University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

(Communications Relaying And Targeted Energy Routing)

CRATER

Approvals

	Name	Affiliation	Approved	Date
Customer	Prof. Marcus Holzinger	CU Boulder		
Course Coordinator	Kathryn Wingate & Chris Muldrow	CU/AES		

2.1. Project Customers

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BALL AEROSPACE 1600 Commerce St, Boulder, CO 80301 Website: http://www.ball.com/aerospace	LOCKHEED MARTIN 6304 Spine Rd, Boulder, CO 80301 Website: http://www.lockheedmartin.com

2.2. Team Members

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Name: Nathan Tonella Email: nato5318@colorado.edu	

3. Problem or Need

As commercial space activity increases in the cislunar space, commercial space companies will need access to power-infrastructure services in order to successfully complete their surface-based mission objectives in regions that are undeveloped. The main problem is the lack of infrastructure in place in the cislunar area to provide these services. The mission of CRATER is to provide reliable and continuous access to power, communication, and navigation. A successful project would be able to provide power to areas missing direct sunlight such as craters near the poles or missions needing supplemental power during lunar night.. CRATER should also be able to provide communications relay to and from the cislunar space while also being able to supply accurate navigation services for maneuvering and positioning of commercial spacecraft.

4. Previous Work

Researchers at NASA Marshall flight demonstrated a lightweight aircraft powered by a 1-kW laser in 2003. The flight demonstration shows the potential of transmitting power to lightweight objects over a distance. The project also showed issues of power transmission. It required the laser to have a direct line to the aircraft, which means any obstacles will prevent power transmission. It would also need a powerful laser to transmit over long distances. Furthermore, the aircraft had no instruments, payload, or anything that drained power besides the motor, so the power consumed was low. Powering cislunar infrastructure will require a greater scale of power transmission than generated here.

The ESA SOLARIS project is a preparatory program on space based solar power for earth installations. SOLARIS explores power transmission from orbit to ground targets as an economically viable option. However, the project is still in early stages of development.

Power transmission from space to ground based targets is a new field. Projects such as SOLARIS are in initial investment stages, while power transmission over large distances is still in early development as shown by the NASA research into laser power transmission. Similarly, lunar constellation systems are also in conceptual stages. However, there is some research that tests the feasibility of lunar communications and support for ground operations.

In 2020, a group of researchers from NASA Goddard space flight center explored a concept for a communication system called LunaNet. LunaNet explores potential design trades for a lunar constellation. However, it is purely conceptual. LunaNet finds that there are several different satellite constellation systems that can support NASA artemis missions scientific objectives.

5. Specific Objectives

Specific Objective	Level 1	Level 2
Space-Based Power Logistics and Services	Power is transmitted and received by the system.	The system transmits power at or above 50% transmission efficiency
Communication Services	The system shall be able to send, receive and decode a RF signal	The system relays a 32-bit word to a target receiver and operate with a to be determined bandwidth, and a to be determined latency

Satellite Network	The system tracks the position of the navigation device relative to target location.	The system uses a cost-function to choose between optimization criteria to reach target location

6. High Level Functional Requirements

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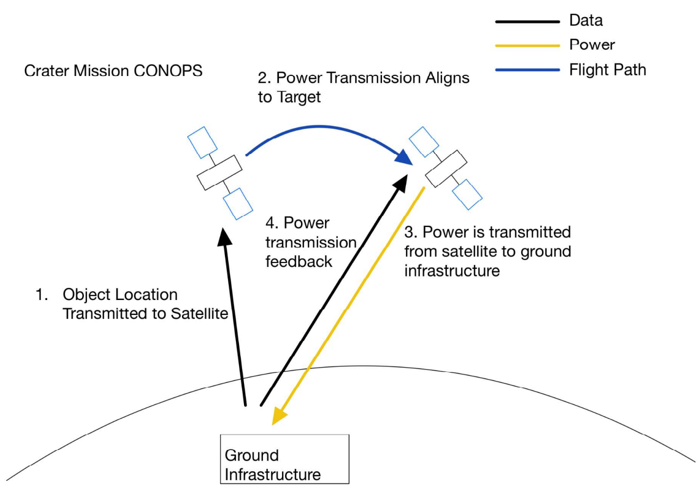


1. Power Delivery

Requirement	**Rationale**
The system shall provide consistent and adequate levels of power to a ground-based unit	In providing infrastructure for commercial space activity in undeveloped regions, power must be provided for ground operations to take place.
The system shall be able to function with minimal ground infrastructure.	In order to provide a cheap and fast power service the ground infrastructure must be kept to a minimum. This will decrease the cost of exploring new regions while also increasing the range of power distribution.

2. Communications

Requirement	**Rationale**
The system shall be able to send and receive a RF signal and decode the message.	The basis for communication is to establish a transmitter and a receiver. The signal is encoded which is why the system will need to decode the received signal and encode the outgoing message. The encoding

	is done through modulation and the decoding through demodulation.
The system shall be able to relay data to other systems and operate over a tbd bandwidth, with minimum latency.	Many space-ground communication operations rely on communications relay. This increases communication availability rather than waiting to pass over a ground station. High bandwidth increases the amount of data per second resulting in quicker downlink. This is achieved by using a wider range of frequencies.

3. Navigation

Requirement	Rationale
The system shall track the position of the navigation device relative to the lunar surface.	Knowing the coordinates of ground receivers, have an optimized satellite/constellation orbit design for power collection, transmission, and communication.
The system, using known ground locations, should calculate the transmission angle for the power system.	By calculating the angle from the satellite to the ground location, the transmission system can align, and the time of transmission can be maximized.

