Advancing Utilization of the Moon using Small Form-Factor Cryogenic Technologies

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INTRODUCTION

The next stage of exploration and utilization of space will require us to operate in extremely cold environments, particularly at cryo-conditions, where the temperature is below -150 ºC. Such capability will enable us to operate in the Permanently Shadowed Regions (PSRs) of the Moon (See Figure 3). In addition, advancing such technology can also provide a multitude of benefits, including the long-term preservation of living cells for safe-keeping and long-duration space travel or even lunar habitats in less extreme conditions.

Figure 1: (a) Svalvard Seed Vault. (b) Noah's Ark

MOTIVATION

The objective of this research is to explore the use of cryogenic applications and insulating technologies for small modules/small spacecraft and for lunar applications. Such an effort can facilitate these next stages of exploration and utilization of space. Our main applications is the conceptual design and feasibility study of the power estimate for operating a robotic lunar ark at -180 ºC to -196 ºC in a lunar lava-tubes.

CHALLENGES

The main challenge to overcome is the power required to keep the desired temperature. Cryogenic applications can be seen from two different points of view:

- The environment is at a cryogenic temperature: FemtoSats exploration in the PSRs
- The payload requires cryotemperature to operate

For the first case, since the size is very small, just by insulation and small heating power, a reasonable temperature for the instruments inside can be achieved. For the second case, the power problem becomes important for two reasons: the size increases and there are more sources of irreversibility involved. Focusing on this case the maximum efficiency that can be achieved with an environment at -25 ºC can be appreciated in Figure 2.

