**Part B)**

**B1) Simulation Completion**

*ISRU Efficiency:* We determined that the ISRU efficiency will not have a significant effect on IMLEO required for each resupply mission due to our analysis of the steady-state system. The main effect of ISRU efficiency on steady state IMLEO (and resulting science value) is the spares mass which accounts for approximately 0.02% of the total IMLEO for any given resupply. Calculating total cost and science utility with the initial emplacement is important and will be part of the future work of this project. However, for this section of the analysis we removed it to focus on development costs associated with future propulsion systems which drive IMLEO for each resupply.

*Launch Cost:* In order to maximize the science return for the mission, we calculated a launch cost based on a constant dollars per mass rate for IMLEO. We chose use the conservative estimate of $10k/kg based on historical systems (Jones, “Estimating the Life Cycle Cost of Space Systems.” 2015). However, the results are expected to be sensitive to this parameter and its sensitivity should be investigated.

*Development Cost:* The development cost necessary for the new propulsion systems was also calculated using the Advanced Missions Cost Model (Jones, 2015). In this model, cost is a function of objective variables like system mass and time to development, and more subjective ones such as ‘difficulty’. These more subjective parameters can also be investigated as future work. For this analysis, we used the values recommended in the reference.

*Value:* We calculated the value of each architecture based on the amount of science utility that the surface crew could provide based on the number of crew, their available hours, quality of landing site, and

**B2) Heuristic Optimization**

**B3) Local Derivative-Free Search**

**i) Algorithm Selection**

Although the design space for this problem consists of discrete feasible points, we attempted to use a local derivative-free search algorithm to find the optimum set of variables to maximize the science value per dollar of the missions.

*Nelder-Mead Method:* The Nelder-Mead method provides local search in multidimensional space through an interesting heuristic method using a morphing simplex polytope. We used Matlab’s fminsearch function to implement that algorithm for our problem. Integrating our code with Matlab’s function required converting our discrete design space into a continuous one for the ND algorithm to search on by rounding values to the nearest integer and including a penalty function when evaluating designs outside of the bounds. This made the resulting behavior of the algorithm very sensitive to the step size, especially for variables with very few alternatives (eg power: solar PV or nuclear). We were able to adjust the step size within the fminsearch function, but were not able to find a proper step size to scale with each variable in such a small, discrete space using the rounding conversion. This led us to try an alternative method.

*Coordinate Search Variation:* We wrote a gradient-free local heuristic method that we felt would work well search the unique design space. This allowed us to restrict the search to discrete variables while still searching in the local region around the current solution. The pseudocode for our algorithm is:

1. Choose initial guess X0
2. For each variable
   1. Evaluate objective at two neighboring (forward and back) variable alternatives while holding all others constant.
3. If better objective found
   1. Move to X1 corresponding to the best objective found.
4. If no better objective is found
   1. Terminate search and save final X and objective value.
5. End

The algorithm works well for our problem because it is able to efficiently search the space using knowledge of the ‘distance’ between each non-dimensional , discrete alternative.

*Full Factoral Evaluation:* We performed a full factorial evaluation of our design space as it is relatively small with 1050 feasible design points. Using the initial default parameters ($10k/kg launch cost, 10 resupply missions), the optimum design was

X\* =

Propulsion – LH2, Isp 445 (min)

Surface Power – Solar

Location – Gusev

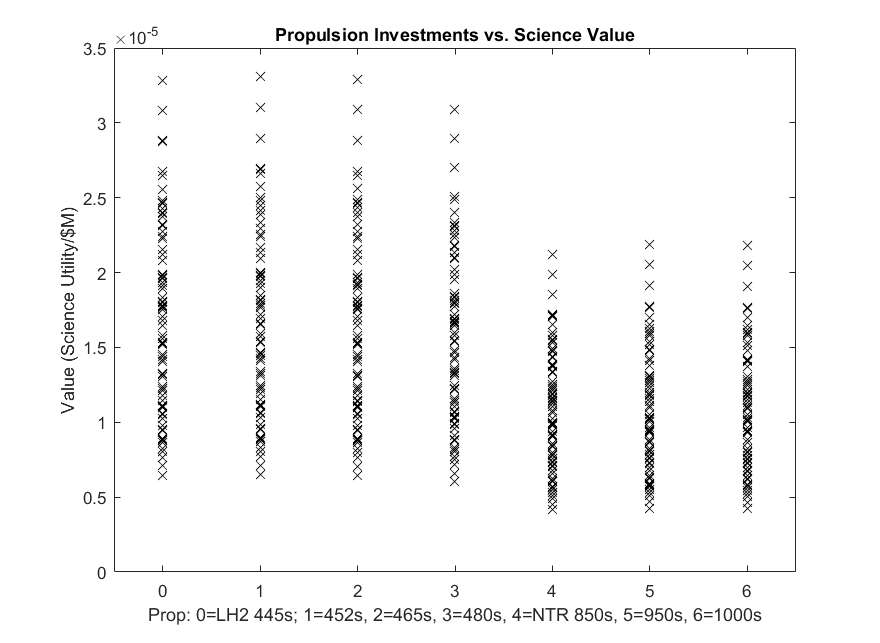
Food – 100% Earth (max)

Surface Crew – 24 (max)

Value(X\*) =

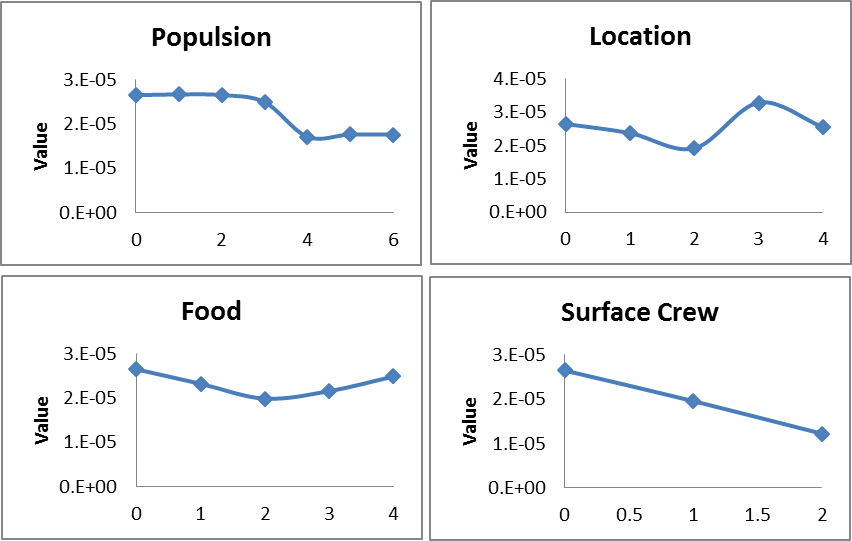
3.31e-5 ScienceUtility/$M

This allows us to compare the results of our local and global search methods with the correct global optimum. The figure below shows all of the architectures with their scientific value plotted against propulsion options (technology and Isp). Here we can see the global optimum (LH2 452s) and a local optimum using NTR with Isp of 950s.



**ii) Single Objective Optimization**





After reordering:



**iii) Sensitivity Analysis**