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ANALYSIS OF ASPECTS OF HEALTH CARE DELIVERY AND SAFETY FOR SPACE TOURISM AND SPACE PASSENGERS

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ANALYSIS OF ASPECTS OF HEALTH CARE DELIVERY AND SAFETY FOR SPACE TOURISM AND SPACE PASSENGERS

by

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Capstone

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To: Mary, Casey, Ryan, and Courtney. May all your dreams come true.

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ANALYSIS OF ASPECTS OF HEALTH CARE DELIVERY AND SAFETY FOR SPACE TOURISM AND SPACE PASSENGERS

Publication No.____________

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Non-career space travelers from around the world will be venturing into space as commercial programs develop and mature. There are multiple forces promoting human suborbital and orbital flight, including; public interest and desire, market and financial drivers, technological advances, and a paradigm shift from governmental to privately funded space enterprises. This Capstone project seeks to evaluate factors of health and safety related to the space traveling general public. These elements involve: (1) pre-mission medical standards and evaluation, (2) medical risk mitigation, (3) physiological impacts of acceleration, microgravity, and radiation exposure, (4) in-flight medical monitoring and health care delivery, (5) pre-flight training, and (6) regulatory issues. Space tourism has indeed started, and the coming decades will see this dream of flight come true for a sizeable number of participants.

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INTRODUCTION

It is inevitable in the years ahead that the world will witness a great increase in space tourism and non-career space passengers. Space travel captivates the imagination of humankind. While space travel is an inherently risk-laden enterprise, the potential opportunity to experience the sensations of microgravity, observe unique and breathtaking views of Earth and space, and in many cases fulfill a lifelong dream are strong incentives for a space journey. (For the general purposes of this document, the terms space tourist, space passenger, private space explorer, and spaceflight participant will be used interchangeably, except where specifically denoted.)

Commercial airplane travel was initially available only to the wealthy during its growth phases in the 20th century, but as costs decreased, the market opened to the general public. It is also anticipated space travel costs will decline over time. The explosion of leisure and adventure travel in recent years to Antarctica, the Arctic Circle, and within deep-diving submersibles demonstrates the public desire for adventure to sites previously only available to scientists, explorers, militaries, and govermnents. In the foreseeable future, families will depart from a “Spaceport” for a variety of experiences, including a suborbital spaceflight, orbital flight, or even days to weeks on-orbit. This is a certain step in the quest for new and exciting experiences. Currently, the cost to launch one pound of material to space is estimated at approximately $10,000.[33] As this cost is reduced through new engine and vehicle designs, as well as material advances, the doors to space access will be further opened to commercial passengers.

On April 28, 2001, Dennis Tito became the 415th person to enter space, and the first person to individually pay for his travel into space. His trip onboard a Russian Soyuz cost a reported $20-million.[2] Tito’s journey to space began at the same launch pad in central Kazakhstan where the Soviet Union Air Force pilot Yuri Gagarin launched atop Vostok 1 on April 12, 1961. Gagarin’s two-hour (one orbit) flight around the Earth was the first for a human. Three weeks later, US Astronaut Alan Shepard completed a suborbital flight into space onboard a Mercury Redstone rocket. Many “firsts” would be achieved; the first woman in space, Valentina Tereshkova in 1963, and the first spacewalk in 1965 by Alexi Leonov.[26] The most climactic moment of the decade was the lunar landing by Apollo 11 on July 20, 1969, with Neil Armstrong's first steps on another celestial body by a human.

In just a short span of eight years, from 1961 to 1969, the doors to outer space were opened up as Astronauts and Cosmonauts launched into orbit, riveting the imagination of the world with their adventures and unbelievable photographic images. In 1971, the first space station, Salyut 1, was placed into orbit by the Soviet Union. At that time many space enthusiasts felt it inevitable that private citizens would be traveling into space in the upcoming decades to orbit the Earth and visit "space hotels." Moon colonies would surely be developed, and the next steps to Mars would be forthcoming. Major airlines, such as Pan American and Trans World Airlines began promotions to make reservations for trips into space.[34]

The 1970s, 1980s, and 1990s witnessed continued government sponsored spaceflights via the United States and the USSR (eventually becoming the Russian Federation). Skylab, the Space Shuttle, Soyuz, and Shuttle-Mir were programs that advanced knowledge, technology, and human experience in space. However, the dramatic pace seen in the 1960s was not duplicated as challenging economic conditions arose in the United States and the Soviet Union. As the Cold War faded over time, the competitive nature of the superpower space programs also diminished. President Ronald Reagan piqued the interests of non-professional astronauts in 1984 when he announced the "Teacher-In-Space" project.[1] An underlying anticipation was that artists, poets, photographers, and journalists would also soon be streaking into space to share their experiences with the public. Only a few non-career astronauts had previously flown on the Shuttle as Payload Specialist, including, a U.S. Congressman, U.S. Senator, Saudi prince, various scientists and engineers associated with expensive payloads, and Department of Defense members. However, the Space Shuttle Challenger disaster in 1986 confirmed the risks of spaceflight with complex launch vehicles. For the private citizens hoping to experience space, the years would slip by, but passion remained.

The early years of the 21st Century brought a new era as technology, market forces, and design expertise converged to open the doors to an exciting period of adventure. Private suborbital vehicle access to space became a reality. On October 4, 2004, the 47th Anniversary of the Sputnik I launch, SpaceShipOne, produced by Scaled Composites LLC and funded by Paul Allen, fulfilled the requirements for the $10-million Ansari X-Prize and completed two sub-orbital flights in less than two weeks.[14] This historic milestone will lead a revolution in private access to space. The accomplishment has encouraged other commercial companies to continue with their own development efforts.

BACKGROUND

Public Interest in Adventure Expeditions

The past several years have witnessed a dramatic increase in public interest in adventure expeditions. Various companies help broker experiences such as; a Russian MiG jet fight, a parabolic flight to experience periods of reduced gravity (microgravity) in a Russian Ilyushin-76 or Boeing 727, a submersible vehicle ride to the sunken ship HMS Breadalbane at a depth of 350 ft, guided trips to Mount Everest and Antarctica, and a North Pole submersible trip to 14,000 ft.[2] The thirst for such adventure appears to be growing as more options become available, good safety records are maintained, and costs are reasonable enough to entice customers across a variety of financial strata. What was once only available to the super wealthy, professional explorer, or military servicemember, is now becoming more available to the general public.

Aircraft with conventional jet engines capable of reaching very high altitudes currently provide "edge of space" experiences. The MiG-25, with a maximum speed of Mach 3, is able to reach altitudes of 82,000 feet, above 99.9% of Earth's atmosphere. (The recognized record climb for a jet aircraft (MiG-25) under powered flight is 123, 524 ft (37,650 m).[2] At an 82,000 ft altitude, passengers can enjoy the curvature of the Earth, see the deep blackness of space, and observe a horizon spanning over 700 miles.

The first privately funded spaceflight of Dennis Tito (USA) to the International Space Station aboard the Russian Soyuz created interest in the public. Being a private citizen, the television and print media were especially eager to showcase his adventure. Tito offered a unique perspective on the excitement of training and completing a spaceflight, different from that of a career Astronaut/Cosmonaut. His preparation for a five-day stay at the International Space Station would require six months of training, with several hundred hours spent training at the Russian Yuri Gagarin Cosmonaut Training Center in Star City, Russia.[36] After extensive medical evaluations required for selection, his training requirements included courses on spacecraft systems, emergency scenarios, Russian language, and physical fitness training. While Tito could afford to pay his own way, opportunities for corporate sponsorship, spokesperson status, in-flight product testing, and TV specials have been touted as mechanisms to defray the cost for private flights to the ISS. In December 1990, Toyohiro Akiyama, a Japanese journalist with Tokyo Broadcasting Company, flew to the Soviet Union Mir space station in a Soyuz seat purchased by his company.[36] Subsequently, in 1991 Helen Sharman, Ph.D. of Great Britain flew to Mir as the first British citizen in space.[31] She was chosen from a pool of nationwide applicants for a Soyuz seat sponsored by a group of British companies.

Market Research on Public Interest in Space Travel

New financial ventures are often accompanied by initial market research surveys. To date, the literature reveals only a few such analyses regarding public travel into space. The National Aerospace Laboratory (NAL) of Japan completed a 1993 survey of 3030 phone respondents.[10] A subsequent 1995 NAL sponsored survey, for North America, was completed with 1020 phone respondents. The percentage of participants in the combined surveys interested in traveling to space was greater than 70% for those less than age 60 (Figure 2). This percentage increased to approximately 80% for those less than age 40. A query of potential flyers on the “length of time” they would prefer to remain in space was highest for a one-week stay (Figure 1). This time interval appeared to be the duration most individuals believed would be appropriate to enjoy microgravity and Earth views before returning. Comparison of the financial outlays customer would be willing to pay for such a trip varied between nationality surveyed, with 10% willing to pay up to one year’s salary (Figure 3).

