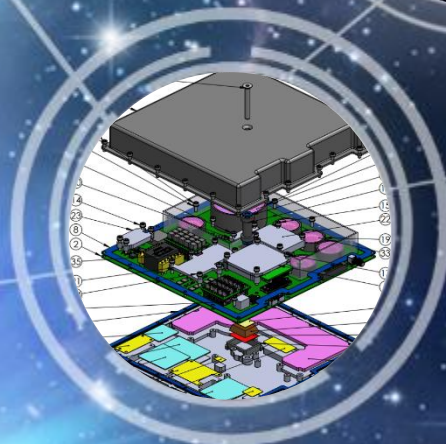
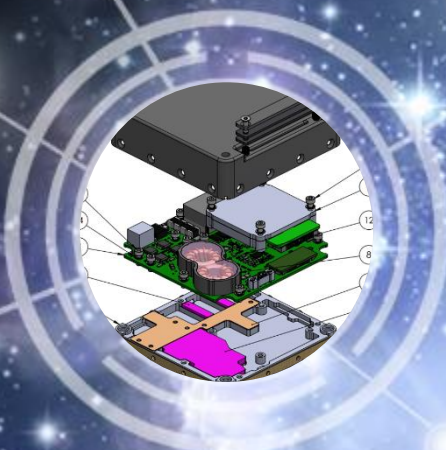
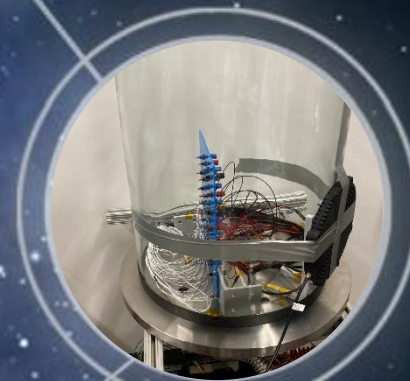




Space Technology Mission Directorate Game Changing Development Program

Presenter: James Eckard | Moderator: Mathew DeMinico | FY22 Ultra Fast Proximity Charger TP Annual Review Presentation | 09.12.22
Name/Email POC: Jay Eckard/ james.eckard@astrobotic.com

Project Overview



➤ Technology Product Capability

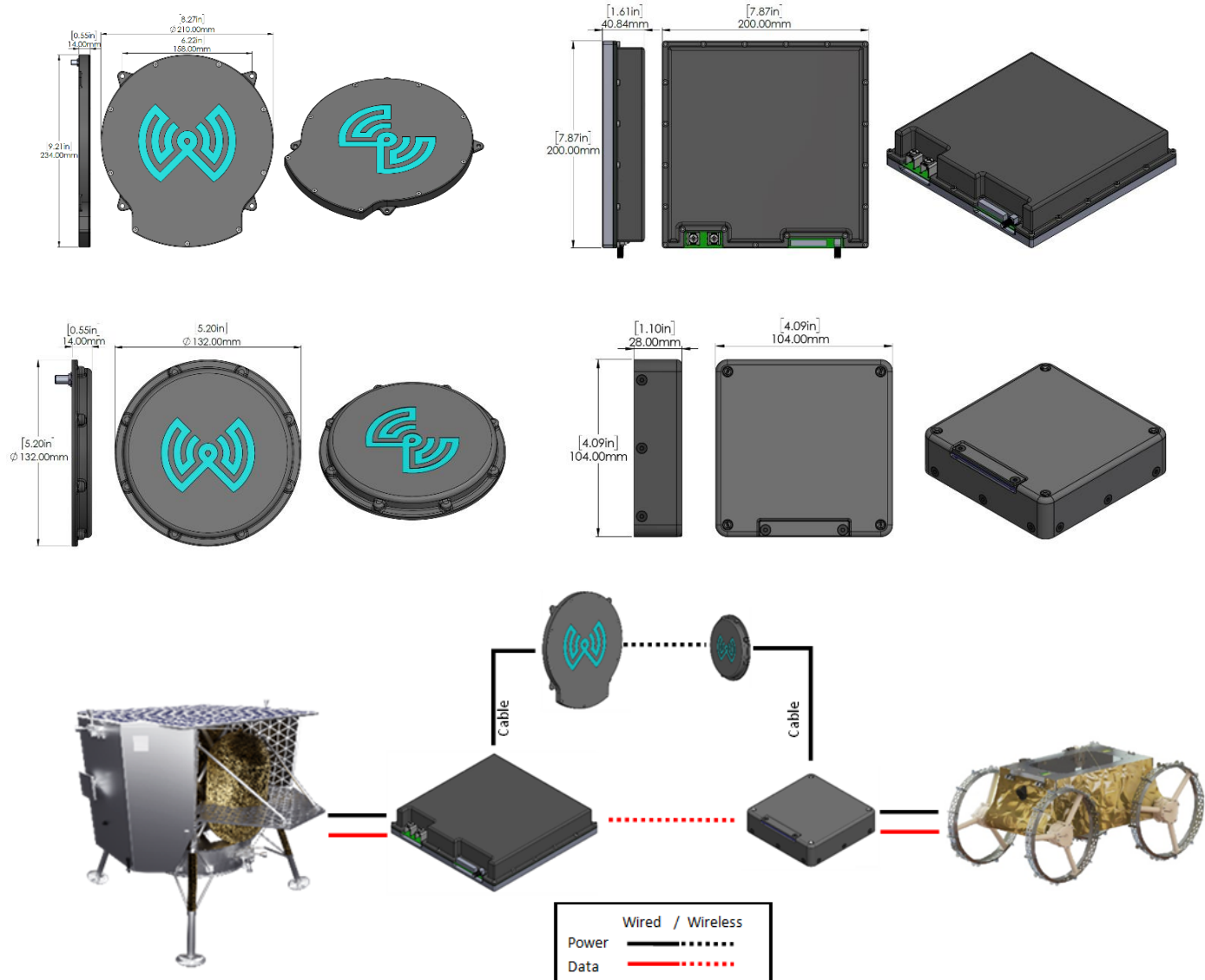
- A space-qualified charging system capable of near field wireless power transfer

