A FOCUSED PATH TO EXTEND HUMAN PRESENCE BEYOND LOW EARTH ORBIT.
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Introduction: Developing a sustainable long-term architecture to move humans out of low Earth orbit and into the Solar System requires a *focused path* built around a series of achievable objectives within a structured time frame. Early milestones can be accomplished through a series of robotic and crewed missions culminating in human activities on the Moon (**Stage 1**). While learning to live and work on another world (the Moon) development can then begin on the next set of tasks focused on initiating human activities on Mars (**Stage 2**), and beyond. Key **Stage 1** tasks include (but not limited to):

1. Test and perfect *automated pinpoint landing* (first robotic, then crewed)
2. Test and perfect *automated hazard avoidance* (first robotic, then crewed)
3. Test and perfect *autonomous roving*
4. Characterize surface radiation environment (robotic) and test efficacy of mitigation strategies
5. Characterize deep space radiation environment and test efficacy of mitigation strategies (robotic)
6. Investigate time sequence of key lunar events (robotic then crewed)
7. Determine presence and location of lunar resources (robotic)
8. Determine grade and tonnage of exploitable lunar resources (robotic then crewed)
9. Test ISRU hardware (robotic)
10. Test advanced ISRU and utilize generated product for lunar surface exploration (robotic and crewed)
11. Test human support systems on lunar surface (crewed)
12. Initiate long term sustained human presence on the surface to learn to live and work on another world: exploit resources, explore, undertake scientific activities (crewed and robotic)
13. Collect and transport materials from one point on the Moon to another point on the Moon (robotic and crewed)
14. Transport materials off the Moon (robotic and crewed)

A mix of robotic and crewed missions should be implemented to accomplish these tasks to minimize risk and cost (**Table 1, Fig. 1**). What is the optimal mix? What is a realistic schedule? Which objectives can be addressed in parallel and which are serial? Beyond technical considerations the answers to these questions depend on the level of funding, international partnerships, and long-range political goals.

Many of the key technology development tasks critical to human landing on the Moon can be tested on small robotic craft that are also retiring other objectives. For example *automated pinpoint landing* could be tested on a small vehicle designed to answer a specific resource or science question (i.e. viability of pits for exploitation). A second test of *automated pinpoint landing* augmented with *automated hazard avoidance* system ensures safe landing of a long-range rover designed to characterize surface properties (geology, resources, radiation environment)? As these two related, yet distinct, technologies mature they can be deployed on a larger crewed vehicle with confidence. The long-range rover addresses key science and engineering objectives while testing *sliding autonomy operations* and opportunistic *automated data acquisition and onboard analysis*. Both technologies are key to human and robotic exploration of both the Moon and Mars.

Within NASA's current human space flight program the Asteroid Redirect Mission (known as ARM [**1**]) can *address* some of the **Step 1** objectives and make incremental progress on others. However, what is missing is a meaningful (in an architecture sense) plan for follow on missions after ARM that ultimately result in lunar exploration and a clear path forward to Mars.

The key to meeting the national goal of placing humans on Mars [**2**] requires a detailed understanding of the scope of the technology and expertise development needed, and the order in which to complete tasks. The challenge is to realistically determine required tasks and design cost effective missions that retire one or more tasks. A decadal plan (or longer) with key milestones accomplished at a frequent pace will keep public and political stakeholders attention, and give a real and meaningful sense of accomplishment to all involved. For example, the **Stage 1** tasks outlined above could consist of twenty robotic and two crewed missions (mission costs spanning $10M to $2000M) spread across 10 years (**Fig. 1**).

The *focused path* invites international cooperation by laying out a key set of objectives with plausible focused mission scenarios; interested nations can negotiate a logical division of responsibility to divide costs and increase the political payoff (critical to sustainability). Along the *focused path*, mission returns will in many cases directly address key NSF decadal goals [**3,4,5**] further strengthening science community, lawmaker, and public support (*Science Enables Exploration, Exploration Enables Science* [**6**]). Possibly the most difficult aspect is starting on a focused path - a process that requires political vision and leadership.

Turning the so-called flexible path into a *focused path* is simply a process of mapping out the required technical objectives with actionable tasks implementable through a series of focused missions. Each mission retires one or more milestones, each of which represents a stepping-stone to larger goals and objectives (ultimately completing **Stage 1** and moving to **Stage 2**). Soon enough, such a sustained *focused path* will extend human presence to Mars and beyond.

