NASA/TM–2013-217981

Advanced-to-Revolutionary Space Technology Options – The Responsibly Imaginable

Dennis M. Bushnell
Langley Research Center, Hampton, Virginia

April 2013

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question to help@sti.nasa.gov

- Fax your question to the NASA STI Information Desk at 443-757-5803

- Phone the NASA STI Information Desk at 443-757-5802

- Write to:
  STI Information Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/TM–2013-217981

Advanced-to-Revolutionary Space Technology Options – The Responsibly Imaginable

Dennis M. Bushnell
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

April 2013

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

Advanced-to-Revolutionary Space Technology Options
The Responsibly Imaginable

Dennis M. Bushnell
Chief Scientist, NASA-Langley Research Center

The Challenge

National space exploration planning/visioning 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 asteroids or the Moon, which provide convenient proving grounds for some of the capabilities required for Humans-Mars. The major fundamental metrics for Humans-Mars and indeed any human/ or non-human space exploration or operations are cost and safety/ reliability. Overall, and in general, mission cost and performance margins should be such that adequate safety margins are enabled. The major human crew safety issues as currently identified include reduced gravity, radiation, potentially extremely toxic Martian dust and the requisite reliability for year's 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/reliability for Human-Mars will require advanced-to-revolutionary technologies.

The major cost centers for Humans-Mars are LEO access, the interplanetary round trip and habitats and surface ops. Much, too much for far too many years, of the Human LEO costs have emanated from flight and launch ops, these being the same order as "rocket"/vehicle costs. High leverage approaches to Humans-Mars cost reductions include reduced crew size, structural weight reductions, more efficient propulsion/ power, pre-deployment on inexpensive "slo-boats" [sails etc.] and/or Serious ISRU [do not haul it there, make it there] and closed loop life support including the "solids."

The nature of the invention and development of advanced-to-revolutionary technologies is such that the usually successful path involves ideation and examination/study of many options and approaches in a triage fashion. Experience indicates it is extremely difficult to pick winners at the outset without doing at least a modicum of study/homework. 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 that 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]. Cost reduction 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 [AKA "pink and warm"] and the equipment for executing exploration mission tasks including a substantial quantity of spares to ensure continued system[s] operation for multi-year missions. 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, reliability/maintainability of system[s], 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. Recent studies of space radiation protection indicate major additional up-mass requirements for long duration missions such as Mars which utilize chemical, relatively slow, propulsion methodologies, unless some form of active radiation protection is employed or the humans are "hardened," their DNA repair is greatly accelerated. Active radiation protection conventionally requires serious energy sources, which would also increase cost and up mass, but perhaps not to the extent that passive radiation protection via material mass would. The issues of reliability with respect to large for long duration human space missions are in an "early days" yet stage, especially with respect to potential issues of space-engendered bio alteration into corrosion and health threat agents.

Space exploration and exploitation which is both safe and affordable, as enabled by Revolutionary Technologies, would have major impacts including enhanced discovery opportunities for carbon and non-carbon based life off the home planet, discovering the reasons behind the many [far too many] shortfalls in current physics, especially at cosmological scales, human off-planet emigration, Mars Terraforming and Planetary defense against asteroids. If we are successful in determining the cause of the shortfalls in physics, that knowledge could conceivably lead to approaches for interstellar travel.

While many-to-most consider Physics as fairly well established [e.g. Relativity Theory and Quantum Mechanics] there are, especially at Cosmological scales, major issues with respect to physics as we know it and the "real world." Perhaps the most striking physics theory shortfall is a lack of understanding of/theoretical explanation for Dark Energy and Dark Matter. Together these constitute some 96 percent of the matter and energy in the universe as we can intuit such and we essentially know not what it is. Quantum Electrodynamics is perhaps the most verified theory extant yet the discrepancy with respect to zero point energy between the observed cosmological constant and QED is over 100 orders of magnitude. When the universe formed it is thought that there were equal amounts of matter and anti-matter, yet we essentially know not what happened to the anti-matter. Non-Locality as exemplified by quantum entanglement, while solid in terms of actuality/being the basis of several practical applications of quantum technology, is essentially not "understood." Quantum and Relatively do not "merge," there is no solid theory yet for quantum gravity. Recent analysis of experimental evidence indicates that Dark Energy has a very high probability of being "real," is a MAJOR portion of what constitutes the Universe yet there is no cogent explication of such.

The discrepancies in and in-between the extant physics theories and reality are embarrassingly numerous, run on for many pages, and have engendered a cottage industry of attempts to develop "Theories of Everything." Thus far there are tens of such, with most adding extra dimensions and some invoking retro-causation at the Plank Scale. The most famous of these, TOE currently is String/M, Brane theory, with up to 11 dimensions. Others include "Many Worlds," The" Bulk" [5 Dimensions], Holographic Universe, several "Aether" theories and non-linear quantum postulates. Thus far none of these theories of everything have experimental verification and perhaps none yet constitute/provide the/a more "correct" modeling of physics, especially at Cosmological scales. Each of these theories enables very different space technology/Engineering possibilities, including "Brane Surfing" and production of negative energy to enable space warps/worms for FTL interstellar space travel.

