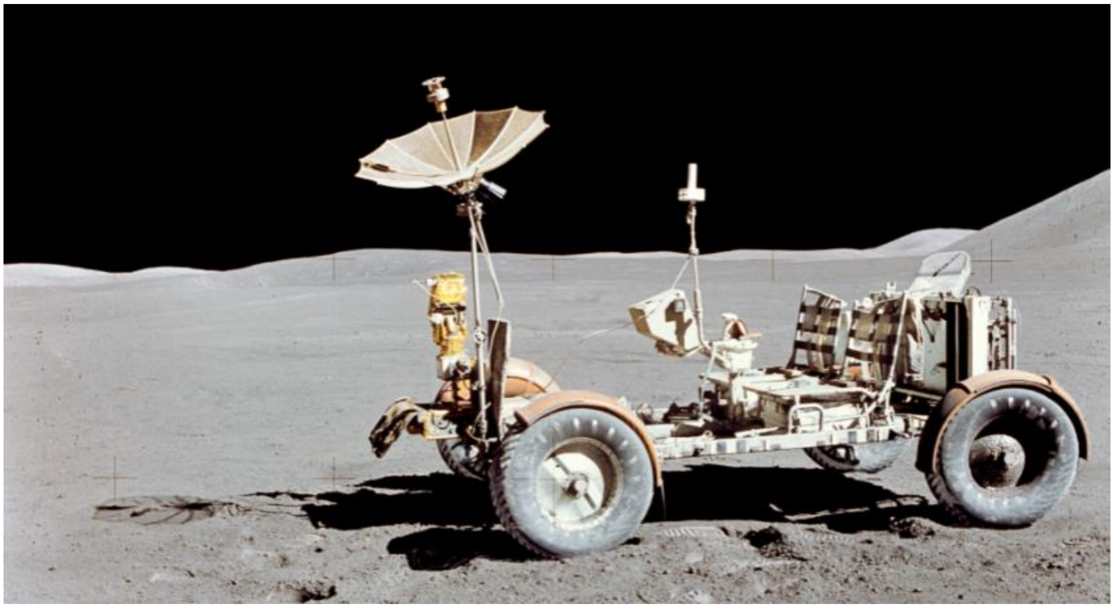

Figure 1: Apollo LRV

NASA has been given direction from the AES Directorate to return to the lunar surface by 2025 under the NASA's Artemis lunar exploration program. Like Apollo, the Artemis program will take astronauts to the Moon, but they will go to the Shackleton crater on the lunar South Pole and explore the lunar surface further away from the lander than the Apollo LRV was capable of. To facilitate crew exploration activities, NASA is seeking a Lunar Terrain Vehicle (LTV) that would allow astronauts to explore distances of up to 20 km without recharging batteries that could be delivered to the surface of the moon by 2027[2]. This is a much larger coverage area that the 1-2 km distances that a crew member would be able to walk without a vehicle. The LTV could interface with science instruments and payloads such as a robotic arm. Technologies and systems developed for LTV could also be used for other exploration objectives in the future[3].

