NASA/TM–2014-218519

Frontier Aerospace Opportunities

Dennis M. Bushnell
Langley Research Center, Hampton, Virginia

October 2014

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–2014-218519

Frontier Aerospace Opportunities

Dennis M. Bushnell
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

October 2014

Available from:

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

Abstract

Discussion and suggested applications of the many ongoing technology opportunities for aerospace products and missions, resulting in often revolutionary capabilities. The, at this point largely unexamined, plethora of possibilities going forward, a subset of which is discussed, could literally reinvent aerospace but requires triage of many possibilities. Such initial upfront homework would lengthen the Research and Development (R&D) time frame but could greatly enhance the affordability and performance of the evolved products and capabilities. Structural nanotubes and exotic energetics along with some unique systems approaches are particularly compelling.

Introduction

Aerospace, originally as Aeronautics and later including Space access, utilization, science and exploration, developed in the Industrial Age and is to a major extent still an artifact of that age. In both the Aerospace and Space arenas a conservatism has developed over the years including reliance upon proven, legacy systems and approaches. Having begun in the Industrial Age, the continued utilization of flight proven, legacy systems, approaches and technologies biases the industry toward maintaining an Industrial Age content and status quo. Systems are updated, (some) materials are improved as are sensors and IT components but overall the aerospace arena, which was the "go-go" industry, the technological cutting edge of the 1950s and 1960s is today often typified by risk aversion and less than aggressive visioning actualization.

We are now in the Information Technology (IT), Biologics (Bio), Nano age heading rapidly into the virtual age, beyond the Industrial Age. We are also beset by apparently long term fiscal issues impacting the affordability of the continuation of Industrial Age approaches, technologies and mantras. Both in the military and civilian aerospace arenas the worldwide "competition" is becoming more aggressive with respect to application of contemporary and developing technologies, systems and concepts. In some cases such utilization alters much, from missions and goals through functionalities and often proffers significant cost reductions. This increasing competition is a result of the essentially level technological playing field worldwide.

The purpose of the present report is to briefly summarize the nature and promise of the ongoing worldwide technological revolutions and posit synergistic applications of such across Aerospace which would/could in most cases greatly alter missions, goals, affordability, safety and in some cases raw do ability. What is suggested herein would require homework and triage across a large number of technological possibilities. The highly successful method of addressing risk in such cases is to ideate/collect many approaches and then do homework, research and triage, putting more resources on a fewer number of possibilities as learn more. This usually ensures a successful outcome and is very different from the current risk averse approach of trying to "pick winners" up front before the requisite homework to enable such a decision is accomplished.

This "homework first" approach to developing advanced systems, which can require a decade or so of research on several approaches, requires decades long foresight regarding goals and missions and such long term strategic planning has not been prevalent within aerospace in recent decades, with folks going to the shelves and trying to pick up available technologies when a goal/mission is decided upon. In many cases, such as National Aero-Space Plane (NASP), X-33, High Speed Research (HSR), Space Launch Initiative (SLI), Next Generation Launch Technology (NGLT), Constellation, this approach of trying to attain revolutionary goals with evolutionary, existing technology has resulted in "negative margins" which went south during the studies, weight and cost increased as they usually do. Need to start with large positive margins which in general require revolutionary technologies, which in turn require homework and foresight/triage of many possibilities to develop. A poster child for such a shift, having both the requisite time scales (a decade for research, a decade for development) and the absolute affordability and safety requirements is "Humans to Mars." A prospective "campaign plan" for Humans to Mars might include the following, per the content herein:

- Rapid development and deployment of virtual Mars exploration via "instrumenting the planet," combining all of the available, obtaining more, sensor etc. information into a virtual reality experience available to anyone, any time. Quite inexpensive and near term, should greatly increase public interest and involvement in exploration. A version of this for younger children could include having a Martian of their choice provide a guided tour of their neighborhood.

Develop and deploy robotics, using increasingly capable In-situ Resource Utilization (ISRU), to prepare equipment and life support etc. onsite/planet for eventual human arrival. Such robotic exploration and preparation is orders of magnitude less expensive than on site humans and is doable near to mid-term.

While the above activities are occurring, conduct the research and development necessary to enable humans both safe and affordable and when the requisite technology is ready, launch a manned mission.

The discussion herein suggests possibilities for major affordability and capability revolutions in aerospace nearly across the board via exploitation and development of advanced, often nascent technologies, deviating from the conventional use of existing legacy approaches, technologies and thinking.

Some "going in" examples of what is now unaffordable and/or unsafe but might be executable given advanced technology capabilities include:

- Routine "humans to Mars"

- Mars colonization and terraforming

- Humans to the outer planets

- Physical interstellar exploration

- Serious ISRU

- Space solar energy

- Commercial Space "Industrialization" beyond privatization of government activities and "earth utilities"

- A $1T/ year market in personal air vehicles

Currently, especially for much beyond Low Earth Orbit (LEO) and for longer missions largely what is affordable is not safe and what is safe is not affordable, for onsite humans, using existing technologies. There has now been more than 2 decades of systems studies, "Design Reference Missions" and creative attempts to rearrange the piece-parts utilizing mostly the proven Industrial Age technology inventory without much success in terms of an affordable and safe mission. As the long duration radiation health impacts have become clearer, more definitive and systems designers have estimated the weights necessary for passive radiation protection, active radiation protection appears to be required to save weight/cost/ensure crew health and there is evidently a possibility that advanced superconducting technology may enable solution spaces for active magnetic radiation protection. In general, to afford safety requires major mission cost reductions and simplistically, along with reducing the marching army such overall cost reductions require weight reductions. As an example aerodynamic capture and aerodynamic braking on Mars, where there is an atmosphere of sorts to enable such, is nearly a mission enabler by obviating the fuel weight required to retro rocket. Many other weight reduction and other cost reduction approaches are needed to enable both safe and affordable long duration human exploration much beyond LEO. These weight reductions may be obtainable nearer term via serious ISRU (for everything possible that makes sense).

One arena that is being pursued somewhat already is utilization of genomic and synthetic biology to "Rad Harden" humans. This research is attempting to increase deoxyribonucleic acid (DNA) repair rates, reduce the health impacts of radiation to enable reduced required radiation protection weights. Other frontier exploration possibilities, discussed herein, include serious

ISRU (make it there instead of hauling it there), vastly improved space access and in space propulsion, frontier energetics, increasing value per pound via multi-functionality and miniaturization, use of holographic crew members for both functionality and psychological support, resulting in reduced crew size and large overall weight/cost reductions, and frontier materials to include structural nanotubes. Interesting life support options going forward range from concentrated nutrients and recycling everything including the solids to various forms, approaches for suspended animation. Also, using/following studies of extremophiles, altering humans to require less sustenance, already being researched for plants (reduced water, nutrients).

The aeronautics metrics and issues are changing rapidly and becoming ever more stringent. These metrics/issues include worldwide technical and economic competition, acoustic strictures, “runway” efficiency as traffic increases faster than new runways can be built (primarily due to permitting issues), emissions, competition from tele-travel, on site printing vice air cargo, security and safety. As an example, short haul aero traffic is challenged by the fact that driving is less expensive by far and air travel trip times are impacted by security issues, traffic and weather delays and scheduling changes. There is some evidence that tele-travel is starting to impact and substitute for physical travel. Some assert that the growth in demand for physical travel overall has slowed to possibly stopped in industrialized countries. For automobile transportation the U.S. is past “peak car,” the miles driven per capita have been in decline for several years now. Air travel for short haul has declined in the U.S. and the Federal Aviation Administration (FAA) growth rate projections for air travel overall is dropping year by year. The precautionary principle dictates that the impacts of ever improved tele everything including tele travel should be factored into strategic planning for both what is needed and how to provide those needs.

Zeroth order technological opportunities include ever better, less expensive and more intelligent robotics, major/serious materials and energetics breakthroughs, accurate regional level climate measurements and projections/predictions, inexpensive immersive presence/virtual reality exploration for everyone 24/7/265, nano sensor revolutions enabling massive networked global and planetary sensor grids, the increasing replacement of physical testing by mod-sim, affordable and safe personal air transportation for everyone as well as effective scientific campaigns to determine explications for the far too many physics issues, disconnects, and unknowns at cosmological scales, dark matter and energy being perhaps the most onerous of such. References 1 and 2 document the requirements for exploration going forward, with Reference 3 providing an extensive collection of frontier technology approaches to enable such.

Synopsis of Current Aerospace Approaches

Aeronautics:

Civilian Long Haul – 707 [1950s] Derivatives in spite of nearly 25 years of serious Blended Wing Body (BWB) studies (and the B-2 military flying version) and the more recent truss braced wing designs/ technology suite proffering up to 80 percent (overall) improvements

Air Traffic Control (ATC) – Largely human operated with long latencies and the inability to enable a massive [~ $1T/ year] autonomous Unmanned Aerial Systems (UAS) (Personal Air Vehicles (PAVs), UAS carrying passengers (pax) worldwide aero market. According to the FAA, “Next Gen,” the current ATC upgrade which is many years out, would enable some 7,000 UAS in controlled airspace in the U.S. when we need many millions for this nascent PAV market.

Military – “Short Legged fighters” and 707 derivative platforms for tankers, transports and sensing. These are increasingly vulnerable to disparate threats.

Space:

Space Access – Derivatives of 1950s era military missiles, “better living through chemistry”/chemical propulsion, small payload fraction, costs too high to enable “commercial space” beyond legacy “earth utilities” (telecom etc.) recent Space X developments are improving this situation

Human Space Exploration – Chemical propulsion (same 1950s era derivatives as military), Apollo mantras, self-contained expeditions, serious cost and safety issues beyond LEO, some interest in electric and fission nuclear propulsion

Space Science – The introduction of post-industrial age technologies (IT, sensing, robotics) has reduced the cost and increased the return from space science activities, increasing “value per pound,” still conducting “self-contained” missions vice establishing/utilizing reusable space infrastructures.

All Aeronautical and Space activities are challenged by several overarching issues:

- Energetics Restrictions, Energy Budgets

- Weight(s)

- Cost(s)

Of these energetics is the key issue, improvements in such could mitigate the issues with weight and costs. We are essentially still largely in thrall to chemical energetics.