A major reason to "explore" space is to determine WHAT is actually happening in Physics. Such explications MIGHT enable faster than light [FTL] energetics and propulsion for inter-stellar travel. Examples of attempts at frontier inter-stellar travel utilizing existing physics include Hal Puthoffs theory to re-engineer the quantum vacuum and engineering/exploitation of space warps and worms. Tachyons are allowed under Relatively theory. The current best in class propulsion approach we have for interstellar is anti-matter, some E9 times chemical vice E6-7 for Fission/Fusion. Antimatter is complete matter-energy conversion but is still FAR short of the propulsion capability required for interstellar travel.

A further purpose of this report is to retort a statement made at a recent USAF workshop on Advanced Spacelift Technology that "Space is a Mature and Declining field of Endeavour in the U.S." and provide ideation/options/ways forward to bolster that retort.

It should be noted that this report/these projections assume the continuation of the ongoing exponential and synergistic It, Bio, Nano, Quantum and Energetics Technology Revolutions and that these technologies and their enablements will be applied to space applications and requirements. Obvious examples of such include Exaflop plus and Quantum Computing, High to-room temperature super conductivity, massive optical free space band widths, brilliant multi-functional materials, machine intelligence approaching human via biomimmetics, orders of magnitude improvements in sensor capabilities via nano and quantum, free form fabrication/fab labs, high density energy storage and high energy density materials, autonomous robotics writ large for such as in space and on planet construction/assembly and autonomous exploration, as well as a multitude of others such as serious telemedicine, which will obviously be required for months-to-years long campaigns. The relatively straight forward applications of the ongoing civilian and military worldwide technology investments will greatly reduce mission cost and enhance safety going forward.

A comment from an NRC report writ human space exploration is of interest in the context of this report. Then year insitu/physical human presence/requirements is equal to total mission requirements minus those requirements that THEN YEAR robots could execute. Thus far the Human exploration justification has considered current robotic capabilities, not those of then year robotics which are slated, even with a linear extrapolation much less the actual exponential increases, to be VERY CAPABLE. Reference 2 provides an extensive analysis of advanced space technology possibilities, albeit mainly of the somewhat nearer term genre. Reference 3 is an earlier, less detailed and less complete version of the present work.

Outlook for Space Commercialization

There are currently efforts to shift LEO access capabilities toward commercial sources for government missions, with initial emphasis upon ISS resupply and human transport to/from LEO. For over four decades NASA has pursued Space Commercialization, at times quite seriously, especially in the run-up to station in particular where there were some 17 funded external centers working this and a 95 million dollar budget. It is of interest going into a study of advanced-to-revolutionary Space Technology to attempt to intuit the extent to which commercial development of such might occur. Thus far, other than privatization of governmental activities, no seriously interesting major newer space commercial areas have evolved to add to the existing successful commercial “positional Earth Utilities” which constitute current “Commercial Space.”

The efforts/investments in microgravity manufacturing have thus far not been that successful. Protein crystal and tissue growth initially appeared to be quite interesting but subsequent studies indicated that tissue grown in Micro Gravity Simulators was of a quality comparable to tissue grown in space. Of interest is that studies of “bio in space” indicate that “bugs go south,” benign life forms become virulent. The serious efforts that went into “Commercializing” the space station which involved hundreds of organizations looking into a very rich set of potential activities industry-by-industry were not that productive. Activities such as off-planet mining, space based solar power and others appear to have relatively weak business cases........WITHOUT SERIOUSLY IMPROVED AND FAR LESS EXPENSIVE SPACE ACCESS. We have, throughout the "Space Age" starting in the 1950's, been in thrall to Chemical Propulsion. Breakthroughs in energetics and propulsion beyond Chemical appear to be required going forward. We have long been moving along the asymptotic portion of the Space Technology cost/benefit curve employing Chemical Energetics/propulsion with little overall change in affordable and safe capabilities. There are several far more energetic Chemical Fuels than those normally utilized, e.g. Fluorine and Beryllium compounds with Isp up to some 700 seconds, but they are, from attempts to engineer/apply them, simply too dangerous/unstable.

Other potential Commercial space options:

1. NANO is a newbe since the last serious Space Commercialization campaigns. Nano Fabrication in space has, to this point, not been seriously considered, involves very small but potentially horrendously valuable [in many instances] weights. Whether there is any there, any microg/vacuum combo value added for Nano writ large is to be determined as Nano develops further and morphs into Quantum Technology.

2. There are several unique space environmental assets/conditions that were not fully explored/exploited previously including Space environmental radiation and all that SPACE….The latter provides opportunities to develop gossamer things at very large scale.

3. A Continuing refrain from all the previous space manufacturing attempts/studies is the need for inexpensive/rapid turnaround in-space experimentation to determine potential viability, discovery and functionalization/optimization. With the increasing replacement of experiment by simulation/computation, there is a possibility going forward that we could, via serious computation/MODSIM, successfully conduct both triage and discovery for potential space manufacturing and other commercial space possibilities virtually, greatly lowering associated R&D costs and rapidly increasing TRL level with seriously reduced product development cycle times.

The apparent current status of Space Commercialization beyond positional "Earth Utilities" -

1. Suborbital Human flights are a supersonic thing, have very little to do with LEO Access/In-Space Tourism. Less than two percent of the energy required for LEO access and does not involve the major safety issues writ large for LEO access and beyond.

2. Space Tourism of the orbital and beyond Genre is currently expensive and not "conventionally," in the airline sense, safe [prevalence of accidents, microg/radiation

impacts upon immune system], and is therefore "uphill" without Revolutionary Technology-enabled changes in cost and safety for Space access and space flight.

