Space Tourism

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Introduction

Since the late 1950's, humans in space (defined herein as Low Earth Orbit (LEO) and beyond) have, with very few exceptions, been restricted to highly trained astronauts. Going forward, there is an increasing expectation that technologies will enable the public to visit and vacation in space. With the ever increasing capabilities of what is now termed digital reality (DR) or immersive presence, there are two approaches to space vacations: virtual and physical. Both will be discussed herein (ref. 1). The potential space tourism experiences include destinations such as space stations, moons, planets, and asteroids. Also, virtually only with currently known or projected technology, planets/moons around other stars. Discussed herein are the space tourism issues that technology needs to address/is addressing to enable space tourism, resultant space tourism experiences and developing commercial deep space. Space is dark, cold, a nearly perfect vacuum, with microgravity, GEV, galactic space radiation, unimaginable distances, where solid matter is a trace species but which supplies the energy that enables human existence. Space is often times referred to as the final frontier, and the general environmental conditions, as stated, are very different than those under which humans have evolved on Earth. Therefore, considerable technology is required to enable humans in space. In fact, even physics appears to change at cosmological scales including dark matter/energy, huge disagreements between quantum theory and the cosmological constant, and the mystery of what happened to the anti-matter, etc. There is also the increasing interest in, and search for, life on other worlds, which may be silicon- or sulfur-based instead of carbon. Overall, there is a lot to learn. Solar system destinations beyond the Moon/Mars/nearby asteroids require greatly increased trip time (years to decade(s)), costs, distances, and health and safety technologies.

The Space Tourism Issues and Options

The basic issues which must be addressed to enable space tourism are safety/reliability and cost/price. Of these, the first is the most difficult and includes many aspects including dust, gravity, radiation, micro/other meteorites and reliability. There are very encouraging approaches to reducing costs/price.

Safety [ref. 2] – Currently, rockets malfunction-to-explode on the order of every 100 launches. That accident rate is on the order of 100 to 1000 times the accident rate of scheduled airlines.

Sampling of safety and reliability related issues in aerospace:

- Human error, a major source of safety problems, crashes, even after many decades of Research and Development (R&D) and technologies to reduce such
- Equipment failures, due to design, installation, operational employment, maintenance, aging, environmental effects, and tipping points for cascading system failures
- Electron/photon related failures including cyber/software issues, Electromagnetic Pulse (EMP)/space weather/radiation, jamming, failure of equipment essential for navigation, controls, sensing, propulsion, and communications, etc.
- Inadequate margins, especially with regard to a cascading system of systems failures where reduced capability does not fail the parent part but adversely impacts in serious ways the functionalities/piece parts that the overall system depends on for robust performance.
- Operation in extreme environments/in the presence of discrete extreme environmental/operational conditions
- Bio becoming more virulent in space (e.g. pathogenesis, corrosives)
- Potential impacts of reusability upon safety and reliability and certification for such
- Human health issues (e.g. micro g, radiation, psychological, accidents, illness, etc.)
- Costs/profits/schedule exigencies, “corner cutting”
- Oxidative chemistry, causing equipment failure
- Electrostatics, causing electronic failures, fires and explosions
- Planetary and moon dust, abrasive, corrosive, oxidative
- Fatigue and fracture, a prime design metric for much of aerospace equipage
- Unknown unknowns; it is usually not possible to anticipate all combinational situations, conditions which will result in a reliability issue; we can become surprised reliability-wise

- Inadequate analysis and testing, due usually to either cost or inadequate knowledge or study

In aerospace in general, some 80% of the accidents are due to human factors. Therefore, the major first order approach to safety would be to utilize autonomous Artificial Intelligence (AI) robotics to both manufacture and operate rockets/space access. Then there is a long list of safety related design/operational precepts that can be applied to greatly improve rocket safety as well as the safety and reliability of the spacecraft, habitats, on-planet transportation and the systems that keep humans healthy in what, externally, is a terminally unhealthy space environment.

The dust on the Moon was found during Apollo to be a problem, and Mars, with its rarefied CO_2 atmosphere, has huge, long lasting dust storms. Therefore, equipment must be designed to keep the inhabited areas as dust free as possible. Also, spacecraft/habitats or habs must be designed to protect against micrometeorites or larger space debris, ensure structural integrity, and be leak tight.