Nature of the Ongoing Technology Revolutions

There has been much written in recent decades of the several and multiplying major ongoing technology revolutions, References 4-7. The first of these, the IT Revolution, provided the means for and ensured that the IT and subsequent revolutions promulgated worldwide to the point where the world is avowedly technologically “flat.” Although extant listings and codifications of the ongoing technology revolutions differ in detail, for purposes of the present report the major areas addressed include IT, Biologics, Nano, Quantum and Energetics, in the approximate order of their appearance. The IT Revolution began in the 1950s with the development of solid state electronics, the Biologics Revolution in the 1960s -1970s with DNA, genomics, nano in the 1990s with self-forming nano systems and carbon nanotubes. Quantum technology is developing rapidly in real time as an enablement of nano and the Energetics Revolution is nascent in terms of new, seriously deviant, non-chemical approaches to energy generation and storage.

IT – The IT Revolution has produced an astounding factor of E9 in computing capability/speed since the late 1950s with another some E8 to E12 to go as we shift from silicon to biologics, optical, nano, molecular and atomic computing. Then there is quantum computing, which for an increasing number of applications is projected to provide up to some E44 improvements, a very large number, TBD. As this is written the fastest computer is a Chinese machine at some 30 plus petaflops, essentially human brain speed.

The development of machine intelligence, after decades of suffering inadequate machine capability to make serious progress and a detour into expert systems, (which have/are proving to be extremely useful/important) is now embarked upon biomimmetics/brain emulation approaches. There is even a possibility of “emergence,” i.e. make something complex enough and it “wakes up.” This latter is by some thought to be the source of human intelligence via evolutionary changes during the million plus years of the hunter-gatherer epoch. In fact, some posit that human intelligence can be improved upon, is only a cul-de-sac of what is conceivable.

The IT Revolution has produced massive changes in human society and econometrics including the internet, its’ impacts upon knowledge ability and an increasingly pervasive trend of “Tele-Everything” – tele–commuting, tele-work, tele-shopping, tele-travel, tele-education, tele-medicine, tele-commerce, tele-politics, tele-socialization, tele-entertainment, tele-communications and recently via printing tele-manufacturing, etc. A relatively recent realization is that the extraordinary compilation, storage and availability of truly massive amounts of information and data could via processes under the mantra of "Big Data" reinvent much of both technical and commercial/business processes and content, including the elucidation of heuristic governing "laws" for various situations.

Yet another major impact of the IT revolution involves enablement of robotics writ large, which is on a clear path to pervasive autonomous systems. The machines are rapidly supplanting humans in ever increasing areas of employment, are proving to be ever more productive and inexpensive and in an increasing number of areas more capable than humans. The major recent and emerging IT human-machine interface communications development, 5 senses virtual reality, bodes well for greatly accelerating the tele-everything trend. The ongoing development of IT enabled 3-D printing is rapidly changing the manufacturing landscape, from central factories employing numbers of humans in the Industrial Age toward robotic home "fab laboratories," with potential major consequent impacts upon the requirements for cargo transport in Aeronautics and ISRU capabilities for space exploration. Finally, what is evolving is a global brain, via the web, which when combined with on-site printing is enabling a planet of inventors, both human and increasingly machine.

Biologics – The major impacts of the Bio Revolution have thus far been in agriculture and medicine. In the former crops have been developed which are insect and disease resistant and which make more efficient use of resources whilst producing greater yields. Genomic medicine is under development for both prevention and treatment. Of especial interest in the Bio arena is the now rapid development of synthetic biology, essentially bio engineering wherein bio systems are assembled out of piece parts for specific technological applications. These applications include bio-production wherein bio processes are utilized for manufacturing and bio-functionalism where bio systems are applied for engineering purposes, an example of which might be "watering your aircraft in the morning." The possibilities are very intriguing.

Nano – Nano, which started out as self-organizing nano systems ala chemistry, is beginning to morph into the original Drexler “Engines of Creation” circa mid 1980s vision of assembling materials and devices atom by atom through mechanical vice chemical processes. This is termed “molecular manufacturing,” essentially the penultimate printing approach. The major nano impacts are in materials, surface chemistry across the board and in sensors. Nano proffers possibilities for “ageless” materials, sans the usual dislocations and inhomogeneity’s that instigate and promote crack growth. Nano also is enabling superb and inexpensive sensing with projections for several trillion networked sensors worldwide in a decade, an excellent start on a ubiquitous global sensor grid to provide input(s) to the emerging Global Brain. Nano systems are also greatly improving robotics and enabling “Brain Chips” to augment/enhance human brains as well as a myriad of other human health and performance related contributions. Then there is nanotubes, both carbon and nitride. The structural material vision for contiguous versions of nano tubes, if such can be developed, proffers a factor of 3 to 8 dry weight reduction almost across the board, not percentages, factors.

Quantum – Quantum is of course the fundamental science behind lasers, superconductivity, quantum entanglement, super fluidity, Bose-Einstein condensates etc. current attempts to engineer around decoherance could result, in just over a decade some opine, in serious quantum computing. Quantum encryption is entering the commercial application stage. Lasers have obviously developed into a massive number of applications, from medicine through entertainment and materials processing to communications, including now free space communications with nearly unlimited bandwidth. Then there are quantum based sensors, quantum developed materials, quantum non-linear optics including plasmonics and photonics, quantum imaging, quantum optimized photo voltaics, and quantum electronics. Overall, Quantum Technology, engineering applications of quantum science, appears to be the next big thing beyond nano.

Energetics – Energetics for nearly all purposes has long relied primarily upon chemistry, with, starting in the mid-1900s, the addition of fission nuclear. Before the Industrial Revolution energy was produced by/via what are now termed "renewables," especially biomass, water and wind. There are now several admittedly nascent but promising energetics alternatives, including Positrons (E9 times Chemical), LENR (from theory, up to E6 times Chemical), low diffraction energy beaming (enables separation of propulsive mass and energy), SBER (E3 faster and cold chemistry), aneutronic inertial electrostatically confined fusion, atomic fuels (e.g. H not H2, 20X Chemical), heat storage in Zeolites, SMES with CNT magnets (batteries at 20X chemical), metal air batteries, Isomers (E5 times Chemical), solid hydrogen (20X Chemical), neutral particle beams, cold fast compression (E3 times Chemical), etc. These are coincident with ongoing reductions in energy requirements via miniaturization and efficiency improvements/conservation writ large. Several of these approaches/concepts would if successfully proven out and developed/engineered enable massive changes across the board in society, climate and econometrics as well as aerospace and technology in general.

Emerging Frontier Technology Enabled Aerospace Opportunities:

1. Energy Rich Aeronautics, Space Science and Space Exploration

Of the frontier energetics options Low Energy Nuclear Reaction (LENR), Positrons and low diffraction energy beaming appear to proffer the most interesting opportunities for aerospace, References 8 and 9. All of these would enable separation of propulsive mass and energy, which are combined in chemical fuels. For LENR and positrons the heat produced could be used either to replace a combustor or to produce electricity for electric propulsion/propulsors via an increasingly interesting rack up of direct conversion approaches including pyroelectrics, thermoelectrics, thermal-photo voltaics and sterling/other thermal cycles. The propulsive mass would no longer have to also be a "fuel"/energy producer, which opens up a vast number of "propulsive mass" sources of opportunity including Regolith and far outer region atmospheric constituents obtainable via "harvesting," obviating the need to loft propulsive mass from the earth initially for in-space propulsion. Conventionally, lofted fuel, a propulsive mass and energy chemical combination, is the order of some 80 percent plus of the nearly 1000 metric tons in Low Earth Orbit (LEO) required for the Humans-Mars expeditions studied thus far. Such “harvested” non-energetic propulsive mass is then made conductive via either alkaline doping or thermal inputs from what is avowedly “energy rich” energetics, propulsive energy sources. This approach produces a very different set of systems, architecture options, tradeoffs and optimizations as well as what should be far reduced costs enabled by the obviation of lofting propulsive mass (as fuel) from earth. The beamed energy options, usually either microwave (MW) or various flavors of lasers, can produce electricity directly via either rectennas or photo voltaics respectively. Having conductive propulsive mass and electricity available, Magnetohydrodynamics (MHD) accelerators, operating at high thrust, could from studies produce Isp levels above 2000 seconds. Obviously for aeronautical, in atmospheric propulsion the propulsion options would also include heating or increasing the conductivity of and accelerating ingested atmospheric air in an open cycle and in lieu of the separate propulsive mass required for in space propulsion. For energy beaming newer developments, including meta materials, appear interesting for reducing beam diffraction, which would make the less expensive MW approaches more useful.

There is another class of advanced energetics which includes atomic fuels (e.g. H not H2) which is a mono fuel and could be utilized via either storage in solid hydrogen or as a result of formation/carriage of metallic hydrogen. Other options include the “slingatron” to loft g-tolerant payloads such as water via a mechanical device and the Russian blast wave accelerator which is a “gun” utilizing semi-continuously staged explosives/detonation waves. Then there are neutral particle beams and even mass drivers as in-space alternatives. All of this is in addition to the more “usual” fission and even fusion zoo of options, along with some chemical fuels improvements such as poly nitrogen. In spite of this array of energetics possibilities, along with their major in most cases potential benefits aerospace continues largely to pursue conventional chemical, and in some cases electric, propulsion along with episodic studies of fission systems

Being “energy rich” (as for example from LENR or Positrons) would produce very much altered cost and operation design spaces, opportunities across the board. Enabled would be such as:

- Light-weight power/energy sources for space probes and instrumentation

- Energetics for long lived and superb performance planetary hoppers and rovers

- Entry Descent and Landing (EDL) wherein atmospheric constituents ingested at higher altitudes would be heated and retroed at lower altitudes

- On planet power and energy, as much as would be needed to prosecute serious ISRU, for exploration and later colonization

- Energetics for planetary terraforming

- High thrust in space propulsion

- Energetics for active radiation protection

- For aeronautics, negligible fuel fraction

- Energetics for electric propulsion

- With efficiency less important, unloaded lift fans, much quieter VSTOL devices, of especial importance for personal air vehicles operating out of neighborhoods vice airports.