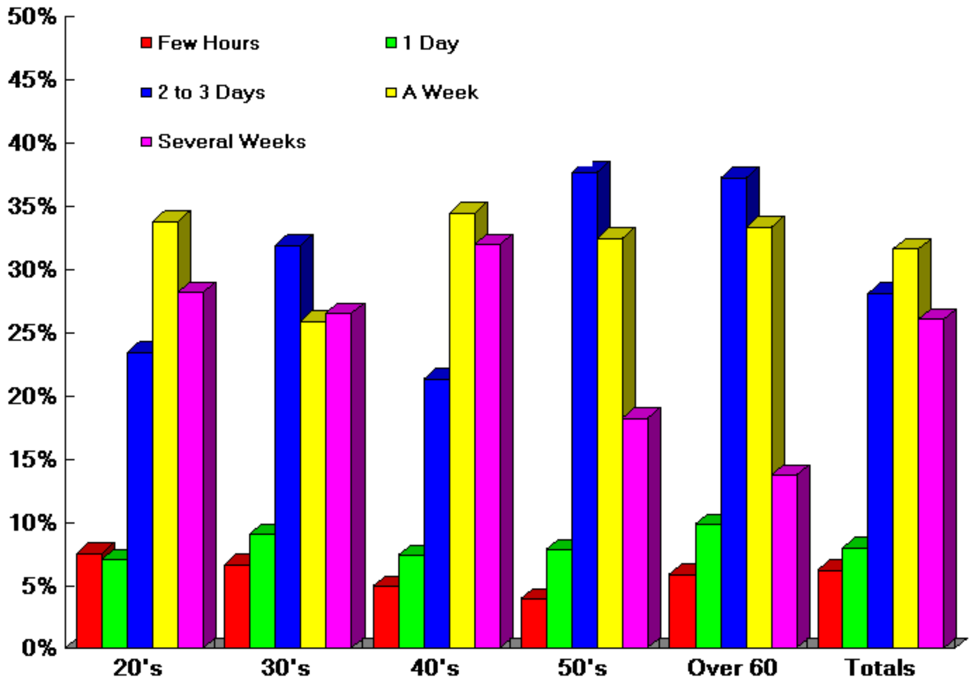

Figure 1. Length of space stay desired based on age group[10]
(Permission received to reproduce by Japan Aerospace Exploration Agency.)

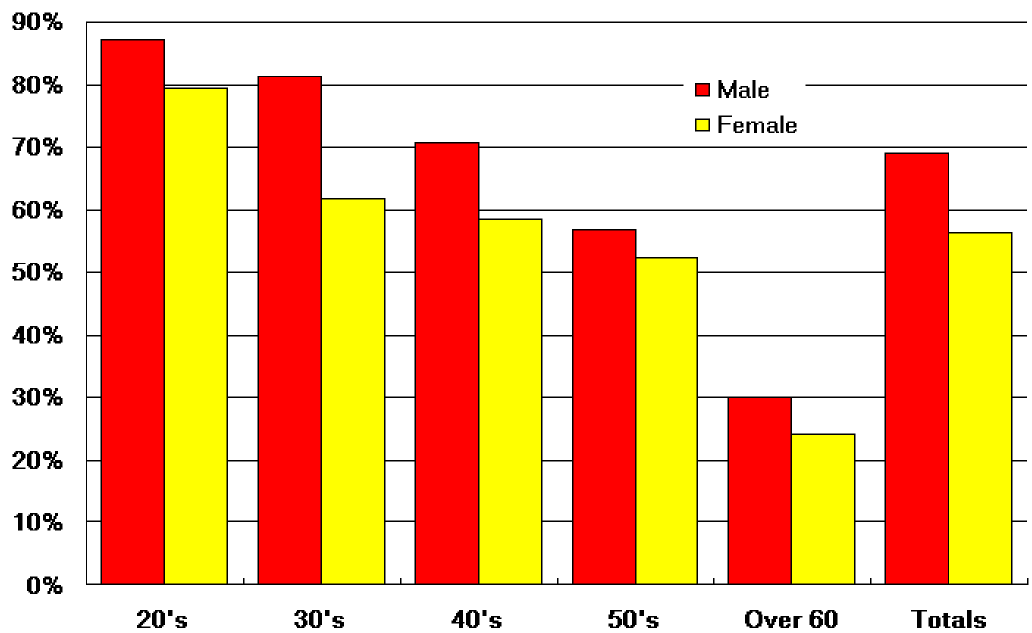

Figure 2. Percentage of respondents interested in traveling to space by age/gender[10]
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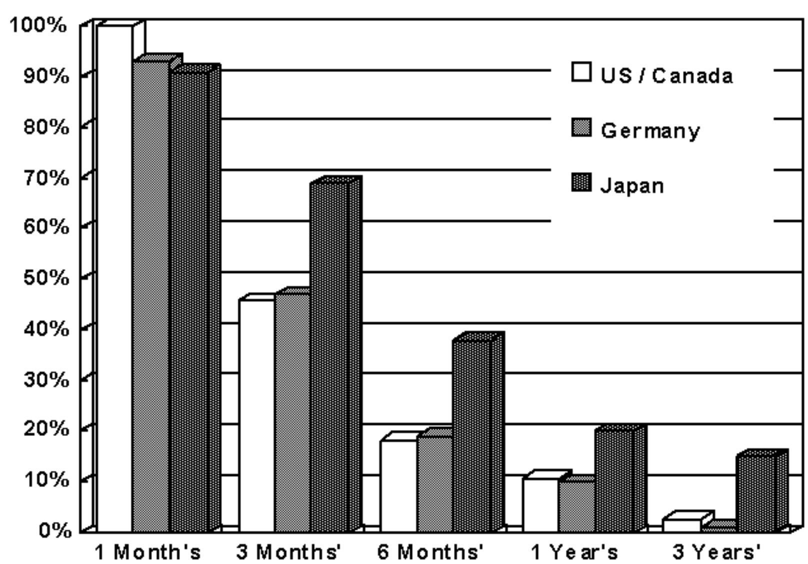

Figure 3. Amount of salary passengers are willing to pay for space flight[10]
(Permission received to reproduce by Japan Aerospace Exploration Agency.)

Futron Corporation, utilizing Zogby International poll service, conducted a survey in 2002 to evaluate the public sector interest in space tourism.[7,18,19] The survey included interviews with over 450 Americans with yearly annual incomes over $250,000 and/or net worth exceeding $1,000,000. Travel scenarios were focused in two arenas: a 15-minute suborbital flight and a two-week orbital flight to a space station. Nearly 20% of respondents stated they would be "definitely likely" or "very likely" to seek out a suborbital flight knowing the price would approximate $100,000. Futron estimates that by 2021, the suborbital travel market could reach over 15,000 passengers annually, with revenues exceeding $700 million (Figure 4, Table 1). Seven-percent of respondents said they would be willing to spend $20 million for a two-week stay to an orbiting space station. The positive responses more than doubled if the price tag came down to the $5 million range. Even at a cost of $20 million, Futron forecasted a potential of up to 60 travelers per year for ISS missions by 2021. The Russian Soyuz is the only current vehicle used to transport space tourists to the ISS. The three-person configuration of Soyuz, with two seats needed for highly trained cosmonauts/astronauts, has periodically allowed for the purchase of a passenger slot. With the impending retirement of the Space Shuttle fleet slated for 2010 and the eventual six-person manning of the ISS, there is uncertainty at this time about availability of future open Soyuz seats. Development of commercial vehicles able to reach orbit with passengers may well be market driven in the decades ahead.

While NASA does not appear to have any direct interest in funding private ventures, the Russian government has clearly embraced capitalism. They have sold a number of seats on Soyuz, filmed sponsored television commercials onboard Mir and ISS, ranging from soft drink commercials to golf ball promotion during a spacewalk.

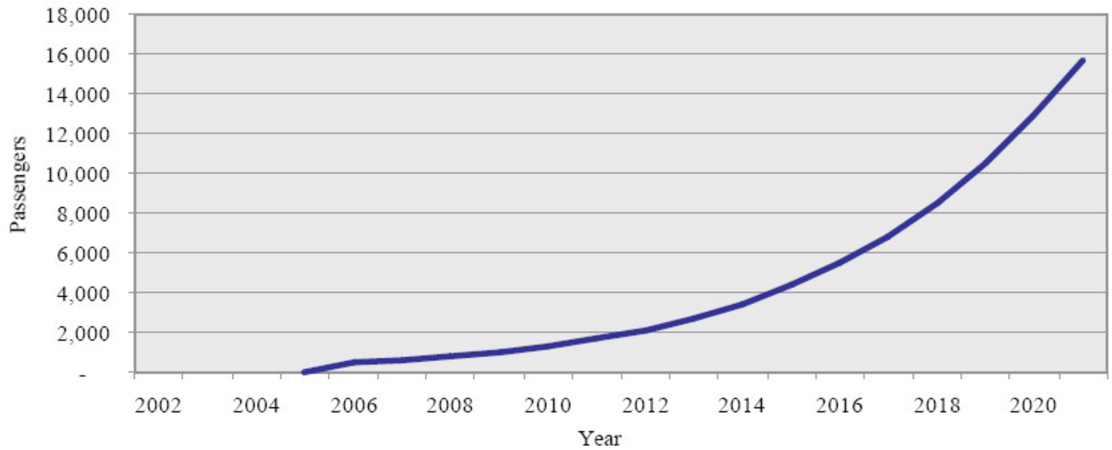

Figure 4. Projected Demand: Suborbital Space Tourism-Futron Study[18]
(Permission received to reproduce by Futron Corporation.)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total Passengers	503	642	820	1,045	1,330	1,692	2,150	2,726	3,448	4,350	5,468	6,842	8,517	10,532	12,923	15,712

Table 1. Projected number of passengers per year for Suborbital flights - Futron Study[18]
(Permission received to reproduce by Futron Corporation.)

Financial Assets of Potential Travelers

There are significant internation financial resources to sustain space tourism programs. According to Forbes Magazine in 2006, there were an estimated 792 billionaires worldwide, up nearly 20% from the prior year, and increased from the 1999 figure of 500 billionaires.[29] Merryl Lynch, in its World Wealth Report of 2006, estimated there were 8.7 millionaires worldwide, over half from the United States.[39] This tally increased from 7.2 million individuals in 1999. (A millionaire is defined as those individuals with financial assets outside of their homes, property, and vehicles ranging from $1 million – $999 million.) Financial trends clearly indicate that the number of exceptionally wealthy individuals continues to grow, and at a pace unprecedented in history. As wealth increases, so too does the desire and means for leisure, recreation, and adventure activities.

X-Prize

Aviation prizes were created early last century to spur advancements toward a variety of aviation milestones. Between 1905-1935, over 100 different prizes were established internationally. Charles Lindbergh is famous for the first Trans-Atlantic non-stop flight, which was completed in 1927. He subsequently received the $25,000 Ortieg Prize for his accomplishment. Although Lindbergh was rewarded for his success, it is notable that many other groups were competing for the Ortieg Prize. It is estimated that over $400,000 was spent (in 1920 era dollars) by other teams in advancing technologies toward winning the Prize.[14] This collective technology initiative helped advance the aviation industry, which is today recognized as a $250-billion plus industry.

