NOVEL STIRLING POWER SYSTEMS FOR EXTREME ENVIRONMENTS. R. W. Dyson[1],
[1]NASA Glenn Research Center, 21000 Brookpark Road, Cleveland OH 44135, Rodger.W.Dyson@nasa.gov.

Introduction: Extreme environmental conditions including high temperatures and radiation fields have limited the range and duration of solar system exploration. This is due to the many practical limits encountered with electronics, instrumentation, materials, organics and other space vehicle components. While much progress has been made in the development of radiation hardened components, high temperatures are still a limiting factor.

In response, NASA GRC began the development of a combined power and cooling system that is intended to operate in very high temperatures while providing the cooling protection necessary for sensitive components[1]. This report will describe the development path taken for this effort and provide some key findings to date.

Specifically, three new Stirling Duplex systems were designed based on thermoacoustic, free-piston Stirling, and a novel free-displacer Stirling concept; a new extreme environment testing chamber was constructed for Technology Readiness Level 6 demonstration; a new five feature variable conductance heat pipe was demonstrated that enables multiple stops and restarts of the RPS system[2]; and a novel Stirling convertor with no moving parts was proposed.

These designs and their implication for enabling exploration to high temperature locations such as Venus[3], Jupiter's troposphere, Io's volcanoes, and other large gaseous outer planet targets are included.

Current Limitations: It is well known that the choice of power system technology for a spacecraft depends on the required power level and expected mission duration. The range of technologies include solar, chemical, radioisotope, and nuclear fission. And complementing each of those power sources are a variety of power conversion options including photovoltaic, thermophotovoltaic, thermionic, thermo-electric, regenerative fuel cell, Stirling, Brayton, and other static and dynamic energy conversion devices. In all cases, external temperatures exceeding 300°C impose a barrier that limits their successful operation. For example, devices with magnetic and organic components either fail or degrade in performance. And in those cases in which the power system can operate in such temperatures, the supporting spacecraft components cannot. Hence it is important to provide both power and cooling.

Approach: Of all the possible power and cooling options, one based on the Stirling cycle offers the most efficiency in a hot environment[1]. One such configuration is shown in Fig. 1. In this configuration both the power and cooler are based on the Stirling cycle and two-stage cooling is employed[4]. The challenge for a location such as on the surface of Venus is to design a Stirling convertor that can operate at temperatures exceeding 1050°C in order to reduce the quantity of Plutonium-238 required. This can be achieved through the use of novel single crystal super-alloys (see Fig. 2) and advanced Stirling configurations. Several such new configurations have been demonstrated with lower temperature prototypes and a full-scale design has been developed but not fabricated yet. The prototype hardware results and the predicted full-scale performance will be shown in the presentation.

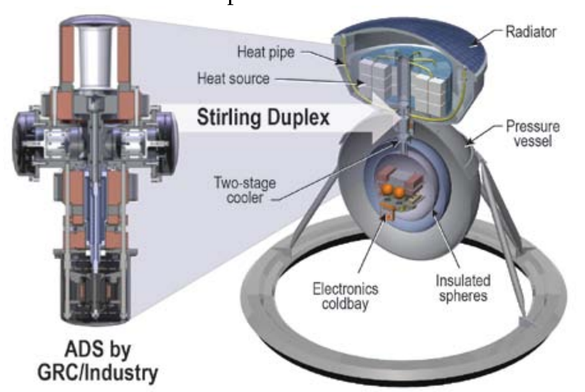

Figure 1. Stirling Power and Cooling System in a Lander

Stirling Improvements: One of the more significant developments in recent Stirling heat engine history has been the reduction in the number of moving parts required to achieve a Stirling power cycle. As shown in Fig. 3, the trend has been towards less mechanical complexity. The most recent concept is a no moving part Alpha Stirling Thermo-acoustically Resonated Electro-acoustically Modulated (α-STREAM) Convertor shown on the bottom right in Fig. 3. These new concepts and their implications for planetary science will be highlighted in the presentation.