- Energy focused upstream to largely obviate sonic boom

- Negligible emissions in the climate sense

- Enables huge loiter for sensor craft

– Via energetics for active flow control, enables extended envelope, bird like flight and flight through weather

- Provides design margins to improve safety including all vehicle parachutes to land safely in the event of mishap, and armored engine surrounds, etc.

- Energetics for direct control of wake vortices to largely obviate the wake vortex hazard, which. along with circulation flow control to provide much greater lift coefficient enables multiple takeoffs on the same runway at the same time, increasing runway productivity, throughput.

Overall, for Aero, far lower gross weights, higher speeds, lower noise, lower costs, lower emissions, greater range, Emissions solved, all weather superb ride quality, greater safety.

- Enables hypersonic air breathing, greater thermal value added than H2 fuel, enabling for high mach number utilization

For the military, greater EMP capabilities, VTOL to obviate need for increasingly vulnerable runways and carrier decks, ultra long loiter are always there vice trying to get there in time, along with the other aero benefits already noted.

Of all the technologies and opportunities discussed herein, advanced-to-revolutionary energetics, beyond chemical energy density and sans the usual fission nuclear radiation safety, weight issues, is the most game changing. Whether the advanced energetics techs will be successful is TBD, but if they are not researched, worked the result is clear, either they will not be available and we keep mainly limping along at the apex of the chemical energetics mantra/solution spaces/agonizing over the various fission nuclear issues or others will develop them first. Many of the advanced/exotic energetics approaches discussed herein would also, along with high altitude wind, apply to the massively important current and future worldwide climate/energy issues.

The benefits of advanced energetics enabled fast transits to Mars are well known:

- Reduced costs overall
- Reduced integrated radiation exposure
- Reduced micro g exposure
- Increased reliability due to reduced "duty time"
- Reduced durability concerns/issues
- Less "boil off"
- Less consumables
- Less "psychological" problems
- Improved public engagement due to enhanced "currency"

References 10–13 document portions of the energetics state of the art/ possibilities for aerospace going forward.

2. Reusable Space Infrastructures

Thus far, space activities have largely to almost exclusively been conducted using expendable, one time vice reusable, launch vehicles, capsules, and on planet equipage, e.g. for transportation, habitability and operability etc. There was an attempt on the Space Shuttle to attain partial reusability especially wrt the orbiter. The extensive refurbishment required flight to flight obviated much of the benefits of such. It is conceivable going forward to employ a much more reusable space exploration-to-commercialization mantra, which should reduce cost(s) and increase safety. Benefits of reusability are obviously a function of the number of reuses and any rework, maintenance required. Integrated Vehicle Health Management (IVHM) possibly including self-healing would be required to ensure safety and operability. What is suggested is essentially a panoply of reusable space "utilities." An initial, simplex inventory of such might include:

- Terrestrial, in-space, on planet/body beamers for propulsion and energetics. As discussed, this allows the separation of propulsive mass and energy as well as reusability. Such beamers could also power tethers for orbit raising where magnetic fields are extant.

- GPS, RF or Optical, for navigation/location on planets/ bodies. Navigation alternatives which could obviate the need for such a central, reusable system include "Atom Optics," aka in USAF parlance – cold atoms proffering orders of magnitude improvements in inertial guidance. Also quantum enhanced graviometers and magnetometers which could utilize the emerging detailed scans, documentation of surface magnetic and gravity fields.

- Space solar satellites around planets, bodies. These would not be impacted by the dust issues that affect on planet/body photo voltaics, have higher 24/7/365 output and be capable of servicing distributed areas, providing both redundancy and reductions in surface infrastructure(s). The nano technology is greatly improving the efficiency of photo voltaics as are combinational photo voltaics and thermal designs which utilize the photo voltaics "waste heat." Obviously the in-space beamers referred to above could also perform this function.

- Establishment of a semi-regular "slow boat" cyclic transportation system, utilizing sails of various flavors or low thrust/high efficiency electric propulsion, between earth and other "bodies." This could over time supply the necessary initial ingredients for serious ISRU (discussed herein) as well as initial equipage and that required for expansion along with whatever critical supplies that could not be produced on site. Such a transportation system would presumably be inexpensive compared to current practices/ approaches.

- Distributed space “service stations,” for repairs, fueling, and most importantly, for possibly saving lives, equipped as life boats in the event of serious vehicle or habitat malfunctions.

- Virtual Exploration, Utilization of in situ inexpensive nano/other instrumentation and other sensors/sensing such as from satellites as input to software which enables virtual reality exploration 24/7/365 for everyone on (personal) demand. Optical free space communications would provide greater band width.

- Reusable Launch Vehicles, the key to serious launch cost reduction for conventional space access approaches, requires reasonable launch rates and durable/low refurbishment designs for viability.

- Momentum Tethers, from planet to solar system scales. These have interesting-to-serious engineering issues of various flavors. Another perhaps related technology in some aspects/issues is space elevators.

3. Serious ISRU

The emerging technologies are greatly increasing the prospective options and capabilities of ISRU, which would be far less expensive [extracting and building it there] than hauling it there. ISRU could then year provide communications, navigation, solar sats, transportation devices, power and energy, robotic adjuncts, fuels, radiation protection, medical facilities/equipage, and habitats and laboratories. Also, since operability and reliability can be demonstrated/ assured before “leaving home (earth), safety is greatly enhanced, and durability, reliability can be demonstrated, proven before committing humans. As already stated, the ISRU initiation packages could be delivered via inexpensive “slow boats (“sails” or high Isp electric). prospective components of an advanced ISRU approach include:

- 3-D printing, on the way to molecular manufacturing. Multiple materials and imbedded electronics capabilities have been demonstrated. The 3-D printing technology is developing very rapidly.

- Autonomous Systems/Robotics, nano functionalization coupled to the increasingly capable machine intelligence on the way via biomimmetics to/approaching human level in one to two decades provides an excellent outlook for the requisite autonomous robotics systems capable of executing serious ISRU.

- Synthetic biology, assembling bio systems from piece parts, could conceivably provide both bio production and bio functionalism as part of an ISRU overall system. ‘Plants for Planets,” using the ongoing research on extremophiles, appear at this point to be do able, for both subsistence and eventual terraforming. Bio-functionalism tasks could include sensing as well as construction aspects. Then there is Bio-mining, wherein biologics are utilized to process ores and minerals, enabling faster extraction rates, lower energy requirements and lower overall extraction system mass than conventional chemical approaches.

- LENR, lacking radiation issues and with some E4 times chemical energy density is especially interesting for both the energetics to execute ISRU and possibly capable, from extant experiments, of transmutations, altering indigenous materials into those desired/required for various ISRU tasks/resulting systems. Then there is long term storage of “inexpensive” positrons at E9 times chemical. Conceivably they could be generated on planet using space solar.

Perhaps the most important ISRU products are fuels and life support “fluids.” There are immense water resources on Mars, for example, including water, CO2, magnesium/other minerals, enabling production of methane, O2, etc. To first order the cost of humans/Mars is proportional to up mass in low earth orbit, and a major portion of that up mass is fuels for transportation writ large and life support on Mars. ISRU could supply these fuels etc. at little direct costs once the ISRU equipage is in place. Many of the humans/Mars costs are in paying people, ISRU can be wholly robotic.

As a simplex example, Martian CO2 could be used for shielding, fuel cells, O2 production, carbon for carbon nano tubes (CNTs), pressurized rockets,

CH_4 production, polyethylene production, and in atmosphere solar pumped lasers.

4. Reduced Cost for Space Access

Probably the greatest cost element associated with space faring, space operations for whatever purpose is space access. Since the 1950s this has been accomplished using variants of military heritage expendable rockets with current costs in the thousands of dollars per pound to low earth orbit. International systems with lower indigenous labor rates are less than U.S. launch costs, although Space X is making progress in bringing down costs and even developing versions that may enable prices per pound below a thousand, possibly far below a thousand. This is accomplished by reducing the marching army and utilizing up to date design and manufacturing approaches and reusability. The ongoing miniaturization, the increasing ability to produce the same functionalization in ever smaller packages is altering in real time the space access landscape for many payloads. Co-operative concepts of operations are being studied as are deployable membranes to enable large apertures using small payloads and the Massachusetts Institute of Technology (MIT) research on Microelectrical Mechanical Systems (MEMS) rocket turbine feed pumps could provide (down) scalable space access for nano satellites. The humans however are not shrinking and therefore they and their equipage which scales to their size continue to present the same cost and safety challenges. There are a vast plethora of alternative space access possibilities that have not yet received serious study, at this point most are at the viewgraph engineering stage, although some are beyond that (References 10 and 14). Note, this particular summary does not include either fission or fusion nuclear approaches due to their innate safety and weight issues. However they should obviously be included as part, an important part, of the overall range of possibilities. The non-fission/fusion alternative space access approaches, which should be triaged and studied sufficiently to allow comparative analysis with extant approaches for cost and safety include:

- Momentum Tethers, These are essentially single point of failure devices that are in the reusable infrastructure category but would constitute major development and employment investments. Some systems studies indicate potential problems with material degradation from upper atmosphere excited states. Tethers could be applied to both space launch and in-space and are apparently “do able” without recourse to nano tube material strength levels although such would possibly allow increased reliability and safety.

- Energy Beaming, enabling the separation of propulsive mass and energy, is a very different space transportation construct that is just now receiving serious study. All requisite technologies including pointing, rectennas or Photo Voltaics (PV), Microwave (MW) or lasers, approaches to reduce beam diffraction, etc. are undergoing rapid development. This requires reusable infrastructures (the beamers) and therefore strategic planning and co-operation to amortize the costs over many future launches. The energy can be used either to heat or to create electricity utilized in very high Isp magnetohydrodynamics (MHD) accelerator propulsors.

- Advanced Materials, Rocket payload fraction is extremely sensitive to dry weight. The dry weight reductions of factors of 3 to 8 proffered by contiguous nano tube structural materials would by itself constitute a revolution in space access. Whether such can be created is at this point TBD but obviously very worth the effort to find out if it can be done.

- Robotics, Much of the costs of space access and space propulsion are directly attributable to paying people. Fuel per se is quite inexpensive. Much of the Shuttle operational cost was due to the “marching army” required to operate and refurbish it. Human labor costs are involved in all facets of space propulsion including R&D, manufacture, transportation and operation. Space X has reduced these costs and they can be reduced much more as we continue to replace humans by robots and develop “printing” manufacturing.