➤ Technical Capabilities

- Develop a rover with integrated power receiver, and a base station, both capable of operating in a lunar environment
- Demonstrate wireless charging as a feasible means of power transfer for lunar missions
- Demonstrate that the system can enable lunar night survival

➤ Exploration & Science Applicability

- Supporting marsupial roving missions, enabling robotic systems that do not contain onboard nuclear or solar power generators
- Charging toolkits on crewed lunar terrain vehicles (LTVs), human landers, and in LEO
- Powering the heaters of critical devices to survive the lunar night, particularly in the case of equipment with small or limited on-board battery capacity



Team Members / Project Org Slide



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Collaborations & Partnerships

NASA Centers

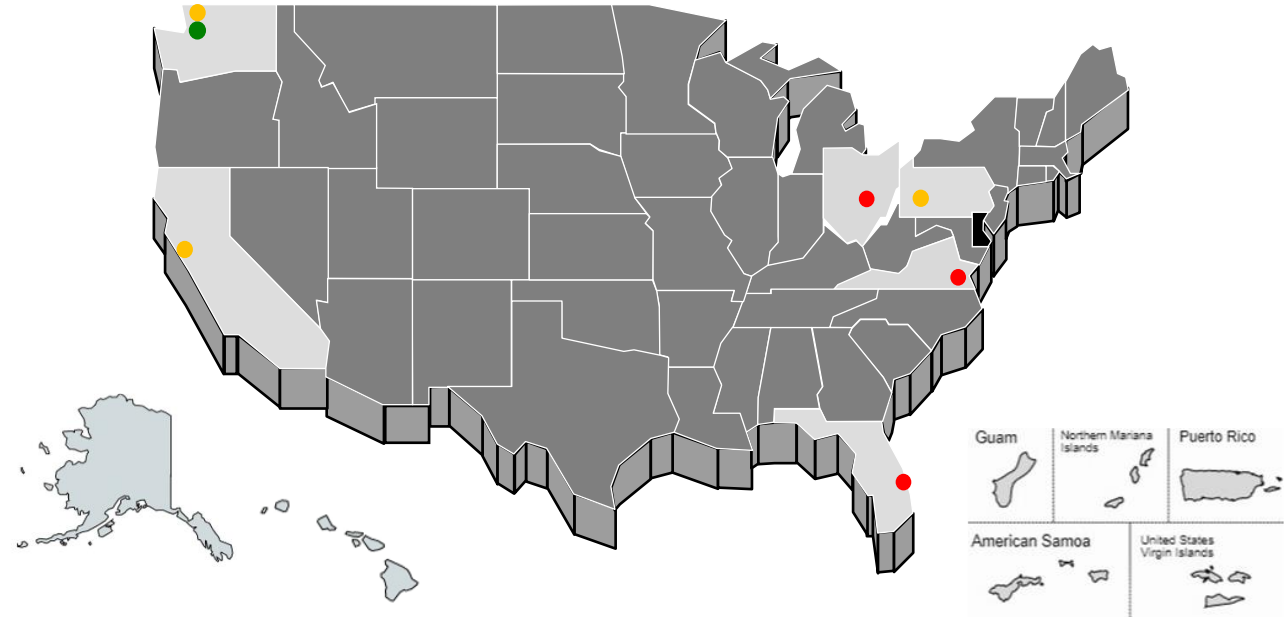
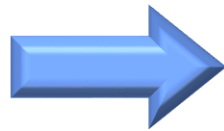
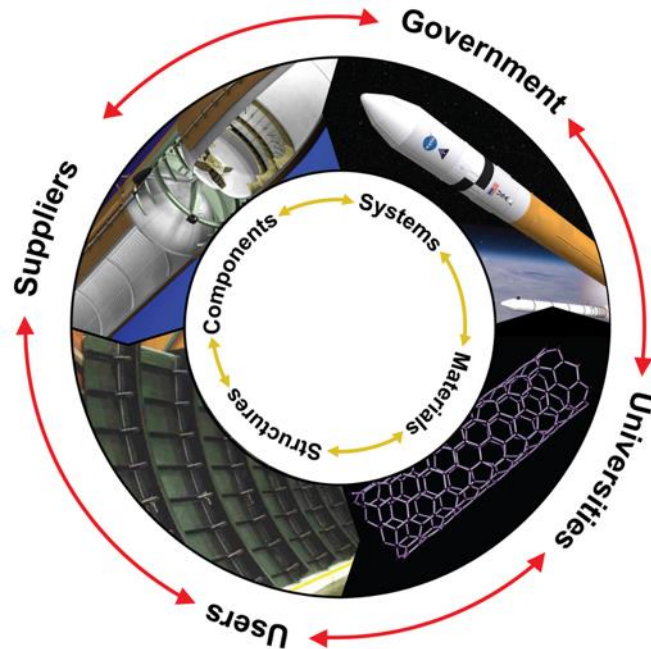
- GRC
- LaRC
- KSC

Public/Private Partnerships

- WiBotic Inc
- Bosch

Industry/Academia

- University of Washington



Collaborative multidisciplinary partnerships to leverage fiscal resources, ideas, knowledge & expertise.