3. For Space Industrialization, Space proffers:

- 'Resources" of various persuasions [on/from the moon, planets, NEO's, Space Debris, Van Allen Belt entrainments [e.g. Anti-protons]]. Thus far, NONE of such has been deemed worth going after from a closed business case viewpoint. He3 from the lunar Regolith [deposited there by the Solar Wind] as fuel for aneutronic Fusion has competition from the alternative fuel set H-B11, which is highly available on the home planet.

- Position," The high ground basis for the ongoing space industry, AKA 'Earth Utilities"

- Telcom, Resource monitoring, NAV, "Intel," Weather, etc. This current commercial "space industry" is able to function successfully with existing launch costs. The emerging technologies are putting ever better functionality in ever smaller packages, dollars/lb. is being replaced by VALUE/Lb. as the dominant metric.

- "Microg", In the 1980's and 1990's etc. the Space Station project and the NASA Commercialization efforts funded university centers to develop an industrial market for microg, with several NASA centers involved [GRC, MSFC, JSC, JPL]. Many experiments were conducted but no obvious "killer Aps" identified.

- Space environmental Radiation fields, Not yet studied as a potential Industrialization resource.

- Increased Solar radiation, the raison d'être for space based solar power, which is deemed too expensive, largely due to launch costs. Terrestrial Renewable energy options are FAR less expensive and have some 2 orders of magnitude greater capacity than needed to replace fossil carbon. Several proffer 24/7/365 base load.

- Hard Vacuum, thus far not in demand per se for space industrialization

- Large Dimensions including large scale cold and warm and a "Dumping Ground"/Trash pit......Access costs are major issue.

Essentially, Space Commercialization going forward is hostage to far lower space access/launch costs, The "Keys to the Kingdom." Therefore Commercial Space provides additional compelling arguments for pursuing revolutionary/enabling Space Technologies.

ALL of this is obviously in addition to Scientific and military space and the Humans in space Government operations. The military, although they tried 3 times early on before robotics became so capable, was never able to justify humans in space. The major current Governmental justification for such is "National Prestige" and metaphysical assertions of "Destiny." The asteroid impact and planet environmental deterioration arguments for humans in space are countered by far less expensive detect/deflect asteroid approaches and "Planet Cleanup" technologies. As discussed herein EVERYONE can explore space going forward via immersive presence/virtual reality/robotics/nano sensors/optical communications at some 1 percent to .1 percent the societal cost of sending humans.

Humans WILL go, but current indications are, unless seriously disruptive enabling cost and safety technologies are developed, the robots will go first, do the exploring and the terra-forming and by the time the ground and atmosphere are ready the technologies for safe AND affordable humans will be there. This latency for affordable/safe humans beyond LEO can be much reduced with courageous ideation and evaluation/development of revolutionary technologies.

ETO Access

Current Space Access capability and approaches devolved directly from the German Missile program of World War II 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 chemical fuel 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.

Civilian Access to Space Metrics:

- Inexpensive/ cost
- Safety/ Reliability
- Simplified Ground Operations
- Environmental Compatibility
- Safe abort/ assured payload return

Additional Military Access to Space Metrics [AKA 'Flexibility]:

- Reduced GLOW/ size [Handling/"Hiding"]
- All azimuth/inclination launch
- Rapid Turnaround
- Enhanced Launch Windows
- Self-Ferry

- Hypersonic Cruise
- Large Cross Range
- Increased Launch Site Options
- Orbital Plane Change
- Launch on Demand
- Orbit, de-orbit, re-orbit

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 space 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, the military has long been 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] 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 change in the payload essentially converts the space access cost problem from dollars/pound to value/pound. 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 [chemical fuel is actually quite inexpensive] 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, fabrication, 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, AKA "Productivity Improvements." 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 [references 4 and 5]], 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, Russian Blast Wave Accelerator, MW [microwave] or Laser energy radiated from the ground or from orbiting beamers to on-board rectennas/PV 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 6], space elevators, momentum and E-M tethers [the latter could utilize beamed energy], 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 and using wave dynamics for valving and ignition], hyper-mixing base region ejectors and MHD adjuncts and variants. Emerging fuel/energy alternatives include LENR, 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

ECF fusion approaches such as P/B-11 and D-He3. Obviously rockets are very far from being mature. As an example, of interest is a NASA evaluation of the Slingatron with a favorable finding during the early 20000 Decadel exploration planning study. The major issue found was protection of the payloads upon launch at orbital speeds into essentially sea level air density with the attendant huge aerodynamic heating pulse. This was “solved” via application of NASA technology from the project RAM flight tests in the later 1960’s where liquid water was injected forward from a .010 inch nose orifice. From the Flight and Tunnel data the liquid water jet and resultant water droplets went FAR upstream, effectively pointing the bow shock and drastically reducing the heating rate, all with a very small weight/expenditure of water.

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. The works of Frisbee [ref. 4] and Davis [ref. 7] contain far greater and more detailed explications of the amazingly diverse and numerous approaches/alternatives for LEO and in-space propulsion. Those mentioned herein are a small subset of the options, those that the author considers the most efficacious. Reference 8 even suggests it is not out-of-bounds to consider teleportation, which is a fast moving / emerging technology focus.

In-Space Propulsion and On-Planet 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, weight and cost appear to be the current issues with fission nuclear in-space propulsion.

<u>Alternative in-space propulsion options</u> – 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, 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.

