

Advanced-to-Revolutionary Technology Options for Humans-Mars

- The Responsibly Imaginable

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The Challenge

The Presidential Space Exploration Vision specifically cites human expeditions to, and human on-site exploration of, Mars [Humans-Mars]. In the nearer term human space exploration beyond LEO [Low Earth Orbit] is focused upon the Moon, which provides a convenient proving ground for some of the capabilities required for Human-Mars. The major fundamental metrics for Human-Mars are cost and safety. Overall, and in general, mission cost and performance margins should be such that adequate safety margins are enabled. The major crew safety issues as currently identified include reduced gravity, radiation, potentially extremely toxic Martian dust and the requisite reliability for years long missions. Current estimates indicate that, using available technology, what is affordable may not be safe and what is safe may not be affordable. The thesis of the present discussion is that simultaneous cost and safety for Human-Mars will require advanced-to-revolutionary technologies.

The nature of the invention and development of advanced-to-revolutionary technologies is such that the usually successful path involves examination of many options and approaches in a triage fashion. Experience indicates it is extremely difficult to pick winners at the outset. Nominal and usual enabling timescales for such technologies are the order of 12-to-15 years for research and triage and another 12-15 years for development. This discussion will examine the frontiers of the responsibly imaginable in various technological areas which could significantly impact Human-Mars cost and safety. Estimates indicate that, after applying the currently envisaged efficacious technological and system approaches such as aero-capture and braking and envisaged evolutionary technology advancements across the board the up-mass to LEO for Human-Mars is on the order of some 500 - to - 1500 metric tons – most of which is fuel and propulsion and power systems [reference 1]. Therefore cost reductions for space access is a major metric, including approaches to significantly reduce the overall up-

mass. Besides fuel, propulsion and power systems, the up-mass consists of the infrastructure and supplies required to keep the humans healthy and the equipment for executing exploration mission tasks. Hence, the major technological areas of interest for potential cost reductions include propulsion [both LEO and in-space], in-space and on planet power, life support systems in-the-large, materials, dry weight in general, and overall architecture, systems and systems-of-systems approaches. Subsequent sections of this discussion will address a sampling of the longer-term technological options in these areas. In general revolutionary goals [such as Mars-Humans] require revolutionary technology. This discussion is specifically proffered in response and as a contribution to goal three of the Presidential Exploration Vision “Develop the Innovative Technologies Knowledge and Infrastructures both to explore and to support decisions about the destinations for human exploration.”

ETO Access

Current Space Access capability and approaches devolved directly from the German Missile program of world war 2 and subsequent inter-continental ballistic missile developments in several countries . For many decades there have been serious efforts to greatly improve upon this evolved ICBM technology and capability, thus far largely unsuccessfully. The current cost of access to space is in the range of thousands -of-dollars per pound-of-payload. Some of the larger, non-man-rated systems and systems from nations with lower labor costs are in the lower portion of that range while man-rated systems and some of the smaller payload systems are in the upper range. There are a plethora of existing space access design options including various classes and types of [conventional] rockets, air-breathing [as opposed to rocket] propulsion, staging, reusability, take-off and landing options, different [conventional] fuels, and material and controls options. Over the past several decades a goodly number of design teams in various countries have tried innumerable combinations within this rich parameter and variable set in search of a winning combination which could significantly reduce the costs of space access. Thus far these efforts have not been particularly successful, leading to comments such as that from Mark Albert [Scientific American] – “If God wanted people to go to space, She would have given them more money “. As an example, currently the military is quite interested in air-breathing space access propulsion systems which could provide their needed flexibility. Unfortunately such systems would, due to a higher dry weight and the lack of ground facilities for development

at Mach Numbers above 3 or so [necessitating development via essentially unaffordable flight experiments], possibly-to-probably increase launch costs overall, especially for man-rated systems. Something different, something not contained in the usual parameter set is evidently required to seriously reduce the costs of space access.