Radiation in space, outside of the protection of Earth's magnetic fields and dense atmosphere, is orders of magnitude worse than that of nuclear weapons. The most worrisome is Galactic Cosmic Rays or particle radiation, such as fully ionized iron at tens of GEV energy levels [ref. 3]. Protection from this requires four meters of material, either regolith (living underground) or for in-space habs the same thickness of materials with a high hydrogen composition to reduce the major health concerns with regard to secondary neutron production. This radiation is carcinogenic and effects nearly all physiological aspects, including the cardiovascular and central nervous systems. An alternative radiation protection approach is fast transits, i.e. 200 day round trips to Mars instead of three years using the usual chemical rockets. There are at least two approaches to provide such fast transits. For destinations beyond Mars, well beyond what the human body can withstand in regard to radiation received during in-space trip time, some form of serious radiation protection will be required.

The in-space micro g, and probably even the .38g on Mars (or the 1/6th g on the Moon), have serious physiological effects on the human body, including wasting bones and muscles, eye problems, etc. [ref. 3]. Rotational artificial gravity incorporated into the design and the functionality of the deep space habs would be efficacious.

Having briefly described the space tourism issues for physical tourism, it is interesting to contrast those with the increasing alternative, immersive presence/digital reality [ref. 1]. The development of digital reality (DR) or virtual/non-physical presence began with the telegraph and progressed to the telephone, then telephones with screens, and now to computers. The nearer term developments of DR include augmented reality, advanced virtual reality (VR) heading toward five senses VR, and holographic projection off of flat screens. Going forward with the availability of ever greater bandwidth and direct machine to brain communications, instead of through the senses, DR is projected to be as good as, or better than, physical reality. Even the current DR technology provides the critical body language aspects of human communication.

Compared to physical travel, DR provides the following benefits:

- Massive cost reductions, not just for transportation, total trip costs are massively reduced (by factors of many millions).
- Large time savings, again, not just transportation time, huge savings in total trip time
- Results in much improved use of time, can visit many planets/moons in a day
- Do not have to be absent from family
- Provides travel/entertainment experiences for all, affordably, on their personal schedule, including the infirm and the young
- Enables expansion of the huge ongoing societal shift, begun some 25 years ago with the Web, into the virtual age with tele-everything such as tele-commuting, work, shopping, education, medicine, socialization, commerce, politics, etc.
- Healthier with regards to diet, sleep, exposure to space radiation, reduced gravity, and other hazards of space

Even before COVID-19, a virtual leisure travel industry was developing (including a wholly virtual "airline"). This industry has greatly expanded during COVID-19. The industry provides virtual tourism as an alternative to physical tourism and along with the many benefits of DR already discussed, includes virtual trips to destinations without the increasing crowding often prevalent for physical travel and virtual trips, traveling adventures which are not physically possible. This includes travel to historical places as they were in previous ages and to inaccessible places in space. This virtual tourism industry has shown good growth/success, especially during COVID. Similar success has been observed with regard to virtual business conferences, with many more able to attend, no venue costs/scheduling issues and excellent networking opportunities.

Immersive presence space tourism to the Moon/Mars is a developing business. What could be put together for children is a Martian experience where, as they round a boulder a Martian of the parents' choice in terms of configuration is there to conduct a tour of their planet. The data to inform and enable building these ever increasingly improving virtual experiences is provided by many countries employing the many sensors, crawlers, etc. conducting scientific exploration of planets, asteroids, moons and now, for the Earth's Moon, industrial development. This increasingly realistic alternative for space tourism is in the context of digital reality and increasingly immersive with five senses haptics and holographic projection under development.

Current Status of Space Tourism

For physical space tourism there has been a near term emphasis upon suborbital flights going forward. Orbital space tourism was begun by the Russians, who in eight trips took seven tourists to the International Space Station (ISS) from 2001 to 2009 on Soyuz, after suitable training [ref. 4]. The nominal cost of such trips is now in the range of $20M to $25M, via Blue Origin, Virgin Galactic, Boeing and Space X. There were several startups to provide orbital space tourism during and after the Russian space tourist trips. These were not successful, perhaps partially due to the economic conditions in that era. The U.S. is planning for Space X Crew Dragon and Boeing Starliner to transport tourists (sometimes termed spacecraft participants) to the ISS, with an ISS accommodation cost of $35K/day each. NASA is largely responsible for the reinvigorated emphasis upon private space travel. The NASA commercial crew program with Boeing and Space X has as one of their objectives fostering commercial/private human space access. With that program thus far a success, there are now serious plans to exploit that space access capability for space tourism [ref. 5]. Bigelow Aerospace and Orion Span have nascent luxury orbital hotel designs. Space X and Space Adventures plan Moon loop flights for $70 to $100 M. A survey indicates that there is significant public interest in spending up to two weeks on the ISS with a spacewalk and some are desirous of a space hotel. Space Adventures plans to fly two tourists to the ISS in 2023 on Soyuz. Axion/Space X plan to fly three tourists to the ISS in 2021 for 10 days. Space Adventures and Space X plan a four to five day space trip, no ISS visit, in the 2021 time frame. Axiom Space is planning a private module addition to ISS as a hotel.