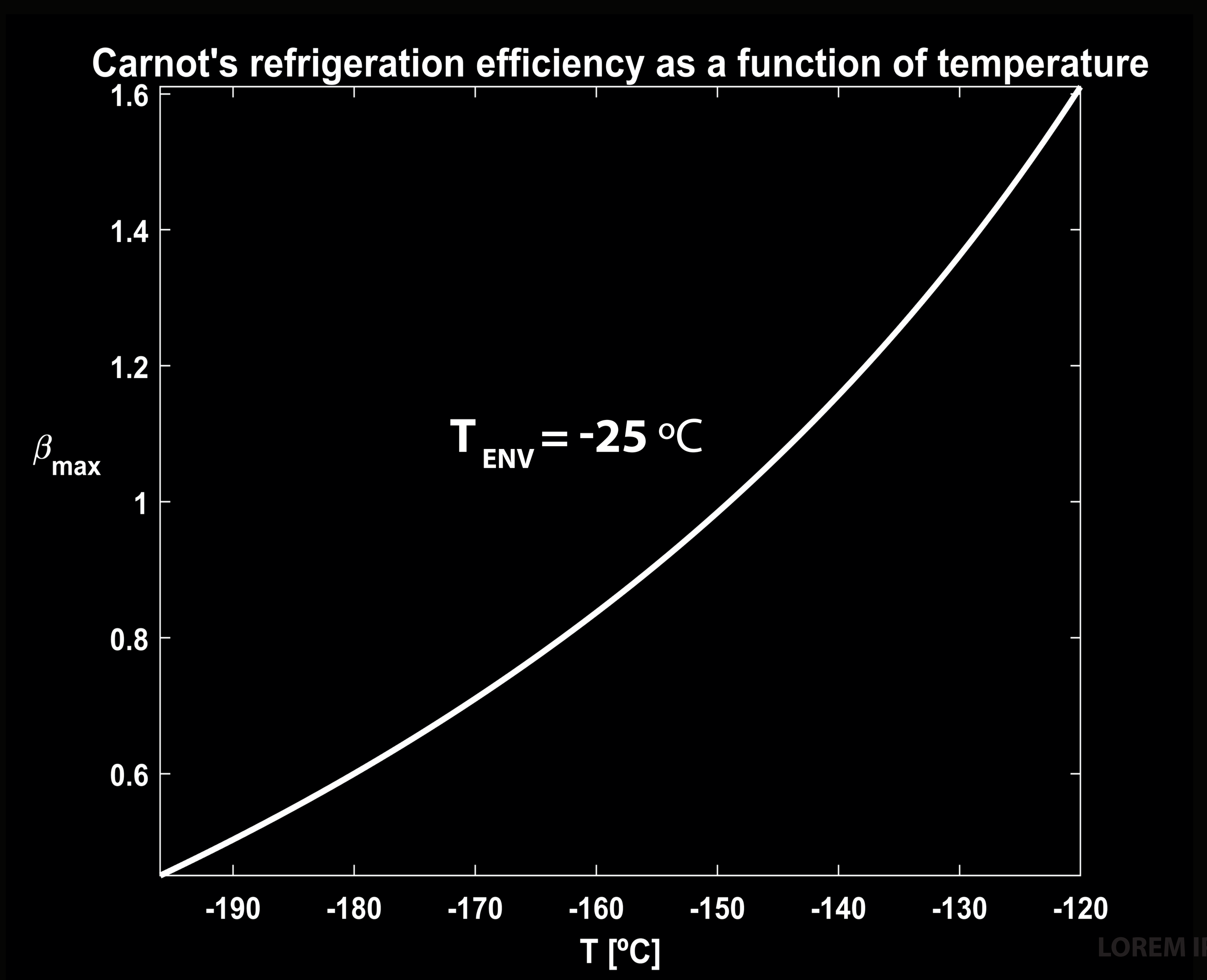

Figure 2: Evolution of the maximum refrigeration efficiency for an environment temperature of -25 ºC.

CRYO-APPLICATIONS LOCATIONS SCHEME

Figure 3: Areas of interest in the Moon

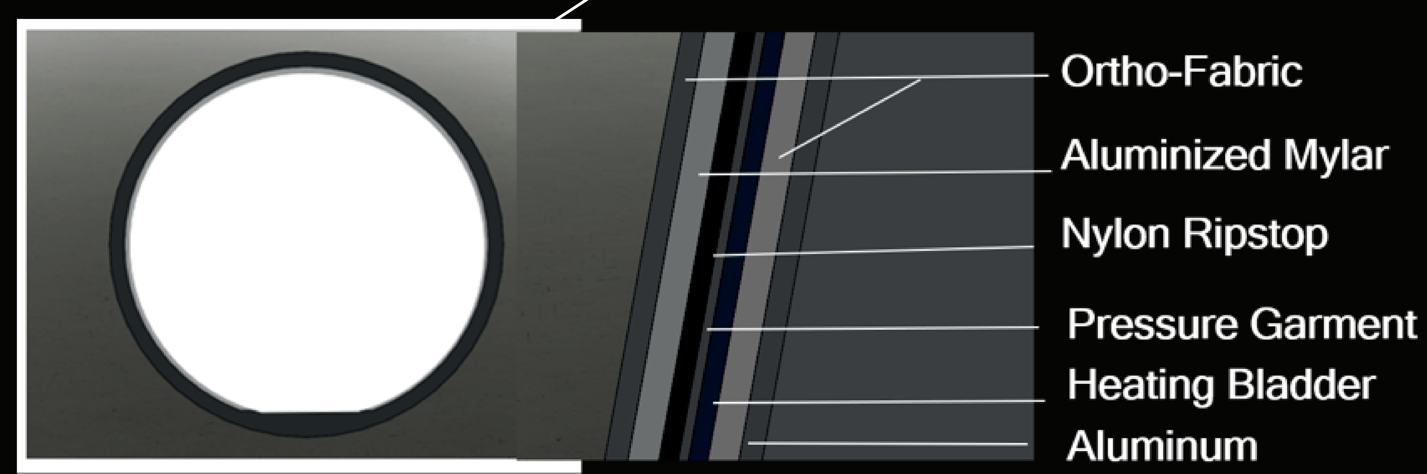

Figure 4: Module insulation materials.

