National Aeronautics and Space Administration

Dynamic Radioisotope Power Systems Development and Potential First Mission Utilization

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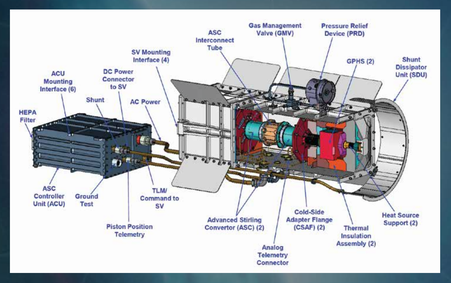
ABSTRACT

Dynamic power conversion offers the potential to significantly enhance Radioisotope Power System (RPS) performance. Potential improvements include higher conversion efficiency (more power per kg of Pu-238 fuel and less waste heat), low or zero degradation beyond fuel decay, and thus higher end-of-mission power. Degradation-free life of Stirling-cycle conversion has been demonstrated on the time scales required by several missions.

DYNAMIC POWER CONVERSION

- Stirling, Brayton, Rankine, Ericsson are suitable for space applications
- Conversion efficiencies demonstrated up to 40%
- 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)

ADVANCED STIRLING RADIOISOTOPE GENERATOR (ASRG)	
Development Timeframe	2006-2013
Heat Source	2 GPHS
Power	140 W_e (DC)
Efficiency	28%
Conversion Technology	Free-piston Stirling
Specific Power	4.4 W_e/kg



CONVERTOR PERFORMANCE GOALS

- Derived from Surrogate Mission Team input
- Encompasses wide range of potential Planetary Science Missions

CATEGORY	GOAL
Design Life	20 years
Efficiency	>24% at T_{cold}>100°C
Specific Power	≥20 W_e/kg
Partial Power	Enables conversion-redundant generators
Size	Enables 200-500 W_e generator
Degradation	<0.5%/year
Hot-end Temp	<1000°C
Cold-end Temp	20-175°C
Random Vibe	Launch qual (14.6 g_{rms})
Static Acceleration	20g for 1 minute, 5g for 5 days
Radiation	300 krad
Robustness	Ample margins, tolerant of user error

PATH TO FLIGHT DEVELOPMENT

PHASE	DURATION	WORK FOCUS	TRL
1	6 months	Design	4
Decision Gate 1			
2	18 months	Prototype Fabrication Performance Demonstration	4, 6
3	12-24 months	IV&V Test Support	6
Decision Gate 2			

GOAL: Begin Flight Development 2021

RECENT CONVERTOR DESIGNS

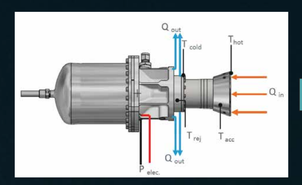
FLEXURE ISOTOPE STIRLING CONVERTOR (FISC) American Superconductor, Inc.	
Power	70 W_e
Efficiency	31%
Hot-end	650°C
Specific Power	21 W_e/kg

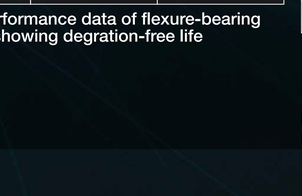
TURBO-BRAYTON CONVERTOR (TBC) Creare, LLC	
Power	355 W_e
Efficiency	26%
Hot-end	730°C
Specific Power	22 W_e/kg

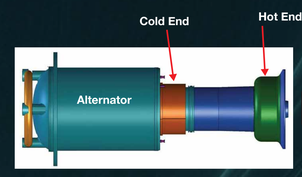
SUNPOWER ROBUST STIRLING CONVERTOR (SRSC) Sunpower, Inc.	
Power	65 W_e
Efficiency	29%
Hot-end	720°C
Specific Power	33 W_e/kg

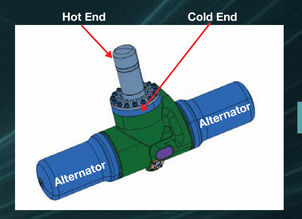
THERMO-ACOUSTIC POWER CONVERTOR (TAPC) Northrup Grumman Aerospace Systems	
Power	110 W_e
Efficiency	26%
Hot-end	700°C
Specific Power	19 W_e/kg

CONVERTORS

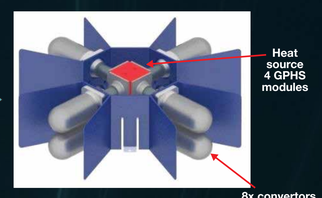


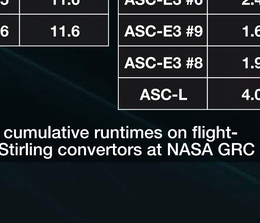


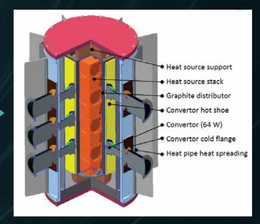




NOTIONAL GENERATOR DESIGNS







MISSION POTENTIAL

- Dynamic power conversion has never been flown in space
- Analogous cryocoolers have operated for up to 20 years in space
- First mission could be much shorter than outer planets (3 yrs vs 20 yrs)
- Lunar mission as flight demo is viable
  - Short cruise time, several destinations that require RPS, short mission duration
- For short missions, life with margin has been demonstrated at flight-prototype level
- For long missions (>15 years), demonstrating 2x life is unrealistic
- First mission must accept some amount of risk, which can be burned down
- Flightlike Stirling convertors have operated in lab setting for over 12 years (at full temp and power)
- NASA GRC test article holds all-time world record for heat-engine runtime (>110,000 hrs)

Flexure-bearing Stirling convertor continuous operation test article

Date	2010	2016
TDC #13	65.4 W	65.4 W
TDC #14	64.5 W	64.5 W

Example performance data of flexure-bearing convertors showing degration-free life

Test Article	Years of Operation
TDC #13	12.6
TDC #14	12.1
TDC #15	11.6
TDC #16	11.6

Test Article	Years of Operation
ASC-0 #3	8.3
ASC-E3 #4	3.1
ASC-E3 #6	2.4
ASC-E3 #9	1.6
ASC-E3 #8	1.9
ASC-L	4.0

Example cumulative runtimes on flight-relevant Stirling convertors at NASA GRC