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/ laser energy is beamed to the rectennas/ PV on 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 diffraction issues, with some future possibility for major reductions in beam diffraction via soliton wave and meta-materials research. Several technologies, including much more efficient/ultra light-weight 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, possibly using regolith as propulsive mass. 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[er] energy gamma radiation which is easier to shield than neutrons. The major issue with positrons is long term storage, which is under active research. 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 5 orders of magnitude greater than chemical in terms of energy density but viable triggering methods are not yet available and the radiation levels are worrisome. 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 9]. 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. Yet another class of alternative in-space energy/ propulsion approaches involves beaming momentum, either as neutral particle beams or as bulk momentum. The projected range of the former is 1 AU and has major cost and power reductions compared to laser energy beaming, also “solves” the beam Diffraction problem. The bulk momentum “beaming” approach involves various flavors of mass drivers and various “catcher” approaches. The concept of utilizing Ponder motive Forces induced by laser/plasma interactions to produce ultra high Isp at high thrust is also worth further serious research.

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 [Thermo-electrics, Pyro-electrics, Thermal photo voltaics and Sterling/ other thermal cycles in the 20 percent to 30 percent 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 loses 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 10]. 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 CO_2 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 or LENR could also be utilized to perform a similar function. A lower Tech approach to regenerative aerobraking is to ingest CO_2 at high speed/energy early in the entry and store such to utilize its’ mass, heat content and pressure recovery for retro injection at low[er] speeds, later in the entry. Clever systems engineering may obviate the need for any additional energy addition. As an odd and perhaps errant thought, it MIGHT be possible to "harvest" kinetic energy from asteroids/ meteorites. A "space" version of the NIA/LaRC "Sky-Walker" project wherein loitering aero platforms keep aloft by sensing and moving from updraft to updraft in the atmosphere. On the more mundane level Space Solar Power satellites around Moon/Mars appear to be efficacious.

Low Energy Nuclear Reactions, the Realism and the Outlook

LENR could, by itself, COMPLETELY Revolutionize Space access and utilization. Although there is a quite long history of "anomalous" observations including transmutations the "recent" consideration of Low Energy Nuclear Reactions begins with the Pons/ Fleishman late 80's observations and assertions regarding what they termed "Cold Fusion". Subsequent difficulties with experimental replication and an utter lack of convincing theoretical explication forced research in this arena "underground" with minimal financial support. The current situation is that we now have over two decades of hundreds of experiments indicating heat and transmutations with minimal radiation and low energy input. By any rational measure this evidence indicates something real is occurring. So, is LENR "Real"? Evidently, from the now long standing and diverse experimental evidence – yes - With effects occurring using diverse materials, methods of energy addition etc. This is FAR from a "Narrow Band"/episodic set of physical phenomena.

The next consideration is "WHAT IS REAL? WHAT IS Happening? For NASA Langley the epiphany moment on LENR was the publication of the Widom-Larsen weak interaction LENR Theory. This theory is currently under study and experimental verification [or not] at NASA LaRC. The theory appears to explain nearly all the various and often variegated experimental observations and shifted the LENR Theoretical focus from some way of "fooling" Particle Nuclear Physics/The Strong Force to Condensed Matter Nuclear Physics, Collective Effects, The Weak Force and "Heavy Electrons". The Strong Force Particle Physicists have of course evidently been correct all along, "Cold Fusion" is not possible. HOWEVER, via collective effects/condensed matter quantum nuclear physics LENR is allowable without any "Miracles". The theory states that once load surfaces with hydrogen/protons and add some energy IF the surface morphology enables high localized voltage gradients then "heavy electrons leading to ultra low energy neutrons will form, neutrons that never leave the surface. The neutrons set up isotope cascades that results in beta decay and heat and transmutations with the heavy electrons converting the gamma from the beta decay into heat.

The theory indicates several key issues/circumstances are required to enable-to-optimize

LENR and explains the various experimental observations, including the often long initiation times required in some experiments. If the theory is experimentally validated in detail it provides the understanding to shift LENR research from discovery into engineering development. The theory indicates energy densities some million times chemical, the current experiments are in the 10's to hundreds range. However, several labs have blown up studying LENR and windows have melted, indicating when the conditions are "right" prodigious amounts of energy can be released/produced. There are some 6 or so groups claiming device outputs in the 100 watt range and 3 others claiming kilowatts. Efforts are ongoing within NASA and other organizations to validate, or not, these claims. It should be noted that these devices are essentially "Edisonian," the result of attempts at experimental "discovery" vice ab-initio design from the weak interaction theories per se.

The LENR situation and outlook is therefore the following: Something real is happening, the weak interaction theories suggest what the physics might be, there are efforts ongoing to explore the validity of the theories, there are continuing Edisonian efforts to produce "devices," mainly for heat or in some cases Transmutations. There are efforts to "certify" such devices. We are still FAR from the theoretical limits of the weak interaction physics and are in fact inventing in real time the requisite Engineering, along with verifying the physics. When we concentrated upon Nuclear Engineering beginning in the 1940's we went, "jumped" to the strong force/particle physics and leapt over the weak force, condensed matter nuclear physics. We are going "back" now to study and hopefully develop this arena.