Ultra Fast Proximity Charger (UFPC) Technology Goals & Project Objectives



Technology Goals

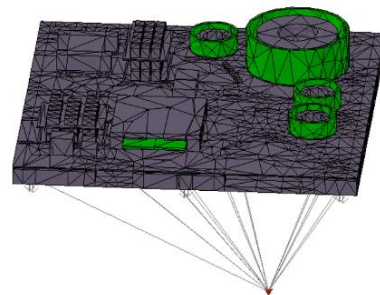
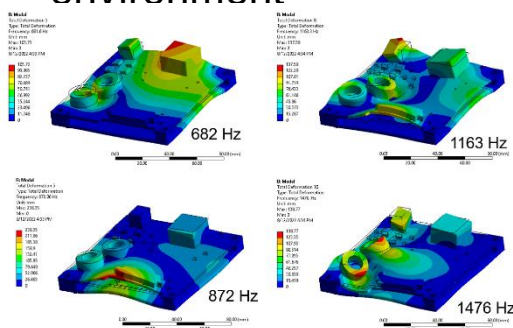
Goal #1	Qualify and commercialize a space-based wireless charging product line through demonstrating the feasibility of wirelessly recharging a rover in a lunar night analog environment.
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Project Objectives

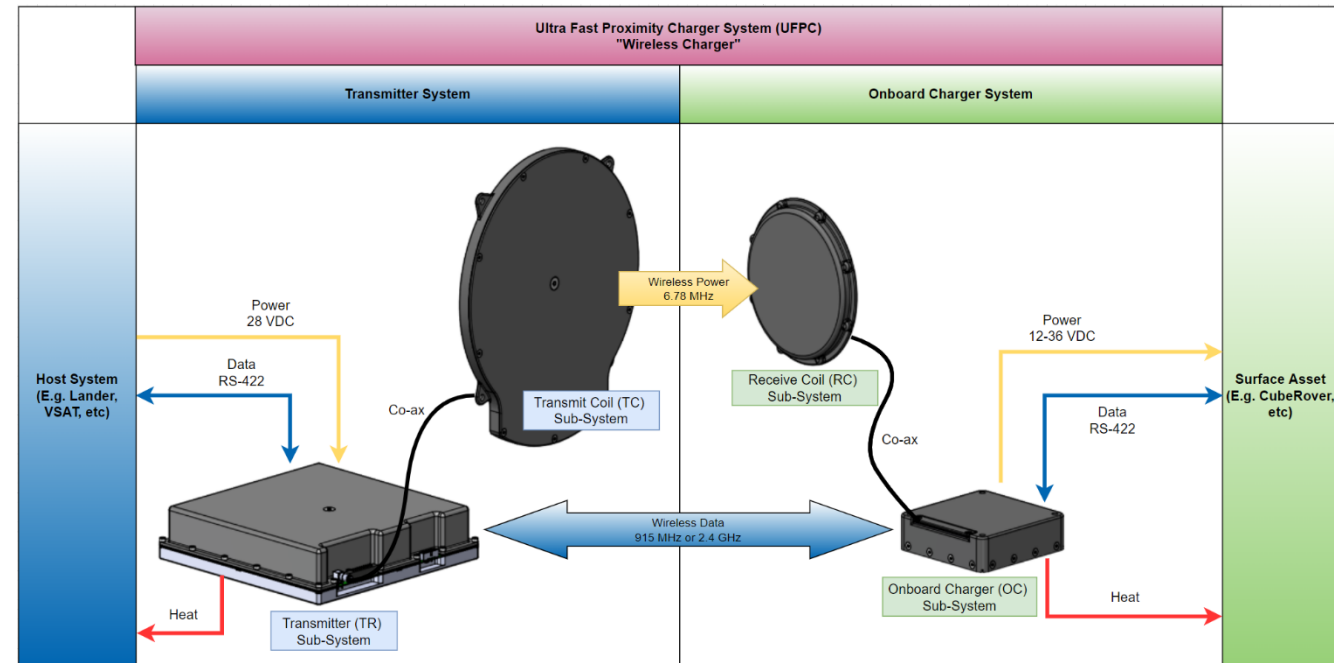
Objective #1	The program shall develop an integrated Onboard Charger (OC), and a Transmitter (TR), both capable of flight qualification.
Objective #2	The program shall demonstrate wireless charging as a feasible means of power transfer for lunar missions.
Objective #3	The program shall demonstrate wireless charging as a feasible means of night survival for lunar surface assets.
Objective #4	The program shall demonstrate a self-docking algorithm that enables CubeRover to align wireless charging antennas without the need for direct drive commands.

Accomplishments

- Objective 1: The program shall develop an integrated OC, and a TR, both capable of flight qualification.
- **Astrobotic and WiBotic** have collaborated on the creation of an architecture that will enable the development of a near-field wireless power transfer system for critical space application
- This system, based on **WiBotic's** terrestrial wireless power systems is designed for **125w of continuous power** transfer at up to **85% end-to-end efficiency**
- With a total system mass less than 3.3 kg, the system has been designed and optimized to withstand the extremes of space flight and the harsh lunar environment



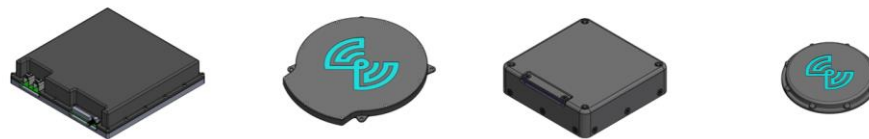
The UFPC design has been optimized through the use of detailed thermal and structural analysis to ensure survival through the harsh environment from launch to lunar operations



