A Perspective on Mars Ascent for Scientists. John Whitehead, PO Box 73343, Davis CA 95617, jcw@dcn.org

Introduction: Over decades, there has been only slight progress toward a Mars ascent vehicle (MAV), needed to launch geology samples from the surface of Mars into orbit. Therefore it is somewhat awkward that sample return was formalized in 2011 as the highest priority of all planetary missions. This workshop presentation will discuss why the MAV is not only beyond proven technology, but also why it is a huge challenge for the social system to address effectively.

The presentation will briefly critique MAV conceptual designs that have been proposed over the past 15 years. Despite the passing of decades, a significant stumbling block has been a persistent notion that there is no time to develop new technology, so organizational machinery only permits the pursuit of MAV designs that can plausibly be described as well understood in advance.

A plea is made for more open discussions with increased participation from the Mars science community. By way of analogy to astronomer participation in planning future telescopes, it is suggested that Mars scientists increase their understanding of the problem to help guide NASA's aerospace engineering endeavors toward a viable MAV solution.

The presenter will offer critical questions that should be asked by the broader community to scrutinize the viability of proposed MAV designs.

Why Mars ascent is technically difficult: MAV propulsive performance requirements (velocity and acceleration in combination) exceed the capability of all small rocket propulsion systems ever built. Lunar return has been done robotically, but the surface gravity of Mars and the orbital velocity are about twice that of the moon [1]. In addition, the foreseeably affordable scale for Mars landers requires the MAV to be less than half the mass of the 1970's Russian robotic lunar ascent vehicles. The velocity and acceleration requirements for Mars ascent are quantitatively contrasted graphically to lunar ascent and other planetary exploration maneuvers.

The fraction of MAV mass which is propellant must be very high. The essence of the engineering difficulty is that engines must be unusually lightweight in relation to the thrust they produce, and propellant storage and delivery subsystems (tanks etc.) must be unusually lightweight in relation to the propellant mass carried.

Why Mars ascent challenges the social system: Essentially all planetary missions to date have had propulsive maneuvering needs that are comparable to what Earth satellites have done routinely for decades. This comparison is readily quantified, e.g. entering orbit about Mars or Saturn is similar to circularizing a geostationary Earth orbit.

Hence there is an understandable tendency to take propulsion for granted within the robotic planetary exploration community. The marginally productive result is that NASA's few dedicated efforts toward a MAV have been constrained by the assumption that MAV development is largely a design-build proposition instead of a challenge to create new technology.

There has been no experience base in the field of miniature launch vehicles for Mars ascent, because the need significantly exceeds the capabilities of both spacecraft propulsion and small missiles. Unlike imaging sensors for example, there are no market forces that would cause MAV technology to appear on the scene in the absence of a dedicated effort. The fact that MAV responsibility has shifted from JPL to Marshall to Glenn is at least partly a testament to the absence of an obvious center of expertise.

MAV designs, 1996-2001: Roughly 15 years ago, planetary program engineers envisioned a 600-kg "Mars ascent propulsion system" for a "Mars ascent spacecraft," wider than tall to fit on a Mars lander [2]. In the same timeframe, the present speaker began writing papers suggesting the miniaturization of pump-fed propulsion, the enabling technology that permits both engines and tanks to be lightweight on the largest launch vehicles [3].

The speaker and a JPL collaborator suggested that the MAV would effectively be a miniature launch vehicle rather than a spacecraft, perhaps lying sideways on the lander to be erected for launch by a tilt-up mechanism [4]. A few years later, a Mars Program robotics engineer won a JPL Directors Award for "solving" the Mars ascent problem. He had proposed an extremely tiny (20 kg) "mini-MAV" consisting of three solid rocket motor stages [5].

However, in the summer and fall of 1999, a NASA-industry study team concluded that a solid rocket MAV would need to be well over 100 kg. The premise of the 1999 study effort was that a MAV would have to be ready to send to Mars for the 2003 launch opportunity, which ruled out creating new technology. That early plan for sample return was fortunately replaced by the highly successful Mars Exploration Rovers, launched in 2003.

The notion persisted that a MAV would result from a straightforward engineering effort, with little or no new technology. In 2000-2001, three industry teams were contracted by NASA to propose and study both solid and liquid-propelled MAV designs. They reported to a new MAV program office at the Marshall Space Flight Center, which published a summary paper [6]. The still-only-conceptual MAV designs had grown to nearly 300 kg, later determined to be too heavy to send to Mars along with a significant science payload.