Payload size/mass reduction: Several of the major on-going technology revolutions, particularly information technology] and nanotechnology are changing the entire business case and option set for [non-human] space access and utilization. These technologies are enabling tremendous functionality and greatly improved performance to be placed in ever-smaller and lighter payloads and packages. Thus far orders of magnitude reductions in size and weight are either available or projected for many space mission elements or, in some cases, whole satellites and payloads with even further improvements in performance potentially on the horizon. Such improvements could and should change to a major extent the space access situation via resulting cost reductions. Aperture and array gain are available either via the burgeoning lightweight inflatable and deployable membrane and smart surfaces technology or co-operative flight management and formation flight. Such changes in the payload essentially converts the space access cost problem from dollars/lb to value/lb. Current launch costs per pound are more acceptable if there are not many pounds to loft. The alternative is to use the micro-rockets under development at, for example, MIT. These are enabled by MEMS turbine feed pumps and could inexpensively launch micro and nano payloads .

The obvious exception to this space business revolution is of course humans. Thus far the humans are not shrinking and therefore human-related space access [humans themselves and as much of their support, infrastructure and equipage as scales with their physical size and weight] is, in the large, not affected by this technology-engendered major change in the space business model and requirements for space access.

Approaches to reducing costs of [conventional] space access: An examination of the cost elements for space access indicates that a major contributor is the cost of human time and labor. The cost-per-pound does not refer to placing these monies in the combustion chamber, the funds are used to pay people. Several studies of the Space Shuttle cost problems point to the standing army issue. The ongoing technology revolutions should enable extremely efficient robotic fabrication and operation of space access systems, thereby greatly reducing direct human and labor costs. Such approaches as IVHM are being worked as is free form fabrication. An ab-initio end-to-end approach to life cycle cost reduction [design, fab, erect,

checkout, operate, store, manage etc.] with an eye to reducing human man-hours via increasingly effective IT/NANO-engendered automatics/robotics should be efficacious. Such approaches, for consumer goods, have resulted in and continue to result in major cost reductions. Another perhaps essential ingredient in reducing the costs, and along the way increasing reliability in major ways, is to provide performance margins, possibly via use of more robust, less costly, less sophisticated approaches and operation below the limits. Overall, cost and performance are not necessarily synonymous.

Farther Term Potential Space Access “Solutions” - There are an amazing number of options and possibilities on the table and the horizon for farther term space access [reference 2], requiring some 10 years or more of research to sort through and evaluate. These possibilities span the spectrum from propulsion cycle to fuels and launch assist. Launch assist options include Tidmans Slingatron, MW [microwave] energy radiated from the ground or from orbiting beamers to on-board rectennas with the energy used to power an exit MHD [magnetohydrodynamic] accelerator [some estimates indicate 2000+ seconds of ISP [specific impulse] at high thrust using this off-board energy, reference 3], space elevators, tethers, and ground-based high pressure, polymer stabilized and laser-guided water jets. Advanced propulsion cycle options include PDW [pulse detonation wave] rockets [possibly with detonation within a liquid fuel], hyper-mixing base region ejectors and MHD adjuncts and variants. Emerging fuel alternatives include N₄, quantum nucleonics [aka isomers] and positrons. Several options are in the research stage for long term storage of positrons, which have some 9 orders of magnitude greater energy density than conventional chemical. Other fuel candidates include metallic H₂, solid H₂ with embedded atomic species, and even some emerging very clean, aneutronic fusion approaches such as P/B-11 and D-He³. Obviously rockets are very far from being mature.

The extent to which these and other emerging and conceptual technologies could improve space access cost and reliability is to be determined. As an example, pulse detonation wave rockets could greatly reduce the pressure in the turbine feed pumps, significantly improving a major cost and reliability problem on conventional pressure fed rockets, the SSME [space shuttle main engine] in particular. Increased ISP per se is not always directly translatable to a cost reduction.