The "Precautionary Principle" demands that we core down and determine realism for this arena, given the truly massive-to-mind boggling benefits – Solutions to climate, energy and the limitations that restrict the NASA Mission areas, all of them. The KEY to Space Exploration is Energetics. Some examples of what LENR might/ could enable in a resultant "Energy Rich" Exploration context include:

- Refrigeration for Zero Boiloff cryo storage
- Active Radiation protection
- High Thrust Vasimir/MHD Propulsion
- Energy Beaming
- Separation of propulsive mass and energy/ energetics to establish the requisite conductivity for most "harvested" propulsive mass including regolith
- Planetary Terraforming
- Ubiquitous in space and on-planet sensors and robotics
- LEO propulsion
- On planet power and energy
- EDL retro via heating of ingested mass

Also, The Key to SST's and neighbor-friendly personal fly/drive air vehicles is Energetics, as simplex examples of the potential implications of this area of research. There are estimates using just the performance of some of the devices under study that one percent of the nickel mined on the planet each year could produce the world's energy requirements at the order of 25 percent the cost of coal. No promises but something[s] seriously "strange" are going on, which we may be closer to understanding and if we can optimize/engineer such the world changes. Worldwide, worth far more resources than are currently being devoted to this research arena. Need to core down and determine "Truth". If useful, need to engineer/apply.

Dry Weight Reduction Approaches

Probably THE greatest possibility for direct revolutionary dry weight reductions overall [space access, in-space propulsion and power, payloads] is the structural application of carbon nano tubes [reference 11]. By this is meant somehow combining the nano tubes into a contiguous nano tube structural material, not simply producing nano tube composites, which have FAR lower performance. Estimates of the potential impact of structural nano tubes 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 less than CNT performance, include "Ageless" Quantum/Nano designer materials, syntactic metal foams, amorphous metals, micro-structured materials and the emerging smart-to-brilliant materials especially important for robotics and IVHM. The "Ageless" approach utilizes atomic/ molecular level design and fabrication to reduce-to-eliminate the various and numerous material defects [dislocations, grain in homogeneities, inclusions, etc.] that are induced by conventional fabrication techniques and are responsible for the observed large strength/ performance decrements with respect to "pure Material" expectations.

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 CO_2 could be utilized for shielding, fuel cells, O_2 production, carbon for CNT's, pressurized rockets, CH_4 fuel production, polyethylene production and in-atmosphere solar pumped CO_2 lasers. Ubiquitous energy harvesting nano sensors and robotics including "smart Dust" to instrument the planet[s]/bodies for virtual and physical exploration would tremendously inform, expedite and reduce the cost and increase the "productivity" of exploration campaigns.

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/transit mass. Potential pre-positioned functionalities/assets include Comm, Nav and Solar Sats, Habitats, "Transportation" devices, Power and Energy, ISRU in the large, Robotic Adjuncts, Radiation Protection, Medical facilities/capabilities, Spare everything for fail safe-safe, ETC. The alternative or adjunct to such is serious ISRU. The emerging Revolutionary Technologies would also enable revolutionary ISRU, including on planet/body molecular manufacturing,/"strong Nano" and LENR enabled Transmutations to produce materials/elements not otherwise/ readily available, with LENR providing the requisite energetics and utilizing Machine Intelligence to manage/direct the processes/fabrication/operations. Conceptually such technologies could produce from Regolith and have up and running/checked out whatever on-site infrastructures/systems is required for either exploration/science missions OR for INDUSTRIAL EXPLOITATION. Wholly robotic planetary etc. expeditions and operations would going forward appear to be feasible at some factor of 500 or so cost reduction compared to such activities involving on-site humans. Such revolutionary ISRU would massively reduce the requisite LEO upmass and is expected to change much the current design reference mission studies which postulate "Hauling it all there," with some possible fuels and building materials produced via ISRU processes.

Then there is the strategic approach to expedition/mission weight reduction – utilization of reusable space infrastructures/utilities writ large including [examples]:

- Fuel depots
- Beamers
- Tethers
- Virtual Tele-presence
- Space Solar Power

IF we are serious about space faring then space utilities/infrastructures are the ultimate "way forward. At this point we are still "exploring" vice "settling" and still evolving the requisite technologies. There are few serious extant studies of tradeoffs between various manifestations of reusable space utilities/ infrastructures vice the current "one time use" approaches at the overall exploration architecture level. Forward work at this point although there are projects regarding fuel depots and studies of "repair bots" in space and space solar power.

Since for long missions radiation protection is emerging as THE major evolving mission weight worry it would appear that serious ideation should be applied to active radiation protection approaches, with emphasis upon weight and energy reduction. A recent concept under study at NASA LaRC termed Jujitsu is of particular interest in this regard. The idea is to utilize the energy of the incoming radiation via E-M fields to energize much of the protective incident energy decrease and deflection. Also, the entire spacecraft architecture should be considered as potential components contributing to the/a synergistic overall radiation protection system of systems. Magnetic vice Electrostatic active radiation approaches appear to be more efficacious.