MAV Progress, 2002-2012: In 2004-2006, the speaker was funded under a Mars Technology Program NRA to do laboratory testing of new component technology for miniature pump-fed rockets [8]. The goal was to enable a smaller MAV, e.g. 100 kg. Such efforts toward new technology for Mars ascent have been incidental, i.e. not the result of any deliberate program intended for developing MAV technology. For years, the official NASA position was that a sample return mission was not being planned, so there was no funding allocation for Mars ascent. Of course that is exactly how organizations operate for spacecraft subsystems that can be built with proven technology.

Dedicated work toward MAV development lay dormant until circa 2008, at which time the program office was relocated to the Glenn Research Center [7]. After a a year or two of funding delays, industry teams received seed money for MAV design studies in 2010-2011. A key criterion was that Technology Readiness Level 6 would have to be reached after a 3-year effort, which again ruled out any major advances. Awards were made to the same contractors that had done the studies a decade earlier. Presentations at an aerospace conference early in 2012 showed MAV designs similar to the decade-old designs [9], [10], [11].

A Case for Increased Scrutiny of Proposed MAV Designs: Typically, whenever the Government demands an aerospace engineering solution that doesn't need new technology, contractors will dutifully report that the problem can be solved within existing technology. Considering the high priority placed on Mars sample return, it is worth being concerned that the proposed MAV designs might not stand up to detailed scrutiny and might not be workable.

Engineering publications necessarily omit how-to details that are proprietary or competition sensitive. Another restriction on publishing is that many specific pieces of how-to technology information in aerospace engineering fields are export controlled. Unfortunately, it is also typical for publications to omit key pieces of big-picture information which would facilitate determining an appropriate level of confidence in the viability of proposed engineering solutions.

The mass budet is the top-level critical information that distinguishes a MAV from just another spacecraft propulsion system. Despite not revealing how-to details, mass budgets tend to be absent from most publications that describe proposed MAV designs.

Primary pieces of confidence-testing information include rocket exhaust velocity and the relative masses of major components. The thrust-to-weight ratio of MAV engines needs to be much high than satellite engines. The ratio of tank mass (or motor case mass) to propellant mass needs to be higher than for satellites. Therefore it is discomforting that little is said about these key pieces of top-level information.

Concluding Key Points: It is strongly suggested that a contribution to MAV progress would be made by applying the kind of curiosity that scientists are well known for. For the same reason that collaboration leads to better progress in science, an increased level of open discussion is suggested for MAV development.

Above all, there is an obvious and immediate need to recognize and mitigate the "Catch-22" situation, in which there is no tolerance for new technology if sample return is on the near-term horizon, and no MAV funding if sample return is on the far horizon.

It should be widely appreciated throughout the Mars science community that advanced technology for a smaller MAV would greatly reduce the scale and cost of sample return missions.

It is suggested to determine a realistic timeframe for Mars sample return, in view of decades of planned and postponed missions. Establishing a corresponding realistic timeframe for MAV development might indicate that time is available for technology development.

Nearly a hundred years ago, Robert Goddard realized that the capability of rockets would be severely limited by pressurizing entire propellant containers to levels at or above combustion pressures. NASA's MAV development leaders made the same point in 2009 by writing that pump-fed propulsion would permit a significantly smaller miniature launch vehicle [7]. Perhaps the time has finally come to replace "technical risk" rhetoric with "opportunity for creativity."

References:

[1] Whitehead J. C. (2008) AIAA-2008-7768. [2] Guernsey C. S. (1998) AIAA-98-4664. [3] Whitehead J. C. (1997) AIAA-97-2950. [4] Whitehead J. C. and Guernsey C. S. IAA-L98-0314. [5] Wilcox B. H. (2001) AIAA-2001-3879. [6] Stephenson D. (2002) AIAA-2002-4318. [7] Dankanich J. W. (2009) IEEE Aerospace Conference 1621. [8] Whitehead J. C. (2006) AIAA-2006-4692. [9] Dankanich J. W. and Klein E. (2012) IEEE Aero. Conf. [10] Trinidad M. A. et al. (2012) IEEE Aero. Conf. [11] Ross D. et al. (2012) IEEE Aero. Conf.