AN AFFORDABLE MARS MISSION DESIGN.

K.Klaus[1], M. L. Raftery[1] and K. E. Post[1], [1]The Boeing Company, 13100 Space Center Blvd, Houston TX 77059, kurt.k.klaus@boeing.com, michael.l.raftery@boeing.com, kevin.e.post@boeing.com.

Introduction: The International space community has declared that our unified long term goal is for a human mission to Mars but major work remains to define how it will be done. We will describe a "stepping stone" based approach that charts a path starting at ISS operations today and ultimately leading to a crewed mission to the surface of Mars. Translunar infrastructure and heavy lift capability are key to this approach and we will show links to other relevant work in this area.[1] A human Mars architecture provides a framework and guidance from which to progress through a myriad of investigations, concept designs, analysis, and testing that lead to new and innovative ways of approaching space exploration, and human space travel in particular. Along the way, triumphs and tribulations, expressed as testing failures and/or the threat of project funding cuts, interweave the human experience into the long-term goal of visiting Mars. In short, a manned mission to Mars will engage the public. [2]

Mars as our Primary Objective: Mars as a destination for human exploration has captured the imagination of the world for decades. It is important to establish the exploration objectives through an inclusive international process, to define what capabilities are needed, and to develop them through incremental steps in exploration missions. Each mission should be compelling, while demonstrating technologies needed for Mars. It should be readily apparent how each mission contributes to the long term goal of sending human explorers to Mars. Key findings of a 2013 Humans to Mars conference panel discussion on mission architectures were; 1) A human mission to Mars is on the same order of magnitude as the effort it took to build the International Space Station (ISS); a substantial effort but one that is likely affordable in the current budget environment; 2) An inclusive, international process should be used to establish the exploration objectives and define the capabilities that are needed to achieve them; 3) As with ISS, an international partnership is seen as a key enabling feature of the plan. All partners participating in the plan should be given opportunities to prove their capabilities as part of this "stepping stone" approach; 4) Heavy-lift launch capability will be needed in order to provide a reasonable number of assembly flights and thereby a reasonable prospect of success.

Stepping Stones to Mars: A human mission to Mars will require the development of a set of new capabilities and steps must be taken to mature and prove out these new capabilities. We will show a step-wise plan developed by the European Space Agency which would address this need. This plan was developed as part of the effort to define the Global Exploration Roadmap whose second update has just recently been released.[3] Early crewed missions are augmented with robotic precursor missions to test capabilities and evaluate potential landing sites. These precursor missions are designed to address Strategic Knowledge Gaps (SKGs) which ultimately represent a risk to the human Mars landing objective. Strategic knowledge gaps for human missions to Mars have been studied by various groups, most recently the Mars Exploration Program Analysis Group (MEPAG).[4] For the life support and crew accommodation equipment, the ISS can be used to reduce risk for the Mars mission. Subsystem equipment can also be tested on ISS, but ultimately, human experience in the deep space environment is needed. Initial missions with the Orion and SLS will allow short duration exposure for crews to deep space but longer duration missions representative of a trip to Mars will require a habitat. Recent analysis has suggested that a habitat-based gateway in translunar space would be helpful as an assembly node for Mars and for many other missions as well.[5]

An asteroid retrieval mission could play a useful role in preparing for a Mars mission. One of the key technologies needed for Mars is a high power solar electric propulsion (SEP) system. Current designs for the asteroid retrieval mission feature a "first generation" SEP system which could form the foundation of the larger SEP systems needed for Mars.

Mars sample return (MSR) is one of the highest priorities of the Science Mission Directorate at NASA.[6] As a stepping stone to Mars, the MSR mission could provide valuable information about the Martian atmosphere, weather, geology, and potential landing sites. A lunar landing could also be on the path to Mars. The Moon could be used as a testbed for the surface systems and lander propulsion systems which will ultimately be needed for Mars. Delta velocity requirement for the Mars ascent vehicle is about 5000 meters/second; very close to what would be needed for a reusable lunar lander.[7] Finally, the moons of Mars itself would provide an excellent stepping stone to the surface.[8] As a "shake-down" cruise before landing, a mission to Deimos or Phobos would test all of the systems except those needed to get to the surface and back. This test would provide confidence for the in-space transportations and crew habitat systems. [9]

An Affordable Mission Concept: We will present a conceptual framework for an affordable Mars mission system. There are six basic elements of a Mars mission system; 1) Orion; 2) Space Launch System (SLS); 3) Transit Habitat; 4) Solar Electric Propulsion (SEP) Tug; 5) Mars Ascent Vehicle (MAV); 6) Mars Lander. Two of the six elements are currently funded for development and the other four represent improvements or scaled-up versions of systems that are operational today.