- Exotic Energetics, Progress is being made in positron storage as positronium. As stated previously, positrons posit energy density some E9 times chemical with very reasonable radiation (.5 Mev Gamma) and no residual radiation. They essentially produce heat which can be used as combustor replacements for open cycles, heat propulsive mass or to produce electricity for various flavors of electric propulsion. LENR, which from the weak interaction theory is some E4 to E6 times chemical, has at this early stage of understanding/development no known radiation issues, also produces heat and therefore can be used in the same way as positrons.

- Launch Assist, There are several flavors of launch assist with capabilities across the speed range. At the upper range is the slingatron, which is alleged to be capable of imparting up to 45,000 feet per second at sea/ground level. In the 1960s under NASA Project Radio Attenuation Measurement (RAM), the agency developed a technique to protect such payloads from the extreme heat transfer and drag encountered during transit of the lower atmosphere. The injection of a very small stream of pressurized liquid water from the nose reduced both drag and heating during flight tests at 18,000 and 25,000 feet/second. Such nose region water jet injection could also be used during ascent within the sensible atmosphere for rockets writ large to reduce atmospheric drag. Other types of ground level launch assist include rail guns, coil guns, and the Russian blast wave accelerator. The Mag Lev approach is a form of rail gun. It is even thought possible to utilize laser guided polymer stabilized water jets to provide an initial boost. Energy beaming can also be considered a form of launch assist. Many of these impart large acceleration forces during launch which restricts the payload possibilities to those that are g tolerant. The Army has developed electronic packages for artillery rounds that can withstand elevated g levels, increasing the potential payload possibilities. Some might consider launching from aircraft as a form of ground assist, others book keep this as an alternative first stage, albeit a reusable one.

- Safety improvements could include pressurized tanks vice turbine feed pumps. Such pressurized tankage would be enabled by advanced materials and eliminate one of the foremost safety issues wrt rocket engines. An alternative approach to the elimination of turbine feed pump safety issues is to employ pulse detonation wave engines, wherein the detonation wave(s) supply much of the requisite pressure increases. Since the turbine feed pumps are also a serious cost issue their elimination might also reduce cost as well as increase safety.

- Advanced fuels, There are an increasing number of advanced fuel possibilities, with performance far less than the beamer/MHD accelerator combination and less than the exotics discussed herein but greater than the current norms. These include “cold silicon,” Metallic H2, Atomic H/C/B, Poly-nitrogen (e.g. N4), and possibly metastable helium. Also in this genre are several avowedly higher Isp fuels (Isp ~ 700 sec) which are currently deemed too reactive/dangerous to be utilized, these include Flourine/ Lithium Hydride and O2/Beryllium Hydride. Then there is Structural Bond Energy Release (SBER), which, via applying shear and pressure to materials enables cold chemistry at orders of magnitude greater reaction rates which would serve as an effective “spark plug” to combust materials not usually considered fuels. Not a fuel per se but proffering greater than chemical energy storage is the, at this point conceptual, possibility of superconducting magnetic energy storage using CNT magnets which provide the material strength to contain the enabled large increases in magnetic field strength with major reductions in losses. Estimates indicate possibilities for a “battery” at some 20 times chemical energy storage density.

- Pulse Detonation Wave Rockets, These nearly constant volume combustion, aka Humphrey cycle rockets enable major reductions in turbine feed pump pressure resulting in serious cost and safety benefits. There are designs extant that utilize wave dynamics for valving and ignition, further reducing cost and weight and increasing cycle efficiency. Detonation while the fuel is a liquid has been suggested as a means of attaining higher thrust.

- Air Breathers, There is a many decade long heritage of and interest in space access studies and research employing air breathers. This is mainly motivated by their much greater Isp than rockets for Mach numbers into the teens. For the many military flexible launch metrics air breathers are a very intriguing approach. However, they have several problems wrt the usual civilian space access metrics of cost and safety. Firstly, space access via air breathers requires several propulsion systems, one to accelerate to

Mach 3ish where the hypersonic air breathing flow path becomes effective, The Ramjet/Scramjet air breathing propulsion system for Mach 3ish to Mach 12ish or less and then a rocket system to accelerate the rest of the way. These multiple propulsion systems increase dry weight and dry weight is what you pay for in space access, not gross weight, fuel is generally relatively inexpensive. Also, the thrust to weight of an air breather is low compared to a rocket and therefore the vehicle has to accelerate over a long distance/time, acquiring drag and heating in the process, requiring yet more heat protection system weight. The dry weight increase usually increases the vehicle cost compared to a rocket.

The other major air breather issue involves development costs. Hypersonic air breathers are very aero/propulsion integrated machines. Cannot, as you can with rocket engines, tie them down in a thrust stand and test them, need a hot hypersonic flow facility to do the development testing and such do not exist at the requisite full vehicle scale. Therefore vehicle development would necessarily entail many hypersonic flight experiments at a large cost per flight, would dictate a huge development cost, as well as an extended one.

It may be possible to reduce these cost issues with air breathers by improving mod-sim to allow reduction of the number of developmental flights required and to optimize the propulsion cycle and flow path to reduce losses and weight. There are a plethora of as yet unoptimized Scramjet design approaches that could be studied to attain reduced losses and weight. These include utilization of the complex internal shock systems and fuel injection flow physics to increase turbulence level/mixing, use of passive separated flow control devices vice using a heavy isolater for Ramjet operation, increasing fuel temperature via body heat regeneration and injector optimization for accruing thrust from fuel injection (especially critical at higher M<ach numbers) and premixing to reduce the length of the combustor/reduce combustor losses.

5. In Space Propulsion and Power Approaches

Photo Voltaics, The Nano Tech Revolution proffers serious improvements in PV efficiency, up to some 70 percent is suggested, along with combined devices wherein the “waste heat” is also harvested, added to the device output. Related alternatives include pyroelectrics for conversion of both waste heat and solar thermal, also alleged to ultimately exhibit high efficiency, utilizes transient thermal inputs.

The exotics, such as LENR and positrons, at some E4 plus to E9 times chemical respectively are obvious in space propulsion and power game changers.

- Sails, Solar/Photon sails, Magnetic sails, mass driver “catchers”

- Beamers, separating propulsive mass and energy, enabling harvesting and utilization of upper atmosphere and regolith etc. propulsive “mass of convenience.”   Included in this category are MWs, lasers, neutral particle beams and “mass beaming/mass drivers.” A key to MW utilization and also lasers is reduction of beam diffraction. Approaches to such include meta materials, and bessel, X waves, bowtie, mathieu and airy beam forms. There is some very nascent research which suggests possibilities for doing energy transfer via teleportation, TBD (e.g. Reference 15).

- Advanced fuels, see previous section/discussion

- Hydrogen Storage, The potential use of nano tubes as structural materials proffers possibilities for non cryo storage of hydrogen, aided by casimir force engineering, within the “pores” of the tubes. This approach to H2 storage would obviate “boil off” issues, which are obviously also addressable by refrigeration, given the energetics to operate such. Such materials are also thought to be configurable as ultra-capacitors, enabling storage of electricity.

- Electric Propulsion, There are a plethora of electric propulsion approaches, mainly producing low thrust but at large to huge Isp values. There are two MHD approaches that proffer high thrust, claim Isp in the 20,000 range and utilize magnetic nozzles – VASIMIR and FRC (Field Reversed Configuration). These are candidates to provide the requisite fast transits for humans beyond LEO, but require a serious energy source. Current concepts concentrate on Nuc fission but going forward positrons and LENR are potentially interesting candidates.

6. Advanced Air Traffic Control (ATC)

The current air traffic control system has many known limitations, utilizes considerable human involvement and is relatively expensive to operate and extremely difficult to modify. Along with increasing traffic delays and cost(s) the major driver for a serious redo of the ATC system is to enable large numbers of UAS in controlled airspace for both civilian and national security applications. The current ATC upgrade project, NEXTGEN, apparently will ultimately allow some 7,000 UAS in CONUS airspace at any one time, whereas the then year need, military and civilian, is for many millions. The ongoing Technology Revolutions could enable a much less expensive, wholly electronic system which would allow the requisite many millions of UAS in controlled airspace, thereby enabling an estimated new ~ $1T/ year worldwide aeronautical market in UAS/ PAVE. Advanced technologies for all of the elements of such an automatic ATC system are either available or nascent, including techs for communications, sensors, navigation, software, computers, machine intelligence and “architectures.”

The major impediment to developing such a seriously updated, enabling ATC system is the time/schedule, cost and safety aspects of modifying the existing system. A breakthrough way forward would be to build, experiment with, prove out the new system as initially piece parts and then as a system in/as a giant simulation operating outside of, not interacting with except to extract data from, the existing system. When the new system has been proven to be fail safe, safe wrt functionalities, piece parts and as a functioning all up system, then the old one would be “disconnected” and the new one employed.

Revolutionary ATC system communications options include ground and space based RF and free space optics and farther term, possibilities for quantum vector/scalar high bandwidth communications that cannot be jammed (Reference 16). Navigation options include passive location (PCL), utilization of TV tower, other ambient RF, which can have many orders of magnitude greater signal strength than GPS, and advanced magnetometers and graviometers, operating in a tercom mode off the detailed mappings from space of the planets gravity and magnetic fields. Then there is atom optics, termed by the USAF cold atoms, a Bose-Einstein (B-E) condensate producing a single stream of atoms at the same quantum state which, using lasers, can provide orders of magnitude improvements in inertial navigation. Sensors include infared (IR), lidar, radar, Electromagnetic (E-M) emissions, acoustics (including infrasound) and electro-optic.

A candidate architecture for an advanced ab initio ATC system is a combination of centrally monitored/oversight and locally controlled/free flight with real and advanced time deconfliction in a swarm environment. Vehicle flow control can be utilized to greatly expand flight envelope and improved energetics and materials could provide margins for crashworthy/ crash proof via ‘chutes and/or a combination of aero and propulsive controls reconfigured to “fly while hurt.”