In-Space Propulsion and Power

Many advanced Human-Mars systems studies include consideration of various flavors of fission nuclear propulsion and power. Such approaches could increase in-space ISP by a factor of 2 to far greater compared to chemical fuels and include a wide range of possibilities from nuclear-thermal through nuclear-electric to exotic gas-cooled and magnetic nozzle very high performance cycles. The downsides include the associated radiation shielding and propulsive system weights, nuclear ash and waste and possibilities for launch accidents with attendant radiological hazards. Fission nuclear in-space propulsion has been studied relatively seriously and engineering solution spaces proffered for these issues. Residual safety concerns and cost appear to be the current issues with fission nuclear in-space propulsion.

Alternative in-space propulsion options – High thrust is a requisite for Human-Mars in-space propulsion. Fast transits are highly efficacious for several metrics including reduced costs, radiation and micro g exposure, minimization of psychological, health, reliability and durability problems and concerns, boiloff, and consumables and maintaining an interesting tempo for public engagement. Therefore many extremely efficient, but low thrust, slow transit approaches such as various types of sails [photonic and magnetic] and ion/electric propulsion are of interest for pre-positioning and re-supply freighters but not for human transport. Among the high thrust revolutionary genre in-space propulsion possibilities is a systems-level approach which would obviate most of the huge percentage of the Human-Mars up-mass which is fuel. The basic approach is to separate propulsive mass and energy vice combining them in a fuel. Also, this approach utilizes a reusable space infrastructure. The starting assumption is that warming and green energy Issues will lead to emplacement and utilization of space solar power satellites. Given the existence of such infrastructure the following revolution in space transportation appears worth examining.

A rocket is sent to LEO and arrives with an empty tank. The rocket is de-orbited slightly and an inlet is opened to ingest far outer region atmospheric air. Once the tank is filled with this propulsive mass [estimates indicate 3 orbits should suffice] the rocket moves to the vicinity of the orbiting beamer and MW energy is beamed to the rectennas on the outer surface of the rocket. This off-board energy powers an MHD accelerator which provides, using the alkaline-doped pressurized atmospheric air as propulsive mass, high thrust at ISP levels of up to 2000 seconds. A rapid acceleration is required due to beam divergence issues, with some future possibility for major reductions in beam divergence via soliton wave research. Several technologies, including more efficient rectennas, make this concept

interesting. Such an approach could be utilized for orbit raising [LEO to MEO, HEO, GEO – low to medium, high and geosynchronous earth orbit] as well as Moon, Mars, and other expeditions. If a beamer is pre-positioned around or possibly on Mars then a similar approach could be used on the return trip. The approach utilizes reusable in-space infrastructure, is very different from current approaches and could possibly obviate much of the huge percentage of the upmass which is fuel.

Other alternative high thrust in-space propulsion approaches include the afore-mentioned positrons, which, unlike anti-protons, are relatively inexpensive to manufacture, and produce only low energy gamma radiation which is easier to shield than neutrons. The major issue with positrons is long term storage, which is currently under active research by the USAF. There are also several even more exotic energetic possibilities including isomers, LENR's [low energy nuclear reactions] and even ZPE [zero point energy]. Isomers are potentially the order of 5 orders of magnitude greater than chemical in terms of energy density but viable triggering methods are not yet available. The LENR situation is in a major state of flux with recent apparently successful theoretical efforts and indications of much higher yields. There are currently several interesting approaches extant and under study to harvest ZPE [reference 4]. Success in such endeavors would literally change everything regarding power and energy in-the-large. Then there are tethers and the aneutronic fusion approaches, especially p-B11 and D-He3 Fusion, which again would have far lower shielding weights than fission nuclear or conventional D-T Fusion systems. The concept of utilizing anti-protons as ICF [inertial confined fusion] triggers/igniters is also interesting. There are NASA Institute of Advanced Concepts studies of harvesting anti-protons from the magnetic fields around the Earth where they are captured from the solar wind.

