Space Times Article

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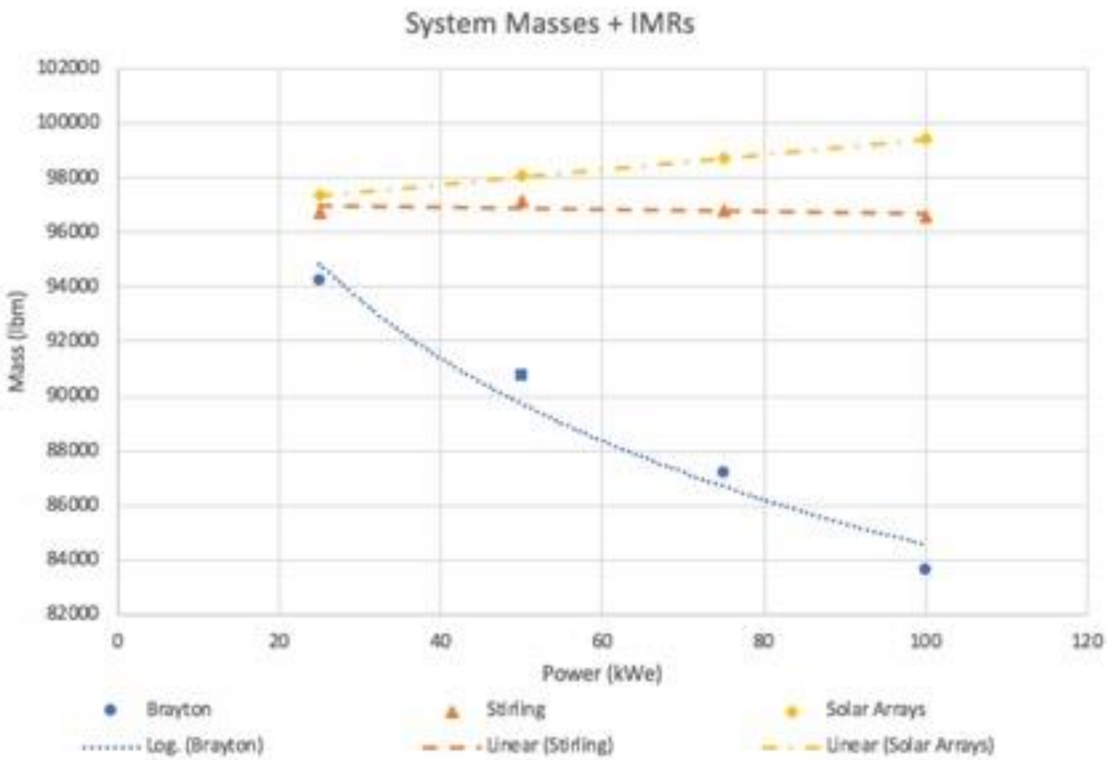
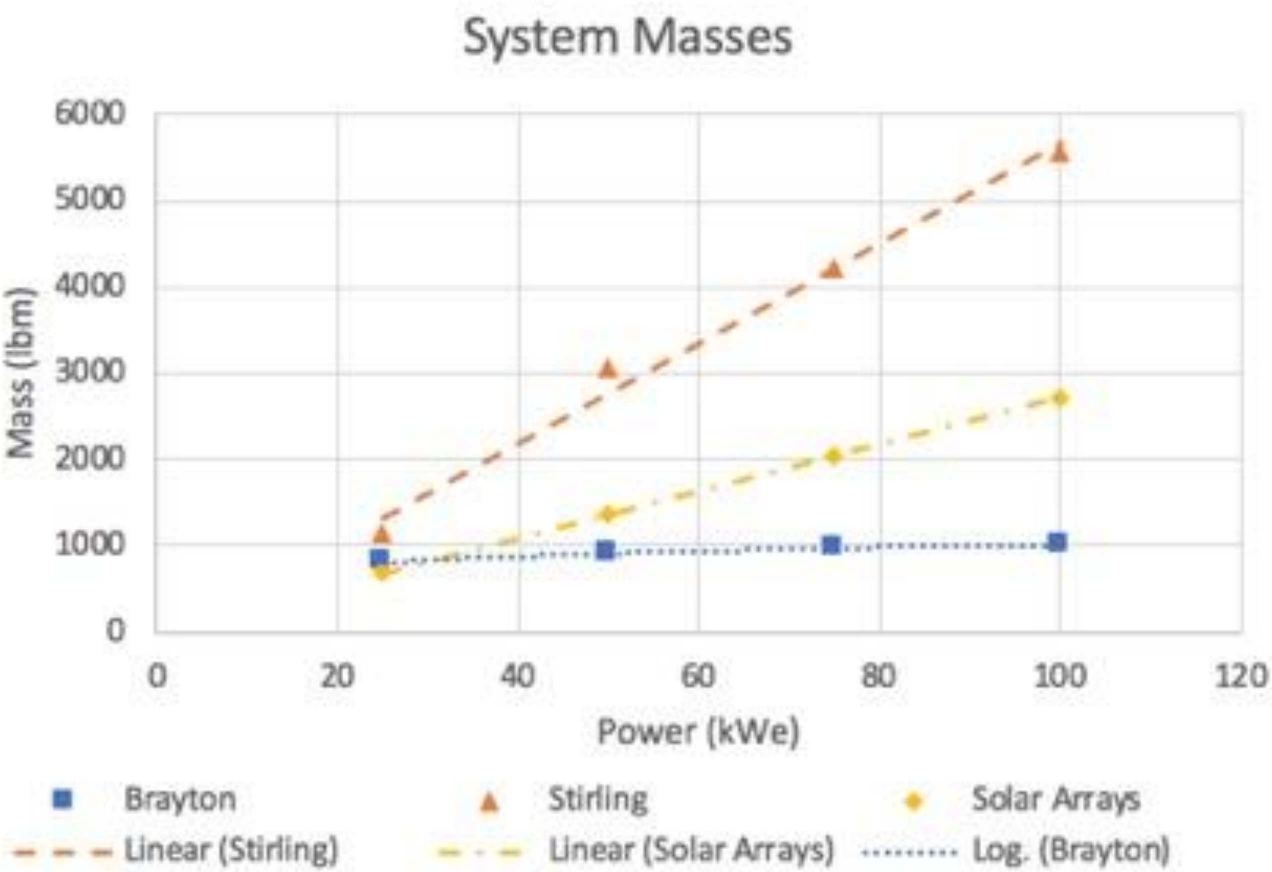
NASA is considering two design ideas for the Nuclear Thermal Propulsion reactor. One cannot be turned all the way off or else the fuel elements will cool below their ductile-to-brittle transition temperature. Below this temperature, the fuel elements face embrittlement issues. For this design, which will be referred to as Design A, after the reactor is used at full power to provide thrust for a burn, the power level will be lowered to an idle mode in order to keep the fuel elements above their ductile-to-brittle transition temperature. At this lower power level, the reactor will be generating about 15 Megawatts-thermal (MWt). The other design idea, which will be referred to as Design B, allows the reactor to be turned all the way off between burns, since embrittlement is not a concern with this design. However, it can be continuously operated in a low-power mode between burns. This paper discusses the use of a Minimally-Intrusive Power generation System (MIPS) for both design scenarios. For Design A, a MIPS can remove some of the heat generated by the rector in idle mode and removed by the non-propulsive hydrogen coolant loop and convert it to usable power for the vehicle without any changes to the reactor design and only minimal changes to the engine design. For Design B, the reactor power will be reduced to just enough power to operate the MIPS, no more. The specific application for this MIPS study is for a crewed Mars Transfer Vehicle (MTV) for a round-trip mission to Mars. The power conversion systems considered were a closed-loop Brayton cycle, a Stirling engine, and thermoelectric generators (TEGs). The masses of these systems were compared to the current system for power generation for the MTV – solar arrays.