To illustrate how these six elements could be used to accomplish a Mars mission we will briefly describe the sequence of events:

The SLS is used to launch the first SEP tug and the cargo lander with the surface habitat to low earth orbit.

The SEP tug is activated and used to deploy the lander out to the translunar assembly site. The second SLS launch deploys the TransHab and the return kick stage directly to the Gateway. All four elements of the cargo mission leave for Mars when the departure window opens. The cargo trip takes ~500 days because only the SEP tug is used to power the trip. The return kick stage will stay in Mars orbit waiting to be used for the crew return. When the cargo mission reaches Mars, the SEP tug is used to spiral down to 5000Km altitude for the cargo lander entry. The lander uses its Hypersonic Inflatable Aerodynamic Decelerator (HIAD) to decelerate the vehicle for landing. The cargo mission provides a good test for most of the major elements that the crew will need for landing. Departure windows for Mars open about every 25 months so while the cargo mission is en-route to Mars, the human mission is being prepared. The human mission starts in much the same way as the cargo mission, with the launch of the SEP tug and the MAV lander. All the elements for the crew mission are assembled at the Gateway and the Expedition crew is the last to launch.

The translunar Gateway provides a small measure of infrastructure which is used to support assembly, store fuel, and respond to contingencies. The Gateway allows NASA and the partner agencies some measure of operational flexibility to resolve off-nominal situations and ensure readiness before the final mission commitment at the trans-Mars injection (TMI) burn. Once the TMI maneuver is performed, the crew is committed to at least a two year expedition.

The crew Mars transfer spacecraft is equipped with a kick stage to help boost the transfer performance. For comparison, while the cargo transfer to Mars takes ~515 days for the trip to Mars, the crew transfer is ~256 days or roughly half. With the exception of the shorter transit time, the crew transfer to Mars looks very similar to the cargo transfer that preceded it. Once at Mars, the SEP stage will spiral down to 5000Km altitude to release the crew lander. The landed mass for both the crew and cargo lander is ~40 tons.

The crew must land fairly close to the habitat if they are going to stay on the surface for their full duration mission. The Mars Curiosity mission was able to land within 3 Km of its target so it seems reasonable that the crew will be able to do this. Assuming all goes well with the landing, the crew would secure the MAV and transfer over to the habitat for their 450 day surface stay.

The MAV is a three stage vehicle with the crew cabin acting as the third stage. Once the return window opens, the trip back to Earth for the crew lasts 205 days.

Conclusions: The release of the Global Exploration Roadmap (GER) has made clear that our unified long term goal is for a human mission to Mars**.** Design reference architectures for human missions to Mars are inherently an evolving story, but together all of them strive to provide a long-term goal and a pathway with signposts to achieve that destination. It rallies diverse communities together for this common, long-term goal and helps to define the technologies of focus. These technologies are the signposts along the way, as each one is approached, developed, tested, and integrated into space (and where applicable terrestrial) systems, the long journey to a mission to Mars becomes palpable and profitable.

References: [1] Raftery M. L. et. al. (2013) *IAC-13, A5, 4-D2.8.4*. [2] Post K. E. et al. (2014) *IEEE 2014, 978-1-4799-1622-1*. [3] Global Exploration Roadmap 2013 http://www.nasa.gov/sites/default/files/files/GER-2013_Small.pdf. [4] Strategic knowledge gaps associated with potential human missions to the Martian system; June, 2012; http://mepag.nasa.gov/reports/psag_files/PSAG_final_report_06-30-12_main_v26.pdf. [5] Raftery M. L and Hoffman J. (2013) *Acta Astronautica, Vol 85*. [6] National Academies Space Studies Board; http://sites.nationalacademies.org/SSB/SSB_059331. [7] Raftery M. L and Derechin A. (2012) *IAC-12.B3.1.10*. [8] Hopkins J. B. (2012) *IAC-12.A5.4.4*. [9] Hopkins J. B. and Pratt W.D (2011) *AIAA Space 2011*.