Alternative in-space and on-planet power – Many of the propulsive energy sources just discussed [positrons, P-B11, LENR, ZPE] , if proven technologically viable, would also be candidates for in space and on planet power. Additional interesting emerging power technologies include direct thermal-to-electric nano conversion approaches in the 20% to 30% plus efficiency range, possibilities for very high temperature superconducting , nano-enhanced high efficiency photo-voltaics and fuel cells and the potential impacts of carbon nano tubes upon SMES [superconducting magnetic energy storage]. Preliminary estimates indicate that utilization of carbon nano tubes [CNT's] for structure and magnets would increase the magnetic field strength and reduce the losses to the point where SMES could provide an energy storage density possibly a factor of 10 or so above chemical. Yet

another power possibility devolves from system considerations. Aero-capture and aero-braking are a fundamental tenant of Human-Mars missions due to the obviation of the huge fuel requirement for propulsive braking. An exciting possibility currently under study is to employ regenerative aero-capture and Aero-braking wherein the plasma produced over the vehicle fore-body by the aero-braking process is ducted through an MHD generator to regenerate the transit energy imparted to the vehicle [reference 5]. The MHD generator could, of course, be designed synergistically with an MHD accelerator utilized for ETO and in-space propulsion via off-board beamed energy as discussed previously. Such recuperated energy could be stored on the vehicle [e.g. using CNT flywheels or SMES] for later use on-planet or beamed down for on-planet storage and utilization. A particularly interesting real time application of this energy is to capture, heat and retro-exhaust Martian atmospheric CO₂ to solve the difficult high entry mass EDL [entry, descent and landing] problem in the thin Martian atmosphere without the use of [expensive/heavy] propulsive conventionally fueled retro-rockets. Advanced energy sources such as positrons could also be utilized to perform a similar function.

Dry Weight Reduction Approaches

Probably THE greatest possibility for revolutionary dry weight reductions overall [space access, in-space propulsion and power, payloads] is the structural application of carbon nano tubes. Estimates of their potential impact define the borders of the imaginable –up to a factor of 8 [some allege even more] dry weight reductions. The physics indicate the potential is there and marching armies around the globe are working the requisite technology to make it happen. Such material capabilities would obviously have tremendous impacts everywhere, upon everything – military and civilian, space and non-space, energy conservation and warming, etc....., the impetus behind the major research efforts worldwide in this arena. Nitride nano tubes are of interest for higher temperature applications. Other prospective space applications for CNTs include flywheels for energy storage, magnetic sails, tethers, ultra-capacitors, advanced sensors, petaflop plus computing at some two or more orders of magnitude reduced energy losses and extremely multifunctional materials combinations of structure and load carrying, imbedded sensors, computing, actuators and energy storage via either capacitance or hydrogen storage possibly optimized through Casimir force engineering]. Other material possibilities, interesting but with far less than CNT performance, include syntactic metal foams, amorphous metals, micro-

structured materials and the emerging smart-to-brilliant materials especially important for robotics and IVHM. Several other major weight savers are already being addressed or considered including ISRU [in-situ resource utilization] of several flavors, inflatables [including habitats], total recycling for life support including the solids and continuous application of the ongoing technology revolutions to reduce size and weight of equipment including Labs on a chip. As an ISRU example, martian CO₂ could be utilized for shielding, fuel cells, O₂ production, carbon for CNT's, pressurized rockets, CH₄ fuel production, polyethylene production and in-atmosphere solar pumped CO₂ lasers. An obvious architecture approach is to preposition everything possible via inexpensive slow-boats and freighters to ensure functionality pre-need, checkout and demonstrate reliability and reduce direct human-related up-mass and transit mass.