7. Approaches to “solve” aircraft emissions

The current approaches to reducing aircraft emissions are partial solutions and include higher load factors, improved routing, increased vehicle efficiency (aero, propulsion, weight) and, on the part of the public, tele-travel (the U.S. is evidently past peak car). There are other approaches which could essentially solve the several aircraft emissions issues (NOx, CO2, Water), e.g.:

LENR or Positron Energetics, except for some NOx produced by heating air which could by design be minimized there are no emission issues with these exotic energetic approaches now known.

Biomass fuels, especially those produced via cyanobacteria or halophytes (salt plants grown on deserts using seawater agriculture) could possibly actually sequester CO_2. Such fuels do not impact except favorably fresh water and arable land issues. They result in a possibly better than a closed CO_2 cycle, proffer massive capacity and their NOx could be much reduced via mod-simulation combustor engineering as is done now. Their water emissions could be addressed via flying below the tropopause where water is thought to be cooling, not warming, in terms of climate. Flying in that altitude range would require lower wing area and some enhanced flow control provided ride quality as would be "flying in the weather."

Electric Propulsion, there is increasingly serious interest in electric propulsion for air vehicles. Such has been used for UAS and several light aircraft, with studies ongoing for application to larger vehicles. As the batteries improve, especially to the storage densities of metal air batteries, this becomes a viable emissions reduction approach. LENR, positrons, energy beaming and Superconducting Magnetic Energy Storage (SMES) with CNT magnets could also provide the electrical energy required sans emissions issues. Then there are fuel cells, possibly using H_2 stored in a nano tube structure. Fuel cells produce water which again would entail flying below the tropopause.

8. Nano Tubes, a Near Ultimate Multifunctional Material

As stated previously, nano tubes have revolutionary potential, nearly across the board, to reinvent aerospace, and much else (Reference 17). If contiguous structural nanotube materials can be invented/developed/fabricated their projected impact on dry weight is factors of 3 to 8. There are some ongoing efforts in this regard, including going beyond conventional materials processing approaches (chemical, thermal, impact/stress, pressure) and exploring ionizing radiation of various flavors, magnetics, plasmonics and shear. Besides dry weight reductions applications include flywheels for energy storage, magnetic sails, tethers, ultra capacitors, advanced sensors, and petaflop computing. Overall, nano tubes are projected to be a nearly optimal multifunctional material, potentially providing/combining superb structural performance with imbedded/integral sensors, actuators, computing and energy storage, either electrical or hydrogen in the “pores” via casimir force engineering.

9. Reinvention of Vertical/Short Take Off and Landing (VSTOL)

Personal Air Vehicles, aka Pave, are projected to be UAS carrying PAX, to subsume much of the domestic scheduled airline and automobile markets, and attain a worldwide market in the range of $1T/year. Enablers for this market level include the/a electronic, revolutionary ATC system discussed herein and the capability to operate out of the street in front of an individual holding, sans airports per se, which requires quiet V/STOL capabilities. The current, usual gold standard for VTOL is rotary wing, which has historically been burdened with high maintenance costs, low cruise efficiency, and safety concerns. There are a plethora of V/STOL alternatives, VTOL per se is not required for PAVE, but Short Take Off and Landing (STOL) is for “neighborhood,” out of the street in front of an individual holding, operation. These STOL alternatives to the “helicopter” for PAVE include:

- Channel wings with circulation control, The first relatively serious manifestation of this was the Custer channel wing, with later versions studied at Antonov. These early versions did not have circulation control, which was added in later NASA-Georgia Institute of Technology work. The approach employs a curved span wise wing configuration (which could be strut braced) with a turboprop engine placed in the curved section. At zero forward speed the engine provides air flow over the curved wing section, producing lift, which can be augmented greatly by employing/adding circulation control. The resulting lift coefficient approaches 12ish, enabling superb STOL performance.

- Auto-gyros, these are well known and zeroth order employ a flow turned rotary wing for lift and a separate engine, device for thrust. There are extant versions that are inexpensive, provide climate controlled carriage for 2 over a respectable range with adequate speed and STOL operation of far less than 100 feet. There are roadable versions under development.

Cyclo-gyro machines, these have a horizontal rather than a vertical axis of rotation and resemble agricultural harvesting machines. They are still, have long been, in the research stage with considerable recent progress made. The concept can provide VTOL and quiet operation, the latter critical for neighborhood operation.

Revolutionary energetics, the energetics capabilities of such as LENR and positrons could provide the energy density to both unload the lift fans, thereby reducing noise, and make direct propulsive lift feasible, economically and performance wise.

CNT Springs, The projected capabilities of CNT springs are several orders of magnitude greater than conventional steel springs, possibly providing an opportunity, either in an adjunctive fashion or as a mainline approach, to "spring into the air," with recompression occurring upon, during landing.

V/STOL concepts also apply to planetary exploration, allowing far greater coverage then crawling around a small portion of the landscape.

10. Drag Due to Lift Reduction

For a well designed cruise aircraft drag due to lift is some 40 percent plus of the total cruise drag, and a huge percentage of the drag during takeoff due to the much higher Lift Coefficient (Cl). While there have been major campaigns to reduce the 50 percent of the cruise drag which is skin friction, primarily via various flavors of Laminar Flow Control, there has not been, for decades, sizable attempts to reduce drag due to lift. Many of the conceptual approaches to Drag Due to Lift (DDL) reduction, beyond that obtainable with winglets, C-tips and other wing tip geometry modifications, involve significant alterations in aircraft configuration, i.e. deviations, often significant deviations, from the canonical 707 derivative prevailing mantra. Such approaches include:

- Strut/Truss braced wings, the most straight forward method of reducing drag due to lift is via increased span. There are limits to this imposed by both structural issues and the 80 meter box at the airport gates. The 80 meter box restriction can be circumvented via folding, hinged outer wing sections, for which there are extant and viable designs. The structural issues can be addressed via utilization of external strut or truss bracing. Work by VPI and others indicates major reductions in drag due to lift are possible using external strut or truss bracing. This approach, besides proffering the possibility of some 75 percent DDL reduction, also enables the wing thickness to be reduced, and therefore the wing sweep. This, along with the concomitant wing chord/Reynolds Number reduction necessitated by the increased span, results in the opportunity to establish "natural" laminar flow over major portions of the wing, reducing skin friction much. Such skin friction reduction is required, having reduced the DDL, to obtain an efficient balanced design. Initial versions of truss bracing are under study in the NASA N+3 research program. Obtaining extreme sweep reductions, from the VPI work, may be facilitated by going to inflatable inner wing sections.

- Wing Tip Engines, these have been studied, primarily using propellers but by Whitcomb using GTEs, to reduce drag due to lift, with often significant results into the 40 percent range. The wing strut/truss bracing discussed herein could provide the structural efficiency necessary to apply this wing tip engine approach for DDL reduction. Since, according to Lighthill, "we build what we can compute," the historical inability to seriously compute the wing tip engine effects may have held up the adoption of this approach. The other issue with this is the engine out effects, which can be countered either by going to thrust vectoring or circulation control on the vertical tail.

There are other potential DDL reduction approaches that require "discovery" class research. These include leading edge bumps, ala the pectoral fins on humpback whales, and the curious bendable portion of the shark caudal fin tip region. Then there is oscillatory span loading, which has been shown to seriously delay-to-obviate the tip vortex rollup, which should alter the rotation of the lift vector into the drag direction – the origin of drag due to lift. There has been some study of horizontal axis ring wings, anchored to the fuselage base. The DDL reduction is order of some 50 percent but there are issues with weight and wetted area increases, design/optimization studies are required.

11. Detailed, Localized Climate Information

The latest Intergovernmental Panel on Climate Change (IPCC) report makes it clear that disruptive climate change is occurring in a time scale of years-to-decades and that human engendered influences are either largely responsible or at least accelerating the processes. The IPCC reports are, by the necessity of their intensive editing processes, based upon the most solid science and their projections have thus far proven over the years to be extremely conservative. There are a series of positive feedbacks for which the scientific observations are not yet complete enough to be included in these reports/projections. However, these positive feedbacks are thought by some to be largely responsible for the faster than IPCC report climate changes that are occurring. Estimates of the potential impacts of these positive feedbacks are very worrisome to dire.

These positive feedbacks include gasification, due to temperature increases, of the massive amounts of fossil methane and CO2 contained in the oceans and the Tundra and the ocean acidification due to CO2 uptake, resultant impacts upon the algae CO2 sequestration and overall ocean CO2 uptake reductions. Then there are the reductions in planet reflectivity due to reduced ice coverage and coverage of that ice by carbon particles, and the increased water vapor content in the atmosphere due to increased evaporation caused by temperature increases. The major worry, the reductions in the ocean Thermal Haline circulation resulting in anoxic conditions and overgrowth of cyanobacteria producing hydrogen sulfide, makes the atmosphere toxic and takes down the ozone layer. All of this occurred previously during the Permian Extinction, which was triggered by CO2 release from Siberian volcanoes at release rates some two orders of magnitude less than the current anthropogenic release rates, we appear to be replaying the Permian at an accelerated pace.

All these climate concerns/issues requires seriously detailed scientific data to develop and verify numerical/theoretical simulations/projections and to quantify the feedbacks in sufficient detail such that they can be included in the IPCC projections. An additional requirement for much more detailed climate information/data devolves from the need to, on a local and regional basis, provide detailed information and support for climate change adaptation by various means. Given the major potential impacts and expense of various climate adaption approaches accurate projections on a localized basis are essential. Current climate data acquisition is mainly comprised of a series of satellite and ground based instruments along with some aircraft insitu campaigns. There is even a potential mitigation/ geoengineering approach involving utilization of lasers to incite aerosol formation. Aerosol measurements/understanding are particularly critical as aerosol climate impacts are approximately equal in magnitude but opposite in sign compared to CO_2. Some half of the aerosols are anthropogenic and a large percentage are formed in-situ in the atmosphere. Potential data augmentation and alternative data acquisition approaches include:

Note – all of these would benefit from, are enabled by the technology revolutions especially nano sensors, IT and materials.

- InSitu Smart Dust, Micron (or larger/smaller) motes which contain, thanks to the IT and Nano Technology revolutions, imbedded communications, sensors, energy harvesting and computing. These could be networked to provide possibly detailed and inexpensive coverage with co-operative concepts of operations and sparse array for aperture as needed.

