National Aeronautics and Space Administration

Dynamic Radioisotope Power Systems Status and Path to Flight

Conference on Advanced Power Systems for Deep Space Exploration

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Project Goal

Utilize dynamic energy conversion technology to manifest a next-generation Radioisotope Power System (RPS) for Planetary Sciences

- Conversion efficiency (thermal-to-electric) up to 40% has been demonstrated
- Non-contacting bearings and seals (enables long-life continuous operation)
- Zero degradation via elimination of wear mechanisms
- Macroscopic engineering challenges (high-temp materials, high-cycle fatigue)
- Long-life, maintenance-free capability demonstrated in laboratory:

Electrically-heated DRPS test station at NASA GRC

Test Article	Years of Operation
TDC #13	14.0
TDC #14	12.1
TDC #15	13.9
TDC #16	13.9
SES-2	1.8

Test Article	Years of Operation
ASC-0 #3	10.6
ASC-E3 #4	5.4
ASC-E3 #9	3.8
ASC-L	6.3

Cumulative runtimes on various Stirling convertors at NASA GRC
Left – Flexure Bearing Designs
Right – Gas Bearing Designs

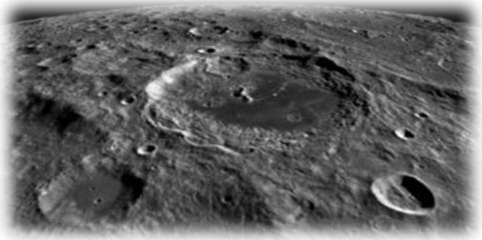
Multi-Mission DRPS Requirements

- Requirements were previously in draft form, and have recently been officiated
- Developed via an interagency team representing mission designers, and Department of Energy
- May be tailored for a 1st mission (i.e. Lunar application design life is only 2 years)

Category	Requirement
Power Output	100 to 500 W_e at Beginning of Life (BOL)
Design Life	17 years (3 yrs storage + 14 yr mission)
Mission Capability	Deep space, Lunar, Mars, Titan, Europa, Enceladus
Efficiency	>20% at T_{cold}>100°C
Specific Power	2 W_e/kg
Fault Tolerance	Single fault tolerant
Degradation	<1.3% per year
Random Vibe	Per GEVS (< 14.1 g_{rms}, depends on mass)
Static Accel	20g for 1 minute, 5g for 5 days
Radiation	100 krad TID


Europa


Titan

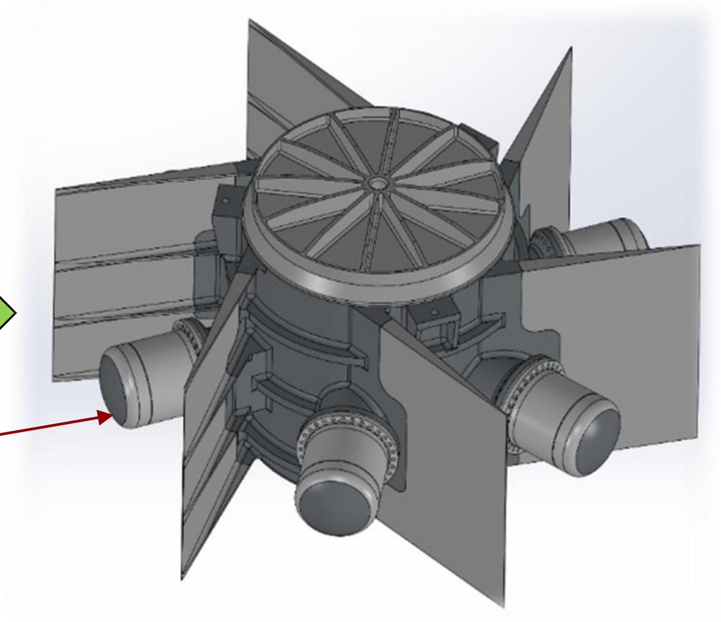

Lunar
(Far side & South Aitken Basin)

Recent Generator Design Progress

Three ongoing dynamic conversion development contracts recently produced several viable generator designs

Flexure Isotope Stirling Convertor (FISC)