References: [**1**] Gates et al. (2014), IAC 14.A5.1.1, 65th Int. Astron. Con. [**2**] http://mars.nasa.gov/ programmissions/science/goal/ [**3**] NSF SSB (2013), ISBN 978-0-309-22464-2. [**4**] NSF SSB (2010), ISBN 978-0-309-15802-2 [**5**] NSF SSB (2012), ISBN 978-0-309-16428-3 [**6**] http://lroc.sese.asu.edu/about/patch.

Class	**Conops**	**Target**	**Cost**	**Objectives**
Cubesat	Multiple low altitude flyovers of poles to inventory volatiles (4)	S. Pole, N. Pole	$10M	7
Cubesat	Multiple low altitude flyovers of localized magnetic anomaly (2)	Reiner Gamma	$10M	4, 7
Orbiter	Communication relay and radiation monitoring	Lunar Orbit	$300M	Enable other missions
Rover	Explore at least four geologic terrains providing ground truth for orbital remote sensing observations, collect samples for return	Oc. Proc., Marius Hills, Aristarchus plateau	$500M	1, 2, 3, 4, 6, 7
Lander	Explore viability of pits for exploitation (2)	Tranq., King crater	$100M	1, 2, 3, 4
Lander	In-situ measure of polar volatiles (2)	Shoemaker and Cabeus craters	$250M	1, 2, 4
Lander	Sample return of late Eratosthenian mare basalt	Oc. Proc.	$600	1, 2, 6, 14
Cubesat	Measure key deep space radiation parameter (3)	Earth L1, etc	$10M	4
Rover	Follow on in-situ measure of polar volatiles	Determined by new observations	$600M	1, 2, 7
Lander	In-situ measure of polar volatiles	Aristarchus plateau	$250M	1, 2, 7
Lander	Sample return of late Copernican basalt	Ina	$600	1, 2, 6, 14
Lander	Test in-situ resource extraction (2)	Poles, Aristarchus plateau	$250M	1, 2, 9
Crewed Lander	Advanced test of in-situ resource extraction, investigate geologic context of key resource	Poles or Aristarchus plateau	$2500M	4, 6, 8, 10, 11, 14
Rover	Autonomously collect and transport materials (science and resources) for crewed pick-up	TBD from above exploration results	$600M	6, 8, 13
Crewed Lander	Investigate geologic terrain investigation key basin age relation, receive materials from rover, exploit resources	TBD from above exploration results	$2500M	4, 6, 8, 10, 11, 12, 14

Table 1. *Notional* missions comprising a focused lunar exploration program completing Stage 1 objectives. Number is parentheses indicates number of missions in that category.

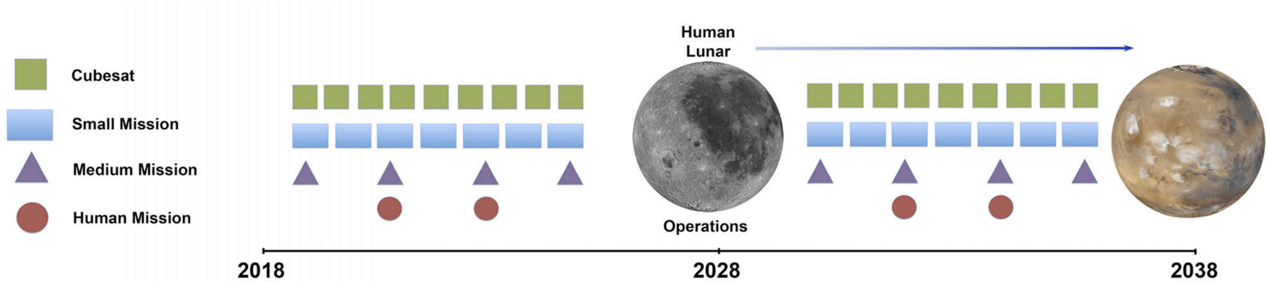

Figure 1. *Notional* number of missions meeting key objectives to meeting national goal of humans on Mars (Table 1). **Stage 1** is to the left of the Moon, and **Stage 2** is to the right.