The Challenges Facing Future Power Conversion Systems for Space Power Applications

Abstract

High-efficiency, Stirling power convertors have been proposed for space power applications, ranging from the relatively low-power radioisotope generators such as the 110 watt SRG110 to the higher-power 100 kWe SP-100. The NASA Glenn Research Center (GRC) has been involved in the supporting technology and development for both of these systems. Although the power levels are quite different, many of the challenges faced by both of these dynamic power conversion systems very similar. A major challenge is found in demonstration of the capability for high reliability and long-life of the power system when the wear mechanisms have been eliminated. A review is presented of the past efforts, including the status of current flight development efforts, and a projection of what the future might bring.

The Challenges Facing Future Power Conversion Systems for Space Applications

- Stirling Development -

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by

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Outline

- Stirling background
  - History
- Development status
  - Previous development efforts
- System analysis overview
  - Future updates needed

Free-Piston Stirling History

- Free-Piston Stirling was invented in mid 1960's
- Free-piston implies that the moving components resonate without a linkage
- This eliminates some losses mechanisms (seals, lubrication pumps, etc)
- Allows all wear mechanisms to be eliminated
- Operates at design resonant frequency
- Generally
  - 1960's Success was getting an engine to resonate
  - 1970's Success was combining engine to alternator or other load to form a Stirling convertor
  - 1980's Success was getting the convertor to operate per the design
  - 1990's Success was demonstration of efficiency and mass goals
  - 2000 and beyond – System integration

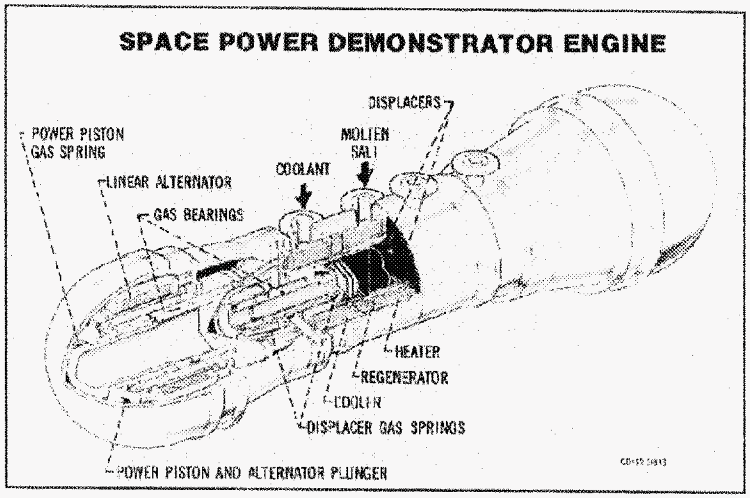
The pace of development is not surprising considering the highly integrated nature of the machine

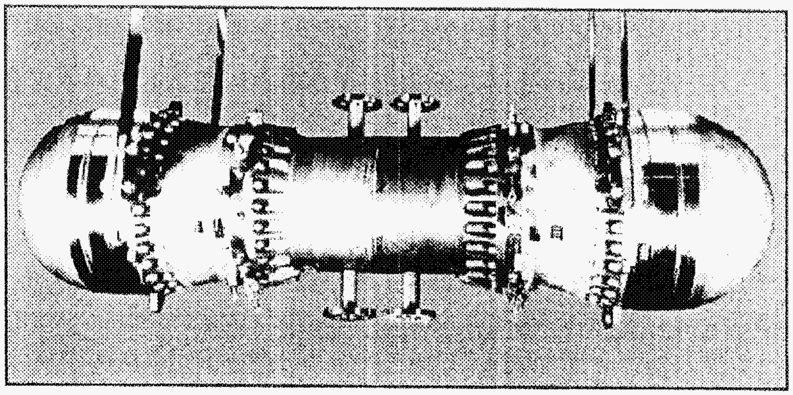
	Concept study at NV Philips	Free-piston engine first operation	Operate but unpredictable, initial work on load	Operate properly following some development	Operate with minimal development	Development into deployed systems
	1950's	1960's	1970's	1980's	1990's	2000's
Significant Stirling convertors of the era			RE-1000	Space Power Demonstrator Engine	Component Test Power Convertor	EG-1000, RG-1000, Technology Demonstrator Convertor