- Extremely long loiter mini-Remotely Piloted Vehicles (RPVs)/ UAS that are energized either by exotic energetics or beamed energy, with advanced sensors and communications.

- Utilization/exploitation of the emerging “global sensor grid,” with some trillions of networked sensors projected worldwide in a decade. We are busily putting sensors on everything, because with the tech revolutions we now can. Inclusion of climate applicable sensors and use of “big data” approaches should improve, inform localized climate knowledge/ projections.

12. Military Frontier Aerospace Opportunities

The increasing vulnerabilities and costs of airfields, short legged fighters, foreign bases and transport airframe based tankers, transports and sensor craft suggests a re-examination of future aerospace power projection approaches. The exotic energetics approaches discussed herein would greatly alter military range, payload, loiter, speed, maneuverability, flight envelope and lethality, providing at the same time serious cost and size reductions. Even in the absence of such energetics breakthroughs there are a collection of alternative global precision strike approaches that are becoming increasingly enabled. These would, could obviate the need for in theater and strategic aircraft and overseas bases, as well as provide major overall cost reductions with far more survivability and enable the qualities of quantity. All of these concepts “stage” out of Continental United States (CONUS), provide global precision strike. The swarm/horde nature of these approaches makes defense quite difficult.

- Swarms of transoceanic UAVs, Folks have thus far successfully flown the Atlantic non-stop with UAVS smaller than 14 pounds. The MIT Aero folks indicate the smallest non-stop over the Atlantic UAV is some 1 Kg or so. All this indicates an opportunity for essentially undetectable ultra inexpensive swarms of aerial strike platforms with, thanks to precision strike and alternative kill mechanisms, an “interesting” set of warheads/effects.

- The “Slingatron,” a mechanical device that uses wall plug power to accelerate thousands of 50 KG projectiles per minute to Intercontinental Ballistic Missile (ICBM) speeds. Uses a spiral tube mounted on 100 Hz vibration motors to put, via a “hula Hoop motion, Coriolis forces into the projectiles.

- The “Blast Wave Accelerator”, an I-beam from which is suspended annular rings of explosives which sequentially detonate, with the detonation waves accelerating a projectile to ICBM speeds

- Micro Rockets/ICBMs, MIT has developed a MEMS turbine feed pump which enables construction of miniaturized ICBS that are Sports Utility Vehicle (SUV) transportable and inexpensive, swarms/hordes of such.

- Global reach unrefueled oblique wing strike aircraft.

- Swarms of transoceanic Unmanned Undersea Vehicles (UUVs) with popup missiles, especially effective against areas with extensive and often largely undefended shorelines. The short time of flight enabled by the historical concentration of population and infrastructure near seacoasts makes interception “difficult.”

13. Reliability for Long Space Missions/Exploration beyond LEO

The various “Design Reference Missions” for long duration exploration (e.g. Mars) have not, thus far seriously considered the mission/weight/cost impacts of ensuring reliability, functionality, providing fail safe safe operability across the board. Reliability issues that should probably be considered, worked, include:

- Planetary Dust. Moon dust caused problems and Martian dust is apparently thought to be far worse in terms of health and mission impacts (carcinogens, oxidants etc.). Provision, design for dust free everything (habitants, transfer locks, suits, “transportation”) will be expensive and difficult. There is concern that the effects of the highly oxidative Martian regolith, containing perchlorates, might be especially damaging at the O2 rich, high pressure and moisture conditions inside the habitats.

- The usual issues, micrometeoroids, micro gravity, radiation effects.

- The long duration of the mission, aging, fatigue, durability etc.

- System level, cascading failures, non-linear effects.

- Verification and validation (V&V) for fail safe, including the psychology of the humans.

The observed effects of space writ large [micro g, radiation] upon bio are that “bugs” become more virulent, worrisome. The human gut contains many thousands of Bio bits that, evidently, might develop over time into either pathogens or corrosives which potentially could become serious problems. We have no long duration experience wrt such issues except on station, which is protected by the Van Allen Belts from full radiation.

Obviously the serious up front ISRU and prepositioning approaches, where functionalities are in place and fully evaluated pre-need, along with system redundancies and serious up front/development testing and extended evaluation under realistic conditions would contribute to the overall reliability issues writ large. However, long duration human missions beyond LEO could more than conceivably have serious unknown unknowns. While we have successfully sent robotic probes etc. on such long duration missions the presence of humans, and the requirement to keep them “pink and warm” and breathing changes greatly the number and details of mission requirements and requisite technologies. The possibility mentioned herein of bugs from the human gut, carried aboard on/with the humans, becoming under deep space conditions and over time serious corrosion and/or pathogenic issues is probably just one of many potential unknowns going in. If this potential issue is determined to be a real problem then solution spaces will be “interesting.” Bugs tend to build up an immunity to “treatment” approaches. The robotic missions are sterilized before launch, cannot sterilize the humans internally. Then there is the extra cost, weight etc. to ensure reliability/operability, given definition of the requisite “design” issues.

14. Initial/Boundary Conditions for Modeling and Simulation (Mod Sim)

The rapid development of computing machine capabilities and algorithms has enabled mod sim to increasingly replace physical experimentation. One result of this shift has been a reduction in wind tunnel usage. The expected development of quantum computing should massively accelerate this trend toward computing for research, design and development. Computation for aerospace usually requires knowledge of applicable initial and boundary conditions. There are several classes of problems for which boundary and initial conditions are particularly critical, these include cases where critical phenomena/physics are rapid-to-exponential, where major changes result from quite small initial/boundary condition changes. Perhaps the most notorious of such is boundary layer transition, where requisite knowledge of all of the ambient and vehicle induced disturbance fields, including details of the ambient particulates, are essentially unknowable to the precision required. Therefore, while transition can be increasingly computed as an initial/boundary value problem, the lack of definitive initial and boundary conditions limits the computational predictive precision obtainable and could even shift/obscure the major causative instability modes.

Other situations where the computability accuracy is affected to first order by the incomplete knowledge of initial and boundary conditions include multi-phase flows, icing, fluid/particle flows, ignition, arcing in gases, atmospheric aerosols, fire(s), fracture/fatigue and durability, corrosion, surface chemistry effects, micro-gravity effects and surface catalysis.

The development, enabled by IT and Nano and Quantum Technologies, of a serious global sensor grid, along with localized application(s) of such superlative sensors should provide some improvement going forward for this serious limit upon mod simulation for aerospace.

15. Other Frontier Aerospace Opportunities:

SBER as an Nondestructive Evaluation (NDE) sensor, It is well known that earthquakes produce E-M signatures. Research and theory of SBER phenomena indicate that shear with some pressure, per the now many decades of SBER experiments, collapses band gaps and produces E-M signatures, along with the much faster cold chemistry previously discussed. Such shear stress induced E-M emissions have been utilized for NDE purposes and would be an interesting addition to the panoply of such.

Aircraft designed in an open thermodynamic system, conventionally aircraft design employs aerodynamics derived from a closed thermodynamic system to which is added a propulsion system. There is no theory per se for a simultaneously optimized Aero, propulsion and structure aircraft design in what would of necessity be an open thermodynamic system. Historically the military has been much more interested in, deployed propulsion assisted aero, primarily for various flavors of high lift or "powered lift." The discussion thus far has mentioned several concepts that take advantage of favorable aero/propulsion interactions, including channel wings with circulation control and wing tip engines. Another concept,that the military has at least experimented with, is thrust vectoring for control in lieu of the weight and drag of an empennage. Flow/boundary layer control, primarily using propulsive power in various ways, has historically been applied for high lift. Supersonic Transport (SST) application of flow control at cruise proffers many potential advantages including increased lift generation on the upper surface, energy projected far forward for wave drag reduction, flow separation control for enhanced favorable shock interaction (as in parasol wings), increased lift carryover onto the fuselage and increased leading edge thrust. The commercial world has researched suction laminar flow control on wings but not thus far on fuselages. The advent of personal view screens proffers the possibility of replacing windows with surfaces more conducive to laminar flow. Given the various nose region flow disturbance generators (windshields and their wipers, pitot tubes, radomes, the forward door) there would be a need to do suction relaminarization on the fuselage before starting maintenance suction. The recent discovery that a single layer of graphene can greatly inhibit corrosion, along with development of meta material and nano surfaces that reduce adherence of bug remains are beneficial to laminar flow control maintenance issues. Additional propulsion/airframe/aerodynamics favorable interaction approaches include the ejector wing, wing tip injection, utilization of LFC suction as a flow separation control approach for takeoff/high lift and several flavors of boundary layer inlets including the as yet unevaluated in detail "Goldschmied" approach which asserts cancellation of a portion of the body viscous drag via establishment of a high static pressure region on the after body.

Advanced configuration Aeronautics, There are a large number of advanced-to-different aircraft configurations which appear to proffer various flavors of benefits and which probably should be studied further given the differing metrics going forward, References 18- 75. At this point the one that has received the most study is the blended wing body, including a military instantiation, the B-2 bomber. Major benefits of BWBs include huge volumetric efficiency and far less fuselage drag yielding an L/D increase in the 25 percent range. The non-circular pressure vessel issue associated with such requires much further research and invention. Advanced configurations mentioned thus far include ring wings, strut/truss braced wings and channel wings. Others on offer are the R.T. Jones yawed wing which he claimed could, for the same fuel burn, increase speed by up to some 50 percent without worrisome sonic boom. Then there is the 'Sky Train" mid wing double fuselage concept.

For SSTs, the advanced configuration options include unswept thin NLF wings, parasol wings for favorable wave interference, multistage aircraft, yawed wings and the Pfenninger strut braced extreme arrow wing, the latter proffers the order of twice the conventional double delta L/D. All of these configurations could profit from R&D into the application/ engineering aspects of the observations of up to 45 percent turbulent skin friction reduction from oscillatory transverse wall motions. The challenge is to have a sizable net benefit.

The major potential benefits proffered by advanced configuration aero across the speed range coupled with the dearth of serious efforts to study let alone apply such is an indication and indictment of the innate conservatism of the aeronautical community. In the ideation of new advanced configurations it is sometimes useful to list the assumptions made in usual aircraft design and attempt to open up the design spaces by attempting to obviate them. Such assumptions include usually contiguous geometry, nearly separate aero and propulsion systems [as opposed to designing in an open thermodynamic system], high lift approach integral to the aircraft vice on the ground, aerodynamic controls for civilian designs and horizontal symmetry. Some attempts to obviate these usual assumptions include multiple fuselages, external wing strut/truss bracing, span loaders, multistage aircraft, ski jumps for takeoff, thrust vectoring for control, skewed/ yawed wing and various flavors of variable geometry.