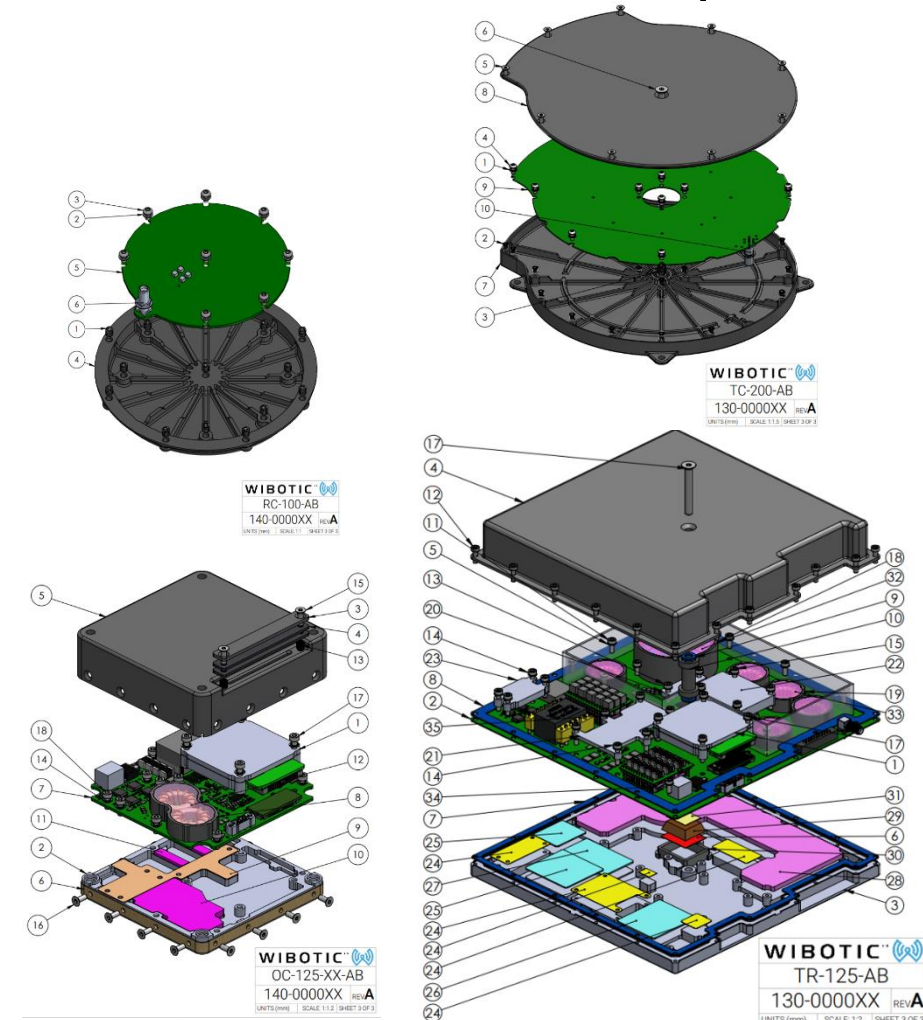
Accomplishments

➤ Objective 1: The program shall develop an integrated OC, and a TR, both capable of flight qualification.

- The system has most recently gone through Preliminary Design Review, and fabrication and test of the first engineering units is underway
- The design featured many material, component, and design upgrades to withstand the thermal, vibrational, radiation, vacuum and extreme dust conditions needed for lunar application
- The system will be subjected to testing for radiation (SEE and TID), Shock/Vibe, Pressure Drop, EMC/EMI, Regolith, and Dirty TVAC in 2023



	Power Transmitter 125W: OC-125-08-SPC 400W: OC-400-15-SPC	Transmitter Coil 125W TR 400W TR	Onboard Charger 125W: TR-125-DC-SPC 400W: TR-400-DC-SPC	Receiver Coil 125W OC 400W OC
Dimensions	200 x 200 x 40 mm	210 mm (dia)	104 x 104 x 28 mm	132 mm (dia)
Mass	2.5 kg	420 g	400 g	90 g
Operating Temp Range	-40 to 70C	-200C to 175C	-25 to 85C	-200C to 175C
Survival Temp Range	-40 to 75C	-200C to 175C	-40 to 85C	-200C to 175C
Interface	RS-422	SMA	RS-422	SMA
Charging Current	8A (125W) 15A (400W)	NA	NA	NA
Voltage	26.6 to 29.4VDC (Input)	NA	12 – 36 VDC Fixed (Output)	NA