The X-Prize was established in 1996 by the X-Prize Foundation in St. Louis. The $10 million prize was planned to be granted to the first team that: privately financed, built, and launched a spaceship capably of carrying a pilot and two human passengers (or weight equivalent of 180 kg (396 lbs)) to at least 100 km (62.5 miles), return safely, and repeat the feat with the same ship within two weeks.[14] (A prime sponsor of the X-Prize became the Ansari family, thus the prize bears that name.) There were over 20 teams registered worldwide competing for the Ansari X-prize. Like the Orteig Prize, there was only one winner, but the total efforts and monies expended by the various participating teams for design, materials, engines, and other technologies will most certainly advance the aerospace industry. Investors and venture capitalists will continue to support financial efforts for lower costs, leading to a renaissance in flight and creation of new industries.

"The way to get things done is to stimulate competition. I do not mean in a sordid, money-getting way, but in the desire to excel." Charles Schwab.

SpaceShipOne and Reusable Launch Vehicles

The successful launch and return of SpaceShipOne (SSI) on June 21, 2004 marked the first privately funded human space vehicle. Built by aircraft designer Burt Rutan and funded by Microsoft cofounder Paul Allen, SSI was a two-stage design. The turbojet launch aircraft, White Knight, climbed to an altitude of 47,000 ft (14.3 km), whereupon SSI was dropped to fire its rocket motor. With a test pilot onboard, SSI then climbed upward, reaching a speed of 2.9 Mach (2,1150 mph, 3460 km/hr), and coasted to an altitude over 62.2 miles (100.1km, 328,491 ft).[38] Upon reaching apogee, the wings of SSI were feathered for atmospheric reentry. Subsequently SSI converted to a conventional glider and made a runway landing.

On September 29, 2004, SpaceShipOne initiated its formal quest for the Ansari X-prize and launched again carrying test a test pilot and the appropriate weight ballast. A historic linkage in the stowage was the inclusion of Charles Lindbergh's book "The Spirit of St. Louis," and designer Burt Rutan's college slide rule.[38] The vehicle flew to 63.9 miles (102.9 km). A week later it performed another successful flight (69.6 miles, 112 km) with a safe recovery, thereby laying claim to the Ansari X-Prize.

Until the October 2003 orbital flight of a Chinese Taikonaut, the US and Russia have been the only nations capable of human access to space. The longest crew stay on the Space Shuttle has been approximately 16 days, with the ISS serving as the only habitat currently available for long duration stays. The Space Shuttle and Soyuz vehicles are technically complex and expensive and utilize expendable components that disintegrate in the atmosphere upon jettison during the launch phase. Reusable Launch Vehicles (RLV) are being heralded as the next generation of vehicles capable of suborbital and orbital flights.[36] Although RLVs offer significantly lower up-mass lift, they are designed to be less technically complex, less expensive, and capable of refurbishment and reuse in a relatively short timeframe (days to weeks).

Examples of RLVs from US companies include the Astroliner (Kelly Space and Technology), K-series (Kistler Aerospace Corporation), XCOR Aerospace, Pathfinder (Pioneer Rocketplane), Space Clipper (Vela Technology Development), and Venture Star (Lockheed Martin).[36] International groups have also worked on developing products, including, the HOPE-X (National Space Development Agency of Japan), Spacecab/Spacebus (Bristol Spaceplanes, UK), AVATAR (Defense Research Development Organization of India, and Cosmopolis XXI (Russia).[36] The range of RLV uses could include suborbital flights, orbital flights, as well as eventual access to "space hotels." The concept of space hotels, where travelers would remain for days to weeks, is gaining significant interest in recent years. A number of professional symposia have taken place in recent years to evaluate potential designs and operational challenges of such structures.

CAREER AND PRIVATE SPACE TRAVELER DIFFERENCES

There are differences which exist between the career astronaut and the general flying public. NASA seeks to select only the most highly qualified individuals, who meet exacting medical qualification standards. The government invests considerable financial assets for astronauts to train in a variety of venues, including; T-38 aircraft and parabolic flight, survival schools, motion-based and virtual reality simulators, altitude chambers, and spacesuit training in a neutral buoyancy laboratory (large pool used to simulate weightlessness). An astronaut's career could potentially span a few decades and include a number of spaceflights. The tax paying public expects astronauts to be selected and maintained at the highest medical levels since they are entrusted to fly onboard expensive national assets. The risks of commercial spaceflight are assumed by the passenger and the operating company, as opposed to federal government responsibility for the astronaut corps.

Commercial ventures wish to open the spaceflight experience to as many paying passengers as possible, which includes older clients who may present with a host of underlying medical conditions. It is estimated the average age will be closer to 55 years, with clients being older and in a financial posture to afford the costs. To date, Senator John Glenn is the oldest human to have flown in space, and was 77 years-old at the time of his STS-95 Space Shuttle flight in 1998.[34] Senator Glenn, who was in excellent health before his public flight announcement, received extensive medical evaluation by NASA prior to clearance for flight. He hoped his mission participation would provide data on various physiological parameters for older fliers, with potential benefits for Earthbound maladies. His successful nine-day flight served as an inspiration to upper age groups that space flight can be tolerated by an older, albeit healthy, senior citizen.

Flight Profiles

Flights can be categorized into three basic domains based on mission duration and profile: suborbital, orbital, and extended orbital. The boundary between the Earth's atmosphere and space is known as the Kármán line and lies at an altitude of 62 miles (100 km).[25] At this altitude the atmosphere is too thin for effective use of aerodynamic controls. This line between the atmosphere and space is accepted by the Fédération Aéronautique Internationale (FAI), which is the international body formulating standards for aeronautics and astronautics. Aspects of suborbital flight include: acceleration changes during ascent/decent and limited periods of microgravity (5-15 minute based on profile). Human experience in suborbital flight is limited to thirteen USAF X-15 Program flights in the 1960s (of the 199 total X-15 flights), the first two NASA Mercury flights, and the recent successful flights of SpaceShipOne.[35] In all cases, the pilots were strapped into their seats for the duration of the flight. For commercial spaceflight, it is envisioned that passengers will likely be allowed to release their seat restraints and float in the confines of the cabin to experience microgravity and the views.

An orbital flight requires vehicles with the speed and energy necessary to achieve an orbital state. Low Earth Orbit (LEO) is generally defined as a minimum distance of 100 miles (160 km) above the Earth's surface. A vehicle achieving a speed of Mach 5, for example, will be able to coast and cross the threshold of space, but will subsequently fall back toward earth. Entering orbit requires acceleration to Mach 25 (17,500 miles per hour) allowing a vehicle in essence to fall around the earth, rather than back to the ground. Although the ratio of speed is five times greater for orbital than suborbital flight (Mach 25 vs. Mach 5), at least twenty-five times the energy is required since kinetic energy is the square of the velocity (kinetic energy = 1/2 mass*velocity^2).[23] For a single-stage suborbital RLV the fuel requirement may account for half the initial mass. With a single-stage orbital RLV fuel may comprise for up to 90% of the initial mass.[23] Staging improves these weight issues but presents other engineering and design challenges.

At an orbital velocity of Mach 25 it takes approximately 90 minutes to circumnavigate the Earth based on orbital inclination, with sunrise or sunset nearly every 45 minutes. Extended orbital stays to the International Space Station, or a space hotel, would include more pronounced physiological deconditioning and impacts to various biological systems. Such missions would allow for extended microgravity, greater propensity for Space Motion Sickness, and various acceleration profiles based on ascent/decent, seating orientation, and vehicle design. These changes have been studied in detail by both the US and Russian space programs and are the foci of ongoing and future research initiatives.[26]

Spaceport Locations

The entrance of private citizens into space will not be solely a United States venture. It is anticipated that other nations will successfully develop their own spaceports and vehicles. The location of spaceport developments will involve several factors, including access, climate, and safe distances from a local population. Launch sites have historically been developed closer to the equator. The Earth's rotational velocity is greatest at the equator and weakest at the poles. The closer a vehicle launches eastward in proximity to the equator, the more it can take advantage of the rotational velocity as it enters orbit. This allows a vehicle to require less fuel and carry more payloads into orbit. Baikonur Cosmodrome in Kazakhstan, founded in 1955, is one of world's oldest operational launch facilities for both unmanned and manned vehicles. The facility plays a key role in the International Space Station program, as does the US facility at the Kennedy Space Center in Florida. Both US and Russian sites are government controlled. Private sector efforts are underway to develop sites throughout the US and overseas. Proposed commercial US sites include facilities in Alaska, California, Florida, New Mexico, Oklahoma, Texas, Virginia, and Wisconsin (Illustration 2).[17,33] Dubai, in the United Arab Emirates, is fast becoming one of the leading worldwide destinations for leisure and recreation. A spaceport at Dubai is being considered by investors due to its favorable climate, proximity to the equator, and growth potential (Illustration 1).[2] Additionally, Singapore and the Woomea launch complex in Southern Australia are also being envisioned sites for development.