High speed nose bluntness optimization, With the development of serious high speed mod sim there is now an opportunity to optimize nose bluntness for the multitudinous applicable design metrics including drag, heating, boundary layer transition delay, weight, cost and volumetric efficiency. The downstream effects of the typical overexpansion and entropy layers give this optimization problem some interesting non-linear aspects. Initial early studies of such nose region optimization for just a few of these issues indicated some interesting results.

Smart Inflatables, There are a plethora of aerospace applications for inflatables including sails, antennas, transonic drag reduction for hypersonic air breathers, decelerators, light buckets, wings, arrays, concentrators, mirrors, lenses, radiators, sunshades, habs and many more. The evolving advanced nano material technologies including IVHM, self healing, imbedded sensors/actuators, computing etc. mitigates in favor of serious development and optimization efforts given the major potential benefits of inflatables writ large.

-EDL, (Entry, Descent and Landing), Landing large payloads/vehicles on Mars without transporting the necessary fuel to retro-rocket is extremely difficult due to the low atmospheric density. Current approaches for small payloads involving parachutes etc. are not suitable beyond a certain payload size. There are several alternative EDL/deceleration approaches that should be studied and triaged that would still save most of the fuel weight required to retro rocket. The first of these is regenerative aero braking, this is analogous to automobile regenerative braking. In one variant Martian CO_2 is taken aboard after being heated by the bow shock at entry speeds, processed through an MHD generator to produce electrical energy which can be stored, possibly in a nano tube skin/structure which is an ultra capacitor, and used to heat ingested CO_2 at lower speeds which can then be retroed to slow the vehicle (Reference 76). It may be possible, TBD, to take CO_2 on board at intermediate speeds and utilize the ram pressure recovery and store the thermal energy to retro the CO_2 at low(er) speeds to slow down without needing the weight and cost of an MHD generator. Another alternative to using CO_2 taken on board during entry is to store energy from the solar cells during interplanetary transit and use that to heat the gas for retro.

Other alternative EDL approaches for large payloads into Mars include utilizing lifting aerodynamics and maneuvering in the atmosphere, doing skips and lateral flight to accrue drag and bleed off speed. Then there is the possibility of using multiple deployable deceleration devices suitably arranged to obtain a multiple shock, much higher, pressure recovery/drag levels. Also, David Kirtley has a concept for EDL termed Plasma MagnetoShell Aero Braking that utilizes charge exchange.

- Reactive Turbulent Drag Reduction in Air, While Laminar Flow Control technology, developed over many decades of research, can provide major skin friction drag reduction in many design spaces, there are many situations where the flow will be turbulent and approaches to providing turbulent drag reduction are required. For air the current SOA is riblet surfaces, small longitudinal grooves which is spite of adding wetted area, reduce turbulent drag overall by some 8 percent or a bit more. There are laboratory and computational experiments which indicate up to order of 40 percent drag reduction via transverse wall motions, but practical systems level applications of this approach are not yet extant. An alternative approach is to attempt to counter the formation of the "wall ejections" known to produce much of the drag in turbulent wall flows. The MEMS and nano, as well as IT advances over the last decade plus proffer the opportunity to revisit this reactive turbulent drag reduction approach. One way forward is to sense the moving adverse pressure gradient that produces the localized near wall embedded shear layers that produce wall ejections/bursts and deform the wall in an attempt to cancel or mitigate this pressure dynamic. There are experiences with several such reactive approaches and the tech revolutions are producing the requisite sensors, actuators and computing to justify a revisit.

- Kite Wings, Delta wings can produce prodigious tip vortices which can be utilized to mix fluids. NASA was involved in a study to mix the waters in

Chesapeake Bay to counter summer anoxic conditions using delta wings moored at angle of attack in the current. Going forward there is concern regarding increased storm/hurricane activity and formation of anoxic oceans due to changes in the thermal-haline circulations, producing anoxic bacteria and resulting in production of hydrogen sulfide which is poisonous and degrades the ozone layer. It may be possible to, at low cost(s), deploy a fleet of robotic “kite wings” to counter both hurricanes and anoxia to some depth. The concept is simplex. Utilize buoyant lift autonomous kites to pull submerged delta wings. Hurricane intensity is first order dependent upon surface water temperature which the kite wings, deployed in front of the storm path, should reduce via mixing with cooler waters at some depth. Such mixing also distributes and adds oxygen to the water column to some depth for the anoxic ocean concerns. Whether such near surface oxygenation would have a material effect upon the hydrogen sulfide issue is TBD.

- Noise Reduction, The key to a viable operate off the street in front of your house PAV functionality and the associated up to $1T/ year market is controlling noise. The most straight forward approach to reducing noise is the development of revolutionary energetics, enabling energy rich operation which allows reduced performance, lower blade loading of lift fans. Electric propulsion would obviously reduce direct propulsion/energetics noise sources. Studies have indicated that turbulent jet noise can be reduced by injecting liquid water which breaks up into droplets which interfere with the turbulence dynamics, reducing the strength of the noise sources. For interior noise, anti-noise or noise cancellation has had some success. For the exterior turboprop noise issue boundary layer devices termed “large eddy breakp devices” are thought to produce a flow configuration that is efficacious. Obviously separated flows, which are a notable noise source, can be “controlled” – reduced to eliminated via flow control. Some tens of flow control approaches extant, which, what is a systems decision. Then there is frequency shifting and possibly noise shielding opportunities via distributed propulsion. Computational Fluid Dynamics (CFD) has developed to a point where source strength computations are an advancing capability, an increasing alternative to experiments.

Synopsis of Frontier Technologies

The following is a listing of the Revolutionary Frontier Technologies which, in the aggregate, have the potential to change mightily essentially all aspects of society, including Aerospace. These technologies are in progress now, and their potential individual, let alone combinatorial, impacts have not yet been fully projected and documented.

- Revolutionary Energetrics – LENR, halophytes, positrons, energy beaming, ultra efficiency PV and energy conversion

- 3 D and 4 D printing on the way to molecular manufacturing

- Structural Nano Tubes, Potential for Factors of 3 to 5 dry weight reduction

- Quantum Computing, For an increasing number of problems a huge number of orders of magnitude faster

- Atom Optics/Cold Atoms, orders magnitude improved inertial Navigation

- Biomimmetics human level machine intelligence

- 5 Senses virtual reality/immersive presence

- Designer/modified/more robust humans

- Vector/scaler quantum potential non E-M communications

- Autonomous robotics

- Global sensor grid/global mind

- Synthetic biology for bioproduction and biofunctionalism

Examples of what these technologies and their combinations proffer include climate solutions (also, in the case of halophytes, solutions for land, food and water), energy rich aerospace, massive cost reductions in many systems/functionalities, Tele-everything/ the Virtual Age, mod sim vice physical experiments, increasing replacement of humans by robotics, increased tele vice physical travel, less cargo/more at home manufacture, human space exploration both safe and affordable,

Concluding Remarks

Aerospace has a significant opportunity to reverse a decades long slide into a conservative posture and mantra by studying and ideating the application of the multitudinous current and projected results of the many technology revolutions to the (morphing in real time) aerospace missions and metrics. This applies to both re-examination of old, existing ideas with these new technologies and opportunities as well as ab-initio ideation of newly enabled solution spaces. The emerging budget realities going forward along with the changing metrics emphasizing simultaneously emissions, acoustics, energetics, safety and cost, along with the potentially massive impacts of printing manufacture, tele-travel, immersive presence and machine intelligence/robotics upon both what is needed/the work to be done and how it is best done should incite a re-examination of the capability of the usual, historical products and capabilities to enable a viable, thriving aerospace industry going forward. The present report provides a cross section of such reexaminations and opportunities.

References

1. NASA Space Technology Roadmaps, NASA , 2012

2. The Global Exploration Roadmap, International Space Exploration Coordination group, 2013

3. Hay, Jason et al, Tauri Group, “Technology Frontiers :Breakthrough Capabilities For Space Exploration”, December 2010, NASA NP-2011-01-324-LaRC

4. Cetron, Marvin “ Technology Timeline 2010”, Professional Pilot, Dec. 2009, ppgs. 54-62

5. Kurzweil, Ray “The Singularity is Near”, Viking Press, 2005

6. Schmidt, Stanley “The Coming Convergence”, Prometheus Books, 2008

7. Manyika James, et al “Disruptive Technologies, Advances that will transform life, business, and the global economy”, McKinsey Global Institute, 2013

8. Bushnell, Dennis M., “Imaginable Technologies For Human Missions to Mars”, Aerospace America, June 2007, ppgs. 24-30

9. Bushnell, D.M. “Advanced-to-Revolutionary Space Technology Options – The Responsibly Imaginable”, NASA /TM-2013-217981

10. 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

11. 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

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

13. 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

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

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

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

17. 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.

