ASRG/DASRG Electrical Power Predictions in Lunar Environment. H. Noravian[1] and R. T. Carpenter[2], [1]ANALYTIX Corporation, 7 Chris Eliot Ct., Hunt Valley, MD 21030, HN4827@Gmail.com, [2]Orbital Sciences Corporation, 20030 Century Blvd., Suite 102A, Germantown, MD 20874, Carpenter.Robert@Orbital.com.

Introduction: The National Aeronautics and Space Administration (NASA) determined a need for Small Radioisotope Power Systems for (potential) future lunar applications. As a result, the Department of Energy (DOE/NE-75) formed a Lunar Radioisotope Power System Assessment Team (LRPSAT) to study the use of Small Stirling RPS or modified Advanced Stirling Radioisotope Generator (ASRG) for the International Lunar Network (ILN) missions, on the surface of the moon [1]. LRPSAT was chartered on March 20, 2009 with team members from Orbital Sciences Corporation (OSC), NASA/GRC, and with customer representatives from DOE and NASA.

In addition to the information from the then current ASRG project, LRPSAT used all pertinent technical information, especially, thermal mathematical models and Stirling generator specific concepts from prior OSC studies, namely, ASRG design concepts, NASA NRA 2005 [2], and ASRG Lunar Applications in 2007 [3].

The details of the ASRG design iterations are documented elsewhere, for example in [1] and many other (Lockheed Martin, Valley Forge (LMVF)) documents.

The ASRG baseline design consists of two ASCs (designed by SUNPOWER, Athens, Ohio), two fully fueled (250 W_t) Step 2 GPHS modules, and thermal insulation (Microtherm HT). The components are packaged inside beryllium housing with corner fins, as shown in Figure 1. The Active Controller Unit (ACU) is located outside the generator housing. The GPHS modules are located at each end of the housing, which are surrounded by thermal insulation and are under axial preloads via two studs and two back-to-back ASCs with an interconnect sleeve. The thermal interfaces between the GPHS modules and the hot ends of the ASCs are via Nickel heat collectors. The intent is to direct as much thermal energy into the ASC's hot ends as possible to maximize electrical output power. The waste heat from each cold end (~ 150 W_t) is transferred out of the convertor via Cold Side Adapter Flange (CSAF). For the details of the ASC design and operation, one has to contact and/or refer to SUNPOWER's numerous publications in the open literature.

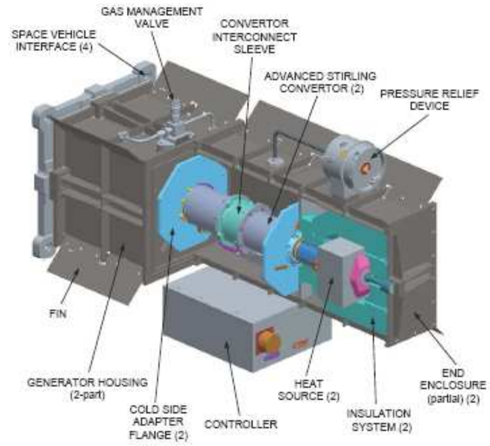


Figure 1. EU ASRG Design Features (2007)

For a single Stirling RPS, shown in Figure 2, a passive balancer is necessary to absorb and/or minimize the single convertor's axial vibrations. Moreover, since this design is derived from the ASRG, it is called Derivative ASRG (DASRG).

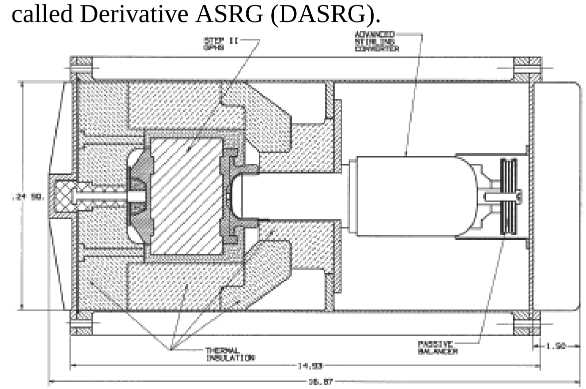


Figure 2. DASRG Design Concept (Square Housing)

In order to assess the performances of the ASRG, DASRG, and other configurations, such as a single ASC inside a full-ASRG housing, we need to have: (1) a reasonably accurate 3D thermal model of each of the generators, (2) a good understanding of the exposed-surface optical properties in the lunar environment, especially the solar absorptivity in the context of lunar dust adhesion, (3) the lunar surface temperature variations at the equator for worst-case studies, and (4) convertor-specific performance maps.

Thermal Models: SINDA-format 3D thermal/electrical models (TEM) of the ASRG and

DASRG were developed for this study. Figure 3 shows the flow diagram of the LRPSAT models for ASRG and DASRG.