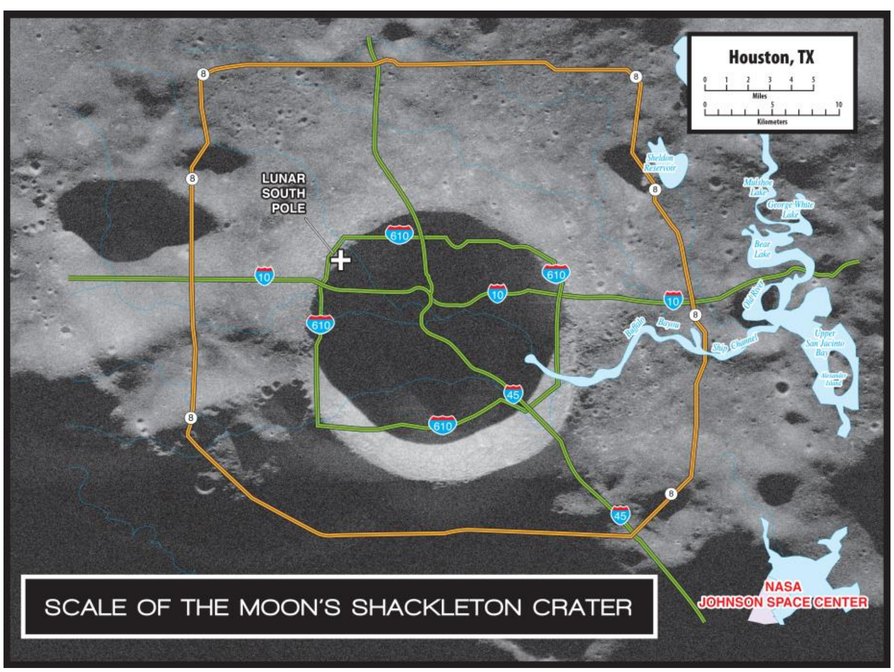

Figure 2: Shackleton Crater

This paper describes an LTV concept designed by the Thermal Design Group at NASA Johnson Space Center (JSC); however NASA will be selecting a private industry partner develop the LTV for Artemis. In 2021, NASA requested additional information from US companies through a Request for Information (RFI) to obtain additional details on potential technologies and solutions that could be used to design a reusable vehicle with a service life of up to ten years on the moon. A previous RFI was issued in 2020 where NASA requested preliminary information on the lunar vehicle. The LTV RFI allows industry to help form the Artemis surface mobility plans and encourages the use of new technologies, particularly for power and thermal management systems[2]. The LTV partnership with industry is important because it will help expand relations with commercial partners for development of technologies for low earth orbit and to the Moon.

II. LTV Requirements

The 2021 RFI from NASA established a few requirements for the type of vehicle that the space agency is willing to fund. Ideally, NASA would like a vehicle that could survive an extended lunar night duration of at least 85 hours, or 125 hours if deemed possible. From an architecture standpoint, the LTV should have a mass and size small enough to be launched on a Commercial Lunar Payload System (CLPS) sized lunar lander and accommodate two extravehicular activity (EVA)-suited astronauts, a driver and passenger. The vehicle should be able to carry a total payload mass of at least 800 kg for as much as 20 km without needing to charge the batteries although it should have recharging capabilities. The vehicle should be available for at least 8 hours per Earth day except for survive the night periods. As far as environmental survivability, the LTV should be able to survive the lunar night temperatures of 50 K on the south pole and in the permanently shadowed regions. Other requirements include an operational lifetime of at least ten years to support multiple Artemis missions and the ability to be operated remotely [2]. Figure 2 below shows an artist concept of LTV on the lunar surface.