Illustration 1. Proposed spaceport to be located in the United Arab Emirates[2]
(Permission received to reproduce by Space Adventures, Ltd)

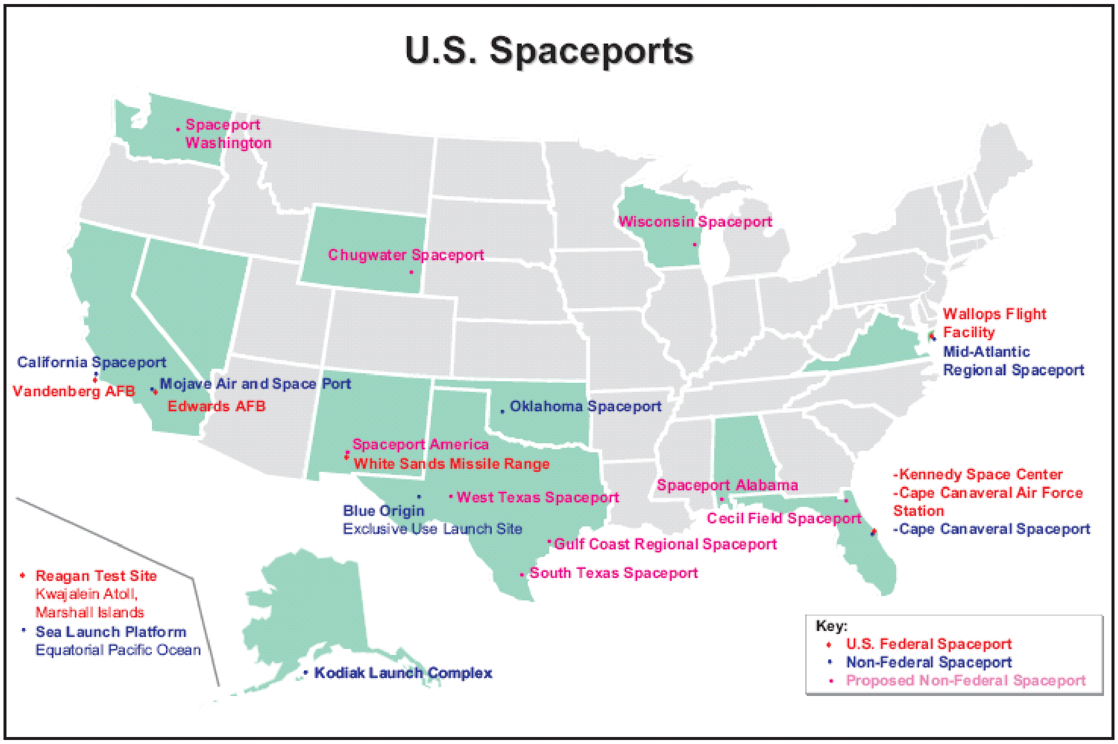

Illustration 2. Existing and potential U.S. Spaceports[17]

Space Destinations

The ISS is currently the orbital destination for space tourists flying aboard the Soyuz. The ISS represents the most complex international engineering project in history, with scientific and technical contributions from 16 nations. Private space stations, primarily designed for tourist travel, are being conceptualized and developed outside the scope of government financing. Bigelow Aerospace has investigated habitable environments using lightweight inflatable technology based on prior NASA TransHab module work.[12] An expanded module could be utilized for space tourism, commercial manufacturing, and research. Prototype modules, known as Genesis I & II, were launched in July 2006 and June 2007 to prove technical feasibility. A full-scale production module, known as Sundancer is slated to be 28.5 ft (8.7 m) long and 20.6 ft (6.3 m) in diameter, with 180 cubic meters of useable volume.[8] Bigelow Aerospace desires to launch an orbital resort by 2010-2012, tentatively known as Commercial Space Station "Skywalker".[8]

The lure of circumnavigating or walking on the Moon remains the ultimate space tourist's dream. Private citizens will certainly one day view Neil Armstrong's first footprint on the moon. A circumlunar private trip is being investigated and may be available to those willing to risk such an advanced venture and also having the financial means (estimated at $100,000,000).[2] Bigelow Aerospace envisions travel to an orbiting lunar hotel as a future goal. Looking back at the Earth from a quarter-of-million-miles away and seeing an Earthrise after passing the dark side of the moon captures the imagination and determination of many.

A future theoretical destination to some visionaries is the location for a space facility at L5, know as the fifth Lagrangian Libration point.[22] Lagrangian Libration points are locations between two celestial bodies where a space vehicle would always remain in a stable gravitational equilibrium position with respect to both bodies (such as the Earth and the Moon, or the Sun and the Earth). L5 would be located outside the Moon's orbit, and theoretically remain fixed without fuel needed to hold position. Futurists believe a facility at L5 could be used to convert solar energy and microwave it to Earth, utilize Moon resources for agrarian projects, and stage development of a permanent space colony.

TECHNICAL FACTOR CONSIDERATIONS

Noise/vibration

Noise and vibration are inherent to any aircraft or space vehicle. Engineering design efforts strive to minimize these elements and any untoward impacts on humans. During a SpaceShipOne flight, pilot Mike Melville experienced rapid rolling of the vehicle at high altitude while traveling at 2.7 Mach.[38] Although the atmosphere was too thin for the roll to cause catastrophic aerodynamic stress on the structure, video from the cabin revealed its violence and potentially disorientating nature. While the seasoned test pilot was able to tolerate the 29 complete rolls, it may be uncomfortable and disorienting for a typical passenger. Technical and procedural corrections were made to rectify the roll problem, however, it was clear that such events could have negative impacts on passengers with reduced tolerances due to age, anxiety, or underlying medical conditions. Such experiences support acceleration/centrifuge training as a component of preflight evaluation and certification.

Acceleration

Specific vehicle design and mission profile will determine the acceleration forces which crew and passengers will experience. The Space Shuttle for example, exposes astronauts to a maximum of 3.0 +Gx axis upon launch (chest to back), and 1.5 +Gz (long body axis from head to feet) during reentry.[26] Most commercial passengers should be able to tolerate up to 4.5 +Gx reasonably well with an RLV launching in a rocket configuration, or exposing passengers to such forces during various phases of flight. The longer the duration of the suborbital phase of flight the greater vehicle trajectory that is required. This leads to higher resultant G-forces experienced during more ballistic re-entry scenarios (6-7 +Gx or greater based on profile). +Gz axis forces lead to pooling of blood in dependant parts of the body, with a resulting decrease in venous return and decreased cardiac output.[26] Passengers with underlying cardiac conditions need to be evaluated to ensure they can tolerate such forces. Since +Gz forces can also strain the spinal system, caution is required for conditions such as osteoporosis, severe osteoarthritis, and spinal cord/nerve root disorders. A history of recent surgery, especially intraabdominal, should delay flying until healing is assured.

Emergency Egress

The decision for use of ejection seats for passengers and crew will be made by commercial companies as vehicle design and perceived risk is taken into account. This would add weight and complexity to the vehicle. The envelope for ejection would also be limited to certain phases of flight. Depending on the altitude designed for ejection, pressure suit and helmet would be required, with helmet/oxygen mask as a minimum for ejections in the envelopes typically available for modern military jet aircraft. Preflight instruction would be required for proper ejection body position and seat/parachute sequencing procedures.

Cabin Atmosphere

Maintaining a sea level cabin atmosphere of 14.7 psi (760 mm Hg) comprised of 21% oxygen/79% nitrogen would allow for travel in a flightsuit without the need for a pressurized suit. Availability of 100% oxygen via a facemask should be provided in case of events such as decompression, reduced cabin oxygen partial pressure, smoke or fumes in the cabin.

Space Suits

A standard aviator/astronaut Nomex (fire resistant) flight suit with boots will likely be minimum apparel. Companies may design flight suits which are fashionable and provide a unique statement about the passengers' flight experience. As companies decide vehicle design and mission profile, they will determine the requirement for pressurized suits. The company Orbital Outfitters has announced the first Commercial spacesuit. Known as the "Industrial Suborbital Space Suit-Crew (IS3C), the prototype is designed to provide a pressurized suit environment for safety and survivability.[27] The suit will also have design elements customizable to the various companies which purchase them. XCOR Aerospace in Mojave, CA, is one of the first customers apparently slated to buy the item.

Orbital Outfitters is also developing a version of a spacesuit which is envisioned for return from space to Earth outside the confines of a vehicle.[27] The suit design incorporates heat-resistance materials and a series of deployable chutes. In the scenario of a catastrophic vehicle failure, the suit would be designed for an individual to enter the atmosphere at 2,500 miles per hour, slow to terminal velocity (120 mph), and gently land on ground by parachute. The availability of a pressurized suit will be a factor for some passengers as they weigh safety and risk to select a flight provider.

Orbital Outfitters is also trying to pioneer the concept of "Space Diving," which would be the "most extreme recreational sport in human history."[27] Work is underway for a possible demonstration jump from 120,000 feet in 2009.

Crash Worthiness/Structural Integrity

Vehicle designs, while attempting to reduce weight and complexity, should provide structural integrity and human protection for potential "out of the envelope" aerodynamic forces. Depending on vertical or horizontal passenger landing positions, consideration should be given to energy attenuating/absorbing seats to prevent injury upon higher energy landings or impacts.

Community Health and Environmental Considerations

A number of health and environmental considerations need to be addressed by private companies involved with space flight and spaceport construction. Air pollution, noise abatement, management of toxic fuels, biological and ecological impacts, effects on sites of threatened and endangered species, and protection of Archeological and Cultural heritage zones need to be addressed. Such efforts will ensure commercial companies meet federal requirements and gain the public trust that companies are not recklessly disturbing the environment in order to achieve profit. Virgin Galactic spaceport designers in New Mexico are even investigating designs to collect rainwater at its facility, use solar panels for generating power, and ensure as clean vehicle emissions as possible.[37]

HUMAN FACTORS CONSIDERATIONS

Suborbital human factor considerations are limited compared to orbital flights due to mission duration and profile. Orbital flights will especially require consideration of several health/safety issues depending on mission duration including: sleep and circadian cycles, personal hygiene, nutritional requirements, medical care of injuries and illnesses, and exercise countermeasures to mitigate physiological deconditioning. Knowledge gained throughout the Shuttle program and longer durations missions on ISS is providing substantial insight into these areas. Astronauts have been performing very well on long duration missions and returning home with minimal physical sequella. Rehabilitation programs (ex., aerobic/resistive exercise and aquatics) are being tailored to effectively return astronauts to Earthbound duties, with some crewmembers flying on repeat long duration missions.