Yet another approach with regard to "weight savings" is to reduce the crew size to a minimum of perhaps two, one a scientist and one an engineer. Holographic crew members could obviously be added and updated daily with the latest information and news to provide socialization as well as expert aid and comfort. Then there are, in some 15 or so years out, the real expectation of robotic crew members with Machine Intelligence approaching human via biomimmetics. Suspended Animation is a further crew alteration possibility that could save considerable cost and weight whilst aiding overall crew mental state. There is recent success in the use of Hydrogen Sulfide and other approaches to induce reversible hypothermic states, e.g. suspended animation. Such approaches reduce temperature, O_2 consumption, heart rate, metabolism etc. and are being developed currently by DARPA and others for medical/surgery/wound applications. For the long transits to Mars or the outer planets spacecraft size/ weight, consumables including oxygen etc. would normally be sized to the needs of the usual human diurnal cycle which includes longish periods of activity, requiring additional consumables and internal volume/weight compared to a crew placed in suspended animation. Also, the "confinement" effect on the crew mental state for longish transits is currently an unevaluated concern/worry which would be assuaged by utilization of suspended animation. A long standing concern with this is "waking them up "well", with them being in a "serviceable "condition upon arrival. Ongoing research is addressing that issue. Obviously the Genomic and Synthetic Bio revolutions could be employed to produce "Designer Humans" more in consonance with suspended animation.

Gossamer membrane materials/structures have, are and should be pursued for a multitude of space faring applications including sails, light buckets, antennas, solar arrays, planet/ life finders, concentrators, mirrors, lenses, radiators, sunshades, habs, etc. The ongoing Mems and Nano Tech Revolutions can provide membrane materials with embedded sensors, actuators, computing, energy storage and other functionalities including “intelligence.” The potential weight savings are massive. Serious development of Membrane space habs is ongoing, notably by Bigalow

.

The Bolonkin and Bekey Concepts………..

The Space Technology concepts due to Alexander Bolonkin and Ivan Bekey constitute the Frontiers of the Responsibly Imaginable – they are bold, audacious, creative, imaginative, and literally define the term “Big Idea” for space going forward. Their concepts are easily accessed from their books [refs. 12, 13 and 14].

Many of the the Bolonkin concepts utilize Electrostatics. His concepts include but are far from limited to:

- An advanced Magnetic Space Launcher

- Direct Blood Oxygenation and nutrition in lieu of a space suit

- Propulsion via establishment of an electrical power/plasma channel in free space and magnetic/plasma forces vice mass ejection for thrust

- Levitation via large S-C rings creating suitable magnetic fields

- An electrostatic climber for space elevator

- An ultra low cost/size/ weight thermonuclear reactor design

- Optimal Space Tower Designs

- Upper atmosphere or solar wind electrostatic ramjet

- Electrostatic Magsail

- Beamed space propulsion via ultra-cold plasma injection and electrostatics

Bekey utilizes and discusses some 14 high leverage principles, including replacing structures with information, utilizing co-operating distributed systems and large gossamer membranes and inflatables for many functionalities including apertures. His major concepts include variations on the central theme of exploiting the varied and revolutionary properties of Nano Tubes, including various flavors of tethers. Bekey Comments with respect to the Nations Space Projects from his chapter entitled the Long Term Outlook for Commercial Space in the NDU book “Toward a Theory of Space Power” are “interesting”………

“The Nation's space programs are in a horrible mess and appear to be locked in a downward spiral. Almost all defense and civil government space programs suffer from similar symptoms:

- no toleration of or planning for failures
- avoidance of risk
- lack of funding for new technologies
- inability of industry to afford research or to develop technologies alone
- suppression of disruptive technologies
- disappearance of the concept of experimental systems in space.

As a result of these symptoms, the following conditions are now the norm:

- absence of innovation
- long timelines for even modestly new developments
- billion-dollar price tags for major systems
- major overruns and schedule slips
- need for long on-orbit life to amortize the investment
- obsolescence of systems upon launch or soon thereafter.”

Mission Reliability Considerations

The Design Reference Missions and other studies of extended Human Missions beyond LEO are at this stage very "top level.” Historically as these studies become more detailed the margins go south and the costs escalate, it is important to start with large positive margins.

One of the "more detailed" issues that needs to be addressed earlier rather than later and is currently not being addressed [except for a few piece parts] for long duration human spaceflight is reliability and surety. These issues/concerns, depending upon applicable research, discovery and engineering invention, could greatly increase the costs and decrease safety of such missions.

Issues/considerations of interest include the SIMULTANEOUS effects of:

- On Planet Dust, especially the Martian dust which is thought to contain hexavalent chromium, the most potent carcinogen known.

- Reduced-to-micro gravity

- Micro-meteoroids

- RADIATION, Effects upon humans, electronics, materials, functionalities

- Long duration "Aging", fatigue Etc.......

- Errors [Human and Machine, including both omission and commission]

Effects of radiation and Micro g upon Genomics/Bio, especially formation of extremely worrisome/nasty pathogens and corrosives. Bugs in space become very virulent, benign viruses when put in space tend to become killers. The Human Gut contains many thousands of bugs which will populate the cabin areas and serve as potential sources of mutated bio organisms.

- Effects of Free O2, other active/reactive/oxidative/excited species

- system non-linearities/cascading failures

- ETC., Etc.........

The engineering, inventions and associated costs including redundancies/fail safe backups to keep the crew "pink and warm" in the face of these issues are currently wholly unknown but will have to be known before realistic mission costs/project plans can be developed.

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 15 and 16] and solar particle events which are both highly carcinogenic and severely impact the immune system. Radiation protection during transit and for the Habs is possibly doable, requiring great weight. 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 was 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 [although a robotic in-space beyond LEO capsule to study such at the tissue/organ level is certainly executable], 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 17]. 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 100 to a 1000 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 and cost decreases of ever smaller/lighter sensor and robotics systems, the emerging autonomous robotics capabilities, improving machine intelligence and the developing five 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 physical 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.