QTY 6



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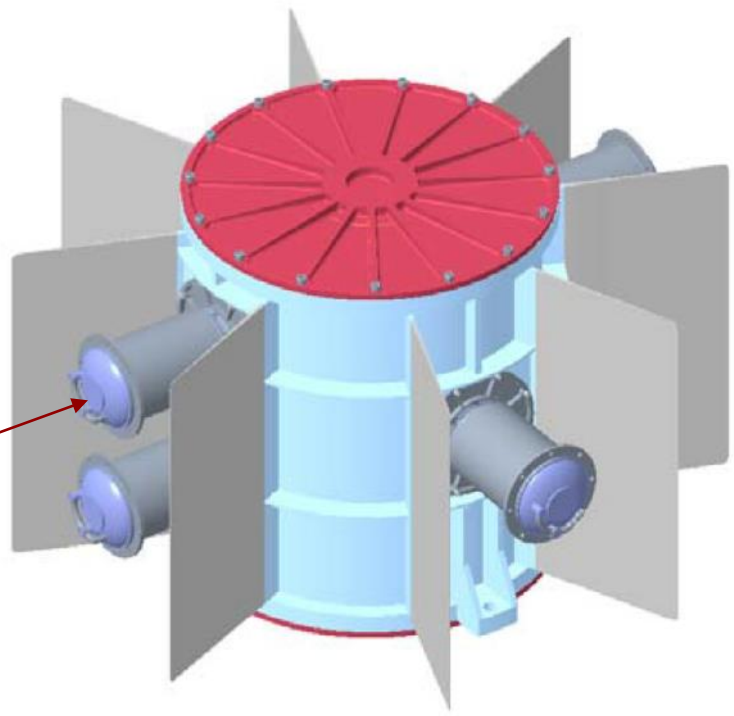
American Superconductor, Inc. with Teledyne Energy Systems	
Power	223 W_e
Efficiency	22%
Mass (w/o power conditioner)	66 kg
# of GPHS	4
Redundancy	50%

Recent Generator Design Progress

Sunpower Robust Stirling Convertor (SRSC)

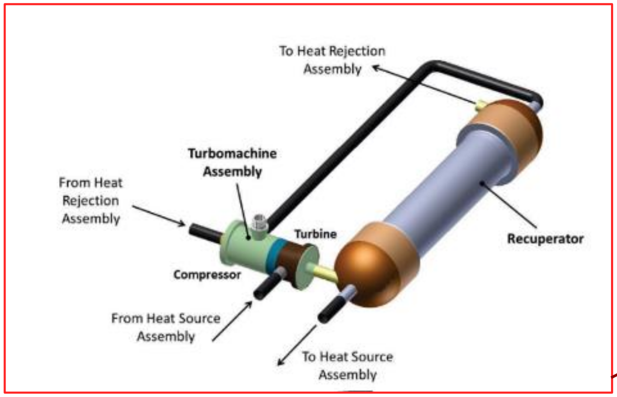
QTY
6



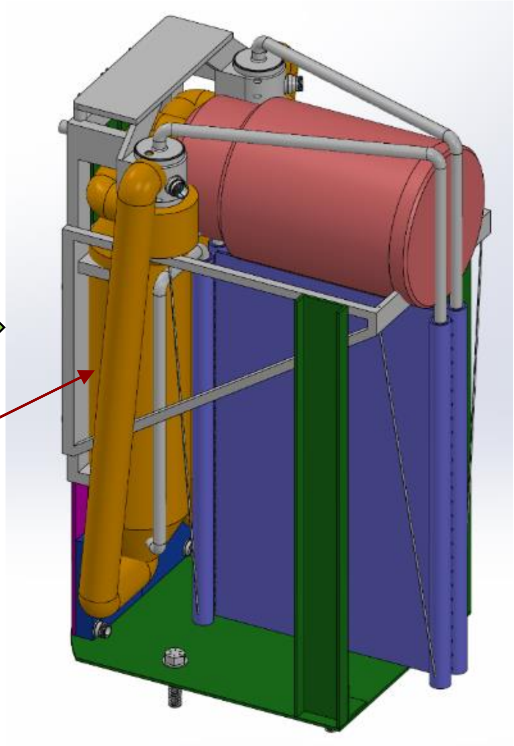
Sunpower, Inc. with Aerojet Rocketdyne	
Power	238 W_e
Efficiency	24%
Mass (w/o power conditioner)	49 kg
# of GPHS	4
Redundancy	50%