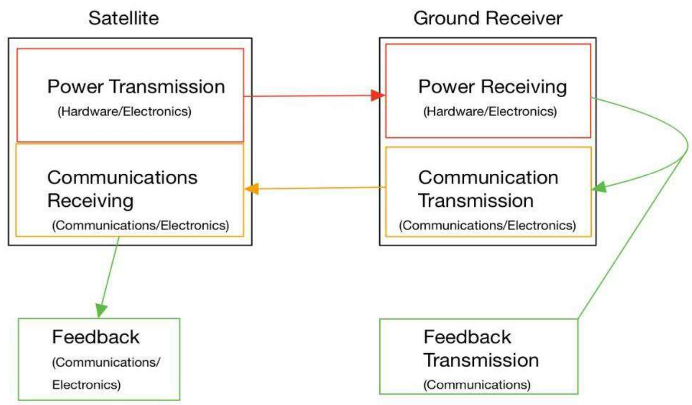
7. Critical Project Elements

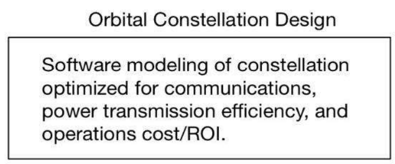
Critical Element	Functional Requirement	Contraint Rationale
Technical		
T1: Survival	Equipment able to survive with standard satellite thermal and shielding.	Proper materials should be used so that the instruments onboard do not fail from the harsh environment in Lunar orbit.
T2: Power Transmission	10% modeled power transmission efficiency in space environment	The power transmission system is able to deliver power to a receiver. Using data collected during tests on Earth, the power delivered in a space environment can be modeled.
T3: Optimized Constellation	Optimized cost function for power delivery	Design a cost function to maximize the satellite constellation efficiency when transmitting power.
T4: Bandwidth	The system shall be able to send and receive a RF signal and decode the message.	The system will need adequate bandwidth for communication transmission.
Logistical		
L1: Return on Investment	Cost function to optimize constellation power delivery and cost	Project will have an economic model for the constellation system. Constellation shall have a positive return on investment determined by TBD.

L2: Policy Constraints	Research into current policy and consult with experts for further methods of discussing with policy makers.	Should demonstrate the reasoning behind the mission to encourage policy makers to back the project and see its potential. Furthermore the mission should align with current policy regarding space.
Validation / Testing		
V1: Earth based simulation	Testing power transmission on Earth with atmospheric losses to verify system efficacy. Initial tests will see close range signal transmission, with later tests increasing the distance.	Budget and time constrains the possibility of space-based validation. Success criteria for the project can be achieved accounting for atmospheric losses. Validation between theoretical and experimental transmission rates verify system efficacy
V2: Vacuum Conditions	To test power transmission in a near vacuum environment with the use of a vacuum chamber to verify transmission rates.	Under vacuum conditions, loss to the environment will be minimized and can prove the viability of wireless power transmission.
V3: Safety	Testing high risk elements in a manner that is safe to life and equipment	Testing high risk elements has inherent risk so processes will be implemented to ensure safety

8. Sub- System Breakdown and Interdependencies

- **Hardware**
  - **Structural**
    - Component housing design.
    - Material analysis.
    - Power acquisition and storage.
  - **Communication**
    - Antenna design.
  - **Electronics**
    - Power transmission system
    - Circuitry
- **Software**
  - **Orbital Design**
    - Compute flight path.
  - **Orbital Navigation**
    - Monitor position of transmitter with respect to receiver.
  - **Communication**
    - Interpretation of encoded signals.





9. Team Skills and Interests

Team Member	Associated Skills/Interests	Critical Project Elements
Mathieu Brawley	MATLAB, C++, Orbital Mechanics, Machining, Space Policy, Bird Law	**T1, T2, L2**
Alec Church	MATLAB, C++, Python, Orbital Mechanics, Arduino, Welding, Soldering	**T1, T2, V1, V2**
Aadhit Rozario Gopinath	MATLAB, C#, Machining, Electronics, Arduino, Attitude Dynamics, Orbital Mechanics	**T2,T4,L1,L2**
Abraham Jaet	MATLAB, C/C++, Electronics, Attitude/Orbital Dynamics	**T3, T4, L1, V1**
Cameron King	MATLAB, Attitude Dynamics, Orbital Mechanics, Physics	**T2,T4,V1,V2,V3**
Ashwin Raju	MATLAB, Python, C++, Attitude Dynamics, Orbital Mechanics	**T1, T2, T3, T4, L2, V1**
Nathan Tonella	MATLAB, Python, C++, Onshape, CAD, technical writing	**T1, T2, V2, L1**
Mark Walvoord	Matlab, Attitude Dynamics, Technical Writing, Circuit Design and Construction	**T2, T4, L2, V2, V3**
Henri Wessels	MATLAB, C/C++, Python, Javascript, Attitude/Orbital Dynamics, Electronics & Communication	**T1, T2, T3, L2, V1**

10. Resources

Critical Project Elements	Resource/Source
T1	**Hardware Vendors**
T2	**Hardware Vendors, CU Boulder Machine Labs, CU Boulder Circuit Labs**
T3	**Dr. Holzinger, STK**
T4	**Hardware Vendors, CU Boulder Circuit Labs**
L1	**Internal Modeling/Research**
L2	**Dr Holzinger, experts in field of space law**
V1	**CU Lab spaces**
V2	**CU LifeLAB Thermal Vacuum Chambers**
V3	**Equipment safety manuals**

11. References

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