The SPDE

SPDE *(Space Power Demonstrator Engine)*

- Demonstrated 13 kW per piston (SOA was 3kW)
- Demonstrated opposed-synchronous operation with common expansion space for dynamically balanced operation
- Demonstrated high efficiency operation at low temperature ratio of 2.0
- Demonstrated non-contacting gas bearings for long life operation
- Designed for nominal room temperature at cold end, therefore ran at ~650K/325K (377ºC/52ºC)
- Used molten salt at hot end, water at cold end through tube and shell heat exchangers
- Designed and built in 16 months by Mechanical Technology Incorporated

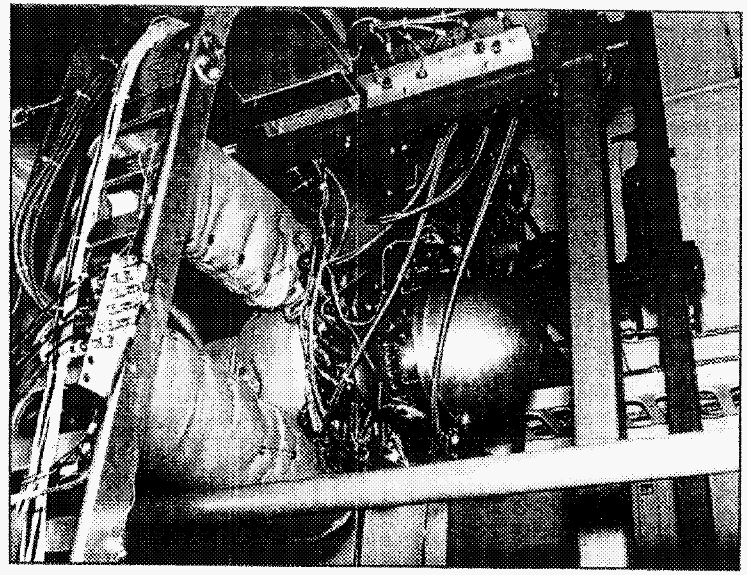


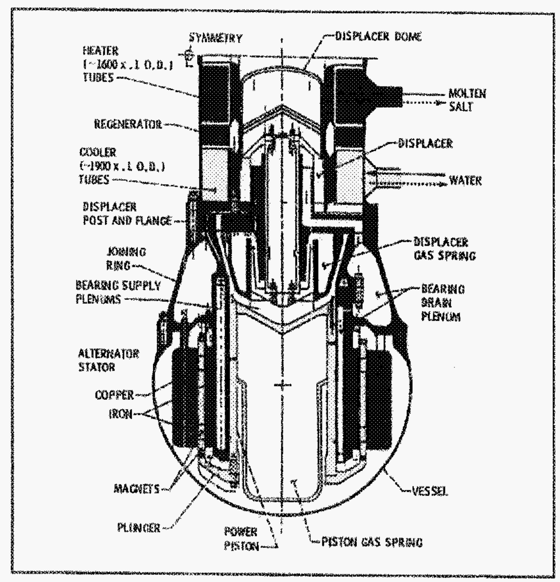


The SPRE

SPRE *(Space Power Research Engine)*

- SPDE was converted into two SPRE's
- Achieved over 12.5 kWe power per cylinder and ~17% efficiency
- Dynamic balancer was designed and tested
- Research was performed with the casing attached to a mass to reduce vibration since dynamically balanced operation had been successfully demonstrated
- Research sensitivity to changes in heat exchanger and bearing configurations
- Demonstrated operation with both hydrostatic and hydrodynamic bearings
- Data was used to further validate codes
- Reduced mass linear alternator was designed, fabricated, and rig tested