A somewhat farther term but “within bounds” approach is to employ the evolving synthetic biology technology revolution to invent/develop life forms [perhaps even those based upon silicon or sulfur vice carbon] that could be nucleated on Mars/other locations and literally LIVE off the land and be “controlled”/co-opted to explore, colonize and terraform. As an example they could conceivably be designed/developed to produce and secrete sensors as they move about. This utilizes both “Bio-Production” and Bio-Functionalism,” AKA “Living Robots”. These entities could conceptually include “flyers” and “hoppers” to ensure adequate coverage of the planet/ body. Obviously, given the current “Planet Protection” mantras such an approach would entail significant soft side negotiation. It would appear to be efficacious to begin that “dialogue” now, as the Bio revolution enables such a capability/approach in real time. Obviously, the same Synthetic Biology Technologies along with the ongoing studies of “Extremaphiles” could be applied to Humans to possibly provide such as Rad-Hardening, reduced O2 requirements/enhanced O2 efficiency, reduced food/liquid requirements–to-direct photosynthesis, Etc…..Altogether, “Designer Humans” designed as” Exploriticus Sapiens”. Not that much of a “leap”/change from the current trend toward “Designer Babies”.

The Frontiers of Space Technology

The following synopsis constitutes the leading edge of prospective Revolutionary Technologies which would/could massively change the cost and safety of Space Technology/Exploration/Exploitation and Industrialization and are therefore of “interest” for serious research efforts, having high risk and even [far] higher payoff.

These derive from the Several “Dominant Themes prevalent in the ongoing simultaneous IT, Bio, Nano, Energetics, Quantum Technology Revolutions. These themes include Miniaturization, Robotics, Machine Intelligence, Genomic/Synthetic Biology, Sensorization, Networks, Optical Bandwidths, Nano/Quantum materials, Energy Density, Quantum Everything………

Fabrication/ Manufacturing – Molecular Manufacturing/ “Strong Nano”,

Materials – Fused/ structural Nano Tubes, “ageless”/ defect free materials

Energetics – LENR, Positron Storage/ utilization, Low Diffraction Energy Beaming, Aneutronic ECF P-B11 Fusion

Communications – Hal Puthoff vector/ scaler Quantum Comms utilizing Josephenson Junctions [ref. 18]

Propulsion – High Thrust MHD [FRC, VASIMIR] possibly using harvested propulsive mass, CNT Magnetic sails, Slingatron, Tethers including E-M tethers/ revolutionary energetics, Pondermotive Forces induced by laser/ plasma interactions, MET [Microwave Electro-Thermal]

Radiation Protection – Active using Revolutionary Energetics

Humans – Via Genomic/ synthetic Biology, greatly accelerated DNA repair

ISRU – LENR Transmutations, Molecular Manufacturing, LENR Energetics

Mars Terraforming – Huge deployable gossamer solar reflectors/ concentrators to melt the poles, enable shallow ocean, add “plants for Planets” to produce O2

IT/ Computing/Nav – Quantum Computing, Atomic computing, Quantum optics/ electronics/sensing/, Atom optics Nav

LEO Access – Beamers, LENR, PDW Rocket, Slingatron

Biologics – Synthetic Biology life forms to explore, colonize, terraform [both bio production and bio functionalism]

Note – Given a massive energetics source nearly ANY mass, harvested from anywhere [in atmosphere, from surface, flying about, etc.] can be utilized as propulsive mass via separation of propulsive mass and energy , traditionally COMBINED in rocket fuels of the Chemical Persuasion. Using small amounts of alkaline material additives or brute force energetics to induce conductivity in/of an arbitrary/harvested propulsive mass enables high Isp high thrust MHD propulsion without hauling fuel around the solar system. Therefore, IF LENR [essentially Nuc Energy Density without the radiation hazard[s]/protection weights/expense] is engineered going forward Space Propulsion and Space writ large [and MUCH else] is changed mightily………….

Commentary

Success in only a few or in some cases one [e.g. LENR or Structural Nano Tubes] of the myriad revolutionary technologies briefly cited herein could have major impacts upon Human-Mars and Space in general with respect to 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 these 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 requisite 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. The essential key to safe and affordable space travel/exploration/exploitation is beyond Chemical Energetics and propulsion. In the nearer term, the dominant opportunities in these areas are fission Nuc thermal or electric and for supply/re-supply slo-boats, “sails” of various flavors. In the mid-term, Advanced beaming [various], LENR, Slingatron, positrons and MHD. The farther term possibilities will derive from whatever and whenever we sort out and understand what is really going on in physics at cosmological scales.

Overall – As mentioned in the Bekey comments cited herein, the pursuit of Revolutionary Space Technologies has over the years been akin to a battle, with the forces of conservatism/evolution consistently winning over those advocating risky/huge payoff REAL “Game-Changing” approaches. The Space Community has simply been unwilling to make the investment of time and treasure to ideate and triage/develop Revolutionary Technologies, resulting in Space being largely and still a high capital investment evolutionary at best Industrial Age Endeavour in the IT age heading rapidly to the Virtual Age.