Conclusion: Extreme environment space exploration to hot locations requires the power and cooling systems presented in this work for extended in-situ operations. Moreover, the basic components for such a system have been demonstrated at low power and temperature. A full-scale design based on these components has been completed and is ready to be fabricated and tested. The supporting technologies for demonstrating Technology Readiness Level 6 have also been developed including an extreme environment facility.

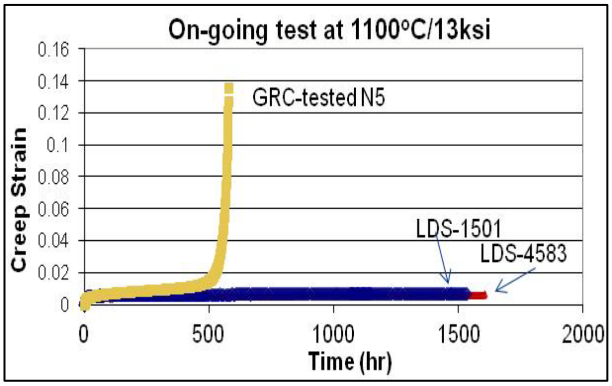

Figure 2. High Temperature Material Performance

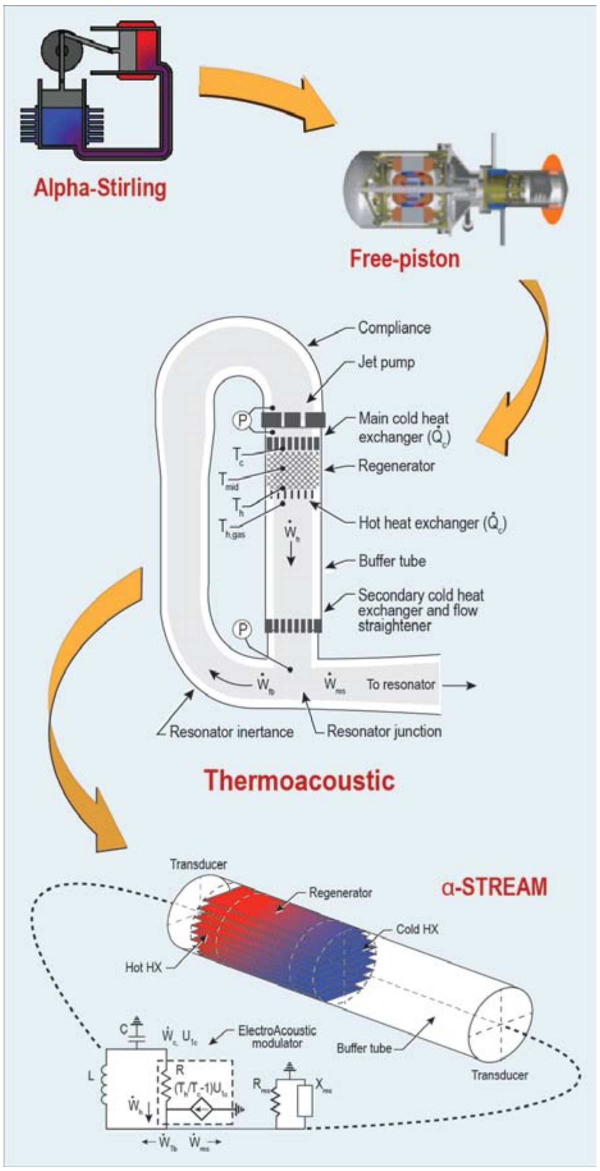

Figure 3. Stirling Technology Development Path

References: [1] Dyson R. W. and Bruder G. A. (2010) AIAA-2010-5917. [2] Tarau, C. (2011) AIAA-2011-5643. [3] Landis G., Dyson R.W., et al. (2011) AIAA-2011-7268. [4] Dyson R. W. (2009) AIAA-2009-4631