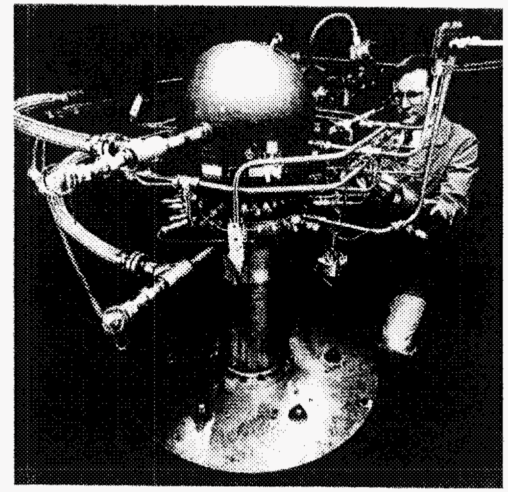




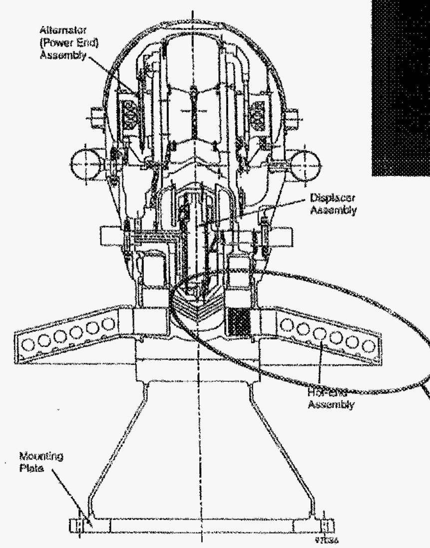
The CTPC

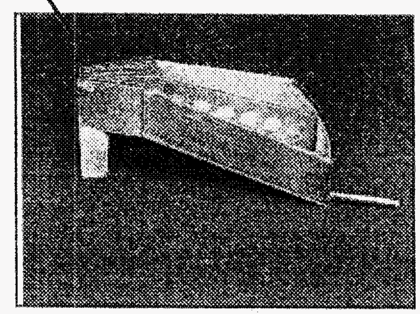
CTPC *(Component Test Power Convertor)*

- Designed for temperature ratio of 2.0 at 1050K/525K
- Heater head was designed to use Udimet 720
- Test hardware was fabricated with IN718 for ease of fabrication and initial demonstration
- Achieved performance goals of 12.5 kWe / 22% efficiency "out-of-the-box" (heat in to AC electric output)
- 1500 hour test completed at 800K/400K with brief testing at 1050K/525K (777ºC/252ºC)
- Tested with sodium heat pipe integrated into "Starfish" heater head to minimize hot-end joints
- Cold-end interface was prototypical for a pumped loop



Half of a CTPC being prepared for test





The CTPC

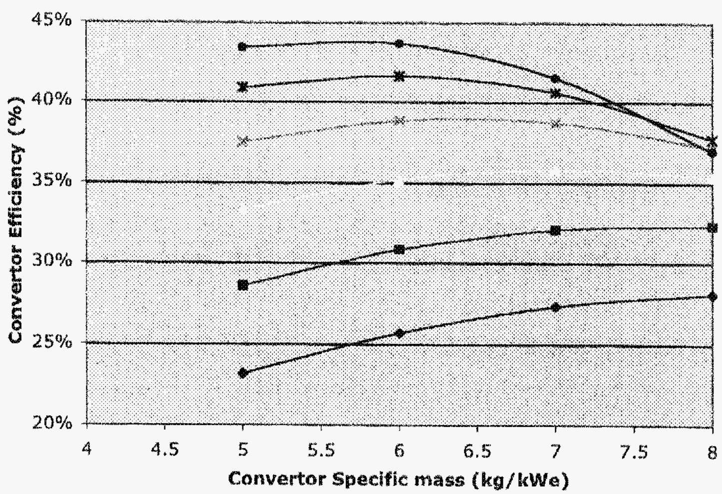
CTPC *(Component Test Power Convertor)*

- Intended for integration with a lithium loop supplying heat from the reactor
- Two lithium-to-sodium heat exchanger design concepts were developed and documented
- Design challenges were in the Starfish heater head and elevated temperature of cold end
- Main challenges remaining include the long-life Ud720 heater head (primarily joining) and ceramic-coated coils for long life at 525K
- 1300K version shown on the roadmap, but there was never a complete design
- Effort ended as the SP-100 and CSTI projects were terminated
- Hardware maintained in storage at GRC
- Program summary and large reference list in "Stirling Space Engine Program", vols. 1 & 2 by Dhar