Motion Sickness

Motion sickness during suborbital flight may best be characterized as similar to that arising during parabolic or acrobatic flight and roller coaster activities. The term Space Motion Sickness is used to describe a range of symptoms that occur early during orbital spaceflight. SMS currently impacts approximately 70% of Space Shuttle astronauts, with symptoms ranging from mild stomach awareness to frank vomiting, often with no prodrome.[26] Its onset begins after shuttle main engine cutoff and orbital insertion when crews begin suit doffing and movement about the cabin. SMS was not an issue with Mercury or Gemini flights since crews were strapped into their seat (except during Gemini spacewalk activities). Approaches to reduce SMS include avoidance of provocative head/body maneuvers, as well as preflight and inflight administration of medications, such as with promethazine.[26]

While some commercial companies plan that passengers remain strapped in their seats during suborbital flights, others will allow passengers to exit their seats to enjoy their minutes of microgravity. Free floating may be provocative to some. Should vomiting arise for a passenger in the small confines of the cabin, it may well trigger similar episodes in others. Preflight training with parabolic flights would familiarize passengers with microgravity and may help identify those susceptible to motion sickness. Optional preflight use of medications such as promethazine - dexamphetamine or scopalamine - dexamphetamine are a routine part of NASA parabolic flights and spaceflights.[26] Preflight medication treatment may be offered to those commercial clients noted to have such susceptibility, or even offered prophylactically as a matter of standard practice. This approach should include prior testing of anti-nausea medication to check for allergic symptoms, tolerance, and compatibility with other regular medications. Preflight parabolic training could also include practice to ingress/egress mock vehicle seats efficiently and safely.

Medication Compatibility

Current spaceflight experience with anti-nausea medications is based on use with healthy astronauts who are typically taking few if any medications (ex. cholesterol lowering agents). Since older passengers and those with preexisting conditions will be flying, it is imperative to understand the interactions of common medications with the stressors of acceleration, microgravity, and potential hypoxia. Medications that could have hemodynamic effects, contribute to neurovestibular symptoms, or interact negatively with anti-nausea medications need to be identified. This lends further credence for preflight passenger evaluation in centrifuges, altitude chambers, and parabolic flight.

Musculoskeletal

Issues of bone and muscle loss are currently being investigated and addressed in the space program, especially for long duration ISS crewmembers. Various exercise countermeasures are being utilized to mitigate losses via aerobic and resistance exercise, and with ongoing assessment for potential adjunctive pharmaceutical agents. Addressing bone/muscle loss allows crewmembers to return to Earthbound activities more quickly and safety, as well as increase their potential ability to exit a vehicle during an emergency landing. For suborbital and brief orbital flights, bone and muscle loss will be inconsequential.

Postlanding Neurovestibular Impacts

Neurovestibular symptoms may develop after orbital flights, with symptoms such as dizziness, unsteady gait, and vomiting. These symptoms could effect a passenger's ability to extricate themselves or assist others in emergency scenarios. Neurovestibular effects are not anticipated to be an issue with suborbital flights due to short mission duration. Passengers will also have several minutes to reacclimatize in their seats as the vehicle returns to a spaceport landing.

Radiation

The space radiation environment includes galactic cosmic radiation, solar flare events, and trapped charged particles in the Earth's magnetosphere (Van Allen radiation belts).[11,26] Space weather can impact communications to spacecraft and satellites as well as create potential hazards to humans onboard orbital vehicles. Sievert (Sv) is the derived unit of dose equivalent to reflect the biological effects of radiation. It is calculated by multiplying the absorbed dose measured in grays (Gy) with a radiation weighting factor accounting for tissues irradiated and time/volume over which the absorbed dose was spread. The harmful effects of radiation are classified as Acute or Late. Acute effects are related to damage to the blood forming organs, skin, eye lens, immune system suppression, and gastrointestinal and neurological systems. Late effects include genetic mutations (including mutations of gametes which are passed to progeny) and cancer.

The average background radiation a person receives in the Unites States from natural background sources is approximately 3.0 milli-Sieverts (mSv) per year.[11,21] Astronauts in LEO receive about the same dose of radiation in one week that a ground based person would receive on average during a year on Earth.[26] Examples of other equivalent dose measurements include; transcontinental airplane flight, 0.04 mSv; standard Chest X-ray 0.10 mSv; one-year mission on ISS, estimated at 250 mSv (at 400 km, 51.6 ° inclination).[11]

During suborbital flights the exposure to radiation will be minimal since altitudes reached will be relatively low and excursion times short. With low latitude inclination flights, reaching altitudes somewhat over 100 km (62.6 miles), the atmosphere and magnetosphere will provide adequate protection to cosmic and solar radiation. Similarly, the factors that affect the amount of radiation received during a commercial airline flight include altitude, duration, geographic latitude, and stage of the solar cycle. The higher the altitude, the greater the cosmic radiation levels. At sea level in the United States the average dose rate received for an individual is 0.035 microSv/per hour. While flying in a commercial flight at 35,000 feet over Oklahoma City the rate is 4.1 microSv/per hour, and increases to 5.1 microSv/per hour if flying over Anchorage.[24] These doses are very small, and pose no threat to health.[11,26]

The Earth's magnetosphere serves to deflect many solar and galactic cosmic charged particles from entering the atmosphere. This protection is greatest at the equator and decreases moving toward the poles.[11] Potential spaceport locations have mostly been envisioned in lower latitudes, although some may closer to polar regions. At airline cruising altitudes over the magnetic poles, the radiation dose is about twice that over the equator. Air travel is increasing over North Pole routes as business and shipping to Asia continues to grow. Airlines are mindful of solar activity events and may restrict certain routes and altitudes to limit radiation exposure for those onboard and maintain good communication systems with the ground.

For space passengers on orbital flights radiation exposures are greater. While trapped particles in the magnetosphere are not of great concern for sub-orbital flights, their extension to lower altitudes in the South Atlantic Anomaly (SAA) is an important consideration for spacecraft in low Earth orbit.[26] With high inclination orbits like the ISS, at 51.6 degrees, crossing the SAA may account for up to 2/3 of the radiation exposure to crewmembers.

Monitoring the space weather environment is important in order to minimize exposure of those in orbit. The ALARA (As Low as Reasonably Achievable) principal is the recommendation used by the National Council on Radiation Protection and Measurements for radiation industry workers.[26] NASA considers astronauts as radiation workers, and embraces the ALARA principal for exposures.[26] Space Shuttle and ISS crews have periodically been advised to work or sleep in shielded portions of the vehicles for added protection during periods of greater solar flux. Habital orbital facility planning and design should consider monitoring of the radiation environment and provision of "safe haven" areas with increased shielding during potentially hazardous solar events. Radiation constitutes one of the most important hazards for humans during spaceflights outside the Earth's magnetic field. Once leaving the relative protection of the Van Allen belts for a lunar excursion, appropriate monitoring and shielding are important.

The general populace is concerned about the nature of radiation exposures during their daily lives, although typically not fully understanding of the science. It is incumbent for commercial companies to properly inform customers of potential radiation hazards during suborbital and orbital spaceflight.

Nutrition

Suborbital flight profiles are too short to involve the need for meals. It would be advisable to eat a few hours in advance of reduced gravity to minimize undigested abdominal contents. Astronauts flying orbital missions have carefully monitored nutritional plans to support metabolic needs and maximize overall health.

Human Waste/Personal Hygiene

For suborbital and short duration orbital missions, a means to collect urine and stool needs to be addressed. Passengers may be excited or nervous during flight, or bothered by previously consumed excess quantities of fluids or coffee. Once strapped in a vehicle, there may be ground, mechanical, or other delays in various phases of flight. An appropriate sized diaper can easily be worn to collect waste for both sexes. Unstrapping in a very small cabin to utilize a urine collection system would be impractical and potentially unsafe. Such equipment would add weight and volume to a suborbital vehicle and require a modicum of privacy. For orbital stays, human waste collection would need to be addressed via a dedicated waste management system.

Personal emesis bags need to be available for each passenger, with preflight instruction on proper use and subsequent stowage. Hand wipes can be available for any cleaning needs. On ISS, crews and spaceflight participants currently do not have a shower facility and use body wipes and waterless shampoo for cleansing. This method has been effective and not led to skin infections despite nearly daily aerobic and resistive exercise. Astronauts had a shower facility on Skylab in the 1970s, but its use proved very time consuming and tedious.[26] Space hotel designers will likely wish to add some form of shower capability for passengers in the future.

Psychological

Certainly one of the most challenging areas of medical screening and management for space passengers will be psychological screening. The professional astronaut is carefully evaluated with psychiatric interviews and a battery of psychological testing during the selection process. Additionally, they are followed by Flight Surgeons and crewmembers throughout their flying and ground-based duties. The spaceflight participant will present a wide range of backgrounds, professions, and ages. They will be less likely than astronauts to have a background in high performance aircraft, isolated environments, or dangerous occupations.

As the use of psychiatric medications has become more commonplace to manage generalized anxiety, panic disorder, personality disorders, substance abuse, and depression, there will certainly be passengers requesting participation who are on single to multiple psychiatric medications. Each day the commercial airlines routinely transport passengers with psychiatric disorders, including serious and chronic mental illness.

For suborbital flights, if potential space passengers are well managed and are effectively screened, it is likely they will perform well during their spaceflight. A list of strict psychiatric exclusionary diagnoses would not necessarily be the most optimal way to evaluate clients. Space tourism companies should consider screening passengers in an interview format with an aeromedical physician to review any psychiatric history and gain understanding of the client's overall personality and demeanor. This would include presentation of any mental health documentation from a private physician regarding history, diagnosis, and treatment. Such an evaluation may help identify those passengers that would be exceptionally eccentric, overly flamboyant, not appropriately understanding risk and safety, and potentially disruptive to other paying passengers. Should the aeromedical physician have any reservations on the suitability of a passenger, a referral should be initiated to an experienced aeromedical psychiatric provider.

For orbital flights, a similar approach to psychological issues can most likely be utilized, but with greater emphasis on understanding the risks of prolonged isolation and reduced return capability. Current private passengers to ISS are psychologically screened and closely observed during ground training. Observations of passengers during training activities, as well as interactions with other passengers, will lend valuable insights. While the business nature of commercial spaceflight must of course strive to fly paying customers, compromises in safety and untoward negative experiences by other passengers could do significant public relations damage to a company.