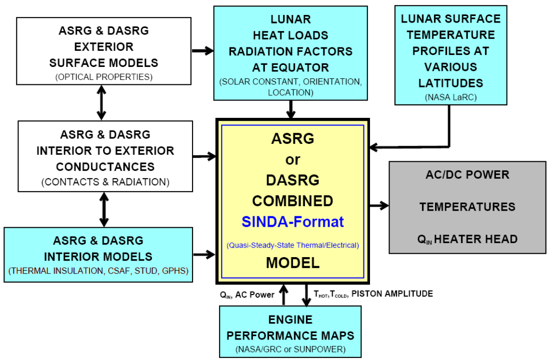


Figure 3. Thermal Model Flow Diagram

The ASRG and DASRG exterior surface models are combined with the lunar surface model (Figure 4)

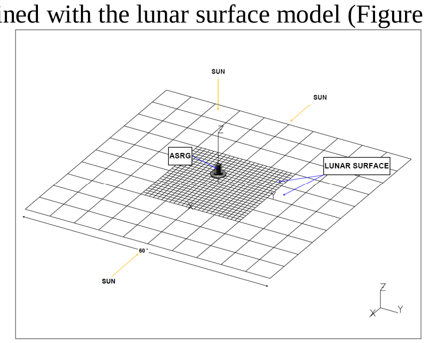


Figure 4. Lunar Surface Geometric Model

to create the appropriate integrated models for a lunar stationary circular platform (Figure 5).

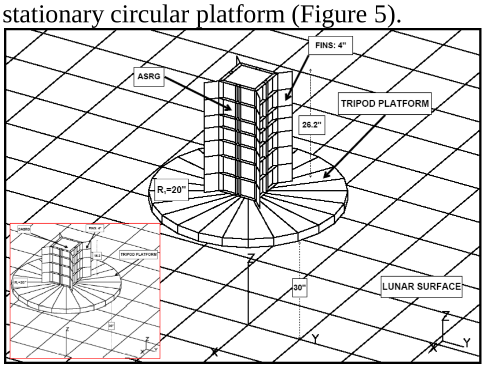


Figure 5. ASRG/DASRG on Stationary Platform

The lunar environmental heat loads (direct and reflected solar & IR heat loads from the lunar surface) and all relevant radiation interchange factors (RADK) are then calculated with ANALYTIX's version of another NASA-domain software, called Thermal Radiation Analysis SYStem (TRASYS) and loaded into SINDA; all optical properties and the ASRG/DASRG platform orientations on the lunar surface are defined in TRASYS. All TRASYS-format geometric models were constructed with ANALYTIX's Integrated Thermal Analysis System (ITAS) software [4]. The ASRG/DASRG interior nodes and all pertinent conductances (linear, radiation) are defined in SINDA. The lunar surface temperature profile (Figure 6) is then added to SINDA.

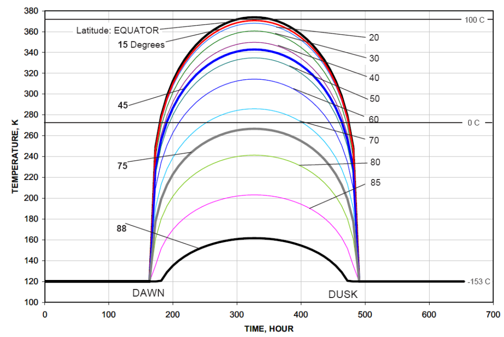


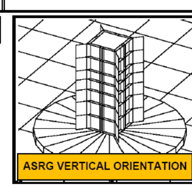
Figure 6. Lunar Surface Temperature Profiles

Finally, the ASC performance map is included in SINDA. The LRPSAT SINDA TEM steps through the lunar "Night, Dawn, Day, Dusk, Night" sequence at pre-defined time intervals and calculates steady-state temperatures, generator AC power (DC power = AC power * ACU efficiency) and the Q_{IN} heater head.

Table 1. Summary of Results for ASRG(*)

FIN LENGTH Inch	PISTON AMPLITUDE mm	ASRG LUNAR DC POWER RANGE, W_e DAY (NOON) - NIGHT	DIFF
	4.3	121-141	20
2.59"	4.5	114-138	24
	4.7	104-131	27
	4.3	124-145	21
4"	4.5	118-142	24
	4.7	109-137	28

$T_{COLD-END}$ < 105 C, $T_{HOT-END}$ < 767 C



(*)NASA/GRC (Sunpower) ASC-E2 Performance Map 2009
Controller Efficiency=90%
GPHS Q_{YR0} = 500 W_t; Q_{YR6} = 477 W_t
Solar Absorptivity: 0.13-0.4; IR Emissivity: 0.9

References: [1] EU-ASRG Final Design Review, LMVF, [2] NASA/NRA Advanced RPS SAT Meeting at ANALYTIX/OSC, March 8-9, 2005, [3] EU-ASRG Lunar Operation, ANALYTIX/OSC, December 17, 2007, [4] Heros Noravian, ANALYTIX, Integrated Thermal Analysis System (ITAS), 26th International Conference on Environmental Systems, SAE Paper #961376, Monterey, CA, USA 1996.