There appears to be accelerating serious near term interest in orbital space tourism. The current costs are, for most, daunting, but the activity, interest and now emerging capabilities to do these trips plus the large Space X LEO access cost reductions bode well for the future of space tourism, providing that there are no accidents and loss of life. The projected mean number of missions for loss of crew on space shuttle was a factor of order two less than what was actually observed. However, shuttle was designed in the 1970's and built for half the projected cost due to budget cuts. We know more now and have more experience. Therefore, space tourism will probably experience at least the historical average on the order of 100 flights between failures. The extent to which rocket safety can be improved and its' public acceptance is TBD. Serious space tourism is starting in Earth orbit over the next few years. The two weeks or less in space, from the available information, should not produce many of the adverse health effects that characterize longer stays. ISS is within the planetary magnetic fields that offer some protection from radiation (even though it's above the protective atmosphere). In fact, the radiation exposure is half of that which would be received in deep space (e.g. during trips to the Moon, Mars, and other destinations). Typical ISS duty periods for highly trained ISS astronauts is six months. A year on ISS for Astronaut Mark Kelly was difficult. In deep space, exposed to full radiation, serious radiation protection and probably artificial gravity will be needed for such as Martian trips and beyond.

With respect to the present status of virtual/digital space tourism, NASA has a number of immersive/virtual tours of destinations such as the ISS and the planets. Companies offer virtual tours of the Moon, Mars, the planets, and the solar system. Google offers a tour of the ISS, space tours are on YouTube, and the VR companies are planning to offer live virtual tours of Earth from space. Digital reality will increasingly provide some 80% of the space tourism experience at some million times less expense and some thousand times safer.

The Outlook for Space Tourism

Due to costs of rocket production and operations including launch, those technologies that provide extreme reductions in the costs of space access are the fundamental enablers for space tourism [ref. 6]. These costs are mainly due to rocket manufacture and operations including those associated with launch. The bulk of the costs are human labor. Space X has been extremely courageous and successful in reducing these launch costs via reusable rockets, cutting manufacture cost per launch, and in increasing automation, printing and robotization for manufacture and operations, thereby cutting human labor costs. The cost of fuel is very minor (less than 1%) and constitutes the limit to which LEO access costs can be reduced. Space X has produced a factor of six reduction in space access costs and is well along in providing a factor of 14 reduction. Such reductions are the basic enabler for affordable space travel. Increased use of autonomy and robotics for manufacture of the other equipment required for space tourism will also provide serious cost reductions with an overall resulting trip cost that will be increasingly manageable by the public. Therefore, of the two major issues/metrics for physical space tourism stated previously, cost and safety, requisite cost reductions are on the horizon. Unfortunately, the many aspects and issues surrounding safety are definitely works in progress. For physical space tourism, short jaunts for the usual week(s) vacation period (e.g. to nearer destinations such as space stations, the Moon, near Earth objects) would be relatively safe with regard to the major health safety issues (E.g. micro g and radiation). However, launch safety and overall reliability probably still require significant improvements for public tourism utilization. Longer trips to Mars and beyond entail much longer trip times and probably artificial gravity and serious radiation protection. Some have posited potential psychological issues would occur for such long trips, which might be alleviated via holographic members of the tourist group with characteristics updated periodically.

Radiation Protection Options in Decreasing Order of Technology Readiness Level (TRL):

For on Moon, planet, etc., ~ under three to four meters of regolith

For in space:
1. Fast transits (e.g. 200 day round trips to Mars) via inexpensive chemical fuel enabled by far lower LEO access costs.
2. Three to four meters reusable polyethylene overcoat, the weight/cost of which is enabled by inexpensive chemical fuel/far less expensive space access
3. Biological/medical countermeasures, a partial solution in space thus far, TBD going forward

4. Fast transits (e.g. 200 day Mars round trip) via 6,000 sec. Isp VASIMR high thrust MHD propulsion powered by an alpha of order one nuclear battery
5. Magnetic redirection of Galactic Cosmic Ray (GCR) particles via superconductive (S C) magnets located extended distances from the spacecraft
6. Silicon crystal reflection of GCR particles plus shielding for Gamma secondaries. This approach may be applicable to space suits, and in that event, an exoskeleton may be required to handle the additional inertial loads.