Disruptive Passengers and Space Terrorism

Plans need to be outlined to handle disruptive passengers. This is imperative in order to provide an enjoyable experience for all passengers and limit the likelihood a flight may have to be canceled or aborted secondary to inappropriate behavior or safety concerns. A passenger may manifest disruptive behavior due to a physiological event, such as from hypoxia, severe anxiety, claustrophobia, alcohol or drug use, or from a stress reaction due to the overall nature of embarking on a spaceflight. Claustrophobia is not compatible with flying in small space-limited vehicles. Astronauts routinely fly in T-38 aircraft, train in pressure suits, and have experience in limited spaces such as hypobaric chambers. Space passengers should be screened for a history of claustrophobia. Centrifuge training, parabolic reduced gravity flights, and altitude chamber runs will provide insight into how passengers will cope in such confines, and lend them confidence and familiarity to handle themselves in such spaces. Familiarity in a simulator/mockup of the space vehicle they will fly in will also provide passengers with a more realistic training experience. Passengers for a given flight should train together to gain comfort with each other and bond together for their upcoming unique experience.

A policy regarding alcohol/drug use and screening should be entertained by operating companies Aside from a ceremonial dinner or toast the evening prior to a flight, alcohol should be avoided to minimize the potential for Motion Sickness and ensure all passengers are able to manage safety procedures unencumbered.

For short suborbital flights with a disturbed passenger, it is unlikely that medical intervention could easily be administered. Soft restraints could be utilized for the safety of the effected passenger and the overall mission. With orbital flights, medications such as parenteral haloperidol should be available for use by a trained attendant to address a disruptive passenger. Regardless of the flight scenario, appropriate medical training for professional attendants should be received to address and manage a change in mental status.

LANDING AND GROUND SUPPORT CONSIDERATIONS

Landing

Medical issues could potentially arise on suborbital landings. This may include protracted vomiting, residual anxiety, cardiac events, and any injuries incurred during free floating (ex. eye trauma) or hard landings. Response medical personnel need to be familiar with any toxicological issues of the vehicle and be trained to safely extract personnel from the cabin. Local medical facilities that could receive patients should be familiar with flight operations to ensure adequate planning for any contingency. With short duration missions, no significant physiological changes should arise in passengers that require substantial knowledge of space medicine by hospital personnel aside from flight profile, medical history and medication use. Based upon limited knowledge from anesthesia performed on rats after a shuttle mission, potential alterations in the pharmacokinetics of anesthetics after spaceflight have been reviewed by NASA.[9]

Changes in metabolism of drugs, baroreceptor alterations, and other physiological variations should promote extra vigilance in use of any anesthetics on humans after orbital missions.

Ground Support

Spaceports will likely be established in remote areas away from the general populace for safety reasons. Should any medical conditions arise close to launch, a healthcare provider should be available to provide care. This could involve evaluating and treating an upper respiratory infection or gastroenteritis to mitigate impact on an upcoming flight. Should more significant illness or injuries arise, arrangements with a hospital facility may be required. Prior plans need to be coordinated to establish transportation from more remote sites to definitive treatment facilities utilizing ground or air modes of transport depending on distance and severity of a condition.

Disaster Planning

A disaster plan clearly needs to be delineated in the event a mishap occurs. A plan should include coordination with local fire/rescue, municipalities, the FAA, NTSB, medical examiner/coroner, and any military facility in proximity. An accident investigation will likely be under the authority of the NTSB. A yearly mishap drill would be advisable to practice the multiple dynamics of disaster management and ensure the commercial spaceflight company is ready for any contingency. In the United States, jurisdiction for human remains in the case of fatalities would lie with the local county coroner. For passengers utilizing a foreign launch facility, this should be clearly understood in advance. The 2003 Columbia Shuttle accident prompted NASA to readdress the entry profile for returning shuttles to minimize transit over densely populated areas. This principle should be utilized with commercial vehicles to protect public safety and reduce negative consequences should an accident arise.

MEDICAL SCREENING GUIDELINES FOR SPACE PASSENGERS

The consideration of medical standards or guidelines for space passengers has evolved over a number of years. The Aerospace Medical Association (AsMA), the premier international aerospace medicine professional society, first addressed this topic with a resolution in 1999.[3] The resolution resolved that "appropriate agencies develop relevant U.S. Federal policies, procedures, guidelines, and regulations to ensure the health and safety of human crewmembers and passengers who will be involved in manned commercial space flights in the near future." AsMA subsequently developed a position paper in 2000 on "Medical Guidelines for Space Tourism."[4] The paper identified the need to address acceleration forces, the effects of microgravity, space motion sickness, radiation exposure, psychosocial dysfunction, as well as cabin environmental issues of air quality, pressure, temperature, humidity, and ventilation. The paper recommended that all space passengers receive some manner of medical clearance and obtain appropriate preflight education on health and safety issues germane to flight.

Subsequently, AsMA established a special Task Force on Space Travel consisting of physician members. The Task Force published "Medical Guidelines for Space Passengers" in 2001.[5] This document included an extensive list of potential disqualifying conditions for spaceflight passengers, with a focus on longer orbital flights. The overarching goal was to identify medical conditions or treatment regimens which could endanger a passenger, fellow passengers, crewmembers, pose a threat to flight completion, or compromise safety.

The AsMA Task Force reconvened to focus on suborbital flights since commercial space companies were actively working toward achieving such flights. The Task Force noted it would be difficult to establish specific medical guidelines which could be applicable to every potential flight vehicle and profile. In its 2002 publication, "Medical Guidelines for Space Passengers-II," the Task Force identified five main assumptions to provide general guidelines for commercial companies and the associated medical community involved with passenger health and safety.[28]

1. "The space vehicle interior will be small and confining with a capacity of 4-6 passengers." (Most suborbital flight profiles currently planned by commercial companies would approximate 5-15 minutes of microgravity.)

2. "The flight will be suborbital of 1 to 3 hours duration including about 30 minutes of microgravity". (Most suborbital flight profiles currently planned by the industry would approximate 5-15 minutes of microgravity.)

3. "The cabin will be pressurized to sea level (760 mm Hg) with 80% nitrogen, 20% oxygen atmosphere; no life support equipment will be necessary for nominal flight." This assumption implied that passengers would travel in a flight suit environment without the requirement for a pressurized suit. It would be prudent to consider providing quick donning oxygen masks in the event of emergencies such as hypoxia, decompression, or toxic fumes in the cabin.

4. "Acceleration will range between 2-4.5 +Gz or Gx (depending on the space vehicle)".

5. "There will be different egress procedures (depending on the space vehicle)". Vehicle designs will dictate egress mechanisms and procedures.

It is advisable that a female space passenger who is pregnant should not be allowed to fly. There is no substantial data providing insight onto the effects of acceleration forces or microgravity on a fetus. Unnecessary radiation exposure to the fetus also creates medical and ethical considerations.

The Task Force emphasized the importance of careful consideration for any medical condition which could deteriorate inflight and result in sudden incapacitation. Attention should be given to passengers particularly prone to developing motion sickness on Earth, or having an underlying health condition potentially exacerbated by vomiting or fluid loss. While there is no identified correlation between SMS and a propensity for air or car sickness, certainly malaise, nausea or vomiting during the free-floating microgravity portions of flight can diminish a flight experience. No recommendation regarding upper and lower age restrictions were offered, but it was advised that each passenger occupy an individual seat with appropriate restraints.

An appropriate medical history should be taken during the flight application process, with an update in the immediate preflight period. The scope of the physical examination or diagnostic tests and interventions should be at the judgment of the evaluating health professional. A urinary screen for Beta HCG test can incorporated into the preflight training period to rule out pregnancy.

Overall, the Task Force provided broad guidelines rather than specifics for short-duration flights. It was felt the application of these guidelines should be left to the discretion of the commercial companies, individual passengers, and the physicians rendering care and consultation.

Regulatory Roles of the FAA

The Commercial Space Act of 1984 established the Department of Transportation (DOT) as responsible for all U.S. commercial space operations.[15] In 1995, the DOT transferred this role to the Federal Aviation Administration (FAA). The FAA created the Office of Associate Administrator for Commercial Space Transportation (AST). The role of AST includes: licensing of commercial space operation launch and reentry sites, growth promotion of the industry, promoting public health and safety, protecting property, and ensuring national security and foreign interests of the U.S. The Commercial Space Launch Amendments Act of 2004 established that the FAA set requirements for commercial human spaceflight crewmembers and space flight participants. The scope of these requirements was to provide an acceptable level of safety to the general public and ensure participants are aware of the risks associated with launch or entry. Any company which desires to launch paying passengers on a suborbital vehicle from U.S. soil must receive a license from the FAA. This process is intended to ensure safety of the general public in addition to property. The act also applies "existing financial responsibility and waiver of liability requirements to human space flight and experimental permits."

The progression of rules and regulations for this new arena of flight operations can be seen through a number of FAA documents. In February 2005, the FAA released "Draft Guidelines for Commercial Suborbital Reusable Launch Vehicle Operations with Flight Crew," and "Draft Guidelines for Commercial Suborbital Vehicle Operations with Space Flight Participants."[15] A Notice of Proposed Rulemaking (NMPR) was published by the FAA in December 2005 entitled "Human Space Flight Requirements for Crew and Space Flight Participants."[16] In January 2006, the FAA released "Guidance for Medical Screening of Commercial Aerospace Passengers."[6] This document provided general guidance to identify those individuals with medical conditions that may result in an inflight emergency or death, or additionally compromise the health and safety of other occupants. It was emphasized that pre-existing medical conditions could be exacerbated by exposure to stressors such as acceleration, microgravity, and radiation. A number of contributing authors also had participated with the prior efforts by AsMA, thus bringing forth a solid background of collective aeromedical experience. The document divided commercial spaceflight into:

1. Passengers Participating in Suborbital Aerospace Flights (or exposed to a G-load of up to +3Gz during any phase of the flight).

2. Passengers Participating in Orbital Aerospace Flights (or exposed to a G-loading exceeding +3Gz during any phase of the flight).