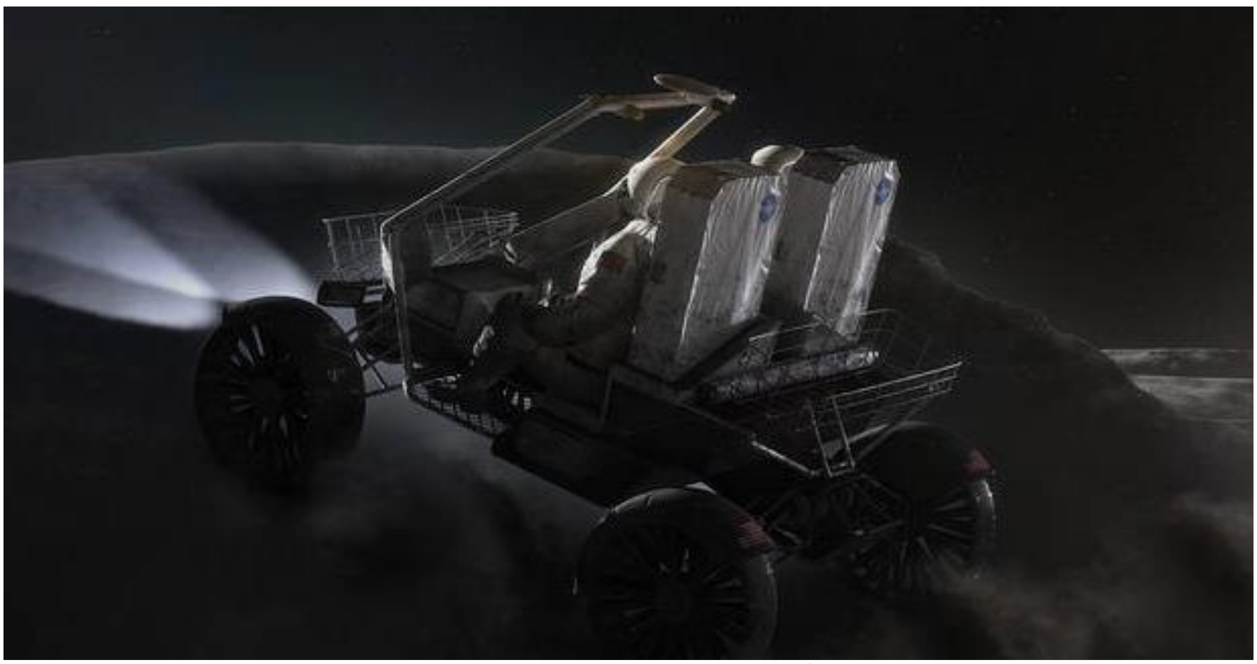

Figure 3: LTV Artist Rendering[2]

III. Thermal Challenges

There are several challenges that must be addressed when designing a crewed lunar vehicle. For the thermal subsystem, some of the challenges that were considered include worst case environments, temperature limits on critical components, programmatic constraints, and the role of the thermal subsystem in the project design process.

A. Worst Case Environments

NASA is interested in exploring the Shackleton crater area in the south pole region of the moon. The south pole is an interesting area because it was not explored by Apollo, but it has been thoroughly investigated with NASA's

Lunar Reconnaissance Orbiter (LRO). This area contains water-ice and other resources vital to advance human exploration on the moon. However, this area presents a thermal challenge as the south pole contains areas of permanently shadowed regions or areas that do not receive direct sunlight.

The LTV will have a 10-year lifetime on the moon and during that period will experience many extreme day and night cycles. Data from the LRO shows that the temperature on the lunar surface can reach up to 300K during the lunar day and as low as 50K during the cold lunar night. (Sam's paper). Another thing to consider is the day and night cycles on the moon which are approximately 28 Earth days. Most lunar night are about 36 hours and occur monthly, but studies done by NASA show that the LTV would experience at least two extended nights, of at least 85 hours, per year. That duration varies depending on the location and if the LTV is traversing or stationary. If stationary, the LTV could have an even longer lunar night of 125 hours[2].

B. Critical Component Temperature Constraint

One of the first steps in the thermal analysis process is to determine which components will require insulation and which will not. Certain components have a short range of operating and survival temperature limits and therefore must be insulated and may require the use of heaters to keep them from reaching harmful temperatures. In the case of LTV, once the mandatory components such as star tracker, batteries, cameras, etc. were defined, a "critical component" was selected in order to determine the minimum heater power needs of the system for the worst-case cold environment. The critical component was defined as the component that has the highest minimum operating temperature. Usually, the critical component is the battery. If thermal controls such as heaters are needed, these would need to activate when that minimum temperature is reached.

With the assumption that a typical battery has minimum operating temperatures of 0 deg C or -10 deg C, this is the temperature constraint used to determine the heater power. If battery cells can be customized to operate at lower temperatures, the thermal management system mass would decrease as a smaller battery and fewer heaters would be needed.

C. Programmatic Constraints

A few previous NASA missions have used radioisotope power systems (RPS) in their spacecraft designs. RPS is a form of nuclear energy that uses heat from radioactive decay to produce electric power for spacecraft or other science instruments. This technology is particularly useful for extreme temperatures or where solar panels are not able to provide enough energy. Although this a NASA heritage technology that has been used for over 50 years, nuclear material is controlled by the Department of Energy and this may present additional complexity to the schedule and cost of the LTV project. A detailed literature review of possible RPS options with lead time and availability can be found in Slusser et al[4]. Currently some of the options, such as Radioisotope Heater Units, are not in production mode. Additionally, NASA is considering launching LTV as a payload on a CLPS vehicle. RPS have not been used on CLPS before, so questions regarding licensing and permits needed by the vendor would need to be answered before nuclear power options are considered[5].