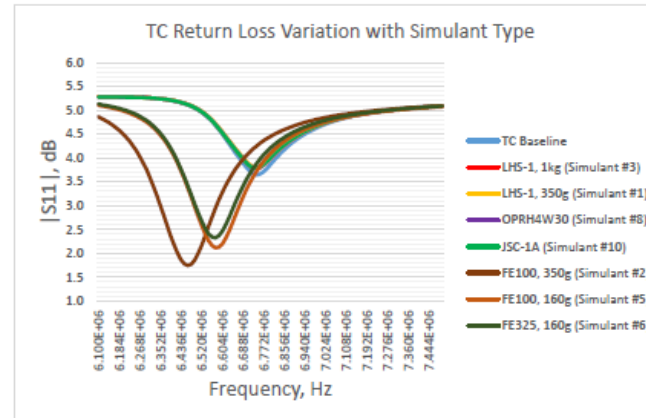
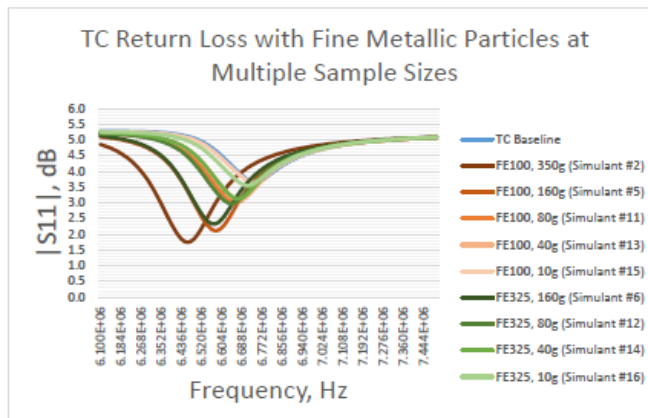
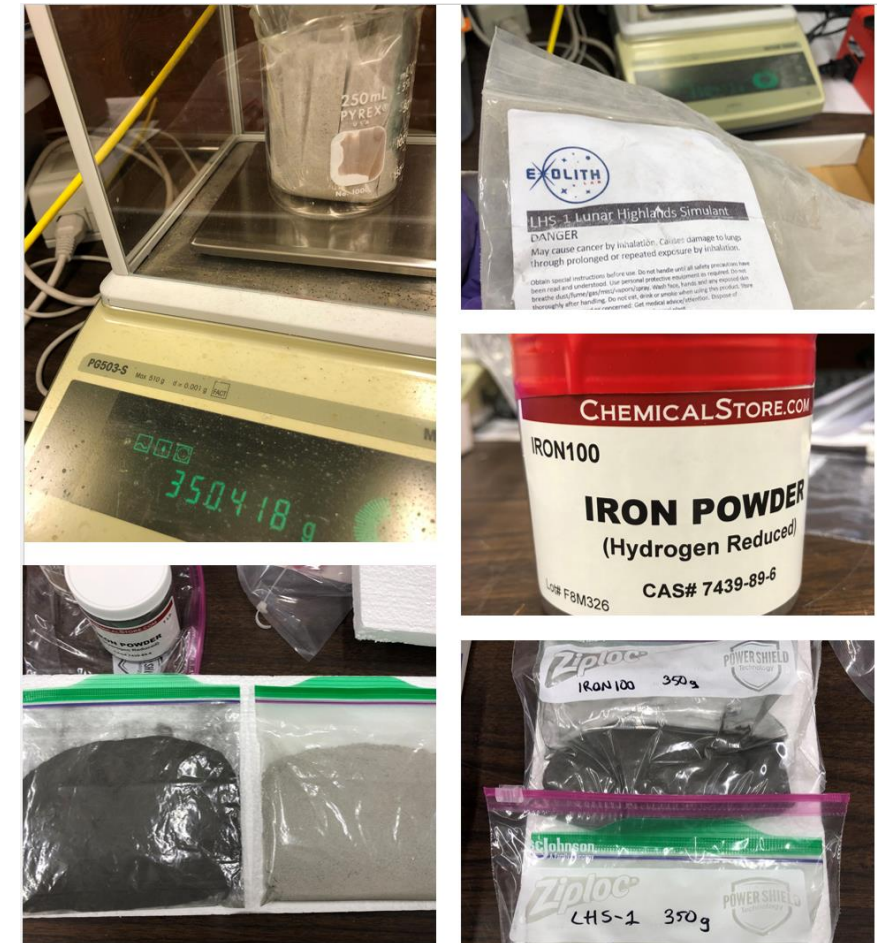


Onboard Charger Assembly Transmitter Assembly

Accomplishments

➤ Objective 2: The program shall demonstrate wireless charging as a feasible means of power transfer for lunar missions.

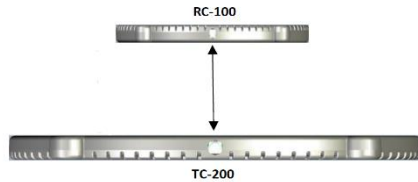
- **University of Washington** has supported **Astrobotic** by studying and characterizing the system's response to regolith and mispositioning
- Results have shown that the system can respond and dynamically tune to compensate for extreme quantities of regolith between coils. Including samples with added regolith content to maintain optimum efficiency
- Fringe cases with pure iron power of varying density and particle sizes were shown to impact efficiency, but did not completely impact the ability to transfer power



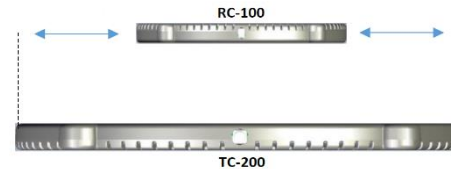
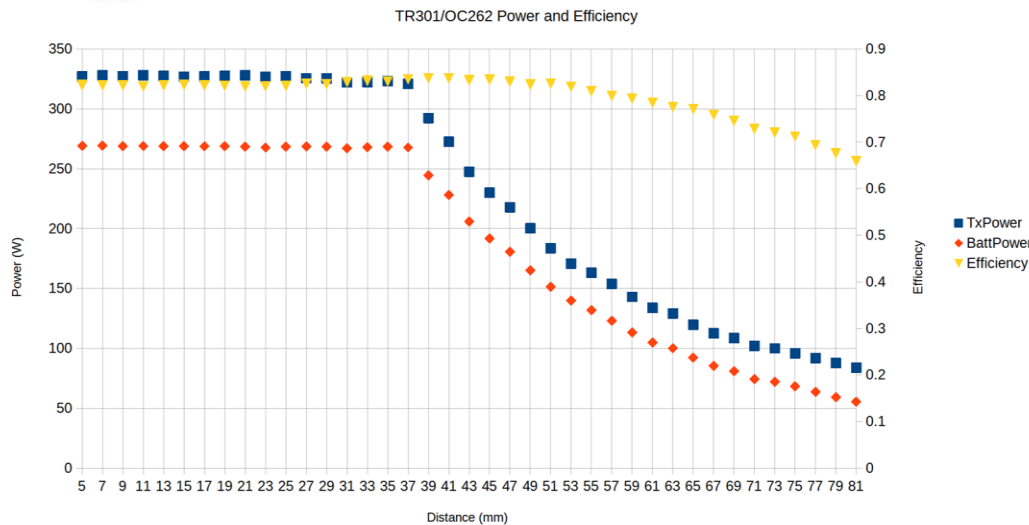
Accomplishments

➤ Objective 2: The program shall demonstrate wireless charging as a feasible means of power transfer for lunar missions.