Prospective Space Activities Related To Space Tourism [ref. 7]

A. Major LEO constellations of small satellites for high-speed internet and Earth observation, expanding the number of satellites from the order of 1,000 now to some 10,000 plus by 2025. The associated Earth observation capabilities could enable "staring" anywhere 24/7/365.
B. "Utilities" for beyond Geosynchronous Equatorial Orbit (GEO) to service both public and private customers, including communications, energy/fuel, transportation, maintenance/repair, life support, etc.
C. Mining of the Moon, Mars, and asteroids for anything commercially viable or needed for colonization such as water, minerals, He3, rare earths, volatiles, "mass," etc. There are purportedly 850 near-Earth asteroids larger than a kilometer in diameter and many smaller ones at lunar distances from Earth or less.
D. Entertainment including virtual reality (VR), videos, virtual presence (e.g. to enable spending an evening exploring Mars from your living room)
E. Asteroid defense including detection, tracking, and diversion of threats deemed capable of causing grievous harm
F. Space solar power for utilization on planets, moons, asteroids, in space, delivered via energy beaming using microwave or lasers
G. "Space Beach Combing," the identification, collection, destruction, repurposing, and/or remanufacturing of space debris. Of special interest is boosting ISS, in due course, into a parking orbit and scavenging its parts and by the piece
H. Space as a trash dump involves putting "trash" in parking orbits for "safe storage," including possibly some components of nuclear waste depending upon if it could be certified "launch indestructible."
I. Space manufacturing in orbit, in-space, on other "bodies" or enroute. This could include initially products that are much improved by production in micro g such as

pharmaceuticals, fiber-optics, ball bearings, LEDs, solar panels, organs, hearts, and protein crystals. There are also products that benefit from the near absolute vacuum of space, and the manufacture of fuels and on planet/body or in space human or robotic equipage.

J. Space hospitals if microgravity or other in space conditions prove to be efficacious for specific human ills

K. Quantum technologies and quantum computing, utilizing the "quiet" conditions in space, vacuum, low temperature, etc. to delay de-coherence and stabilize quantum states

L. Enhanced positional Earth utilities including telecom, internet, navigation, weather, imagery/Earth observation, resource monitoring, etc., at lower cost and with larger apertures and greater resolution

M. Space weather forecasting for prediction of potential space condition impacts upon electronics both in space and on bodies including Earth

N. Communications and navigation, other satellite functionalities for the Moon, Mars, etc. to replicate or improve as is useful the extant "positional Earth utilities" that constitute most of current commercial space

O. Refueling depots-The fuel to supply such depots could be sourced from Earth, the Moon, Mars, asteroids, etc., anywhere that provides the fuel at lowest cost. These depots could be located in Earth orbit/Earth environs, anywhere suitable/convenient/required in space or on "bodies." The fuel could be chemical of various flavors including CH_4, H_2/O_2, nuclear reactor, or nuclear battery "fuel." Where propulsive mass and energy have been and can be separated, such as utilization of solar or beamed energy using the various flavors of nuclear energy including positrons, propulsive mass for propulsion utilizing external energy addition could be supplied. The total refueling depot system architecture includes fuel sourcing, production, transportation, storage, and disbursement.

P. Repair/servicing/maintenance functionalities-could be either itinerant or fixed, probably both, could be connected with fuel depots in some cases, and ultimately capable, possibly via printing, etc., of repair/maintenance of nearly everything. Reusability implies possible refurbishment, repair, maintenance, which are not as much of a major operational issues with a one-time use approach.

Q. To service humans, a combination lifeboat, hotel, search and rescue functionality, which could also be sited at fuel depots, utilized for survivability, transit, and space tourism

R. Energy beamers-nuclear or solar powered, including by positrons, the cheap anti-matter. These could be located on bodies, in orbit or in space, and provide an alternative energy/powering source, perhaps involving less cost than producing, handling fuel per se. This would still require propulsive mass for utilization of beamed energy for propulsion instead of the many other uses of beamed energy including asteroid defense, mass drivers, on body/spacecraft power and energy, space manufacturing, and other industrial/commercial activities

S. Momentum tethers, space elevators, utilized as alternatives for rocket transportation, some have envisaged these as Earth/Moon transport or for even longer distances and they are rather major putative reusable infrastructures, capital projects

T. Propulsive Ground Assist-propulsive infrastructures for space access including the slingatron, blast wave accelerators and mass drivers-alternatives to rockets or tethers or as a partial launch assist

U. Space manufacture facilities and space "Business Parks" - located in space and/or on bodies, all types of bodies, depending upon the business to be conducted, resource availability, transportation costs and products produced

V. Utilities for space colonization including sourcing, transfer, storage, disbursement of food, water, energy, "supplies", including from In-Situ Resource Utilization (ISRU) activities

W. Space tugs, in-space transfer, including cyclers, to move raw materials and products. In the absence of time criticality, these could employ sails-solar sails, laser sails, magnetic sails, or particulate sails, aka "sloboats"

X. On-body transportation, nuclear powered or "fueled" otherwise, for "freight" and humans. Due to the typically rough terrain of bodies, in atmosphere, near-body flying is probably the most efficacious transportation approach for other than very localized transportation.