Recent Generator Design Progress

Turbo-Brayton Convertor (TBC)



QTY 2



Creare, LLC. with Aerojet Rocketdyne	
Power	319 W_e
Efficiency	21 %
Mass	133 kg
# of GPHS	6
Redundancy	100%

DRPS Sources Sought Notice

DOE released a Sources Sought Notice for DRPS providers August 2019
Industry Day Q&A held October 2019

- Purpose : Identify system contractors that could provide a DRPS with draft requirements, tailored for the Lunar mission application
- Interagency team evaluated responses, and determined 4 entities to be qualified bidders
- Requests for proposal will be sent to these qualified bidders in the near future
- **System integration contract will build and verify an electrically heated qualification unit**

Lunar mission is a good choice for first use of DRPS

- Short cruise, short design life, RPS enables lunar night survival
- However, Lunar equatorial is perhaps the most tortuous thermal condition
- Commercial Lunar Payload Services (CLPS) mission cadence offers several opportunities
- Tech Demo missions are viable
- DRPS could be used for lander power, or for the science payload, or both
- A system capable of a Lunar mission will likely be capable of all other planetary science missions

NASA GRC's In-house DRPS Testbed

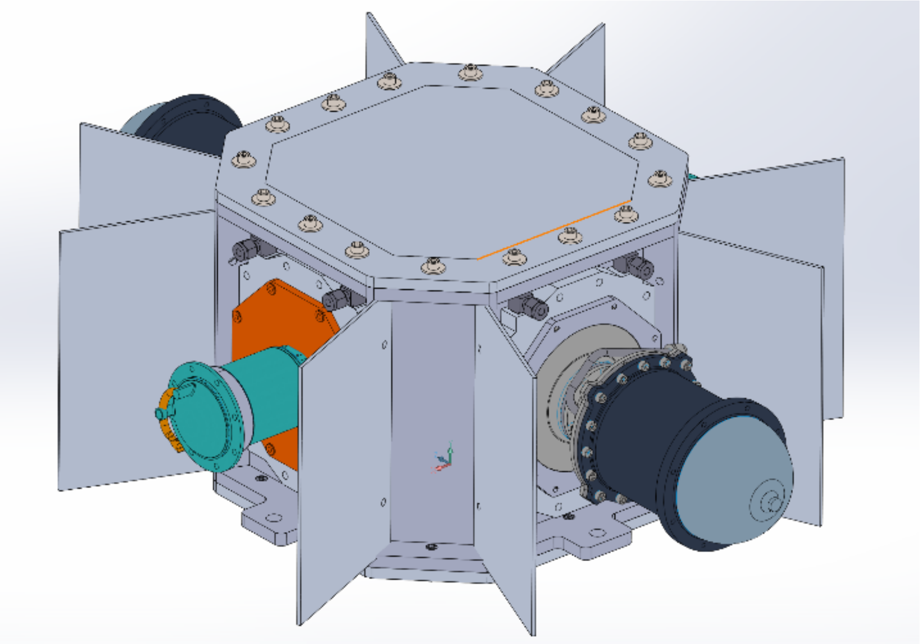
The Thermal Energy Conversion Branch is building a DRPS testbed with in-hand Stirling convertors, to demonstrate the latest system topology

- Will utilize available spare Stirling-cycle machines
- Will enable compelling range of tests not previously possible, that would not be possible until well into a system-development contract:
  - Balancing of the radial array of convertors
  - Disabling one pair and throttling up the other pair (convertor-level redundancy)
  - Convertor redundancy is a critical and compelling feature to encourage the 1st use of dynamic energy conversion on a NASA mission
  - Radiant coupling of heat source to convertors
- Schedule:
  - March 2021: Design review, begin fabrication
  - November 2021: Assembly begins
  - March 2022: Testing begins

