# A COMPARISON OF ALTERNATE MARS SAMPLE RETURN MISSION ARCHITECTURES.

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**Introduction:** For the past 2+ decades, a Mars Sample Return (MSR) mission has oscillated back and forth in scientific priority, technical viability, and fiscal possibility. Prior to 1996, MSR was viewed as the endpoint of a deliberate series of missions to map the red planet, scout selected surface sites, and eventually pre-select the site to which a MSR mission would be delivered. Following the announcement of possible life found in Martian meteorites[1], sample return became a more urgent priority, and NASA responded with a program to launch a MSR mission as early as 2003. Following the loss of two mars missions in 1999, NASA again re-thought its aggressive strategy and once again placed MSR at the end of a series of precursor orbital and landed missions. MSR is now again in discussion as the Martian robotic landers and orbiters complete the delivery of their considerable data sets, and scientists look to the capabilities of ground-based laboratories to uncover the next layer of Mars' mysteries using returned samples.

MSR is a technically difficult mission, perhaps the most technically challenging robotic mission yet conceived. The difficulty lies in the many sequential steps that must successfully occur in order to return a sample to Earth. A MSR mission is in fact a scaled-down version of a human Mars mission, requiring almost all of the same capabilities to return a sample as would be required to return a human crew – launch, interplanetary cruise, entry/descent/landing, surface activity, ascent, trans-Earth cruise, Earth entry and recovery – the only differences being the scale, human support sstems, and levels of acceptable risk.

Over the years, mission designers have devised creative methods to implement the series of steps required for sample return missions. The Russian Luna mission used an elegantly simple system to return samples from the moon. Luna 16, 20 and 24 used a simple surface sampling system (a drill), a short surface duration (hours), and direct return to Earth to perform their mission[2]. NASA LaRC and JPL engineers began MSR studies beginning with Viking Mars Surface Sample Return (MSSR), studying mission modes that could reduce the risk to their overall mission success [3]. The MSSR first debated the issue of orbital rendezvous sample return versus direct return, and chose to advocate direct return from the surface of Mars to Earth to eliminate "the most complex and potentially risky" operation of automated rendezvous, docking and sample transfer. Mars Rover Sample Return (MRSR) studies a decade later advocated large and capable rovers for extended sample collection sorties, a large ascent vehicle and Mars orbit rendezvous (MOR). In 1996, an international JPL/CNES team (later adding ASI and CSA) collaborated on a funded sample return project [4]. Though this project was cut short by the loss of the 1999 NASA Mars missions, the team did re-visit many of the mission architecture-level decisions that shape the MSR mission.

In each case, mission designers specifically chose among options for each of the series of steps required to perform a MSR mission. And though the options are many, most all of the MSR studies performed over the past 25 years have followed the same series of choices. Whether this phenomenon is a limitation of physics, programmatic, technology or imagination requires further analysis.

**Mission Architecture Decisions:** A technique used by systems engineers to represent the choices available to them is an architectural decision tree. A complete tree for a MSR mission would involve a great many decisions, and the multiplicative branching would produce far many more options than could ever be studied. In the final analysis, alternative mission concepts will be evaluated on the basis of cost, science return, implementation schedule and their probability of success, so the many decision variables can be reduced to only thos that have a significant impact upon these metrics. Further, since science return is essentially fixed for a MSR mission (return samples), and schedule is fixed by planetary physics, the essential decisions can be reduced only to those that are distinguishable by cost, and risk [5]. The following table lists many (but not all) of the decisions needed to complete a MSR mission, and the boldface type indicates the five decisions that most directly affects cost and risk.

These 5 decisions are arranged in an architectural decision tree, and branches of the tree that are logically inconsistent were removed. The resulting MSR architecture tree terminates in 12 possible MSR mission architectures. Each of these 12 options retains a common decision relating to the complexity of the surface sampling strategy, which is somewhat independent of the options and separated for clarity in Figure 1.

- ➡ **Number of individual spacecraft**
- ➡ **Single vs. Multiple launches**
- **Trans-mars injection propulsion**
- **Mars encounter mode**
- **Mars orbit insertion mode**
- **Mars entry mode**
- **Mars descent mode**
- **Mars landing mode**
- ➡ **Sample acquisition strategy**
- **Number of samples collected**
- **Total sample mass**
- **Sample identification mode**
- **Sampling X,Y,Z dimensions**
- **MAV mobility**
- **Planetary protection scheme**
- **Sample segregation**
- **Sample return environment**
- **Post-ascent surface mission**
- ➡ **Earth return mode**
- **Trans-Earth injection propulsion**
- ➡ **Earth encounter mode**

Table 1 – MSR Misison Architecture Decisions

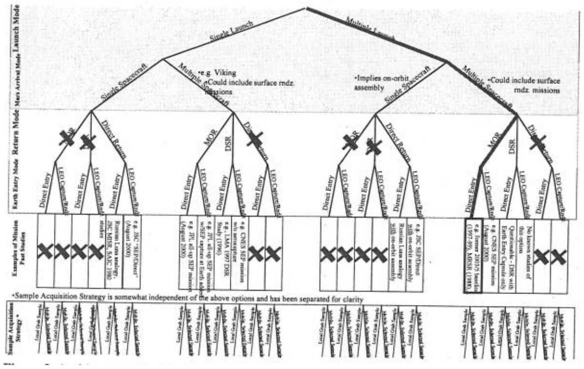

Figure 1. Architectural Decision Tree with logical deletions and examples of past studies illustrating paths

The architectural decision tree provides a framework for analyzing alternative mission concepts. Each of the remaining paths through the tree can be identified by a relative cost, mission risk, and descriptive title. A NASA-funded study in 2000 [6] applied success probability numbers to each of these paths, and found that launch mode, the number of independent spacecraft, and Earth return mode account for the great majority of the risk differences.

Perhaps the most surprising result of this analysis is that the MSR studies conducted by NASA seem to repeatedly follow the same path through this decision tree (multiple launch, multiple spacecraft, Mars orbit rendezvous, direct Earth entry, mobile sample selection), and that this path offers the lowest probability of mission success. This path has a great deal of heritage – much of it owes to the technologies developed for the Viking program in the 1970's and the Mars rover missions of the 1990's and 2000's, and that heritage still permeats Mars mission design (Viking entry heatshield and aftbody, E/D/L design, sample selection via rover to a fixed ascent vehicle). Breaking out of the Viking and rover mission "boxes" would allow designers to investigate other mission architecture paths, but this comes with the cost of the development of alternative systems.

**Conclusion – Explore Alternate MSR Mission Design Architectures:** Additional analysis of the paths illustrated in Figure 1 is needed to fully explore the range of MSR options that have been presented. The cost and risk associated with each architectural path must include all the factors involved in following that path, including the cost and risks of new technology developments and the benefits of partnering options with other NASA directorates or international partners.

Far too many NASA studies have followed the same MSR mission design path. The MPPG activity affords an opportunity recognize other conceivable solutions, and to fairly trade the costs and risks of each.

**References:**

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