MARS ASCENT VEHICLE NEEDS TECHNOLOGY DEVELOPMENT WITH A FOCUS ON HIGH PROPELLANT FRACTIONS.

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Introduction: Launching geology samples from Mars to orbit requires a miniature launch vehicle, to provide a combination of velocity and acceleration beyond the capability of known spacecraft propulsion technology. The ultimate development challenge for a Mars ascent vehicle (MAV) is to achieve an unusually high propellant mass fraction for one or more tiny rocket stages. Reducing stage inert mass offers high leverage for the cost of Mars Sample Return (MSR).

MAV design studies and development efforts have mostly emphasized propellant selection and thrust generation, so a renewed emphasis is needed for creating unusually lightweight hardware.

Mass budgets: A MAV needs to be roughly 75 percent propellant at Mars departure, with approximately enough thrust to lift itself in Earth gravity [1]. A MAV propulsion stage without its payload needs to be 80 percent propellant or more. As shown in Figure 1, a stage propellant fraction of 85 percent permits a single-stage MAV to be about half as heavy as for 80 percent. Despite this steep dependence, most publications suggesting MAV designs have not highlighted mass data.

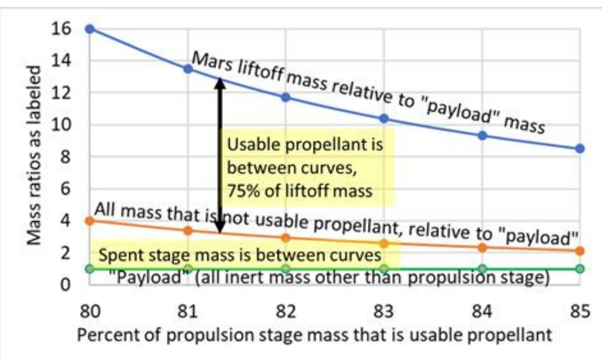

Figure 1. MAV mass relative to payload mass.

Stages of Earth launch vehicles are more than 90 percent propellant, which is made possible by using low tank pressures to permit thin structures, along with much higher combustion pressures so that engines can be compact and relatively lightweight. It is a huge challenge to do the same on a sufficiently small size scale for a MAV (hundreds of kg), although 85 percent propellant is a worthy goal. While the propulsion research community has done well to maintain continuity of expertise in propellants and combustion, there is no apparent pipeline of expertise for building small tanks, engines, pressurization systems, and directional control systems that must weigh far less than on satellites.

MAV design studies: Recent efforts at NASA JPL in particular offered new propellant ideas and insights for possible MAV designs [2-5]. However, mass calculations were only theoretical, for the sake of comparative propellant analyses. Aggressive component mass reduction is not noted as an opportunity, and mass growth does not appear on a list of risk items [2]. Mass is treated as a separate concern from propulsion functionality in a discussion of advancing TRL [3].

A dozen years ago, the NASA Mars Program funded the author's testing of miniature reciprocating pumps, discontinued despite encouraging results [6]. Subsequently, tiny turbopumps were tested by another group, recently acknowledged in one JPL MAV paper as probably not the answer for scaling down launch vehicles [4]. Electric pumps were found to offer only a slight advantage over pressure-fed propulsion, perhaps due to battery mass. The author has thus been inspired to refine concepts for miniature piston pumps.

Over a dozen years ago, the author's trajectory simulations quantified the disadvantages of a solid propellant MAV and the advantages of single-stage liquid [7]. For tiny solid rockets, excess thrust results in high atmospheric drag and requires heavy directional control parts, while leaving little time for steering corrections.

For many years, the notion of a solid propellant MAV was favored at NASA, so it is a step forward that the author's 2005 explanations were repeated more recently, along with a trajectory graph nearly identical to Figure 4 in reference 7 [5].

The full paper will show supporting details, including equations for Figure 1. The primary intent is to raise awareness in the MSR community that a new kind of space propulsion expertise is needed, with detailed physical insight into why things are heavy or not, with brainpower applied to aggressive mass reduction for a MAV and its components.

Regardless of what MAV design ultimately works, there is an urgent need to cultivate specialized team expertise for this unique application. By analogy, consider the uniqueness of Mars rovers and the decades that were required to develop working rovers while growing and maintaining appropriate expertise.

References: [1] Whitehead J.C. (2008) AIAA-2008-7768. [2] Karp et al (2017) IEEE Aerospace Conf. [3] Shotwell et al (2017) IEEE Aero Conf. [4] Vaughan et al (2016) IEEE Aero Conf. [5] Shotwell et al (2016) IEEE Aero Conf. [6] Whitehead (2006) AIAA-2006-4692. [7] Whitehead (2005) *J. Spacecraft 42:6*, 1039-1046.