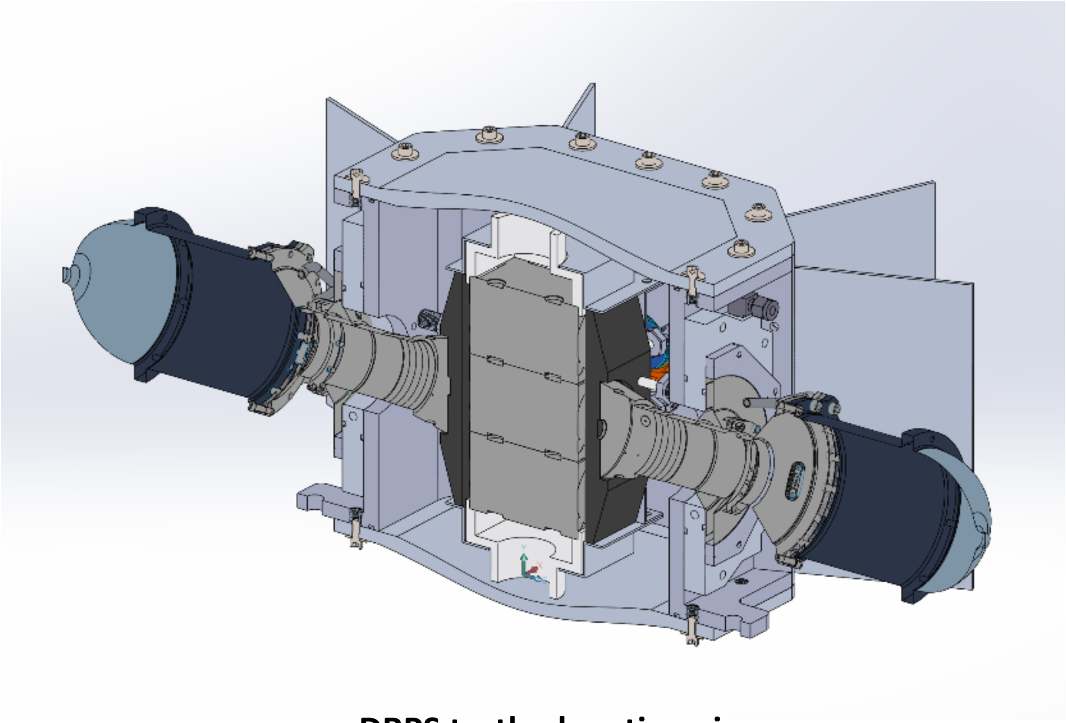
NASA GRC’s In-house DRPS Testbed

Requirements

- Radial array of free-piston Stirling convertors
- Allows integration of 2 to 4 Stirling convertors
- Centrally located electrical heat source, simulating 2 or 3 GPHS modules
- Radiant heat transfer coupling between electric heat source and convertors
- Maintains the cold-end convertor operating temperature below 100°C, with ambient natural convection
- The inner volume of the housing can be evacuated or filled with an inert cover gas
- Radiator fins are detachable
- Capable of attachment of passive balancers for the two in-plane axes



DRPS testbed



DRPS testbed section view

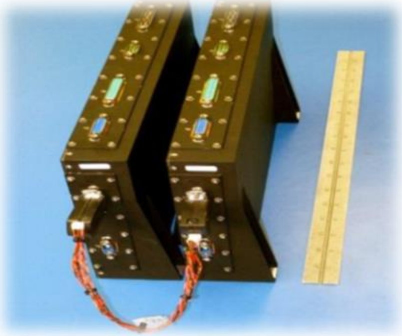
Controller Development

Dynamic energy convertor output requires power conditioning, and development of this hardware continues

- The recently developed DRPS requirements include new controller fault handling behavior to better mimic RTG characteristics
- Efforts focused on demonstrating availability of control designs that can be used for upcoming DRPS qualification unit contract

Dual Convertor Controller (DCC)

- Engineering unit hardware exists
- Predecessor has operated with Stirling machine for > 6 years
- Currently being upgraded to improve efficiency
- Status: Awaiting upgrades by APL