Figure 5: 2F FemtoSat prototype for PSR exploration.

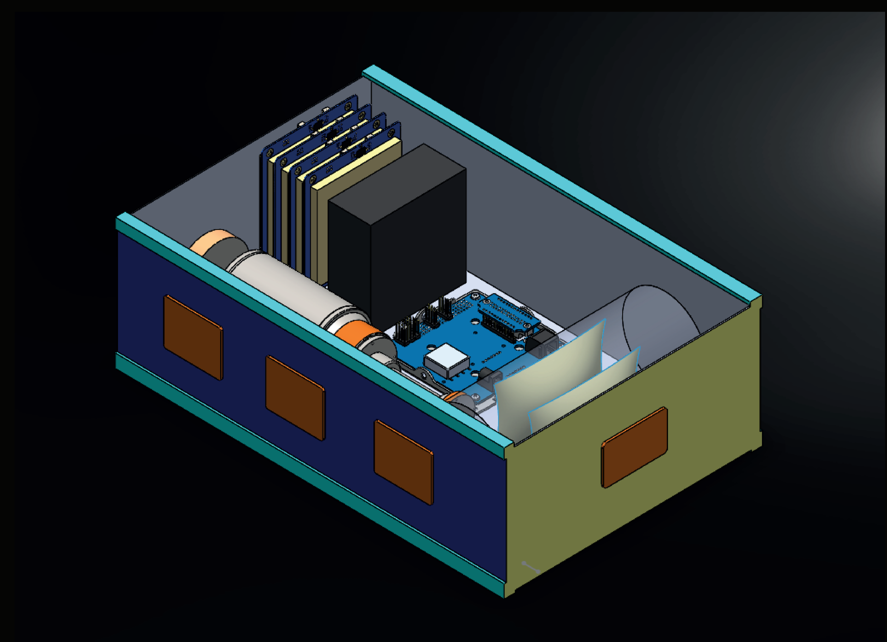

Figure 6: 6U CubeSat for microgravity stem cell survival.