It was determined that for Design A, the Stirling MIPS and Brayton MIPS resulted in lower masses when compared to the solar arrays. This is because for this design of the reactor, all of the idle heat not taken in by the MIPS still needs to be radiated out through the Idle Mode Radiators (IMRs). Therefore, it is necessary to consider the mass of both the power generation system and the mass of the IMRs. In fact, the Brayton MIPS resulted in more mass savings as the power requirement for the vehicle increased. This is because the more power the vehicle requires, the more heat will be drawn in from the reactor. Therefore, there is less heat that needs to be radiated out through IMRs. The reactor itself can be exposed to a constant 7 kWt, but anything more than that will have to be radiated out through the IMRs. In the case of the solar arrays, there is no MIPS to take in any of that extra heat. Therefore, all 14.993 MWt must be radiated out through the IMRs. However, in the case of the MIPS, the MIPS takes in some of that heat, leaving less heat to be radiated out through the IMRs. This allows the IMRs to be smaller, and therefore less massive. The mass of the Brayton MIPS architecture is less than the mass of the IMRs that would have to be utilized otherwise. The Brayton MIPS plus the IMRs for this design ranged from 94,000 lbm at 25 kWe to 84,000 lbm at 100 kWe. The Stirling MIPS plus the IMRs stayed at about the same 96,000 lbm for all power levels considered. This conveys that the mass savings associated with the smaller IMRs for an increased power level is essentially cancelled out by the mass of the larger Stirling engine. The TEG MIPS mass plus the IMRs ranges from 202,000 lbm for 25 kWe to 518,000 lbm for 100 kWe. This is because the mass savings associated with the smaller IMRs is overtaken by the mass of more TEG modules in the MIPS. This is due to the low efficiency of the TEG MIPS. Because of this low efficiency, a lot of TEG modules are needed to produce the required power to the vehicle. For example, 1,620 modules were required to provide 25 kWe to the vehicle and 6,479 modules were required to provide 100 kWe to the vehicle.

It was determined that for Design B, the Brayton MIPS was the least massive for power levels above about 30 kWe, and the solar arrays were least massive for power levels below 30 kWe. For this design, the Brayton MIPS mass ranged from about 800 lbm for 25 kWe to just over 1,000 lbm for 100 kWe. The Stirling MIPS ranged from over 1,000 lbm for 25 kWe side to over 6,000 lbm for 100 kWe. For the TEG MIPS, the mass ranged from over 100,000 lbm for 25 kWe to over 400,000 lbm for 100 kWe. Finally, the solar array masses ranged from under 700 lbm for 25 kWe and over 2,600 lbm for 100 kWe.

In conclusion, the MIPS can make use of the Nuclear Thermal Propulsion reactor already onboard to provide power to the vehicle, negating the need for heavy solar arrays. For Design A of the reactor, the Stirling and Brayton MIPS result in mass savings when compared to the solar arrays the vehicle would be forced to carry otherwise. For Design B of the reactor, the Brayton MIPS resulted in mass savings for power levels above about 30 kWe.


System Masses + IMRs
Mass (lbm)
102000
100000
98000
96000
94000
92000
90000
88000
86000
84000
82000
0
20
40
60
80
100
120
Power (kWe)
Brayton
Stirling
Solar Arrays
Log. (Brayton)
Linear (Stirling)
Linear (Solar Arrays)


System Masses
Mass (lbm)
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
Power (kWe)
Brayton
Stirling
Solar Arrays
Linear (Stirling)
Linear (Solar Arrays)
Log. (Brayton)