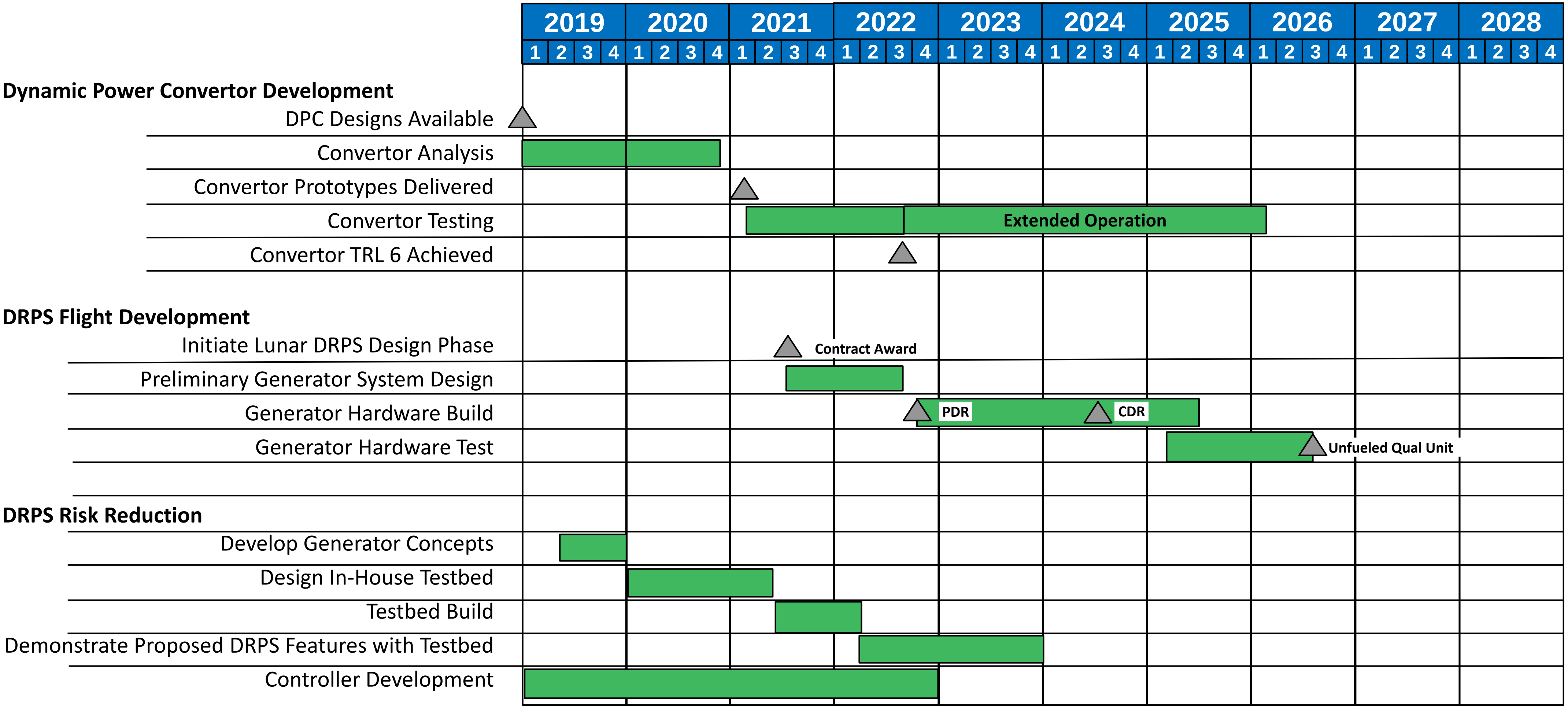
High Voltage Convertor Controller (HVCC)

- Enables DRPS with higher voltage convertor output (i.e. 50 V_{rms})
- Will incorporate latest fault tolerance requirements
- Status: Breadboard being designed

NASA Analog Controller (NAC)