An Orthogonal Systems and Architecture Solution Space

The safety aspects of Humans-Mars are worrisome. There are assertions that the martian dust contains hexavalent chromium, an extremely potent carcinogen, and highly oxidative components, necessitating a dust-free environment for the humans - for habitats, suits, transporters, interlocks. The near absence of a magnetic field on Mars and the rarefied nature of the martian atmosphere provides only minimal protection from galactic space radiation [30-50 GeV of Iron nuclei and such, reference 6] and solar particle events which are both highly carcinogenic and severely impact the immune system. Radiation protection during transit and for the Habs is doable, requiring as an example some half a meter of liquid hydrogen or equivalent. However, serious radiation protection for, while in, space suits requires a breakthrough. Also, reduced gravity affects both bone growth and [adversely] the immune system. The only humans exposed to both full space radiation and reduced gravity simultaneously were the Apollo astronauts, and that exposure was for days not years. We can study parts of the problem via station at less-than-full radiation but with reduced gravity. Also, we are placing tissue samples in the Beam Line at Brookhaven where we can study radiation but without the concomitant effects of reduced gravity and not in vivo. There are no combined microg and radiation facilities extant, and therefore we know very little concerning their potentially highly negative synergistic combinational effects upon crew immune system and overall health. There are several mitigation approaches either being worked or potentially interesting including oscillating low level electromagnetic fields to remediate bone growth, pharmaceuticals and genomic treatments for

immune system augmentation/tissue repair as well as the out-year potential of designer humans.

There is, however, a rapidly emerging orthogonal alternative solution space for Humans-Mars [reference 7]. This solution space is enabled by the ongoing IT, nano, energetics and quantum technology revolutions and proffers the opportunity for everyone to go and explore while reducing the cost of exploration some factor of 50 to possibly much more. This orthogonal approach is increasingly enabled by many synergistic technology advances including high band width free space optical communications, the increasing functionality of ever smaller/lighter sensor and robotics systems, the emerging autonomous robotics capabilities, improving machine intelligence and the developing 5 senses superb virtual reality and immersive presence. The overall approach is to send the micro/nano sensors and the increasingly autonomous robots to explore Mars, i.e. instrument the planet. Utilize the optical free space communications to stream back the multi-sensory/multi-physics data to the web to enable the five senses virtual reality to provide a potentially far better than being there [and many orders of magnitude safer/less expensive] Mars exploration experience for everyone anywhere at any time. The technologies to execute this orthogonal humans-mars mission construct are developing, largely by commercial entities, faster than the technologies, briefly touched upon herein, which could enable on-site human Mars both safe and affordable. Early versions of this orthogonal approach are currently the approach of choice for exploration of the outer planets due to the extreme distances involved. The huge and rapidly growing international interest and participation in online gaming and virtual worlds [even on the current flat screens, before virtual reality] attests to the probable success of virtual exploration. Going forward, the machines and robots could do the initial exploration and even terra-forming for Mars and the humans physically go there when the ground and air are right. By that time the energetics technology should be there for them to do this economically and safely.

Commentary

Success in only a few or in some cases one of the myriad revolutionary technologies briefly cited herein could have major impacts upon Human-Mars cost and safety. For Human-Mars we have the time, before we have to commit to development, to conduct the research necessary to evaluate and sort out those technologies and probably many others not included to determine which advanced technologies are viable. As mentioned in the first

section, going-in the nature of the situation is such that cannot, ab-initio, pick winners. A triage process is necessary wherein low level investments are initially made in a wide spectrum of approaches, with a winnowing process as more is learned. Many of the technologies of interest are being developed by and for commercial or military applications. Historically, serious problems occurred in many major national space and aeronautics projects due to selection of evolutionary technology suites which lacked the capability to enable attainment of the mission metrics - necessitated in some cases by the perception that the schedule would not allow the necessary homework to include revolutionary technologies. In those programs tardy attempts were sometimes made to work the right stuff under the guise of risk reduction via parallel development and research tracks. This approach was unsuccessful – too little and far too late. Need to enter the development phase of a project with a surfeit of margins, weight always increases, costs always go up. Exploration budget realities provide the time to do Human-Mars right in this respect.

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