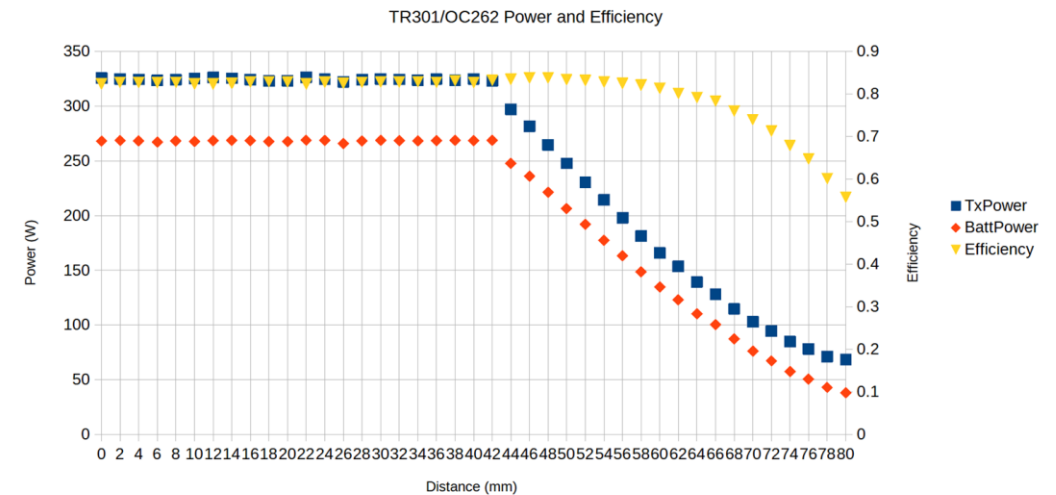
- Additional work has been done to characterize the coils tolerance for misalignment.
- **4 cm of offset** in both the longitudinal and latitudinal, as well as up to **40 degrees of angular misalignment** can be tolerated with little to no impact to transfer efficiency, simplifying robotic and crew lunar ConOps



Coil to Coil Longitudinal Distance



Coil to Coil Lateral Distance

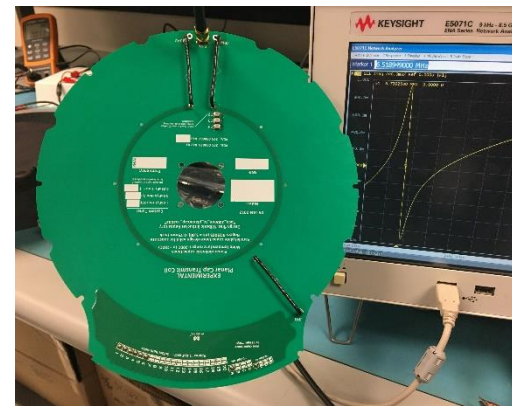
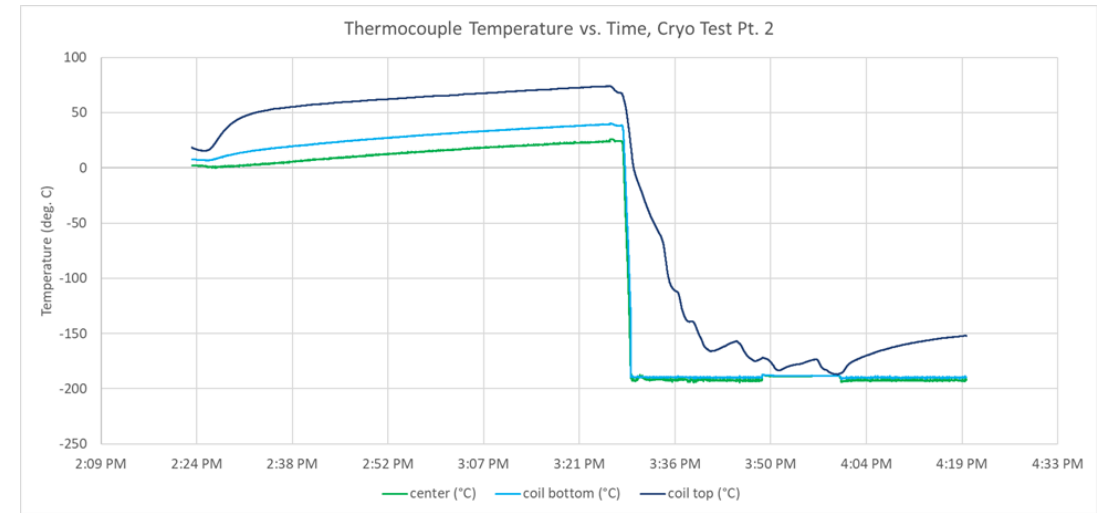


Accomplishments

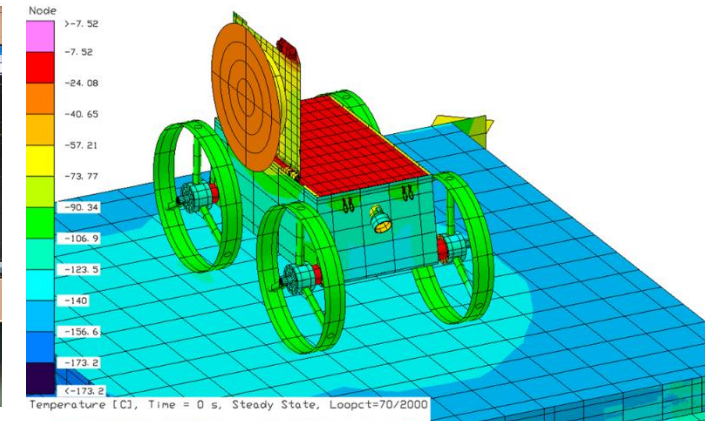


➤ Objective 3: The program shall demonstrate wireless charging as a feasible means of night survival for lunar surface assets.