Scaling Study

- Based on ~1990 technology and limitations, MTI published the Stirling Scaling Study
- To maintain confidence, the range was limited to 5 kg/kWe
- Since that time, significant improvements have been demonstrated in convertors designed for non-nuclear applications
- The currently available Stirling trade space needs to be assessed
- Indicated feasibility up to 150 kWe per piston

Convertor Efficiency as a Function of Temperature Ratio and Specific Mass

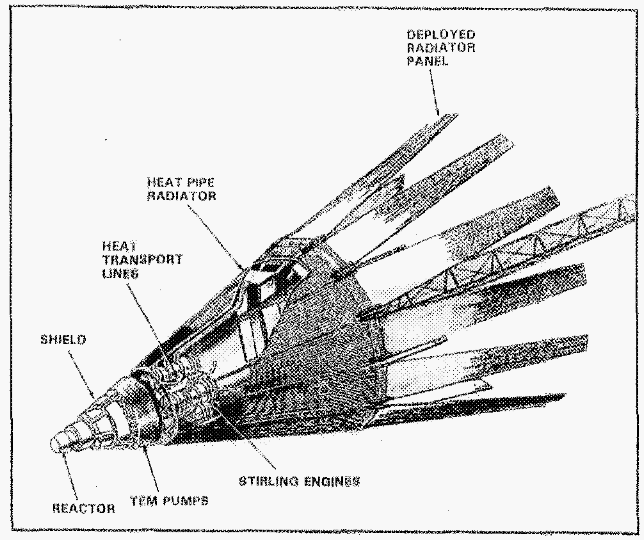


- Based on Scaling Study performed by MTI following development of the CTPC
- Relationships are validated by CTPC hardware

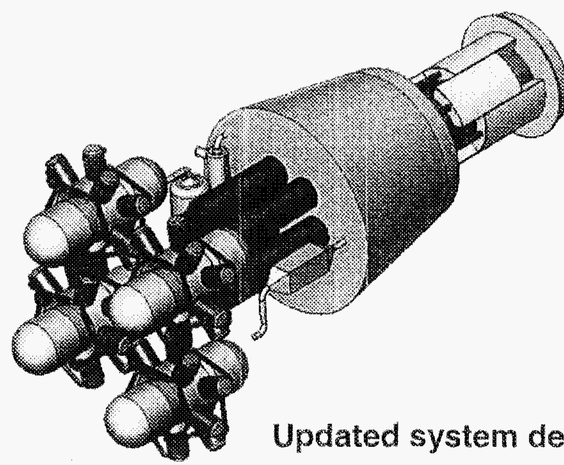
System Analysis

Need to look at:

- Liquid metal reactor coupled to a Stirling convertor
- Perform trades to find minimum mass system
  - 50 kWe to 300 kWe net output
- Baseline Component Test Power Convertor (CTPC) for performance and efficiency trades
- Perform "What if" analysis by updating the CTPC to current SOA performance (i.e. improved efficiency and lower mass)
- Assess the pros and cons of a Stirling based system
  - Sensitivity to radiator area
  - Redundancy
  - Thermal integration
  - Power management & distribution
  - Power turn-down ratio
  - Efficiency at off-nominal operating condition



SP-100 era system design



Updated system design

Conclusion

- What has been completed:
  - Demonstrated high conversion efficiency
  - Demonstrated high temperature operation
  - Demonstrated 7 kg/kWe
  - Technology for significant mass reduction exists
  - Demonstrated long life heat pipe interface
  - Design completed for hot end thermal interface to reactor
  - Potential for improved specific mass with increase in frequency