Y. On-body infrastructures-habs, mines, manufacturing plants, energy sources, life support, etc. especially for colonization

The Potential Closed Business Cases for Commercial Deep Space Include:

1. Commercial space utilities beyond GEO including communications, energy/fuel/transportation, maintenance/repair, life support, etc. These in various forms and flavors will be needed for both government and commercial deep space activities, and especially for colonization. Development has already begun for several of these including communication.

2. Space mining-asteroid water is particularly interesting, especially if the quantity of Moon water proves to be significantly less and/or extraction costs prove

significantly more than anticipated. Given the extant competitive ocean (accessed via the increasingly low cost of renewable terrestrial energy)/other Earth resources, space mining may be more applicable to deep space utilization(s) than for use on Earth.

3. Space beach combing/cleaning up space debris-given the current situation with respect to space debris and the plans to loft many more satellites, we will probably have to move on from avoidance of space debris/decommissioned satellites to removal. The legal issues and costs have held that in abeyance. The costs could be addressed via use of E-M tethers powered by NTAC or solar, fuel-less transportation to collect space debris for space manufacture repurposing/remanufacturing.

4. Space manufacturing–with the space access cost reduction in the offing from reusable rockets, the major impediments to space manufacturing, which are cost and schedule, are greatly mitigated. This capability would also enable in-space manufacture of equipage not suitable for launch (e.g. it's too large or too fragile) even in piece parts. Also, there are many products that are either enabled or much improved by in-space micro g and/or deep vacuum conditions.

5. Space tourism–when human health/safety issues including safety, reliability, radiation, and microgravity are addressed, which are major mission design issues, the inexpensive space access enabled by reusable rockets should greatly accelerate space tourism.

6. Quantum computing/technologies in space–this is a "new-bee," with viability and realism yet to be determined. However, for delaying decoherence, maintaining quantum conditions, the temperature, vacuum, and "quiet" conditions of space appear to be of interest (initial experiments are in progress).

7. Space solar power–especially for other bodies and in-space utilization initially, and eventually with the potential for Earth use, depending upon the business case vis-à-vis the ever reducing cost of terrestrial renewables/storage with their massive potential capacity

8. Earth positional utilities–this is the current, very successful, commercial space. Inexpensive space access will make it even more so and several additional areas/functionalities will be enabled.

9. Colonization of bodies such as Mars with all of its resources, would create a wholly new economy that could be essentially self-contained. Mars could, with its resources, become the department and building supply store for the solar system as human colonization moves beyond Mars.

Concluding Remarks

The bottom line on space tourism is that after some 60 years of highly trained astronauts going into space, space related technologies and their costs have altered to the point where increasing numbers of private citizens can become space tourists. Initially, space travel would be suborbital for minimal times and Earth orbital for up to two weeks, with nearer term plans by Space X to do lunar flybys. There has also developed a now rapidly improving digital reality/immersive virtual presence technology providing space tourism experiences at minimal cost and available essentially to everyone. The safety aspects of physical space tourism need further development, but those that relate to the space environment are tolerable for a few weeks from the 60 years of manned space flight experience. As space tourism expands beyond Earth orbit to the Moon, Mars, asteroids, and other planets, the safety issues will need to be seriously worked, and that is doable. The apparent breakthrough in the resurgence of space tourism was the NASA commercial crew program, which was partially targeted on space tourism and has led to the transportation necessary to enable the nearer term, very few years out now, plans for a goodly expansion of physical space tourism. This is only a portion of what will become major opportunities and expansion of commercial space beyond Earth utilities/up to GEO into deep space, initially the Moon, Mars, asteroids, and near Earth objects. All of this is greatly enhanced by the ongoing major reductions in the costs of space access. Given the wonderous ongoing progress in AI-enhanced autonomous robotics, for goodly cost and safety reasons, much to most of this commercial deep space will probably not include onsite humans. There are projections that travelers that colonize Mars will, over time, due to the reduced g and radiation exposure, evolve into Martians.

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