REFRIGERATION TECHNOLOGY

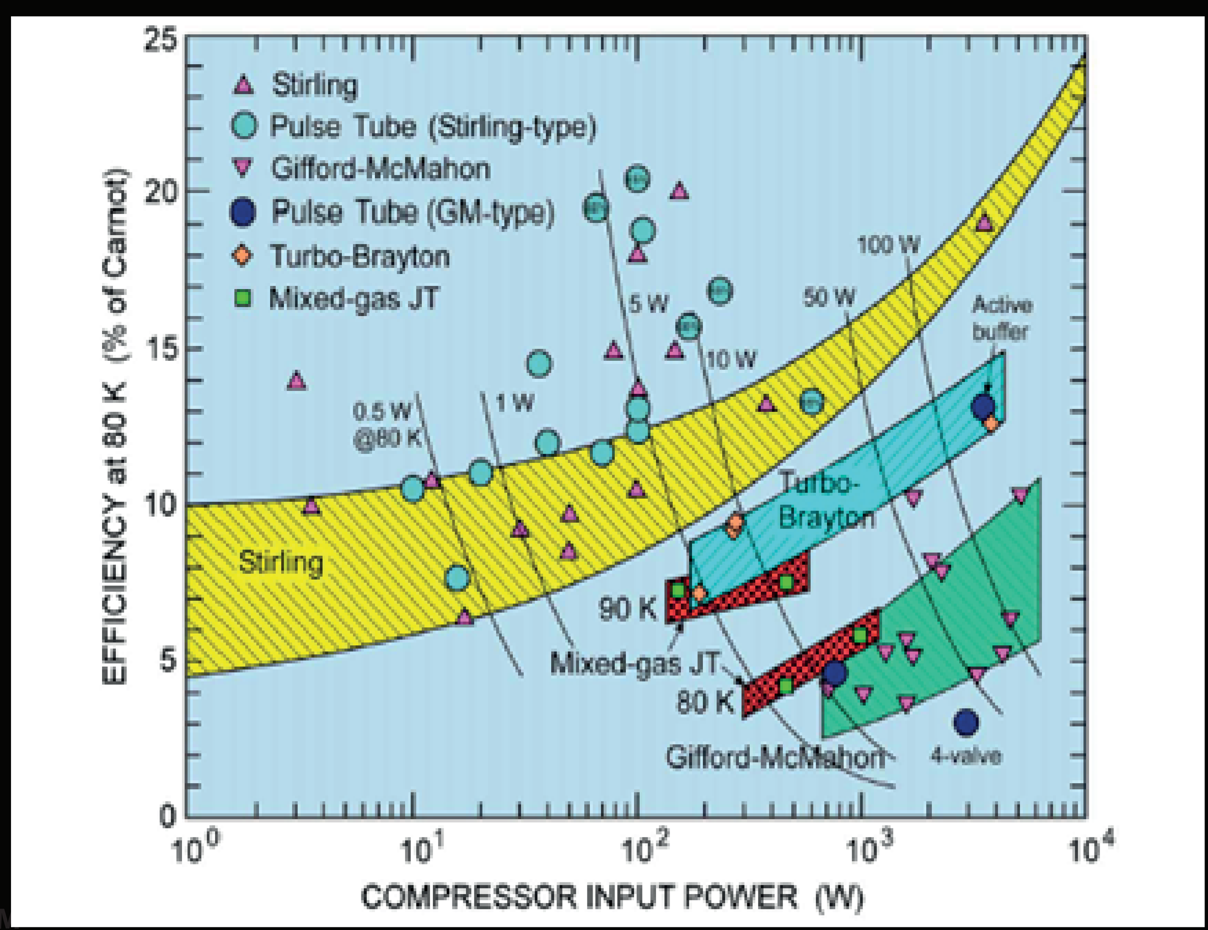

Figure 7: Efficiency of different refrigeration cycles at 80 K [Radebaugh 2004].

This type of projects require active cooling due to weight and maintenance. In addition since efficiency is very important pulse-tube Stirling engines are preferred. The maximum efficiency to operate at 23 ºC and refrigerate to 80K is 22%.

Minimizing energy consumption is important, therefore choosing the right materials is a primary task, Figure 4. Depending on the application cryogenic MLI can be combined with low conductive materials.

However, choosing the right material it is not the only way to reduce the heat transfer, we can also use new technologies such as superconductivity.

Specifications

- High α/ε ratio
- Stirling cryocooler: CryoTel MT 5W sunpower
- 50% efficiency at 25 ºC to -20 ºC (end to end)
- Superconductivity to minimize conduction

COMPLEMENTARY TECHNOLOGY

The main complementary technology for cryogenic applications is superconductivity. The levitating properties added to the low lunar gravity can allow us to hugely reduce conduction. However this technology requires that temperatures are below - 150 ºC. Currently superconductivity has been achieved at higher temperatures but it requires a great pressure which would introduce heat exchange through convection. Nonetheless this is an option worth studying.

Figure 8: superconductivity and quantum levitation.

CONCLUSIONS

- Refrigeration is a key concept to set a base in the Moon, Figure 4.
- Energy cost and efficiency is a key factor thus new strategies like superconductivity must be studied.
- If stem cells are able to germinate after being in microgravity, Figure 6, it is possible to advance to the next stage.

FUTURE WORK

- The thermal designs performed for these applications are not definite, hence they allow for optimization and comparison with finite element model for greater precision.
- Comparing the energy cost by using high temperature conductivity with heat extraction to achieve conductivity is required.
- Finally, testing the efficiency of the 6U CubeSat for stem cells survival refrigeration system.

Resources

R. G. Ross, «Chapter 6 - Refrigeration Systems for Achieving Cryogenic Temperatures,» 2016, pp. 109-182.