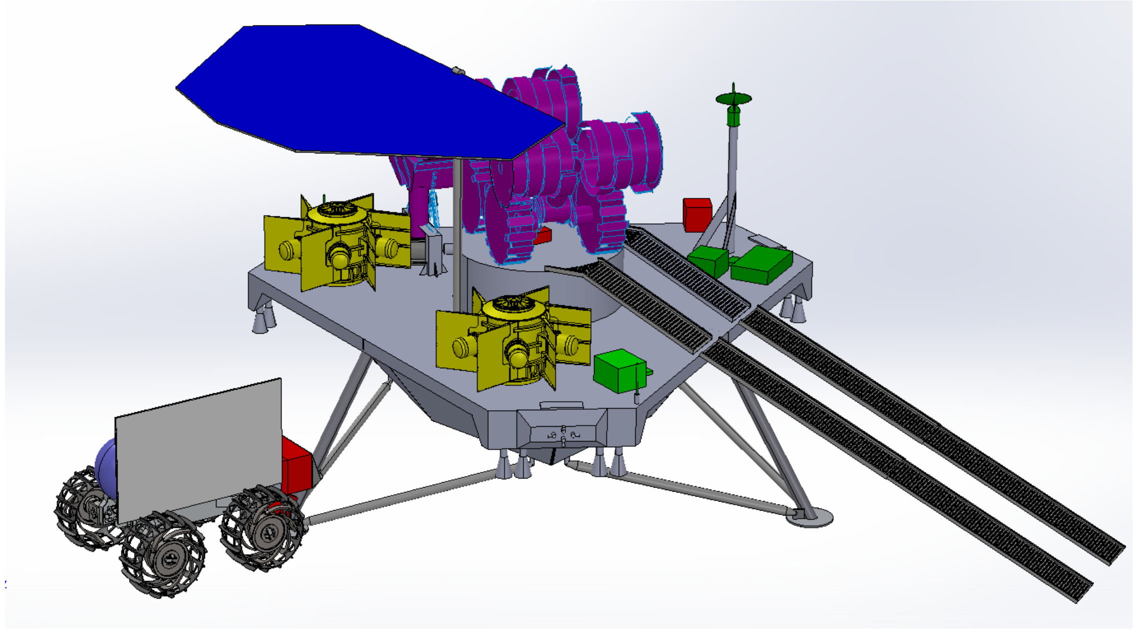
- In-house GRC design
- Analog components for simplicity and robustness
- Achieves most recent fault tolerance requirements
- Status: Hardware ready for laboratory testing with Stirling convertor

DRPS Notional Schedule

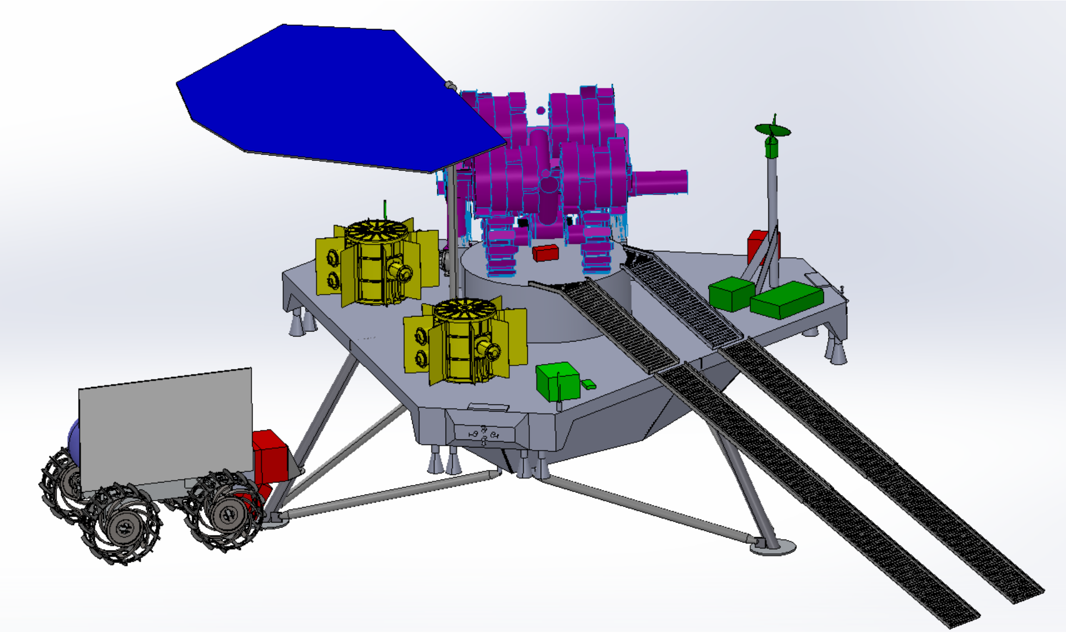


Summary

- DRPS has demonstrated viability for NASA missions via laboratory testing
- Ongoing dynamic energy conversion development contracts have produced system designs, in addition to their multiple conversion prototypes
- System integration contractors have been qualified via a Sources Sought Notice
- An RFP will soon be released to these qualified organizations
- The design phase of a Lunar DRPS contract will begin in FY21
- NASA GRC is designing and building a DRSP testbed to demonstrate the proposed topology and latest operational features being pursued
- Controller methods and hardware continue to be developed for future use in DRPS designs



2x DRPS on concept Lunar ISRU lander



2x DRPS on concept Lunar ISRU lander