18. Kroo, Ilan, "Innovations in Aeronautics", AIAA Paper 2004-0001, 2004

19. Bushnell, D.M., Frontiers of the "Responsibly Imaginable" in [Civilian] Aeronautics", AIAA paper, 98-0001, 1998

20. Torenbeck, E. and Deconinck, H. Editors, "Innovative Configuration and Advanced Concepts For Future Civil Aircraft", Lecture Series 2005-06, Von Karman Institute for Fluid Dynamics, 2005

21. Huebner, L.D. et al Compilers, "Transportation Beyond 2000:, Technologies Needed For Engineering Design", NASA CP 10184, parts 1 and 2, 1996

22. Bushnell, D.M. Editor, “Potential Impacts of Advanced Aerodynamic Technology On Air Transportation System Productivity”, NASA TM 109154, 1994

23. Bushnell, D.M., “ Fluid Mechanics, Drag Reduction, and Advanced Configuration Aeronautics”, NASA TM 2000-210646, 2000

24. Ro, Kapseong et al, “Flight Testing of a Free-Wing Tilt-body Aircraft”, AIAA paper 2010-3449, 2010

25. Moore, Mark D., “21st Century Personal Air Vehicle Research”, AIAA paper 2003-2646, 2003

26. Englar, R.J. and Campbell, B.A., “Development of Pneumatic Channel Wing Powered-Lift Advanced Super-Stol Aircraft”, AIAA paper 2002-2929, 2002

27. Yaros, S.F. et al, “Synergistic Airframe-Propulsion Interactions and Integrations”, NASA TM 1998-207644, 1998

28. Saeed, B. and Gratton, G.B. “An Evaluation of the Historical Issues Associated With Achieving Non-Helicopter V/STOL Capability and the Search For the Flying Car”, Aero. J., V. 114, No. 1152, ppg. 91-102, Feb. 2010

29. Spearman, M. Leroy, “Aerodynamic Characteristics for Airplane Configurations Having Several Body Arrangements”, AIAA Paper 2003-6810, 2003

30. Spearman, M. Leroy, “An Airplane Design Having a Wing with a Fuselage Attached to Each Tip”, AIAA 2001-0536, 2001

31. Spearman, M. Leroy, “Innovative Concept For a Heavy-Load Aircraft Utilizing a Two-Dimensional Wing”, AIAA paper, 2007-4439, 2007

32. Gur, O. et al “Design Optimization of a Truss-Braced-Wing Transonic Transport Aircraft”, AIAA J. of Aircraft, V. 47, No. 6, ppg. 1907-1917, 2010.

33. Gur, O., Schetz, Joseph A., and Mason, William H., “Aerodynamic Considerations In the Design of Truss-Braced-Wing Aircraft”, AIAA J. of Aircraft, V. 48, No. 3, ppg. 919-939, 2011

34. Nickol, Craig L., Hybrid Wing Body Configuration Scaling Study”, AIAA paper 2012-0337, 2012

35. Conner, D. William, “Outlook For Advanced Concepts in Transport Aircraft”, NASA TM 81810, 1980

36. Liebeck, Robert H. et al “Concepts For Advanced Subsonic Transports”, NASA CR 4624, 1994

37. Liebeck, R.H., Page, M.A. and Rawdon, B.K. “Blended-Wing-Body Subsonic Commercial Transport”, AIAA paper 98-4736, 1998

38. Liebeck, Robert H., “Design of the Blended Wing Body Subsonic Transport”, AIAA J. of Aircraft, V. 41, No. 1, ppg. 10-25, 2004

39. McMasters, John H. et al “ Advanced Configurations For Very Large Subsonic Transport Airplanes”, NASA CR 198351, 1996

40. Wood, Richard M. and Bauer, Steven X. S. “Flying Wings/ Flying Fuselages”, AIAA paper 2001-0311, 2001

41. Lange, Roy H., “Review of Unconventional Aircraft Design Concepts”, AIAA J. of Aircraft, V. 25, No. 5, ppg. 385-392, 1988

42. Lange, Roy H., “Future Transport Aircraft Design Challenges”, AIAA paper 84-2416, 1984

43. Lang, R.H. “Parametric Study of Advanced Long-Range Military/commercial Cargo Transports”, AIAA paper 77-1221, 1977

44. Lange, R.H. “Design Concepts For Future Cargo Aircraft”, AIAA paper 75-306, 1975

45. Sterk, F.J. and Torenbeck, E. Editors “Unconventional Aircraft Concepts”, Delft University Press, 1987

46. Gallman, John W., Smith, Stephen C., and Kroo, Ilan M. “Optimization of Joined-Wing Aircraft”, AIAA J. of Aircraft, V. 30, No. 6, ppg. 897-905, 1993

47. Pfenninger, W., “Long-Range LFC [Laminar Flow Control] Transport”, ppg. 89-115, Part 1, NASA ‘Research In Natural Laminar Flow and Laminar-Flow Control”, 1987

48. McGeer, Tad and Kroo, Ilan “Fundamental Comp[arison of Canard and Conventional Configurations”, AIAA J. of Aircraft, V. 20, No. 11, ppg. 983-992, 1983

49. Lange, R.H. and Moore, J.W. “Large Wing-in-Ground Effect Transport Aircraft”, AIAA J. of Aircraft, V. 17, No. 4, ppg. 260-266, 1980

50. Zhang, Jiaqiang. et al, “Research on Aerodynamic and Hydrodynamic Performance of Conformal Semi-Ring Wing Configuration”, Procedia Engineering, V. 29, ppg. 3100-3104, 2012

51. Lanhe, R.H. et al “Feasibility Study Of the Transonic Biplane Concept for Transport Aircraft Application”, NASA CR – 132462, 1974

52. Berger, Clemence et al “Supersonic Bi-Directional Flying Wing Configuration With Low Sonic Boom and High Aerodynamic Efficiency”, AIAA Paper 2011-3663, 2011

53. Welge, H. Robert, Nelson, Chester and Bonet, John “Supersonic Vehicle Systems For The 2020 to 2035 Timeframe”, AIAA Paper 2010-4930, 2010

54. Pfenninger, W. “Design Considerations of Large Global Range High Subsonic Speed LFC Transport Airplanes”, ppg. 3-63 to 3-75, “Special Course On Concepts For Drag Reduction”, Agard Report No. 654, 1977

55. Pfenninger, Werner and Vemuru, Chandra S., “Suction Laminarization of Highly Swept Supersonic Laminar Flow Control Wings”, AIAA Paper 88-4471, 1988

56. Wintzer, Mathias, Sturdza, Peter and Kroo, Ilan “Conceptual Design of Conventional And Oblique Wing Configurations For Small Supersonic Aircraft”, Collection of Technical Papers, 44th AIAA Aerospace Sciences Meeting, ppg. 11116-11132, 2006

57. Callaghan, Jerry T. and Liebeck, Robert H. “Some Thoughts On the Design of Subsonic Transport Aircraft For The 21st Century”, SAE Transactions, V. 99, Sect. 1, ppg. 2104-2111, 1990

58. Vandervelden, A.J.M. and Kroo, I., “Aerodynamic Design of the Oblique Flying Wing Supersonic Transport”, NASA, 1990 [N90285404, A90168]

59. Jones, Robert T., New Design Goals And A New Shape For The SST”, Astronautics and Aeronautics, V. 10, No. 12, ppg. 66-70, 1972

60. Jones, R.T. “Reduction of Wave Drag By AntiSymmetric Arrangement of Wings and Bodies”, AIAA J., V. 10, No. 2, ppg. 171-176, 1972

61. Krieger, R.J., Gregoire, J.E. and Hood, R.F. “Unconstrained Supersonic Cruise and Maneuvering Configuration Concepts”, AIAA paper 79-0220, 1979

62. Kulfan, Robert M., High-Transonic-Speed Transport Aircraft Study”, NASA CR 2465, 1974

63. Morgenstern, John, “Final Report For The Advanced Concept Studies For Supersonic Commercial Transports Entering Service in the 2030 to 2035 Period, N+3 Supersonic Program”, NASA CR 2010-216796, 2010

64. Gohardani, Amir S., Doulgeris, Georgios and Singh, Rita, “Challenges of Future Aircraft Propulsion: A review of Distributed Propulsion Technology and Its Potential Application For the All Electric Commercial Aircraft”, Progress in Aerospace Sciences, V. 47, ppg. 369-391, 2011

65. Gray, D.E. “Study of Unconventional Aircraft Engines Designed For Low Energy Consumption”, NASA CR 135065, 1976

66. Wolf, John D. and Warren, Dale S. “Air Transports in the 21st Century”, Aerospace Engineering, Sept. 1992, ppg. 29-34

67. Houbolt, John “Why Twin Fuselage Aircraft”, Astronautics and Aeronautics , April, 1982, ppg. 26-35

68. Chaplin, Harvey R. ,”Application of Very Thick BLC Airfoils to a Flying Wing Type Transport Aircraft”, SAE paper 90-1992, 1990

69. Boyd, J.A. “Optimal Utilization of Supersonic Favorable Interference To Obtain High Lift-Drag Ratios”, AIAA Paper 65-752, 1965

70. Kulfan, R.M. “Application of Hypersonic Favorable Aerodynamic Interference Concepts to Supersonic Aircraft”, AIAA paper 78-1458, 1978

71. Gibson, B.T. and Gerhardt, H.A. “Development of an Innovative Natural Laminar Flow Wing Concept For High Speed Civil Transports”, AIAA Paper, 93-3466CP, 1993

72. Fuhrman, Henri D., “Application of Natural Laminar Flow To a Supersonic Transport Concept” AIAA paper 93-3467 CP, 1993

73. Roskam, Jan and Rogers, Dan , “Study of the Economic Feasibility of Composite [staged] SST Configurations”, SAE paper 90-1989, 1990

74. Jones, R.T. “The Flying Wing Supersonic Transport”, Aeronautical J. March 1991, ppg. 103-106

75. Galloway, T., Gelhausen, P., Moore, M. and Walters, M. “Oblique Wing Supersonic Transport Concepts”, AIAA paper 92-4230, 1992

76. Moses, Robert W., “Regenerative Aerobraking”, STAIF 2005, AIP Conference Proceedings, V. 746, pp. 1361-1370, 2005

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

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01- 10 - 2014	Technical Memorandum	

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER**
Frontier Aerospace Opportunities	**5b. GRANT NUMBER**
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Bushnell, Dennis M.	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER 432938.00.01.07.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
NASA Langley Research Center Hampton, VA 23681-2199	L-20449
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)** NASA
National Aeronautics and Space Administration Washington, DC 20546-0001	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)** NASA/TM-2014-218519

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 01
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Discussion and suggested applications of the many ongoing technology opportunities for Aerospace Products and Missions, resulting in often revolutionary capabilities. The, at this point largely unexamined, plethora of possibilities going forward, a subset of which is discussed, could literally reinvent aerospace but requires triage of many possibilities. Such initial upfront homework would lengthen the R&D time frame but could greatly enhance the affordability and performance of the evolved products and capabilities. Structural Nanotubes and exotic energetics along with some unique systems approaches are particularly compelling.

15. SUBJECT TERMS

Aerospace; Missions; Nanotubes; Products; R&D; Reinvent; Revolutionary; Space

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	56	(443) 757-5802

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18