- Early in the year, **NASA GRC and Astrobotic** collaborated on a study to characterize the amount of energy and power required to keep an Astrobotic CubeRover (ref. mission) alive through the lunar night. The study concluded that a UFPC equipped CubeRover had the ability to maintain survival temperatures through the night. Key areas of improvement were identified for the charger.
- The most critical of which was upgrading the temperature tolerance of the exposed transmitter coils
- **WiBotic** has since developed a novel coil design that leverages passive design and materials with deep space heritage to vastly improve temperature tolerance
- **Astrobotic** subjected the coil to direct exposure to liquid nitrogen during operations and verified coil operating temps down to **-189 C**



Updated coil design for lunar night operations

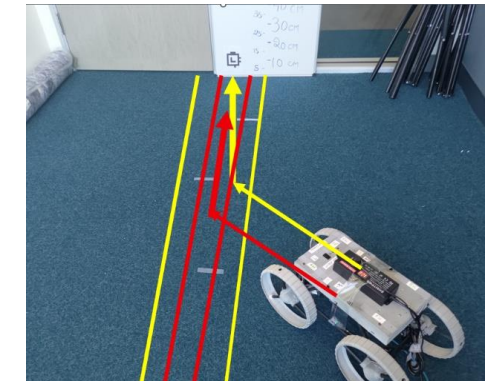
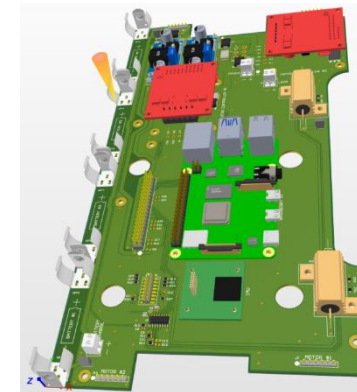


Thermal model of a CubeRover and integrated UFPC analyzed in partnership with GRC for lunar night feasibility

Accomplishments

➤ Objective 3: The program shall demonstrate a self-docking algorithm that enables CubeRover to align wireless charging antennas without the need for direct drive commands.

- While the system can support any space application where power is transferred, **Astrobotic's** tipping point team will develop software to streamline integration with a CubeRover, including software to autonomously dock and optimize position
- **Bosch** leads the development of this software using CubeRover's camera or a multi-sensor fusion to localize and path plan to the rover's home base to charge
- Work to date includes the development of a low cost CubeRover analogue for algorithm development, and an extensive series of experiments in optimizing visual fiducial recognition and lighting.
- The rover is currently capable of recognizing its base and docking; however, optimization of path planning and increased sensor fusion robustness will continue into early 2023



A low cost CubeRover analog was designed and built for development of docking autonomy



Fiducial Visibility at Various Ranges

Project Assessment Summary



Project Name	Performance				Comments
	C	S	T	P	
Mid Year	G	G	G	G	Technical – All technical TRL advancements remain on target Cost – Budget remains on or slightly under target for all concurrent tasks Schedule – Critical path remains on target Programmatic – All programmatic elements remain stable
Annual	G	G	G	G	Technical – All technical TRL advancements remain on target Cost – Budget remains on or slightly under target for all concurrent tasks Schedule – Critical path remains on target Programmatic – With the resignation of the previous PI, this item was very briefly yellow, but the position was filled right away and transitioned back to green before any issues were allowed to occur

Plans Forward and Transition / Infusion Plan



- Following completion of the Tipping point program, **Astrobotic** and **WiBotic** will maintain joint IP ownership of the Space Rated UFPC system.
- **Astrobotic** will act as a channel partner offering commercial sale of the system to government and private spacecraft integrators.
- The system has currently been infused into the Pilot Excavator tech demo flight mission in 2026

Astrobotic Wireless Power
Receiver Coil

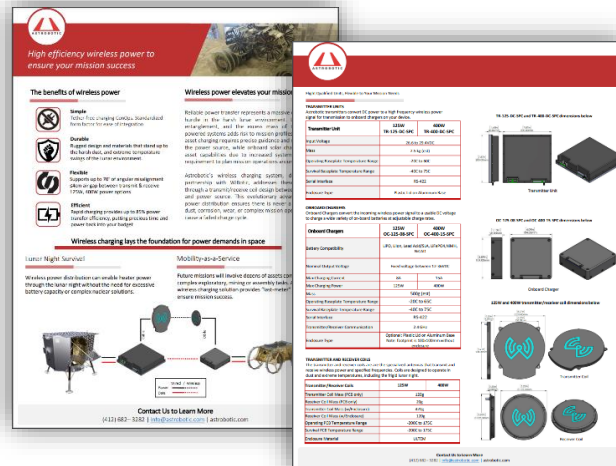


Education/Public Outreach



EPO Involvement

- Astrobotic has maintained a very active role in providing presentations and product demonstrations to generate awareness of the product's capabilities.
 - Lightning talks, abstracts, and workshops centering around the UFPC and related technology have been a part of recent LSIC meetings and workshops
 - Astrobotic has maintained presence at conferences such as Lunar Exploration Analysis Group (LEAG), Space Photovoltaic Research and Technology (SPRAT), and Keystone Space Collaborative presenting and distributing literature centered around the UFPC's capabilities