It was advised that suborbital passengers complete a medical questionnaire prior to each flight (Appendix A). Although a physical examination or complete laboratory assessment was not mandated, the judgment of a physician knowledgeable in aerospace medicine should drive appropriate steps. For orbital flight or G-loads above +3Gz, a more comprehensive history should be obtained, including a physical exam with laboratory assessment (Appendix B, Appendix C, and Appendix D). The guidance assumed a cabin pressure not exceeding 8,000 ft (10.9 psi), lack of pressure suit use, and the ability for unaided emergency egress. Based on human tolerances, it was also advised that the acceleration environment should not exceed +4Gz, -2Gz, ±4Gx, and ±1Gy.

In December 2006, the FAA issued "Human Space Flight Requirements for Crew and Space Flight Participants; Final Rule.[15] The Final Rule was completed by the FAA with review inputs from forty-two entities, including aerospace companies, service providers, associations, other U.S. Government agencies, and private individuals. Specifically regarding medical requirements, the Final Rule deemed that Crew Members (those with a safety-critical role, must possess and carry a FAA second-class airman medical certificate issued no more that 12 months prior to the month of launch and reentry. For participants, no medical requirements were established. However, the rule did emphasize that commercial spaceflight operations:

a) Must inform the participant in writing about the risks of launch and reentry, including the safety record of the launch or reentry vehicle type.

b) Provide disclosure that all hazards are not known, and that serious injury, death, disability or total or partial loss of physical and mental function can arise.

c) Provide acknowledgement that the U.S. Government has not certified the launch and any reentry vehicle, and a waiver of claims against the government is signed.

d) Ensure training is received on response to emergency situations, such as fire, smoke, loss of cabin pressure and emergency exit.

e) Implement security measures to ensure no carry on of explosives, firearms, knives, or other weapons.

The FAA will surely reassess its crew and passenger medical and special requirements as experience and data is obtained in the years ahead.

Voluntary reporting systems of medical issues

An overarching paradigm describing space medicine is to expose the normal physiology of a career astronaut/cosmonaut to microgravity and subsequently mitigate the changes which could jeopardize on-orbit health as well as readaptiation to Earth.

Commercial spaceflight will involve flying a population presenting with a host of preexisting medical conditions, with subsequent physiological responses which are relatively unknown. Gregory Olson, Ph.D, the third spaceflight participant to ISS, was exceptionally forthcoming in allowing his complex medical case to be published in the medical literature. The article "Medical Qualification of a Commercial Spaceflight Participant: Not Your Average Astronaut" documented the efforts to take an initially medically disqualified individual and successfully fly him after appropriate intervention.[20] Knowledge gained from this case and other future challenging cases will provide space medicine with an evidence-based approach to address medical standards and onboard medical care systems.

A voluntary national reporting system could potentially be established to create a repository of knowledge on items such as: types of medical conditions evaluated and approved/disapproved for flight, scope of diagnostic evaluations or treatments utilized to clear a given patient, medical or safety incidents arising during preflight training and all phases of flight. This system would help promote health and safety by increasing knowledge in space medicine about the physiological impacts of flight on a host of underlying pathologies and conditions. Participation by foreign companies in such a system would certainly add to this information, thus serving passengers and crew safety internationally.

NASA, wishing to broaden its knowledge of space medicine and promote safety, may be well suited to become a data management clearinghouse for such a reporting system.[9] The current NASA Longitudinal Study of Astronaut Health (LSAH) is an established database compiling and evaluating information on active and retired astronauts across a spectrum of physiological/clinical parameters and mission profiles. The LSAH would be a logical venue for data being received from participating commercial spaceflight companies. Although there is a competitive nature to commercial enterprises and potential reticence with reporting medical issues, cooperative sharing of information, with ensured measures of privacy, will be of great long term importance.

Such a program can mitigate risk and decrease liability as both the medical community and business enterprises strive to maximize health and safety for the flying public.

ONBOARD MEDICAL CARE

Due to the relatively short time period of suborbital flights, it is unlikely that any special medical intervention would be required or able to be administered. Specific real-time medical monitoring, such as with electrocardiogram, would be impractical as a routine practice. Such evaluation should be performed during preflight medical assessment. Passengers should consider carrying a few simple items in their flight fight suit, such as: emesis bags, decongestant nasal spray for sinus blocks, band aids for minor cuts or scrapes, and spare eyeglasses if required. Parabolic flight has lent itself to minor injuries in close quarters, such as ocular insults from floating cameras or particulate material, and inadvertent physical contact. A medical first aid kit should be located in the cabin in case of a contingency landing away from the planned return site. For a special needs passenger, appropriate medical equipment could be taken for use by a medical attendant accompanying the passenger on a case-by-case basis.

During orbital flights, medical kits could be tailored for flights depending on mission duration and number of passengers. NASA has extensive experience with Space Shuttle and ISS medical kits based on years of spaceflight experience and data from analog environments such as Antarctica and the US Navy submarine forces. Orbital flights may benefit from having a flight crew attendant trained in basic medical care and procedures, as is the case with NASA's Crew Medial Officers, who are mostly non-physicians. NASA currently utilizes Flight Surgeon support for Shuttle crew in an audio/video daily Private Medical Conference (PMC) to address health related issues. The use of telemedicine technologies offers the ability to transmit clinical information about a passenger's condition to terrestrial health care providers who can provide guidance on care and treatment. This would include psychological support for anxiety and stress reactions. The cost of training and traveling for spaceflight is exceptionally expensive, and medical support must be available to ensure safety, maximize the flight experience, and avoid premature or unnecessary returns to Earth.

THE CASE FOR THE AEROSPACE MEDICINE SPECIALIST

It will be incumbent upon medical personnel utilized by commercial companies to maximize health and safety of the flying public and reduce corporate risk and liability. The scope of a commercial spaceflight company's medical assets could range from a staff physician to a consulting group to an established medical clinic at a spaceport. The approach to medical support will evolve as experience is gained in the early growth phases of private flight. Preflight training evolutions may benefit by having healthcare professionals in proximity to monitor physiological responses, and allay anxiety for the clients.

The balanced approach to health and risk will require health professionals to be knowledgeable and experienced with both aerospace medicine and clinical medicine. Physicians who are residency trained and board certified in Aerospace Medicine have demonstrated competencies in the complex nature of the human being in aviation and aerospace environments. Such training can be received via military or civilian training programs. This unique professional background offers the best insight and credibility into management of the medical, physiological, and psychological issues of flight. Physicians who have additional clinical medicine training may provide even further depth in evaluating and managing medical issues. Ultimately commercial spaceflight companies will determine what type of medical specialist and support structure will best serve their organization, business plan, and clients.

To date, for the private citizens who have traveled to the ISS via Space Adventures, medical evaluation and mission support has been provided through medical consultants trained in aerospace medicine with prior experience in the U.S. space program. These physicians have been affiliated with a university medical center offering a range of consulting and diagnostic services.

It is important that passengers be able to perform all duties without injury or compromise to the safety of others. While the ability of unaided egress is a viable goal, it can be anticipated that commercial companies utilize aeromedical expertise to decide on flight potential for elderly clients and special cases. For example, an amputee or wheel-chair bound person may strongly desire to fly to experience the joys of microgravity, unencumbered by their physical limitations. Proper advanced planning with a special medical attendant or trained crewmember may serve such passengers, who will certainly lobby to become part of the spaceflight market. A wonderful and inspirational example is the 2007 parabolic flight of Steven Hawking, a world famous wheelchair-bound physicist, onboard a Zero-Gravity Corporation flight in Florida.[40] Hawking became the first quadriplegic to float in a weightless state, unfettered from his chair for the first time in over forty years.

TRAINING FOR PASSENGERS

Three key elements of training advised for suborbital flight to evaluate passengers and maximize their preparation and safety include hypoxia awareness, G-force exposure, and parabolic flight. Medical monitoring by a physician would be advised during these sessions. Hypoxia awareness training will give clients the opportunity to experience symptoms of reduced oxygenation as from a cabin leak. This can be accomplished in an altitude chamber or via a device such as the Navy's Reduced Oxygen Breathing Device (ROBD). The ROBD uses an aviator's mask to deliver reduced levels of oxygen delivered without having the complexity or expense of an altitude chamber. Training for passengers to feel comfortable with a face mask is in itself valuable. G-force exposure can be accomplished in a centrifuge capable of replicating the mission profile to be flown. The White Knight ferrying vehicle for SpaceShipTwo is being designed to carry passengers, slated for an upcoming flight, to experience some of the flight profile and G-forces of the suborbital vehicle upon its release.

Training in areas noted above will provide the passenger situational awareness of the flight environment to be encountered, lend confidence, enhance overall safety, and help evaluate medical conditions. Historically researchers studying human tolerance and performance in centrifuges and altitude chambers have employed young healthy subjects. Limited data exists on older subjects, those with various medical conditions, or those taking specific medications. It seems prudent that ground-based controlled testing offers the best method to evaluate potential fliers. This allows an understanding of potential risk of health decompensation for a given individual. As flight and medically related experience is gained during the early waves of passengers into the suborbital market, adjustments can be made to the degree of evaluation and training merited for future fliers.

NOTABLE TRENDS IN COMMERCIAL HUMAN SPACEFLIGHT

The momentum gaining for private spaceflight is evident by a growth in a number of companies hiring former astronauts. Benson Space Company hired former Astronaut Robert "Hoot" Gibson as its CEO and Chief Test Pilot. CAPT Wendy Lawrence (USN, Ret) has been hired as a Senior Advisor for human spaceflight and crew safety for Andrews Space. Col Rick Searfoss, USAF, (ret) has been involved with the X-Prize Foundation, serving as chief judge during the competition. Commercial enterprises wish to gain direct insight by having astronauts on staff and demonstrate credibility to investors and the public.

A testament to the aeromedical community's interest in Commercial Space Flight has been the establishment of a Commercial Space Flight Workshop at the May 2007 Aerospace Medical Association (AsMA) Annual Scientific Meeting. The meeting included a number of presentations on the growth and challenges of Commercial Space Flight. Once a topic of fanciful thought, private spaceflight and related aeromedical concerns will become a regular part of future conferences and symposia.