“The battle is within. It is a cultural one: between glorifying the past or marching toward the future, between protecting successes or cannibalizing them, between averting risk or embracing it. The battle is for the soul of the of the Industry [and the Future of Humankind in Space]”

There does appear to be a possible change in direction on this, TBD. In the discussion of the Space Technology Grand Challenges NASA recently stated:

“The future demands active curiosity, open minds and a determination to resolve challenges as they present themselves”

Also:

“The challenges of flying in space are such that a truly radical improvement in nearly any system used to design, build, launch or operate a spacecraft has the potential to be transformative. To meet the broad challenge of maintaining a robust and vibrant space program, investments will be considered in any space technology that has the potential to be transformative.”

References

1. Rapp, Donald, "Initial Mass In Low Earth Orbit Required to Transfer Space Vehicles to Mars Orbit or Mars Surface," Appendix 9 in "Human Exploration of Mars – Reality or Fantasy," www.mars-lunar.net.

2. Hay, Jason et al, Tauri Group, "Technology Frontiers: Breakthrough Capabilities for Space Exploration," December 2010, NASA NP-2011-01-324-LARC

3. Bushnell, Dennis M., "Imaginable Technologies for Human Missions to Mars," Aerospace America, June 2007, pp. 24-30.

4. Frisbee, Robert H., "Advanced Space Propulsion for the 21st Century," J of Propulsion and Power, V. 19, No. 6, Nov.-Dec. 2003, pp. 1129-1154

5. Ketsdever, Andrew D. et al, "An Overview of Advanced Concepts for Space Access," USAF AFRL, Report - RZ-ED-TP-2008-238, 2008

6. Lineberry, John T., Chapman, James N., Litchford, Ron J., and Jones, Jonathan, "MHD Augmentation of Rocket Engines Using Beamed Energy," AIP Conference Proceedings, V. 664, No. 1, pp.280-291, 2003, First International Symposium on Beamed Energy Propulsion

7. Millis, Marc G. and Davis, Eric W. Eds., Frontiers of Propulsion Science," V. 227, AIAA Progress in Astronautics and Aeronautic, 2009

8. Davis, Eric W. "Teleportation Physics Study," USAF, AFRL-PR-ED-TR-2003-0034, 2004

9. Davis, E.W., Teofilo, V. L. ., Haisch, B., Puthoff, H. E., Nickisch, L. J., Rueda, A. and Cole, D. C. "Review of Experimental Concepts for Studying The Quantum Vacuum Field," STAIF 2006, AIP Conference Proceedings, V. 813, pp. 1390-1401, 2006

10. Moses, Robert W., "Regenerative Aerobraking," STAIF 2005, AIP Conference Proceedings, V. 746, pp. 1361-1370, 2005

11. Harris, C. E., Shuart, M. J., and Gray, H. R., "Emerging Materials for Revolutionary Aerospace Vehicle Structures and Propulsion Systems, "SAMPE Journal, Vol. 38, No. 6, November/December 2002, pp. 33-43

12. Bolonkin, Alexander, "New Concepts, Ideas and Innovations in Aerospace, Technology and Human Sciences," Nova Science Publishers NY, 2008

13. Bolonkin, Alexander and Cathcart, Richard "Macro-Projects, Environmental and Technology," Nova Science Publishers, NY 2009

14. Beckey, Ivan, "Advanced Space System Concepts and Technologies," The Aerospace Press, 2003

15. Simonsen, Lisa C, Wilson, John W., Kim, Myung H., and Cucinotta, F. A., "Radiation Exposure For Human Mars Exploration," Health Physics, V. 79, No. 5, Nov. 2000, pp. 515-525

16. Adams, J. H. Jr., et al "Revolutionary Concepts of Radiation Shielding for Human Exploration of Space," NASA/TM-2005-213688

17. Lindberg, Ronnie, "Importance of Human Presence in Space Exploration – Man or Machines?" IAC paper 03-IAA.1.1.01 International Academy of Astronautics meeting Breman Germany, 2003

18. Puthoff, Harold E., Communication Method and Apparatus wioth Signals Comprising Scaler and Vector Potentials Without Electromagnetic Fields," U.S. Patent 5,845,220, 1998

REPORT DOCUMENTATION PAGE						*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* 01- 04 - 2013	**2. REPORT TYPE** Technical Memorandum	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE Advanced-to-Revolutionary Space Technology Options - The Responsibly Imaginable	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Bushnell, Dennis M.	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 432938.09.01.07.01
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199	**8. PERFORMING ORGANIZATION REPORT NUMBER** L-20240
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001	**10. SPONSOR/MONITOR'S ACRONYM(S)** NASA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/TM-2013-217981

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 91
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Paper summarizes a spectrum of low TRL, high risk technologies and systems approaches which could massively change the cost and safety of space exploration/exploitation/industrialization. These technologies and approaches could be studied in a triage fashion, the method of evaluation wherein several prospective solutions are investigated in parallel to address the innate risk of each, with resources concentrated on the more successful as more is learned. Technology areas addressed include Fabrication, Materials, Energetics, Communications, Propulsion, Radiation Protection, ISRU and LEO access. Overall and conceptually it should be possible with serious research to enable human space exploration beyond LEO both safe and affordable with a design process having sizable positive margins. Revolutionary goals require, generally, revolutionary technologies. By far, Revolutionary Energetics is the most important, has the most leverage, of any advanced technology for space exploration applications.

15. SUBJECT TERMS
Expeditions; Frontiers; Ideation; LEO; Mars; Revolutionary; Safe; Technologies

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER ***(Include area code)***
U	U	U	UU	31	(443) 757-5802