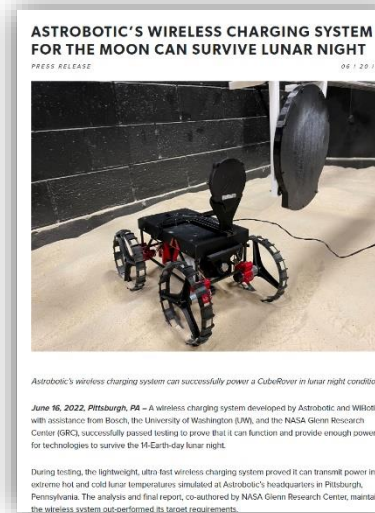


EPO Calendar Outlook (High Priorities):

6 Month Look-Ahead

Global Clean Energy Action Forum (GCEAF)

September 20, 2022



Product demonstrations and presentation:

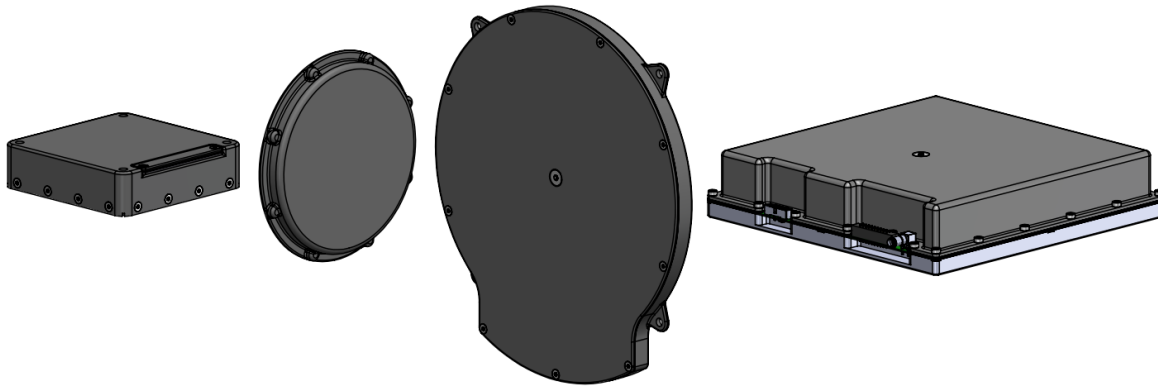
- Members of NASA Office of the Administrator including Bill Nelson
- Heads of the NASA Mission Directorates
- KSC Swamp Works
- NASA xEVAs portfolio management
- NASA ESDMD Artemis
- Multiple members of industry



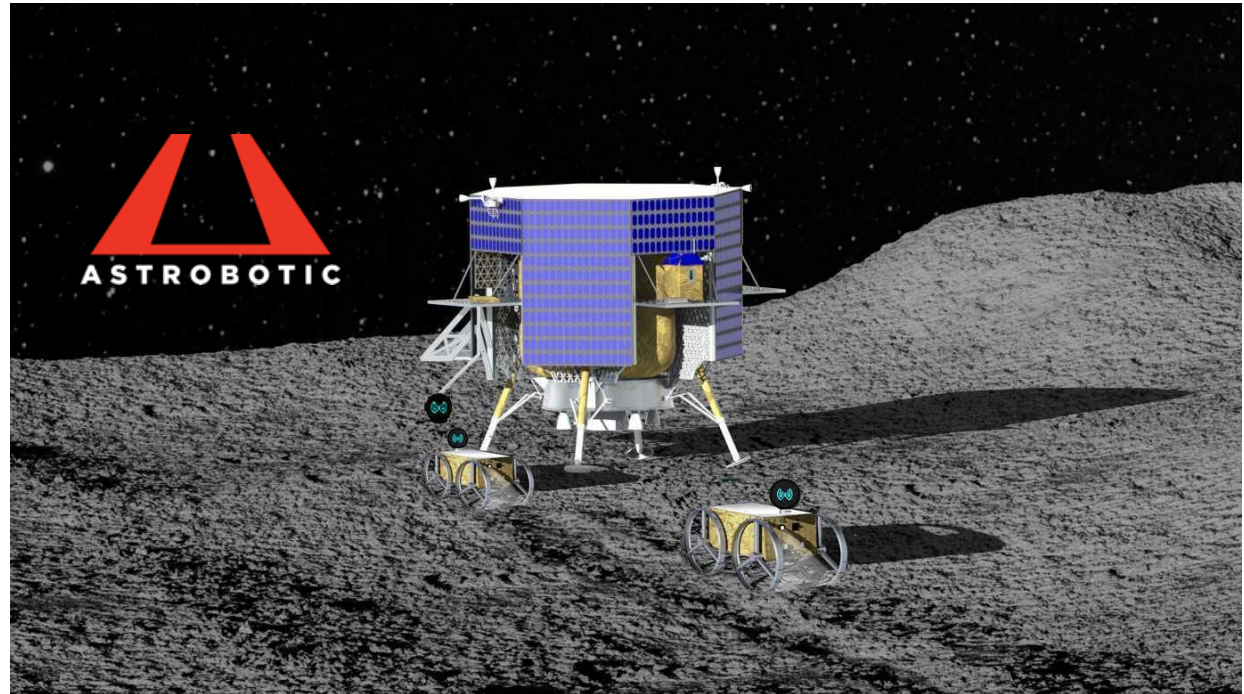
Summary



- The program has seen major success and is proceeding very close to baseline in all criteria. This signals a strong sign for program success,
- This Tipping Point aims to conclude with the promise of a high-quality, TRL 7 product with substantial commercial viability in Space applications.



CAD Models of Major UFPC Sub-systems



A rendering of an Astrobotic Peregrine lander serving as a UFPC host for CubeRovers cooperating on the lunar surface