A further sign of the gaining momentum in private spaceflight has been the establishment of a Commercial Human Spaceflight Office as a Division of Wyle Laboratories. The office will be geared toward addressing issues of preflight screening and remediation, training, standards development, contingency plans, and risk mitigation. The University of Texas Medical Branch at Galveston, Department of Preventive Medicine and Community Health, has an Aerospace Medicine office which has provided medical consultative services and support to Space Adventures and Virgin Galactic.

After a successful 2005 International Symposium for Personal Spaceflight took place in New Mexico, annual meetings have continued to follow. Agendas have addressed a range of industry, regulatory, human physiology, and technology issues. The Symposium has been gaining national notoriety, with participation by former astronauts and Masters of Ceremonies with notables such as Sam Donaldson of ABC News.

Interesting positive strides in public sentiment have also taken place regarding regional support of spaceports. The New Mexico County of Dona Ana approved a sales tax of $0.25 to every $100 spent.[32] The tax is expected to help raise $49 million per year in bonds toward a state-supported $198 million spaceport. The launch site is to be known as "Spaceport America." with Virgin Galactic currently planning on being the first tenant. The complex would be sizeable and cover 27 square miles near the White Sands Missile Range. New Mexico's Governor, Bill Richardson, applauded the vote for its support of high-tech jobs and leading edge vision for the state. Amazon.com founder Jeff Bezos and his Blue Origin team have been acquiring land for development and establishing an engineering team for a spaceport in West Texas.

Other upcoming paying space passengers to the International Space Station have been announced. Richard Garriott, a multimillionaire video game developer, will train for a spaceflight on the Soyuz.[2] Garriott, age 46, is the son of former NASA Astronaut Owen Garriott, who flew twice in space. (On Skylab 3 for 59 days in 1973 and a flight in the early Space Shuttle program.) Richard Garriott stated his poor eyesight had prohibited him from attempting to become a NASA Astronaut. Garriott will be the first offspring of an American astronaut to visit space.

Even a backup seat for a Soyuz flight is being marketed. Space Adventures is offering a $3 million backup seat for training to support Garriott.[2] The backup will progress through all training events and medical evaluations. The $3 million price tag can be used as credit for a future spaceflight. Anousheh Ansari served as a backup for Japanese businessman Daisuke Enomoto, who was not able to fly due to an apparent medical issue. Ansari subsequently stepped into position as a prime flyer and became the first female private paying passenger.

Scaled Composites and Virgin Galactic recently unveiled SpaceShipTwo, which is their next generation vehicle planned for actual passenger suborbital flights.[13,37] The former Chief Operation Officer for Virgin Galactic, Alex Tai, reported the company has $31 million in deposits for a suborbital flight (155 individuals at $200,000 per ticket).[37] The willingness to make such a financial commitment shows confidence and great excitement by a group of travelers who wish to be among the first wave to fly.

CLOSING

Humans have always had an innate desire to explore the unknown, look over the next horizon, cross the open sea, or go beyond the next mountain range. This desire helped lead mankind on an amazing journey into space over forty-seven years ago. Suborbital spaceflight will be the first step for many private citizens to peek into the door of space. The next decade will certainly see the advancement and maturation of private space ventures. These efforts bring together designers, scientists, health professionals, visionaries, engineers, policy makers, and investors to develop new technologies and spawn new industries. It is incumbent upon commercial spaceflight companies to carefully address the issues of health and safety for upcoming passengers. Risks must be understood and mitigated to maintain the highest levels of safety and achieve the public trust.

Commercial human spaceflight is being pursued for many reasons, including adventure, entertainment, and financial gain. Many of those who have experienced orbital spaceflight state they have been deeply moved to see the beautiful Earth from above and grasp its fragile nature. As private citizens from around the world personally share suborbital and orbital flight, perhaps one of the greatest benefits will be bringing peoples and cultures closer together to take greater care of “Spaceship Earth.”

APPENDIX A

Medical History Assessments of Passengers in Suborbital Aerospace Flights[6]

Prospective aerospace passengers should complete a questionnaire about their medical history of any of the following conditions:

- Otitis, sinusitis, bronchitis, asthma, or other respiratory disorders
- Dizziness or vertigo
- Fainting spells, or any other loss of consciousness
- Seizures
- Tuberculosis
- Surgery and other hospital admissions
- Visits to physicians in the last 3 years
- Recent significant trauma
- History of decompression syndrome (DCS)
- Anemia or other blood disorders
- Heart or circulatory disorders, including implanted pacemaker or defibrilator
- Mental disorders
- Claustrophobia
- Attempted suicide
- Use of medications
- Alcohol or drug dependence or abuse
- Date of last menstrual period, current pregnancy, recent post-partum (less than 6 weeks), or recent spontaneous or voluntary termination of pregnancy
- Diabetes
- Cancer
- Rejection for life or health insurance

APPENDIX B

Medical History Assessments of Passengers in Orbital Aerospace Flights[6]

Prospective orbital aerospace passengers should complete a questionnaire about their medical history if they have a history of any of the following conditions:

- Otitis, sinusitis, bronchitis, asthma, upper respiratory infections, or other respiratory disorders
- Allergies
- Dizziness or vertigo
- Significant motion sickness requiring medication
- Fainting spells or any other loss of consciousness
- Seizures, convulsions, epilepsy, stroke, muscular weakness, or paralysis
- Tuberculosis, hepatitis, AIDS, or other chronic infectious disorder
- Surgery, recent or remote, or other admission to hospital
- Recent significant trauma
- Anemia or other blood disorders
- Heart or circulatory disorders, including implanted pacemaker or defibrillator
- Uncontrolled high or low blood pressure
- Mental disorders (including depression, anxiety, fear of flying, fear of heights, fear of closed spaces, fear of open spaces, etc.)
- Attempted suicide
- Use of medications
- Alcohol or drug dependence or abuse
- Date of last menstrual period, current pregnancy, recent
- Post-partum (less than 6 weeks), or recent spontaneous or voluntary termination of pregnancy
- Severe hay fever or allergies

- History of pneumothorax (collapsed lung)
- Kidney stones or blood in urine
- Gallstones or gallbladder disease
- Diabetes
- Cancer
- History of radiation treatment or occupational exposure to radiation
- Rejection for life or health insurance
- History of decompression syndrome (DCS)
- History of previous space flights

APPENDIX C

Physical Examination Assessments of Passengers in Orbital Aerospace Flights[6]

Prospective aerospace orbital passengers should receive a general physical examination that includes:

- Vital signs (heart rate, respiratory rate, temperature,
- blood pressure)
- Head, face, neck, and scalp
- Nose, sinuses, mouth, throat, ears (including eardrum integrity and function, Eustachian tube function)
- Ophthalmological evaluation (including pupil function, ocular motility)
- Lungs and chest
- Heart (including precordial activity, rhythm, sounds, murmurs)
- Peripheral vascular system
- Abdomen and viscera (including hernia)
- Genitourinary system
- Upper and lower extremities
- Spine
- Lymphatics
- Rectal, pelvic, and breast examination should be performed only if indicated by medical history
- General neurological evaluation
- General psychiatric evaluation (appearance, behavior, mood, communication, and memory)

APPENDIX D

Medical Testing of Passengers in Orbital Aerospace Flights[6]

Prospective passengers in Orbital Aerospace Flights should complete the following general medical tests:

- Routine hematology
- Clinical chemistry (serum)
- Urinalysis
- Resting EKG
- Chest X-rays (PA & lateral)
- Visual acuity (corrected)
- Pregnancy testing (optional)
- Hearing (conversational voice at 6 ft)
- Tympanometry and/or tonometry (if clinically indicated)
- Pulmonary function testing (if clinically indicated)

LIST OF ABBREVIATIONS

DOT	Department of Transportation
FAA	Federal Aviation Administration
ISS	International Space Station
LEO	Low Earth Orbit
MECO	Main Engine Cutoff
NASA	National Aeronautics and Space Administration
RLV	Reusable Launch Vehicle
SMS	Space Motion Sickness
SSI	SpaceShipOne
SS2	SpaceShipTwo
STS	Space Transportation System

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VITA

Joseph Paul Dervay, son of Joseph and Mary Dervay, was born in 1958 in Binghamton, NY and raised in nearby Johnson City, NY. He was a 1976 Graduate of Johnson City Senior High School. He received a Bachelor of Sciences degree from Cornell University in 1980, and a Doctor of Medicine from the State University of New York, Upstate Medical College, Syracuse, NY in 1984. Dr. Dervay completed a General Surgery Internship at Bethesda Naval Hospital, and subsequently training at Naval Air Station Pensacola, FL to receive designation as a Navy Flight Surgeon. He served aboard the aircraft carrier USS John F. Kennedy from 1986-1988. Upon completing active duty, he affiliated with the US Navy Reserves. Dr. Dervay completed a residency in Emergency Medicine at The George Washington/Georgetown/Univ. of Maryland Combined Residency Program from 1988-1991. He subsequently worked as a staff physician in the Washington, DC area, and concurrently served as Manager, Operational Medicine, for Lockheed Engineering & Sciences Company supporting NASA Headquarters. In 1994, Dr. Dervay was selected into the second class of the UTMB Galveston/NASA Johnson Space Center Fellowship in Space Medicine. Upon completion of the two-year program, he accepted a position as a NASA Flight Surgeon. Additional training included completion of a Residency in Aerospace Medicine at UTMB Galveston. In 1991, he was awarded a Master of Medical Sciences degree from UTMB Galveston. Dr. Dervay is board-certified in Aerospace Medicine, Emergency Medicine, and Undersea & Hyperbaric Medicine. He has served as Crew Surgeon or Deputy Crew Surgeon for numerous Space Shuttle and International Space Station missions. In the United States Navy, he holds the rank of Captain with over twenty-five years of service, and has supported Navy & Marine Corps aviation squadrons and units in deployments throughout the world.

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