D. Design Process

One of the challenges for the thermal subsystem is that typically that group is not involved in the design process. This is especially challenging because going to the moon is a thermal driven problem. If the space exploration vehicles cannot survive the extreme lunar temperature environments, the mission has failed. When the thermal subsystem is not part of the design process, the thermal management system is not optimized and additional mass, heater power, and complexity are introduced.

IV. Proposed Solution

Unlike most project where the structural and mechanical designers create a design and the thermal subsystem must work around that design, for this concept, the thermal team was fully involved in the design process. Keeping the thermal challenges in mind, the team designed a fully passive thermal control system that would survive during all phases of the mission. Passive thermal systems are beneficial because they are typically lower cost, lower mass, and even lower risk. As the name implies, passive thermal systems do not require active systems or moving mechanisms such as fluid loops or pumps. “Multi-layer Insulation (MLI), coatings/surface finishes, interface conductance, heat pipes, sunshades, thermal straps, interface materials, and louvers are some examples of passive thermal control technology[6].” Other common components that were used in this concept were heaters, radiators, and dust covers. Dust covers are basically MLI with a robust external layer to help with rock penetrations in select areas of the vehicle. An additional feature and arguably the most important part of the thermal design is a nested box concept. Within this double box, components such as the batteries and electrical systems are co-located to help contain the waste heat generated and keep each other warm. This is especially useful during the cold lunar night.

On the other hand, for the temperatures experienced on a warm lunar day, radiators are needed to help reject heat. For this challenge, a flight heritage approach was used. During Apollo, instead of having one or two large radiators on the LRVs, small radiators were individually mounted to components. A similar concept was adopted for this LTV concept. With the double box, the radiators’ view to space would be obstructed, therefore, a hatch would be added to the external box that could open at a view away from the sun and allow a view to space. This would ensure that components do not overheat but would remain shielded for the night cycles. Component sized radiators are desirable over a large radiator because it would allow the thermal control system to remain completely passive. Larger radiators require heat pipes that introduce added complexity and risk.

As mentioned in the thermal challenges section of the paper, nuclear power options were not included in the baseline LTV concept because further information is needed to determine whether they would be suitable for a CLPS vehicle and if so, which options would be available within the schedule and cost constraints.

The thermal model of the LTV design can be seen in Figure 3. For more details about the thermal design and modeling of this LTV concept, please see the referenced document “Surviving the Lunar Night: A Non-Nuclear Thermal Control System Approach for an Unpressurized Vehicle at the Lunar South Pole[7].”

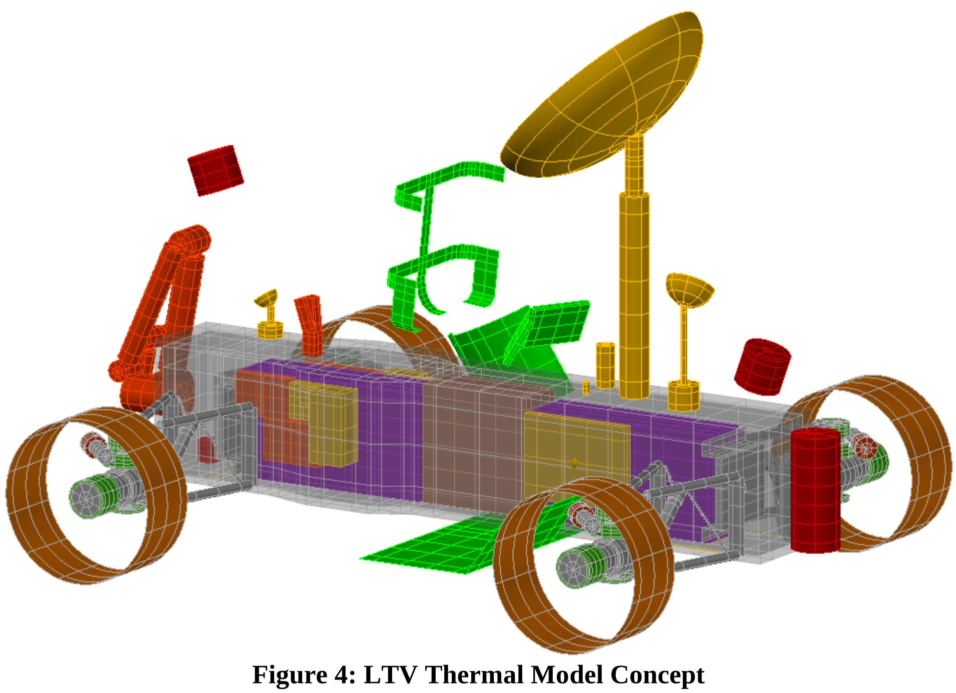

Figure 4: LTV Thermal Model Concept

V. Conclusion

NASA will be partnering with a commercial industry partner to develop a crewed vehicle, LTV, that will be delivered to the lunar surface by 2021. Although like the Apollo LRV the object of transporting EVA suited astronauts, the LTV will experience a different environment on the lunar south pole and have different requirements such as a larger payload limit and have a service life of 10 years which will require it to be rechargeable. The design of the LTV has thermal challenges including the worst-case temperatures, the temperatures of the components in the vehicle, programmatic constraints, and other factors that must be considered when working on with other subsystems. This paper discusses the thermal challenges and an LTV design concept using a passive thermal control system that addresses the challenges. NASA is currently reviewing the information received from the RFI and changes to this design are likely as the requirements are matured.

Acknowledgments

The authors would like to thank the NASA JSC LTV Reference Design team for providing inputs for the various subsystems that would be required for a lunar vehicle including power, mobility, and navigation among others.

Contact

Zaida Hernandez is an engineer for the Structural Engineering Division at NASA JSC. She has been working in the Thermal Design Branch since August 2017. She received a Bachelor of Science in Mechanical Engineering and Master of Industrial Engineering from the University of Houston. She can be contacted at Zaida.y.hernandez@nasa.gov.

Sam Wilcox is a lead thermal engineer at Airbus U.S. Space & Defense working on satellites in low Earth orbit. He received a Bachelor of Science in Mechanical Engineering from Utah State University. He can be contacted at swilcox695@gmail.com.

Thomas Slusser is an engineer at NASA JSC currently supporting the Volatiles Investigating Polar Exploration Rover (VIPER) project. He has a bachelor's degree in Aerospace Engineering from the University of Alabama. He can be contacted at thomas.b.slusser@nasa.gov.

References

[1]Williams, D. D. (2016, May 19). *The Apollo Lunar Roving Vehicle*. Retrieved from https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_lrv.html

[2]National Aeronautics and Space Administration. (2021, August 30). Lunar Terrain Vehicle (LTV) Request for Information 7.0 RFI No. NNH20ZCQ001L. Washington, D.C., USA: NASA Headquarters Advanced Exploration Systems Division.

[3]NASA's Jet Propulsion Laboratory. (n.d.). *What Is Radioisotope Power and Why Does NASA Use It?* Retrieved from Radioisotope Power Systems: https://rps.nasa.gov/about-rps/overview/

[4]Gernhart, M. (n.d.). *NASA Internal Moon2Mars.* Retrieved from LTV Background and Considerations for Artemis: https://moon2mars.ndc.nasa.gov/ltv/LTV%20Documents/000%20-%20LTV%20Presentations/LTV%20Background%20and%20Overview.pptx?d=wd9db09cebc5443ddb9e4c31c4c664add

[5]Slusser, T. W. (2021). *Surviving Night at the Lunar South Pole: Exploring Viability of Radioisotope Power Systems for a Crewed Rover.*

[6]National Aeronautics and Space Administration SmallSat Institute. (2023, February 1). *7.0 Thermal Control*. Retrieved from State of the Art Small Spacecraft Technology: https://www.nasa.gov/smallsat-institute/sst-soa/thermal-control

[7]Wilcox, S. S. (2022). *Surviving the Lunar Night: A Non-Nuclear Thermal Control System Approach for an Unpressurized Vehicle at the Lunar South Pole.* NASA Technical Reports Server.